ENVIRONMENTAL ENGINEERING

FIFTH EDITION

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WILEY

JOHN WILEY & SONS, INC.

This book is printed on acid-free paper. ♾

Published by John Wiley & Sons, Inc., Hoboken, New Jersey
Published simultaneously in Canada

Library of Congress Cataloging-in-Publication Data:

Salvato, Joseph A.
Environmental engineering / Joseph A. Salvato, Nelson Nemerow, Frank Agardy. — 5th ed.
p. cm.
ISBN 0-471-41813-7 (cloth)
1. Sanitary engineering. 2. Environmental engineering. 3. Sanitation. 4. Environmental health. I. Nemerow, Nelson Leonard. II. Agardy, Franklin J. III. Title.
TD145 .S2397 2003
628—dc21
2002010809

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Doctors Nemerow and Agardy would like to dedicate this fifth edition of Environmental Engineering *to Joseph A. Salvato, Jr., who passed away at the age of 87 in November of 2001. Joseph Salvato was largely responsible for much of the material in this text. He was a highly respected Sanitary Engineer who published extensively in this field and was known personally to be an energetic, conscientious, thorough worker for the cause of our field, known now as environmental engineering. He should be remembered as one of the original sanitation researchers of our time. He was a licensed Registered Professional Engineer, a Principal Public Health Engineer, a Grade 1 Public Water Supply Operator, and a Grade 1 Sewage Treatment Plant Operator. He held many memberships in most of the active public health organizations and received many honorary awards from these same organizations. He was also an army veteran of World War II.*

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PREFACE

Workers in environmental health and in environmental protection who have had experience with environmental sanitation and engineering problems have noted the need for a book that is comprehensive in its scope and more directly applicable to conditions actually encountered in practice.

Many standard texts adequately cover the specialized aspects of environmental health, engineering, and sanitation, but little detailed information is available in one volume dealing with the urban, suburban, and rural environment and community.

In this text emphasis is placed on the practical application of sanitary science and engineering theory and principles to comprehensive environmental control. This is necessary if available knowledge is to benefit humans now and in future generations without transferring an environmental problem from one media (air, water, or land) to another. In addition, and in deliberate contrast to complement other texts, empirical formulas, rule of thumb, experience, and good practice are identified and applied when possible to illustrate the "best" possible solution under the particular circumstances. It must be recognized, however, that knowledge and conditions change and that this may be hazardous when blindly applied by the practitioner. It is sincerely hoped, however, that individual ingenuity and investigation will not be stifled by such practicality but will be challenged and stimulated to always consider new developments and alternatives.*

A special effort was made to include general design, construction, maintenance, and operation details as they relate to plants and structures. Examples and drawings are used freely to help in the understanding and use of the subject matter. The reader is referred to the references and bibliography in each chapter for more information on complex designs and problems that are beyond the scope of this text.

Since the field is a very broad one, the following subjects are specifically covered in this new revised edition:

1. control of communicable and certain noninfectious diseases,
2. environmental engineering planning and impact analysis,
3. water supply,
4. wastewater treatment and disposal,

* "Education is a continuing process, the distillation of life experiences, and not only something dispensed in schools and based on books alone." [Author unknown.]

5. solid waste management,
6. air pollution and noise control,
7. radiation uses and protection,
8. food protection,
9. recreation areas and temporary residences,
10. the residential and institutional environment,
11. environmental emergencies and environmental preparedness, and
12. soil and groundwater remediation.

The objectives of the fifth edition were to eliminate information and practices that have become either nonapplicable or obsolete and to insert new data and practices that are now available and useful for the beginning of the twenty-first century. Relevant data and practices that are still pertinent and/or used were left in this edition purposely to offer the reader a broader perspective of the subject material. The reader will have the choice of utilizing this information or foregoing it in favor of other alternative data.

In this edition, each chapter is either updated or written by one or more individual contributors deemed to be knowledgeable experts in their subject material. Although the 12 chapter contributors had the primary responsibility for presenting the contents of their chapters, Nelson L. Nemerow and Franklin J. Agardy suggested subject material and reviewed the entire chapter contents.

The control of diseases is discussed to emphasize the health basis for environmental regulation and the proper application of sanitary and epidemiological principles in disease prevention. This is particularly important for areas of the world where communicable and related diseases have not yet been brought under control; what can happen in the more advanced countries when basic sanitary safeguards are relaxed is also discussed. Without discussing this important subject, this text would be as incomplete as one dealing with preventive medicine or planning that failed to discuss water supply, sewage disposal, solid waste management, air pollution control, and other phases of environmental health, engineering, and sanitation. Also, in view of the progress made in most developed areas of the world in the control of the communicable diseases, attention is given to the environmental factors associated with the noninfectious diseases. Although complete knowledge concerning the specific cause and the prevention of many noninfectious diseases is lacking, it is considered desirable to identify and apply such knowledge that does exist so that it can be expanded and refined with time.

Teachers and students of environmental health and the environmental sciences, as well as of civil, chemical, mechanical, environmental, sanitary, municipal, and public health engineering, will find much of direct and general value in this text. Others too will find the contents especially useful. These would include the health officer, professional sanitarian, environmental scientist, social scientist, ecologist, biologist, conservationist, public health nurse, health educator, environmental health technician, and sanitary inspectors of towns, villages, cities, counties, states, and federal governments both in the United States and abroad. City and county engineers and managers, consulting engineers, architects, planners, industry representatives, equipment manufacturers and installers, contractors, farm extension personnel, and institution, resort, and camp directors can all benefit from the contents. The many environmentalists who are interpreting and appying the principles of sanitary science and environmental health, engineering, sanitation, and hygiene to both the advanced and the developing areas of the world will find the material in this text particularly helpful in accomplishing their objectives.

In view of new knowledge, environmental legislation on both the federal and state levels, and higher expectations of the people, many professionals, public officials, and individuals concerned with protection of the public health and the environment are finding themselves unprepared to deal effectively with the current and emerging problems. These people will find *Environmental Engineering* a valuable reference for continuing education and career development.

This fifth edition omits obsolete material, refines and updates existing material, and adds new information to the fourth edition. Some of the highlights follow.

Chapter 9 has remained as it was written in the fourth edition and Chapters 10 and 12 have been removed from this edition. Two completely new chapters have been added to the fifth edition and become Chapter 11, Environmental Emergencies and Environmental Preparedness and Chapter 12, Soil and Groundwater Remediation. The other chapters have been reviewed and updated from the fourth edition by known experts in their fields. Their names appear at the beginning of each chapter.

Chapter 1, on the control of communicable and certain noninfectious diseases, adds more definitions of terms, rate calculations used in epidemiology, survival of pathogens, newly recognized pathogens, and discussions of environmentally related illnesses, in addition to communicable and noncommunicable diseases. Some historical waterborne disease background and information on the impact of environmental factors on cancer mortality are given.

Chapter 2, on environmental engineering planning and impact analysis, reemphasizes the commonality of the planning process elements in comprehensive community planning, planning for community or regional solid waste management, wastewater disposal, water supply, and other institutional needs. The discussion of site investigation, environmental assessment, and environmental audit is expanded.

Chapter 3, on water supply, expands on pollution travel; updates the federal Safe Drinking Act standards, regulations, and treatment requirements; explains the new wellhead protection regulations; expands on microbiological, physical, and inorganic and organic chemical standards and their significance;

adds limitations of household treatment units; and discusses removal and treatment of organic chemicals from groundwater as well as bioremediation.

Chapter 4, on wastewater treatment and disposal, adds some definitions: discusses nonpoint pollution, water quality classification, and groundwater contamination; updates and adds information dealing with onsite sewage disposal for unsuitable soil conditions; small- and medium-size treatment systems; sludge disposal; water quality classification; biomonitoring; and the National Pollutant Discharge Elimination System.

Major changes have been made in Chapter 5, on solid waste management, to reflect the U.S. Environmental Protection Agency changes to the Resource Conservation and Recovery Act as amended. Many definitions have been added. The prevention, reduction, recovery, and recycling of solid wastes, including hazardous wastes, are emphasized. The new regulations governing the siting, design, operation, and maintenance of solid waste landfills and incinerators are explained, illustrated, and summarized; and the handling, treatment, and disposal of medical wastes, including infectious and pathological wastes, are discussed. The storage of bulk petroleum and hazardous materials is also reviewed.

Chapter 6, on air pollution and noise control, adds and updates information on global warming, ozone destruction, acid rain, sampling and measurement, emission control equipment, and the Clean Air Act of 1990.

Chapter 7, on radiation uses and protection, updates material on ionizing and nonionizing radiation, waste management, and emergency planning and response and adds information on new equipment and effects of electromagnetic fields.

Chapter 8, on food protection, discusses newly recognized food pathogens and their survival; summarizes information on food preservation, including food irradiation; outlines the hazard analysis critical control point procedure; and reemphasizes the importance of refrigeration and proper heat treatment at all stages of food handling, storage, preparation, and service. The milk control section recognizes the new Grade A Pasteurized Milk Ordinance (1989), and the shellfish section is updated to reflect the 1988 National Shellfish Sanitation Program Manual of Operations, Parts I and Part II.

Information on swimming pool, spa, and hot-tub design and operation in Chapter 9, on recreational areas and temporary residences, is still considered current, so it stands as it was in the fourth edition.

Chapter 10, on the residential and institutional environment, adds World Health Organization principles of health needs and information on housing and health and Public Health Service/Centers for Disease Control and Prevention Recommended Minimum Housing Standards. A major addition is a section on indoor air quality, including radon, formaldehyde, biological contaminants, ventilation, thermal and moisture requirements, and respiratory illness control. The handling of hospital and related wastes is added to the institutions discussion.

Chapters 11 and 12 are entirely new chapters also written by qualified experts in their respective fields.

As a general note, the editors point out that although chapters have been updated as regards to current references, the older references remain so as to add an historic and still valid perspective to each chapter.

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ACKNOWLEDGMENTS

The editors gratefully acknowledge Joel Stein, the Editorial Director for Engineering Publications of Professional/Trade Publishing for John Wiley & Sons, who made a major contribution of time and energy to the completion of this major update. Without his assistance and constant reminders, this edition would not have been possible.

INTRODUCTION

In many parts of the world, simple survival and the prevention of disease and poisoning are still serious concerns. In other areas, maintenance of an environment suited to efficient performance by human beings and the preservation of comfort and enjoyment of living are the goals for the future. These levels of life and progress can be the basis for action programs in environmental health.[1] As urbanization increases, our impact on the environment and the impact of the environment on us, must be controlled to protect the human and natural resources essential to life while at the same time enhancing the well-being of humans. However, the simultaneous movement of people from the cities to suburban and rural areas, often to uncontrolled environments, makes it important that the environmental sanitation lessons of the past are not lost and the environmental impact of human activity on individuals and our natural resources is controlled.

The environment encompasses ''the aggregate of all the external conditions and influences affecting the life and development of an organism.''[2] This definition includes the air, water, and land and the interrelationship that exists among and between them and all living things. This means that our goal should be ''the control of all those factors in man's physical environment which exercise or may exercise a deleterious effect on his physical development, health, and survival.''[3] Required is ''the application of environmental sciences and engineering principles to the control, modification, or adaptation of the physical, chemical, and biological factors of the environment in the interest of man's health, comfort and social well-being.''[4]

Environmental health has been defined as ''the systematic development, promotion, and conduct of measures which modify or otherwise control those external factors in the indoor and outdoor environment which might cause illness, disability or discomfort through interaction with the human system. This includes not only health and safety factors, but also aesthetically desirable conditions in accordance with community demands and expectations.''[5] This calls for control of ''the causative agents of disease while they are in the environment before they get to man and possibly overcome the body's defense to the point where it requires therapeutic medicine.''[6] The prevention of disease and the achievement of a better quality of life requires competent implementation of programs such as those described in the chapters of this book.

The chapters that follow point out major areas of concern to be attacked by a host of disciplines working in close harmony. Effective, comprehensive, and balanced control and management of these concerns will help achieve the highest possible quality of environment and living, keeping in mind the physical, social,* and economic factors involved and their interdependence.

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*This includes political, cultural, educational, biological, medical, and public health. Social health is the "ability to live in harmony with other people of other kinds, with other traditions, with other religions, and with other social systems throughout the world" (ref. 3). "The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition" (ref. 3).

CONTENTS

1 Control of Communicable and Certain Noninfectious Diseases

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GENERAL

Definitions

Certain terms with which one should become familiar are frequently used in the discussion of communicable and noninfectious or noncommunicable diseases. Some common definitions are given here.

Age-Adjusted Death Rate Shows what the level of mortality would be if there were no changes in the age composition of the population from year to year and is therefore a better indicator than the unadjusted rate of change over time in the risk of dying. Age-adjusted rates are computed by applying the age-specific death rates for a given cause of death to the standard population distributed by age, such as children, adults, and senior citizens.

Antigen(s) Foreign substance(s) inducing the formation of antibodies. In some vaccines, the antigen is highly defined (e.g., pneumococcal polysaccharide, hepatitis B surface antigen, tetanus, or diphtheria toxoids); in others, it is complex or incompletely defined (e.g., killed pertussis bacteria; live, attenuated viruses).[1] Antibodies are specific substances formed by the body in response to stimulation by antigens.

Antisepsis The application of chemical agents to living tissue to kill or control microorganisms.

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0-471-41813-7

Body Burden The total effect on the body from ingestion or exposure to a toxic chemical in the air, water, or food. Can be determined by examination of samples of human hair, tissue, blood, urine, and milk, also by measurement of the amount in air, water, and food, and then the intake from these sources, including contact.

Carcinogen Any factor or combination of factors that increases the risk of cancer. Cancer is a disease in which derangement of body cells is involved. The effects of carcinogens on human tissue, if exposure is sufficient, are irreversible. Carcinogens that produce cancer in experimental animals are found in low concentrations in food, food additives, some air and water pollutants, and certain pesticides. The carcinogenic potential of many carcinogenic substances acting singly or in combination with other carcinogens and chemicals is unknown.[2] Most scientists agree that a chemical causing cancer in animals is a potential cancer hazard for humans; however, many chemicals carcinogenic to animals are not carcinogenic to humans. But chemicals known to cause cancer in humans have been found to do so in animal species.

Carrier A person or animal that harbors a specific infectious agent in the absence of discernible clinical disease and serves as a potential source of infection. The carrier state may exist in an individual with an infection that is inapparent throughout its course (commonly known as *healthy* or *asymptomatic carrier*) or during the incubation period, convalescence, and postconvalescence of an individual with a clinically recognizable disease (commonly known as *incubatory carrier* or *convalescent carrier*). Under either circumstance, the carrier state may be of short or long duration (*temporary* or *transient carrier*, or *chronic carrier*).[3]*

Communicable Disease An illness due to a specific infectious agent or its toxic products arises through transmission of that agent or its products from an infected person, animal, or inanimate reservoir to a susceptible host, either directly or indirectly through an intermediate plant or animal host, vector, or the inanimate environment.[3] Illness may be caused by pathogenic bacteria, bacterial toxins, viruses, protozoa, spirochetes, parasitic worms (helminths), poisonous plants and animals, chemical poisons, prions (infectious proteinlike particles)[4], rickettsias, and fungi, including yeasts and molds. In this text, communicable diseases are grouped and discussed under respiratory diseases, waterborne diseases, foodborne diseases, insect-borne diseases, zoonoses, and miscellaneous diseases. The terms *communicable disease* and *infectious disease* are used interchangeably.

Contact A person or animal that has been in an association with an infected person or animal or a contaminated environment that might provide an opportunity to acquire the infective agent.[3]

*From ref. 3. Copyright by the American Public Health Association. Reprinted with permission.

Contamination The presence of an infectious agent on a body surface; also on or in clothes, bedding, toys, surgical instruments or dressings, or other inanimate articles or substances, including water and food. *Pollution* is distinct from contamination and implies the presence of offensive, but not necessarily infectious, matter in the environment. Contamination on a body surface does not imply a carrier state.[3]

Disease In its broadest sense, the communicable and noninfectious diseases. Disease may be considered the antithesis of health, defined as "a state of physical, mental and social well-being and ability to function, and not merely the absence of illness or infirmity." (WHO definition as modified in ref. 5, p. 1037.)[5]

Disinfection The application of microbicidal chemicals to materials (surfaces as well as water), which come into contact with or are ingested by humans and animals, for the purpose of killing pathogenic microorganisms. Disinfection may not be totally effective against all pathogens.

Disinfestation Any physical or chemical process serving to destroy or remove undesired small animal forms, particularly arthropods or rodents, present upon the person or the clothing, in the environment of an individual, or on domestic animals. Disinfestation includes delousing for infestation with *Pediculus humanus,* the body louse. Synonyms include the terms *disinsection* and *disinsectization* when only insects are involved.[3]

Endemic The constant presence of a disease or infectious agent within a given geographic area; may also refer to the usual prevalence of a given disease within such area. *Hyperendemic* expresses a persistent intense transmission and *holoendemic* a high level of infection beginning early in life and affecting most of the population, e.g., malaria in some places. See *Zoonosis.* (ref. 3, p. 505).

Endotoxin The toxin produced by a microorganism that is retained within the cell but is liberated when the cell disintegrates (as in the intestine) causing intoxication. Intoxication may also be produced by the ingestion of a poisonous chemical. The toxin withstands autoclaving.[6]

Enterotoxin A toxin produced by certain microorganisms. It is associated with the symptoms of food poisoning and is heat stable.

Epidemic The occurrence in a community or region of cases of an illness (or an outbreak) clearly in excess of expectancy. The number of cases indicating the presence of an epidemic will vary according to the infectious agent, size and type of population exposed, previous experience or lack of exposure to the disease, and time and place of occurrence; epidemicity is thus relative to usual frequency of the disease in the same area, among the specified population, at the same season of the year. A single case of a communicable disease long absent from a population or the first invasion by a disease not previously recognized in that area requires immediate reporting and epidemiologic investigation; two cases of such a disease associated in time and place are sufficient evidence of transmission to be considered an epidemic (ref. 3, p. 505).

Epidemiology The study of the occurrence, frequency, and distribution of disease (communicable and noncommunicable) in selected human populations, leading to the discovery of the cause and an informed basis for preventive action—social, biological, chemical, or physical.

Exotoxin A toxin produced by a microorganism and secreted into the surrounding medium, inactivated at 142 to 176° F (61–80°C).[6]

Host A person or other living animal, including birds and arthropods, that affords subsistence or lodgment to an infectious agent under natural (as opposed to experimental) conditions. Some protozoa and helminths pass successive stages in alternate hosts of different species. Hosts in which the parasite attains maturity or passes its sexual stage are *primary* or *definitive hosts;* those in which the parasite is in a larval or asexual state are *secondary* or *intermediate hosts.* A *transport host* is a carrier in which the organism remains alive but does not undergo development.[3]

Immunobiologic Immunobiologics include vaccines, toxoids, and antibody containing preparations from human or animal donors, including globulins and antitoxins. These products are used for immunization (ref. 1, pp. 1–2):

1. *Vaccine:* A suspension of attenuated live or killed microorganisms (bacteria, viruses, or rickettsias) or fractions thereof administered to induce immunity and thereby prevent infectious disease.
2. *Toxoid:* A modified bacterial toxin that has been rendered nontoxic but retains the ability to stimulate the formation of antitoxin.
3. *Immunoglobulin* (*IG*): A sterile solution containing antibody from human blood. It is a 15 to 18 percent protein fraction obtained by cold ethanol fractionation of large pools of blood plasma. It is primarily indicated for routine maintenance of certain immunodeficient persons and for passive immunization against measles and hepatitis A.
4. *Specific immunoglobulin:* Special preparations obtained from donor pools preselected for a high antibody content against a specific disease [e.g., hepatitis B immunoglobulin (HBIG), varicella zoster immuno globulin (VZIG), rabies immunoglobulin (RIG), and tetanus immuno globulin (TIG)].
5. *Antitoxin:* A solution of antibodies derived from the serum of animals immunized with specific antigens (diphtheria, tetanus) used to achieve passive immunity or effect a treatment.

Incubation Period The interval between effective exposure of a susceptible host to an agent (infection) and the onset of clinical signs and symptoms of disease in that host.

Infection The entrance and growth of a pathogen in humans or animals that, under favorable conditions, grows and causes illness.

Infectious Disease Any disease caused by the growth of pathogenic microorganisms in the body; may or may not be contagious (communicable).[7]

LC_{50} The median lethal concentration of a substance in the air, causing death in 50 percent of the animals exposed by inhalation; a measure of acute toxicity.

LD_{50} The median lethal dose, causing death in 50 percent of the animals exposed by swallowing a substance; a measure of acute toxicity.

Mutagen A chemical capable of producing a heritable change in genetic material; it can cause miscarriage, stillbirth, or birth defects (ref. 2, p. 17). Many chemicals that pollute the environment in large doses are mutagenic, but their hazard is not known for the levels found in the environment.

Neurotoxin A toxin that attacks nerve cells (i.e., botulism).

Noninfectious or Noncommunicable Disease The chronic, degenerative, and insidious disease that usually develops over an extended period and whose cause may not be entirely clear. In its broad sense, cancer, alcoholism, mental illnesses, tooth decay, ulcers, and lead poisoning are regarded as noncommunicable or noninfectious diseases. Also included are cardiovascular diseases, pulmonary diseases, diabetes, arthritis, nutritional deficiency diseases, malignant neoplasms, kidney diseases, injuries, and illnesses associated with toxic organic and inorganic chemicals and physical agents in air, water, and food. For the purposes of this text, discussion of noninfectious diseases emphasizes the environmental media or factors serving as the vehicle for transmission of the disease. The usual environmental media are air, food, water, and land (soil, flora, fauna); other factors leading to injuries and contact may also be involved.

In contrast to communicable diseases, *chronic diseases* may be caused by a variety or combination of factors that are difficult to identify, treat, and control. The resulting illness may cause protracted or intermittent pain and disability with lengthy hospitalization. A *degenerative condition* is the result of the deterioration or breaking down of a tissue or part of the body (aging).

No-Observed-Effect Level (NOEL) The no-observed-effect level, or the minimal-effect level, expressed as a dose in milligrams of chemical per kilogram of body weight, is divided by a safety or uncertainty factor to obtain an acceptable daily intake (ADI). The magnitude of this factor will generally range from 10 to 1000 and reflects the quantity and quality of the toxicologic data, the degree of confidence in the data, and the nature of the effects of concern.

Pathogen An infectious agent capable of causing disease.

Pathogenic The potential for producing disease, if the organism is sufficiently virulent to enter the body and overcome the defense mechanism of the host.

Personal Hygiene Those protective measures, primarily within the responsibility of the individual, that promote health and limit the spread of infectious diseases, chiefly those transmitted by direct contact. Such measures encompass (a) washing hands in soap and water immediately after evacuating bowels or bladder and always before handling food or eating; (b) keeping hands and unclean articles, or articles that have been used for toilet purposes by others, away from the mouth, nose, eyes, ears, genitalia, and wounds; (c) avoiding the use of common or unclean eating utensils, drinking cups, towels, handkerchiefs, combs, hairbrushes, and pipes; (d) avoiding exposure of other persons to spray from the nose and mouth, as in coughing, sneezing, laughing, or talking; (e) washing hands thoroughly after handling a patient or his belongings; and (f) keeping the body clean by sufficiently frequent soap-and-water baths (ref. 3, p. 506).

Pollution The undesirable change in the physical, chemical, or biological characteristics of air, land, and water that may or will harmfully affect human life or that of other desirable species, industrial processes, living conditions, and cultural assets or that may or will waste or deteriorate raw-material resources.[8] Examples of pollution are inadequately treated municipal and industrial waste discharges, leachate and runoff, toxic discharges from incinerators and industrial processes, discharge of a liquid causing an increase in water temperature that does not support sport fish, algae, and decaying aquatic weeds in bathing areas, and drainage from abandoned mines. See *Contamination.*

Prevention, Primary Prevention of an etiologic agent, substance, or action from causing disease or injury in humans; intervention; regulation of exposure to environmental hazards that cause disease or injury to decrease morbidity and mortality. Action to promote health and prevent disease or injury. Includes immunization, adequate supply of safe water and basic sanitation, prevention education, food and nutrition, and maternal and child care.

Prevention, Secondary Early detection and treatment to cure or control disease. Surveillance, screening, and monitoring the environment. Also measures to protect the public (e.g., treatment of public water supplies, fluoridation for dental control).

Prevention, Tertiary Amelioration of a disease to reduce disability or dependence resulting from it. Conventional medical treatment and restoration of health and well-being to the extent possible. Voluntary action by the individual.

Primary Health Care Application of the principles of health education, nutrition, immunization, water and sanitation, maternal and child care and family planning, control of endemic diseases, treatment of common diseases, and provision of essential drugs [World Health Organization (WHO)].

Prospective Study (Forward in Time) Interprets information collected on disease prevalence in a selected exposed population for a finite period of time in the *future,* after a study starts; also called cohort study. It is then compared with a nonexposed population or control group. See *Retrospective Study*.

Public Health "Public health is the science and art of preventing disease, prolonging life, and promoting physical and mental health and efficiency through organized community efforts for the sanitation of the environment, the control of community infections, and education of the individual in principles of personal hygiene, the organization of medical and nursing services for the early diagnosis and preventive treatment of disease, and the development of the social machinery which will ensure every individual in the community a standard of living adequate for the maintenance of health."[9]

Reservoir (of Infectious Agents) Any person, animal, arthropod, plant, soil, or substance (or combination of these) in which an infectious agent normally lives and multiplies, on which it depends primarily for survival, and where it reproduces itself in such manner that it can be transmitted to a susceptible host.[3]

Retrospective Study (After the Fact, Back in Time) Draws conclusions from events or information (people with and without disease) that occurred in the past, in which the related facts are likely to be vague and inaccurate. In either type of study, individual physiologic and environmental differences and other uncontrolled variables usually limit the validity of the results; nevertheless, the study can be very valuable. See *Prospective Study*.

Sanitation The effective use of measures that create and maintain healthy environmental conditions. Among these measures are the safeguarding of food and water, proper sewage and excreta disposal, and the control of disease-carrying insects and animals.

Sanitize To reduce microorganism level to an acceptable level, usually by the continuous application of heat or chemicals at suitable concentrations and times.

Source of Infection The person, animal, object, or substance from which an infectious agent passes to a host. Source of infection should be clearly distinguished from *source of contamination,* such as overflow of a septic tank contaminating a water supply or an infected cook contaminating a salad. See *Reservoir* (ref. 3, pp. 506–507).

Sterilization The process of killing all microorganisms, including spores.

Susceptible A person or animal presumably not possessing sufficient resistance against a particular pathogenic agent to prevent contracting infection or disease if or when exposed to the agent.[3]

Teratogen An agent (radiation, virus, drug, chemical) that acts during pregnancy to produce a physical or functional defect in the developing offspring. Substances that have caused defects are methylmercury and thalidomide. Some environmental pollutants may be both carcinogenic and teratogenic (ref. 2, p. 17).

TLV (Threshold Limit Value) The *average* 8-hr occupational exposure limit. This means that the actual exposure level may sometimes be higher, sometimes lower, but the average must not exceed the TLV. TLVs are calculated to be safe exposures for a working lifetime.

Toxicity, Acute Condition Adverse effects occurring shortly after the administration or intake of a single or multiple dose of a substance (oral rat LD_{50}). Conditions classified as acute include viruses, colds, flu, and other respiratory conditions; headaches, gastrointestinal disorders, and other digestive conditions; accidental injuries; genitourinary disorders; diseases of the skin; and other acute conditions. A condition that has lasted less than three months and has involved either a physician visit (medical attention) or restricted activity.[10]

Toxicity, Chronic Condition An injury that persists because it is irreversible or progressive or because the rate of injury is greater than the rate of repair during a prolonged exposure period (cancer or liver damage). Conditions classified as chronic include major categories of chronic illnesses such as heart disease, hypertension, arthritis, diabetes, ulcers, bronchitis, and emphysema. Any condition lasting three months or more or one of certain conditions classified as chronic regardless of their time of onset.[10]

Toxin A poisonous substance of animal or plant origin.[7]

Transmission of Infectious Agents Any mechanism by which an infectious agent is spread from a source or reservoir to a person. These mechanisms are:

(a) *Direct transmission*. Direct and essentially immediate transfer of infectious agents to a receptive portal of entry through which human or animal infection may take place. This may be by direct contact, such as touching, biting, kissing, or sexual intercourse, or by the direct projection (droplet spread) of droplet spray onto the conjunctiva or the mucous membranes of the eye, nose, or mouth during sneezing, coughing, spitting, singing, or talking (usually limited to a distance of about 1 m or less).

(b) *Indirect transmission*

(1) *Vehicleborne:* Contaminated inanimate materials or objects (fomites) such as toys, handkerchiefs, soiled clothes, bedding, cooking or eating utensils, surgical instruments, or dressings (indirect contact); water, food, milk, biological products including blood, serum, plasma, tissues, or organs; or any substance serving as an intermediate means by which an infectious agent is transported and introduced into a susceptible host through a suitable portal of entry. The agent may or may not have multiplied or developed in or on the vehicle before being transmitted.

(2) *Vectorborne*

(i) *Mechanical:* Includes simple mechanical carriage by a crawling or flying insect through soiling of its feet or proboscis or by passage of organisms through its gastrointestinal tract. This does not require multiplication or development of the organism

(ii) *Biological:* Propagation (multiplication), cyclic development, or a combination of these (cyclopropagative) is required before the arthropod can transmit the infective form of the agent to humans. An incubation period (extrinsic) is required following infection before the arthropod becomes *infective*. The infectious agent may be passed vertically to succeeding generations (*transovarian transmission*); *transstadial transmission* indicates its passage from one stage of life cycle to another, as nymph to adult. Transmission may be by injection of salivary gland fluid during biting or by regurgitation or deposition on the skin of feces or other material capable of penetrating through the bite wound or through an area of trauma from scratching or rubbing. This transmission is by an infected nonvertebrate host and not simple mechanical carriage by a vector as a vehicle. However, an arthropod in either role is termed a *vector*.

(c) *Airborne:* The dissemination of microbial aerosols to a suitable portal of entry, usually the respiratory tract. Microbial aerosols are suspensions of particles in the air consisting partially or wholly of microorganisms. They may remain suspended in the air for long periods of time, some retaining and others losing infectivity or virulence. Particles in the 1- to 5-μm range are easily drawn into the alveoli of the lungs and may be retained there. Not considered as airborne are droplets and other large particles that promptly settle out (see *Direct Transmission*).

(1) *Droplet nuclei:* Usually the small residues that result from evaporation of fluid from droplets emitted by an infected host (see above). They also may be created purposely by a variety of atomizing devices or accidentally as in microbiology laboratories or in abattoirs, rendering plants, or autopsy rooms. They usually remain suspended in the air for long periods of time.

(2) *Dust:* The small particles of widely varying size that may arise from soil (e.g., fungus spores separated from dry soil by wind or mechanical agitation), clothes, bedding, or contaminated floors (ref. 3, p. 507).

Vaccination and Immunization Today, these terms are often used interchangeably. The words *vaccination* and *vaccine* derive from vaccinia, the cowpox virus once used as smallpox vaccine. Thus, vaccination originally meant the inoculation of vaccinia virus to render individuals immune to smallpox. Some people still prefer that the term vaccination be restricted to this use, but many have come to use the term in a more general sense to denote the administration of any vaccine or toxoid without regard to whether the recipient is successfully made immune.

Immunization is a more inclusive term denoting the process of inducing or providing immunity artificially by administering an immunobiologic. Immunization can be *active* or *passive*.

Active immunization denotes the production of antibody or antitoxin in response to the administration of a vaccine or toxoid. *Passive immunization* denotes the provision of temporary immunity by the administration of preformed antitoxin or antibodies (e.g., immunoglobulin, maternal antibodies). Three types of immunobiologics are used for passive immunization: (1) pooled human immuno globulin (IG), (2) specific IG preparations, and (3) antitoxin.

Although there is lack of consensus that vaccination and immunization are completely synonymous, these words are used interchangeably in Immunization Practices Advisory Committee (ACIP) statements when referring to active immunization. Regardless of which term is used, it must be emphasized that administration of an immunobiologic cannot be automatically equated with the development of (or conferring of) adequate immunity because of a variety of specific factors, many of which are discussed in this statement (ref. 1, pp. 1–2).

YPLL Total years of potential life lost, a measure of premature mortality from all causes over the span from age 1 to 65 years based on age-specific death rates (*MMWR*, "Annual Summary 1984," p. 118).

Zoonosis An infection or infectious disease transmissible under natural conditions from vertebrate animals to humans, may be enzootic or epizootic.[11]

Common Rates Used in Public Health

Data are used to compare rates at different times or in different areas. Data must be reliable and carefully analyzed for differences in, for example, population, age distribution, geography, and employment. Statistical tests should be made to determine significance of data (the asterisks indicate that rates are also expressed as per 100,000 population):

Age-specific death rate

$$= \frac{\text{death in a specific age group in a specific population in a calender year}}{\text{estimated midyear population of that age group in the specific population}} \times 1000^*$$

Age-specific mortality rate

$$= \frac{\text{number of people in a given age group who died during a given time period (year)}}{\text{average number of people in a given age group during that time inteval (at midyear)}} \times 1000^*$$

Birth rate

$$= \frac{\text{live births in a population during a given time interval (year)}}{\text{average population during that time interval (year)}} \times 1000^{*}$$

Case–fatality rate (in percent) $= \frac{\text{individuals dying from a certain disease}}{\text{individuals who have the disease}}$

Cause-specific mortality rate

$$= \frac{\text{deaths due to a certain cause in a given population during a specified time period}}{\text{average number of people in that population during that time interval}} \times 100{,}000$$

Incidence rate

$$= \frac{\text{new cases of a disease in a population during a specified time period}}{\text{persons at risk of developing the disease during that time period}} \times 1000^{*}$$

Infant mortality rate

$$= \frac{\text{deaths occurring under the age of 1 year in a population}}{\text{live births in that year in that population}} \times 1000^{*}$$

Morbidity rate

$$= \frac{\text{cases of a disease existing at a particular time or cases occurring in a defined period of time}}{100{,}000}$$

Mortality rate (crude death rate)

$$= \frac{\text{deaths from all causes occurring in a population during a given time period (year)}}{\text{average number of people in that population during that period (at midyear)}} \times 1000^{*}$$

Prevalence rate

$$= \frac{\text{total cases of a disease existing (new and old) in the population at a given time}}{\text{persons in the population at that time}} \times 1000^{*}$$

Standardized mortality ratio

$$= \frac{\text{deaths due to a given cause in a given group}}{\text{deaths expected in that group based on adjustment for demographic variables}} \times 100$$

Life Expectancy and Mortality

The life expectancy at birth has varied with time, geography, and the extent to which available knowledge concerning disease prevention and control could be applied. Table 1-1 shows the trend in life expectancy with time. The gains in life expectancy in the United States between 1900 and 1990 shown in Table 1-2 have occurred mostly in the early years (26.2 years at birth and 16.2 years at age 5), reducing to 17.5 at age 25, 13.2 years at age 45, and 6.8 years at age 75. The life expectancy gains since 1900 are typical of developed countries and are due primarily to better sanitation (water filtration and chlorination, sanitary excreta and sewage disposal, milk pasteurization, hygiene) and nutrition, immunization and chemotherapy, and improved medical care and surgical procedures. These measures have led to a reduction in infant mortality, the conquest of epidemic and infectious diseases, and an improved quality of life. Developing countries can also achieve such gains if similar preventive measures can be instituted.

The vital statistics in Table 1-3 are of interest in that they show the changes in major causes of death in 1900 related to 1999 and the net reduction in the total death rate. Table 1-4 shows the leading causes of death in recent years. Future increase in life expectancy in the United States (and other developed countries) is dependent in part on our ability to identify the causes and control the chronic and degenerative noninfectious diseases such as cardiovascular diseases, malignant neoplasms, and cerebrovascular diseases, provided we maintain and strengthen existing barriers to infectious diseases as needed.

The prevention of deaths from a particular disease does not increase the life expectancy in direct proportion to its decreased mortality.[13] Keyfitz[13] gives an example showing that if a general cure for cancer were found, there would be nearly 350,000 fewer deaths per year (cancer deaths in 1970). It would seem, then, that the mortality would be lowered by one-sixth, since cancer deaths were one-sixth of all deaths, and the life expectancy increased by one-sixth. But this would hold true only for a homogeneous population (ref. 13, p. 954): "Only in such a population would the reduction of the deaths and of the death rate by one-sixth extend the expectation of life by one-sixth. Only then could each of us expect to live 12 more years (assuming a life expectancy of 72 years) as a result of the discovery of a cure for cancer." But because the population is not homogeneous and the risk factors for cancer, and other diseases, vary with age [such as for a 20-year-old man (1 : 10,000) compared to a 70-year-old man (1 : 100)], the "universal elimination of can-

TABLE 1-1 Life Expectancy at Birth

Period or Year	Life Expectancy
Neanderthal (50,000 B.C.–35,000 B.C.)	29.4[a]
Upper Paleolithic (600,000 B.C.–15,000 B.C.)	32.4[a]
Mesolithic	31.5[a]
Neolithic Anatolia (12,000 B.C.–10,000 B.C.)	38.2[a]
Bronze Age, Austria	38[a]
Greek Classical (700 B.C.–460 B.C.)	35[a]
Roman Classical (700 B.C.–A.D. 200)	32[a]
Roman empire (27 B.C.–A.D. 395)	24
1000	32
England (1276)	48[a]
England (1376–1400)	38[a]
1690	33.5
1800	35
1850	40
1870	40
1880	45
1900	47.3[b]
1910	50.0[b]
1920	54.1[b]
1930	59.7[b]
1940	62.9[b]
1950	68.2[b]
1960	69.7[b]
1970	70.8[b]
1980	73.7[b]
1988	74.9[b]
1999	76.5[c]

Source: J. A. Salvato, Jr., "Environmental Health," in *Encyclopedia of Environment Science and Engineering,* E. N. Ziegler and J. R. Pfafflin (Eds.), Gordon Breach Science, London, 1976, p. 286.

Note: The 1981–1982 average life expectancy for Japan was 77.0, Sweden 76.1, and Netherlands and Norway 76.0.

Life expectancy figures after 1690 are for the United States. The average life expectancy for the world in 1984 was 61 years and for Africa in 1975 it was 45 years. The world population was reported by the United Nations as 4 billion in 1975 and projected to 6.25 billion in 2000. The U.S. Census Bureau in 1986 predicted 6.2 million.

[a] E. S. Deevy, Jr., "The Human Population," *Sci. Am.,* 203(3), 200 (September 1960).

[b] *Health United States 1989,* U.S. Department of Health and Human Services, Public Health Service, March 1990, p. 106.

[c] From ref. 12.

TABLE 1-2 Increase in Life Expectancy between 1900 and 1990 at Selected Ages, U.S. Total Population

Age	Life Expectancy 1900[a]	Life Expectancy 1990[b]	Gain During 1900–1990
0	49.2	75.4	26.2
1	55.2	75.1	19.9
5	55.0	71.2	16.2
15	46.8	66.3	19.5
25	39.1	56.6	17.5
35	31.9	47.2	15.3
45	24.8	38.0	13.2
55	17.9	29.0	11.1
60	14.8	24.8	10.0
65	11.9	20.8	8.9
70	9.3	17.2	7.9
75	7.1	13.9	6.8
80	—	10.9	—
85 and over	—	6.1	—

[a]Department of Commerce, U.S. Census Bureau, *United States Life Tables 1890, 1901, 1910, and 1901–1910,* by J. W. Glover, U.S. Government Printing Office, Washington, D.C., 1921, pp. 52–53.
[b]National Center for Health Statistics, *Vital Statistics of the United States,* 1990, Vol. II: *Mortality,* Sec. 6, Life Tables, p., U.S. Department of Health and Human Services, U.S. Government Printing Office, Washington, DC, 1994.

cer would increase life expectancy by only about two years—not the 12 years that would apply if the population were homogeneous'' (ref. 13, p. 955). Keyfitz[13] goes on to say, ''But even the gain so calculated (two years if cancer is eliminated) is almost certainly an overestimate of the benefit. For within any given age group, the people subject to any one ailment tend to have higher than average risks from other ailments'' (p. 955). To extend average life expectancy beyond 70 years, Keyfitz feels it is necessary to focus on prevention of ''deterioration and senescence of the cells of the human body'' (p. 956).

Taeuber[14] estimates that the life expectancy of a 65-year-old man would be increased by 1.4 years if there were no cancer; $2\frac{1}{2}$ years would be added to the average life expectancy for 35-year-olds. Also, of the nearly 2 million deaths that occurred in 1973, 356,000 were attributed to cancer. Two-thirds of those saved lives, according to Taeuber, would have died of heart conditions or strokes.[14] It would seem, then, that a general improvement in the ''quality of life''* to slow down premature aging, together with prevention

*In addition to elimination, insofar as possible, of the communicable and noninfectious diseases, a desirable quality of life implies a decent home, comprehensive health care, adequate preventive services, adequate and safe water and food supply, proper waste disposal, clean air and water, absence of poverty, a suitable level of education and cultural opportunity, balanced diet, nondestructive life style, safe working conditions, safe and adequate recreation and transportation facilities. See Chapter 2, Statement of Goals and Objectives.

TABLE 1-3 Leading Causes of Death, 1900, 1960, 1970 and 1999 in the United States

Rank	Cause of Death	Deaths per 100,000 Population[a]	Percentage of All Deaths
	1900		
	All causes	1719	
1	Pneumonia and influenza	202.2	11.8
2	Tuberculosis (all forms)	194.4	11.3
3	Gastritis, etc.	142.7	8.3
4	Diseases of the heart	137.4	8.0
5	Vascular lesions affecting the central nervous system	106.9	6.2
6	Chronic nephritis	81.0	4.7
7	All accidents[b]	72.3	4.2
8	Malignant neoplasma (cancer)	64.0	3.7
9	Certain diseases of early infancy	62.5	3.6
10	Diphtheria	40.3	2.3
11	All other and ill-defined causes	615.3	36
	1960		
	All causes	955	
1	Diseases of the heart	366.4	38.7
2	Malignant neoplasms (cancer)	147.4	15.6
3	Vascular lesions affecting the central nervous system	107.3	11.3
4	All accidents[c]	51.9	5.5
5	Certain diseases of early infancy	37.0	3.9
6	Pneumonia and influenza	36.0	3.5
7	General arteriosclerosis	20.3	2.1
8	Diabetes mellitus	17.1	1.8
9	Congenital malformations	12.0	1.3
10	Cirrhosis of the liver	11.2	1.2
11	All other and ill-defined causes	148.4	15
	1970		
	All causes	945.3	
1	Diseases of the heart	362.0	38.3
2	Malignant neoplasms (cancer)	162.8	17.2
3	Cerebrovascular diseases (stroke)	101.9	10.8
4	Accidents	56.4	6.0
5	Influenza and pneumonia	30.9	3.3
6	Certain causes of mortality in early infancy[d]	21.3	2.2
7	Diabetes mellitus	18.9	2.0
8	Arteriosclerosis	15.6	1.6
9	Cirrhosis of the liver	15.5	1.6
10	Bronchitis, emphysema, and asthma	15.2	1.6
11	All other and ill-defined causes	144.8	15

TABLE 1-3 (*Continued*)

Rank	Cause of Death	Deaths per 100,000 Population[a]	Percentage of All Deaths
	1999		
	All causes	877.0	
1	Diseases of the heart	265.9	30.3
2	Malignant neoplasms	201.6	23.0
3	Cerebrovascular diseases	61.4	7.0
4	Chronic lower respiratory diseases	45.5	5.2
5	Accidents (unintentional injuries)	35.9	4.1
6	Diabetes mellitus	25.1	2.9
7	Influenza and pneumonia	23.4	2.7
8	Alzheimer's disease	16.3	1.9
9	Nephritis, nephrotic syndrome, and nephrosis	13.0	1.5
10	Septicemia	11.3	1.3
11	All other and ill-defined causes	177.6	20.1

Sources: For 1900, 1960, and 1970 data: *President's Science Advisory Committee Panel on Chemicals, Chemicals and Health,* U.S. Government Printing Office (GPO) Washington, DC, 1973, p. 152; DHEW, PHS, "Facts of Life and Death," DHEW Pub. No. (HRA) 74–1222, GPO, Washington, DC, 1974, p. 31. For 1999 data: "Deaths: Final Data for 1999," *Natl. Vital Statist. Rep.*, **49**(8), 6 (September 21, 2001). Cause of death is based on *International Classification of Diseases,* 10th rev. 1992, WHO, Geneva.

[a]Crude death rate. Cannot be compared among populations differing in relative age distribution. Does not reflect high percentage of older population dying of natural causes.

[b]Violence would add 1.4%; horse, vehicle, and railroad accidents provide 0.8%.

[c]Violence would add 1.5%; motor vehicle accidents provide 2.3%; railroad accidents provide less than 0.1%.

[d]Birth injuries, asphyxia, infections of newborn, ill-defined diseases, immaturity, etc.

and control of the noninfectious as well as communicable diseases, will accomplish a greater increase in life expectancy than concentrating *solely* on elimination of the major causes of death. This appears to be a sound approach since it is known that "mortality levels are determined by the complicated interplay of a variety of sociocultural, personal, biological, and medical factors" (ref. 15, p. 966). On the other hand, if the causes of a disease are also contributing factors to other diseases, then elimination of the cause of one disease may, at the same time, eliminate or reduce morbidity and mortality from other diseases, thereby resulting in an additional overall increase in life expectancy. For example, the ready availability of potable water can not only greatly reduce gastrointestinal diseases but also promote personal hygiene and cleanliness, prevent impetigo, reduce stress, and save time.

There seems to be a consensus that further increase in life expectancy in developed countries is dependent primarily on the extent to which personal behavior will be changed—obesity, poor nutrition, lack of exercise, smoking,

TABLE 1-4 Causes of Death in the United States, 1975, 1980, 1986, 1990, 1999

	Crude Death Rate per 100,000 Population				
Cause	1975	1980	1986	1990	1999
Diseases of the heart	336.2	336.0	317.5	289.5	265.9
Malignant neoplasms (cancer)	171.7	183.9	194.7	203.2	202.7
Cerebrovascular diseases	91.1	75.1	62.1	57.9	61.4
Chronic lower respiratory diseases[a]	—	—	—	—	45.5
Accidents	48.4	46.7	39.5	37.0	—
Unintentional injuries[a]	—	—	—	—	35.9
Motor vehicle	(21.5)	(23.5)	(19.9)	(18.8)	
All other accidents	(26.8)	(23.2)	(19.7)	(18.2)	
Influenza and pneumonia	26.1	24.1	29.0	32.0	23.4
Certain diseases of early infancy	12.5	7.4	—	7.1	—
Arteriosclerosis	13.6	13.0	9.4	7.3	—
Diabetes mellitus	16.5	15.4	15.4	19.2	25.1
Alzheimer's disease[a]	—	—	—	—	16.3
Nephritis, nephrotic syndrome, and nephosis[a]	—	7.4	—	8.3	13.0
Septicemia[a]	—	4.2	—	7.7	11.3
Bronchitis, emphysema, asthma	12.0	—	—	—	—
Chronic obstructive pulmonary diseases	—	24.7	31.8	34.9	—
Chronic liver disease and cirrhosis	14.8	13.5	10.9	10.4	9.6
Suicide	12.7	11.9	12.8	—	10.7
Congenital malformations	6.2	6.2	—	—	—
Homicide	10.0	10.7	—	10.0	6.2
Essential (primary) hypertension and hypertensive renal disease[a]	—	—	—	—	6.2
Other hypertensive diseases	3.0	—	—	—	—
Aortic aneurysm and dissection[a]	—	—	—	—	5.8
Human immunodeficiency virus	—	—	—	10.1	—
Other and ill-defined	112.2	106.8	150.1	116.9	139.0
Total, all causes	885.5	878.3	873.2	863.8	877.0
Population in millions	214.9	226.6	241.2	245.4	281.4

Sources: For 1975, 1980, 1986, and 1990 data: National Center for Health Statistics, *Vital Statistics of the United States, 1975, 1980, 1986, 1990,* Vol. II: *Mortality,* Part A, Sec. 1, Tables 1-5, 1-5, 1-5, 1-6, U.S. Department of Health and Human Services, Washington, DC, 1979, 1985, 1988, 1994. For 1888 dataL "Deaths: Final Data for 1999," *Natl. Vital Statist. Rept.,* **49**(8) (September 21, 2001). Cause of death is based on *International Classification of Diseases,* 10th rev., WHO, Geneva, 1992.

[a]Data not available for 1975, 1980, 1986, and 1990.

Note: Although the above data list a specific cause of death, multiple chronic conditions may be the major contributing cause. This is important in interpreting the data and designing preventive programs.

alcohol and drug intake, stress—and environmental pollutants will be controlled—industrial and auto emissions, chemical discharges into our air and waters, use of pesticides and fertilizers, interaction of harmless substances forming hazardous compounds[16]—together with a reduction of accidental and violent deaths and an improvement in living and working conditions. The average biological life expectancy in 1990 is estimated to be 85 years of age.

It must also be recognized that although life expectancy is a measure of health progress, it does not measure the morbidity levels and the quality of life.

Disease Control

The communicable diseases (malaria, yellow fever, pneumonia, tuberculosis, cholera, schistosomiasis, onchocerciasis, trachoma, intestinal parasitosis, and diarrheal diseases) and malnutrition are considered the core health problems of developing countries, many of which are aggravated by contaminated drinking water, unhygienic housing, and poor sanitation. However, illnesses associated with contaminated drinking water and food and poor personal hygiene are not uncommon in the so-called developed countries. In 1975 diseases of the heart, cancers, and cerebrovascular diseases caused 67 percent of all deaths in the United States. In 1988 they accounted for 65 percent of all deaths and in 1999 they accounted for 60 percent (Table 1-4). The age-adjusted death rates (Table 1-5) for the same diseases totaled 63 percent of all deaths in 1970 and 64 percent in 1984. However, there was a significant decrease in deaths due to diseases of the heart and cerebrovascular diseases. For overall comparison, the crude death rate for all causes decreased from 888.5 in 1975 to 863.8 in 1990 and to 877 in 1999. The age-adjusted death rate for all causes decreased from 714.3 in 1970 to 520.2 in 1990. See Tables 1-2 to 1-5. The major age-adjusted reductions in causes of death between 1970 and 1990 were those related to diseases of the heart, cerebrovascular diseases, pneumonia and influenza, chronic liver disease and cirrhosis, diabetes mellitus, and accidents. Overall, deaths due to malignant neoplasms increased somewhat and deaths due to chronic obstructive pulmonary diseases increased significantly. Tables 1-4 and 1-5 give an indication of where preventive efforts should be directed.

Sound factual information upon which to base programs for the prevention and control of morbidity and mortality associated with chronic diseases, aging, mental stress, destructive life styles, environmental hazards, and injury in many cases is not adequate or available. Multiple causes of disease and delayed effects compound the uncertainties. Nevertheless, it is prudent to apply and update known preventive environmental, physiologic–medical, and health education–motivational measures, including screening for early disease detection and treatment, with the full knowledge of their limitations and without raising unreasonable expectations of the public. The environmental preventive measures for disease control are elaborated on here, but the importance of the other measures is not to be minimized.

TABLE 1-5 Age-Adjusted Death Rates[a] per 100,000 Resident Population for Selected Causes of Death According to Sex and Race: United States, Selected Years

Sex, Race, and Cause of Death	1950[b]	1960[b]	1970	1980	1985	1990	1992
All Races, Both Sexes							
All causes	840.5	760.9	714.3	585.8	546.1	520.2	504.5
Diseases of the heart	307.2	286.2	253.6	202.0	180.5	152.0	144.3
Ischemic heart disease	—	—	—	149.8	125.5	102.6	95.7
Cerebrovascular diseases	88.6	79.7	66.3	40.8	32.3	27.7	26.2
Malignant neoplasms	125.3	125.8	129.8	132.8	133.6	135.0	133.1
Respiratory system	12.8	19.2	28.4	36.4	38.8	41.4	40.8
Colorectal	19.0	17.7	16.8	15.5	14.8	—	—
Prostate[c]	13.4	13.1	13.3	14.4	14.6	—	—
Breast[d]	22.2	22.3	23.1	22.7	23.2	23.1	12.0
Chronic obstructive pulmonary diseases	4.4	8.2	13.2	15.9	18.7	19.7	19.9
Pneumonia and influenza	26.2	28.0	22.1	12.9	13.4	14.0	12.7
Chronic liver disease and cirrhosis	8.5	10.5	14.7	12.2	9.6	8.6	8.0
Diabetes mellitus	14.3	13.6	14.1	10.1	9.6	11.3	11.9
Accidents and adverse effects	57.5	49.9	53.7	42.3	34.7	32.5	29.4
Motor vehicle accidents	23.3	22.5	27.4	22.9	18.8	18.5	15.8
Suicide	11.0	10.6	11.8	11.4	11.5	11.5	11.1
Homicide and legal intervention	5.4	5.2	9.1	10.8	8.3	10.2	10.5
White Males							
All causes	963.1	917.7	893.4	745.3	688.7	644.3	620.9
Diseases of the heart	381.1	375.4	347.6	277.5	244.5	202.0	190.3
Ischemic heart disease	—	—	—	218.0	180.8	145.3	134.8
Cerebrovascular diseases	87.0	80.3	68.8	41.9	32.8	27.7	26.3

TABLE 1-5 (*Continued*)

Sex, Race, and Cause of Death	1950[b]	1960[b]	1970	1980	1985	1990	1992
			White Males				
Malignant neoplasms	130.9	141.6	154.3	160.5	159.2	160.3	157.3
Respiratory system	21.6	34.6	49.9	58.0	58.2	59.0	56.7
Colorectal	19.8	18.9	18.9	18.3	17.6	—	—
Prostate	13.1	12.4	12.3	13.2	13.3	—	—
Chronic obstructive pulmonary diseases	6.0	13.8	24.0	26.7	28.5	27.4	26.8
Pneumonia and influenza	27.1	31.0	26.0	16.2	17.4	17.5	15.8
Chronic liver disease and cirrhosis	11.6	14.4	18.8	15.7	12.6	11.5	11.1
Diabetes mellitus	11.3	11.6	12.7	9.5	9.2	11.3	11.6
Accidents and adverse effects	80.9	70.5	76.2	62.3	50.4	46.4	41.9
Motor vehicle accidents	35.9	34.0	40.1	34.8	27.6	26.3	27.2
Suicide	18.1	17.5	18.2	18.9	19.9	20.1	19.5
Homicide and legal intervention	3.9	3.9	7.3	10.9	8.1	8.9	9.3
			Black Males				
All causes	1373.1	1246.1	1318.6	1112.8	1024.0	1061.3	1026.9
Diseases of the heart	415.5	381.2	375.9	327.3	301.0	275.4	264.1
Ischemic heart disease	—	—	—	196.0	164.9	147.1	138.2
Cerebrovascular diseases	146.2	141.2	122.5	77.5	60.8	56.1	52.0
Malignant neoplasms	126.1	158.5	198.0	229.9	231.6	248.1	238.1
Respiratory system	16.9	36.6	60.8	82.0	84.4	91.0	86.7
Colorectal	13.8	15.0	17.3	19.2	19.5	—	—
Prostate	16.9	22.2	25.4	29.1	30.2	—	—
Chronic obstructive pulmonary diseases	—	—	—	20.9	23.9	26.5	24.8
Pneumonia and influenza	63.8	70.2	53.8	28.0	26.8	28.7	25.0
Chronic liver disease and cirrhosis	8.8	14.8	33.1	30.6	23.4	20.0	17.2
Diabetes mellitus	11.5	16.2	21.2	17.7	17.7	23.6	24.2

Black Males							
Accidents and adverse effects	105.7	100.0	119.5	82.0	66.7	62.4	56.7
Motor vehicle accidents	39.8	38.2	50.1	32.9	27.7	28.9	25.0
Suicide	7.0	7.8	9.9	11.1	11.3	12.4	12.4
Homicide and legal intervention	51.1	44.9	82.1	71.9	49.9	68.7	68.1
White Females							
All causes	645.0	555.0	501.7	411.1	390.6	369.9	359.9
Diseases of the heart	223.6	197.1	167.8	134.6	121.7	103.1	98.1
Ischemic heart disease	—	—	—	97.4	82.9	68.6	64.1
Cerebrovascular diseases	79.7	68.7	56.2	35.2	27.9	23.8	22.5
Malignant neoplasms	119.4	109.5	107.6	107.7	110.3	111.2	110.3
Respiratory system	4.6	5.1	10.1	18.2	22.6	26.5	27.4
Colorectal	19.0	17.0	15.3	13.3	12.3	—	—
Breast	22.5	22.4	23.4	22.8	23.3	22.9	21.7
Chronic obstructive pulmonary diseases	2.8	3.3	5.3	9.2	12.9	15.2	16.1
Pneumonia and influenza	18.9	19.0	15.0	9.4	9.8	10.3	9.7
Chronic liver disease and cirrhosis	5.8	6.6	8.7	7.0	5.6	4.8	4.6
Diabetes mellitus	16.4	13.7	12.8	8.7	8.1	9.5	9.6
Accidents and adverse effects	30.6	25.5	27.2	21.4	18.4	17.6	16.1
Motor vehicle accidents	10.6	11.1	14.4	12.3	10.8	11.0	9.6
Suicide	5.3	5.3	7.2	5.7	5.3	4.8	4.6
Homicide and legal intervention	1.4	1.5	2.2	3.2	2.9	2.8	2.8

TABLE 1-5 (*Continued*)

Sex, Race, and Cause of Death	1950[b]	1960[b]	1970	1980	1985	1990	1992
Black Females							
All causes	1106.7	916.9	814.4	631.1	589.1	581.6	568.4
Diseases of the heart	349.5	292.6	251.7	201.1	186.8	168.1	162.4
Ischemic heart disease	—	—	—	116.1	100.8	88.8	84.9
Cerebrovascular diseases	155.6	139.5	107.9	61.7	50.3	42.7	39.9
Malignant neoplasms	131.9	127.8	123.5	129.7	130.4	137.2	136.6
Respiratory system	4.1	5.5	10.9	19.5	22.5	27.5	28.5
Colorectal	15.0	15.4	16.1	15.3	16.1	—	—
Breast	19.3	21.3	21.5	23.3	25.3	27.5	27.0
Chronic obstructive pulmonary diseases	—	—	—	6.3	8.7	10.7	11.2
Pneumonia and influenza	50.4	43.9	29.2	12.7	12.4	13.7	12.2
Chronic liver disease and cirrhosis	5.7	8.9	17.8	14.4	10.1	8.7	6.9
Diabetes mellitus	22.7	27.3	30.9	22.1	21.1	25.4	25.8
Accidents and adverse effects	38.5	35.9	35.3	25.1	20.7	20.4	19.3
Motor vehicle accidents	10.3	10.0	13.8	8.4	8.2	9.3	8.7
Suicide	1.7	1.9	2.9	2.4	2.1	2.4	2.1
Homicide and legal intervention	11.7	11.8	15.0	13.7	10.8	13.0	13.0

Sources: National Center for Health Statistics, *Vital Statistics Rates in the United States, 1940–1960,* by R. D. Grove and A. M. Hetzel, DHEW Pub. No. (PHS) 1677, Public Health Service, U.S. Government Printing Office, Washington, DC, 1968; National Center for Health Statistics, *Vital Statistics of the United States, 1970, 1980, 1985, 1990, 1992,* Vol. II *Mortality,* Part A, Sec. 1, Tables 1-6, 1-7, 1-7, 1-8, 1-8, U.S. Department of Health and Human Services, Washington, DC, 1974, 1985, 1989, 1994, 1996.

Notes: For data years shown, the code numbers for cause of death are based on the then-current *International Classification of Diseases,* Appendix II, Tables IV and V. Some numbers in this table have been revised and differ from previous editions of *Health United States*. As reported in *Health United States 1989,* U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, Hyattsville, MD, March 1990, Table 23, pp. 121–122.

[a] These are total rates in which differences between two or more populations in age distribution have been removed. Only age-specific differences remain.

[b] Includes deaths of nonresidents of the United STates.

[c] Male only.

[d] Female only.

The goal of environmental health programs is not only the prevention of disease, disability, and premature death but also the maintenance of an environment that is suited to humanity's efficient performance and the preservation of comfort and enjoyment of living today and in the future. The goal is the prevention of not only communicable diseases but also the noncommunicable diseases, the chronic and acute illnesses, and the hazards to life and health. This requires better identification and control of the contributing environmental factors in the air, water, and food at the home and the place of work and recreation as well as changes in personal behavior and reduced individual assumption of risk. Lacking complete information, the best possible standards based on the available knowledge must be applied for the public good. Standards adoption and regulatory effort should be based on the risk that society or the individual is willing to assume and pay for, taking into consideration other risk factors and needs.

Communicable and certain noninfectious diseases may be controlled or prevented by taking steps to regulate the *source,* the *mode of transmission,* or the *susceptibility* of persons as appropriate and feasible based on the knowledge available. This is shown in Figure 1-1 and for communicable diseases is sometimes pictured as a three-link chain. Although the diseases can be brought under control by eliminating one of the links, it is far better to direct one's attack simultaneously toward all three links and erect ''barriers'' or ''dams'' where possible. Phelps called this the *principle of multiple barriers.* It recognizes as axiomatic the fact that ''all human efforts, no matter how well conceived or conscientiously applied, are imperfect and fallible'' (ref. 17, p. 347). Sometimes it is only practical to control or break one link in the chain. Therefore, the number and type of barriers or interventions should be determined by the practicality and cost of providing the protection, the benefits to be derived, and the probable cost if the barriers are not provided. Cost is used not only in the sense of dollars but also in terms of human misery, loss of productiveness, ability to enjoy life, and loss of life. Here is a real opportunity to apply professional judgment to the problems at hand to obtain the maximum return for the effort expended.

Communicable and certain noninfectious diseases can usually be regulated or brought under control. A health department having a complete and competent staff to prevent or control diseases that affect individuals and animals is usually established for this purpose. The preventive and control measures conducted by a health department might include supervision of water supply, wastewater, and solid wastes; housing and the residential environment; milk and food production and distribution; stream pollution; recreational areas, including camps, swimming pools, and beaches; occupational health and accident prevention; insects and rodents; rural and resort sanitation; air pollution; noise; radiological hazards; hospitals, nursing homes, jails, schools, and other institutions; medical clinics, maternal and child health services, school health, dental clinics, nutrition, and medical rehabilitation; medical care; disease control, including immunizations, cancer, heart disease, tuberculosis, and

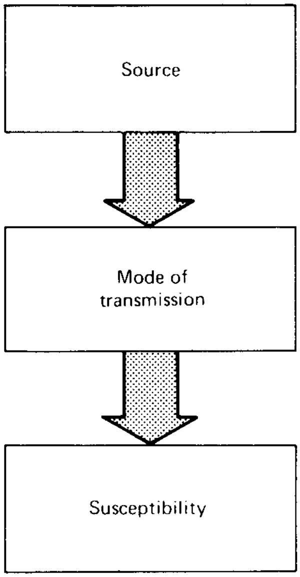


Figure 1-1 Spread of communicable and noninfectious diseases.
Source (agent factors–physical, chemical biologic); food and infected or infested animals; poisonous plants and animals; parasites; toxic solid, liquid, and gaseous substances and natural deposits; genetic and inherited materials; ionizing and monionizing radiations; noise.
Mode of transmission or contributing factors (environmental factors):; environmental pollutants; contact; animals; personal behavior; level of hygiene, sanitation, standard of living; work, recreation, travel, home, climate.
Susceptibility (host factors):; all animals or susceptibles, resulting in acute, chronic, or delayed effects; depending on portal of entry, dose, and virulence or toxicity of the agent; natural and acquired resistance of the host, and life-style.
Animals include humans and arthropods. *Arthropods* include insects, arachnids, crustaceans, and myriapods. *Environmental pollutants* may be transmitted by air, water, food, or contact. *Personal behavior may involve cigarette smoking, drug use, poor nutrition, stress, lack of exercise, cultural habits, and obesity. Physical agents* may be heat, cold, precipitation, and causes of accidents. *Biologic agents* include arthropods, helminths, protozoa, fungi, bacteria, rickettsiae, and viruses. *Chemical agents* include inorganic and organic chemicals.

venereal diseases; vital statistics; health education; epidemiology; and nursing services. Personnel, fiscal, and public relations support functions would be carried out by the office of business management. In some states, certain environmental and medical activities are combined with the activities of other agencies and vice versa, making the achievement of a comprehensive and coordinated preventive services program difficult.

Control of Source (Agent Factors)

General sources of disease agents are noted in Figure 1-1. Elimination or control of the source and environmental exposure to disease agents or vectors is a primary step carried out to the extent feasible. Individuals frequently are not aware that they are being exposed to a potential source of disease, particularly when it is a minute, insidious and cumulative substance, such as certain chemicals in the air, water, and food. This calls for regulatory action as noted in the discussion of noninfectious diseases under Prevention and Control in this chapter.

In many instances control at the source is not only possible but practical. Some measures that might be taken are as follows:

1. Change the raw material or industrial process to eliminate or adequately minimize the offending substance. For example, use low-sulfur fuel or substitute natural gas; terminate production of a chemical such as polychlorinated byphenyl (PCB); or remove waste products, such as by means of air pollution control devices or wastewater treatment plants, to reduce toxic discharges into the environment to acceptable levels. The U.S. Environmental Protection Agency (EPA) "zero-discharge" *goal* is a step in this direction.
2. Select the cleanest available source of drinking water, as free as possible from microbiological and toxic organic and inorganic chemicals.
3. Make available water with optimum mineral content, such as through fluoridation and water hardness control.
4. Prohibit taking of fish and shellfish from contaminated (pathogen, methylmercury, PCB) waters.
5. Regulate food production, processing, and service to ensure freedom from toxic substances and pathogens and to assure food of good nutritional content.
6. Provide decent housing in a suitable living environment.
7. Provide a safe and healthful work and recreational environment.
8. Promote recycling, reuse, and zero discharge of hazardous wastes.
9. Eliminate disease vectors (arthropods and other animals, including rodents) at the source. Practice integrated pest management.
10. Isolate infected persons and animals from others during their period of communicability and treat to eliminate disease reservoir.
11. Educate polluters, legislators, and the public to the need for regulation and funding where indicated.
12. Adopt and enforce sound standards.
13. Support comprehensive environmental health, engineering, and sanitation planning, surveillance, and regulation programs at the state and local levels.

See also Disease Control and Control of Susceptibles (Host Factors) in this chapter and Future Preventive Environmental Program Activities.

Control of Mode of Transmission or Contributing Factor (Environmental Factors)

The means whereby specific agents or factors may become the vehicle or vector for the transmission of disease are numerous. Prevention of disease requires the continual application of control measures such as those listed below and elimination of the human element to the extent feasible:

1. Prevent the travel of disease vectors and control disease carriers.
2. Assure that all drinking water is at all times safe to drink and adequate for drinking, culinary, laundry, and bathing purposes.
3. Provide adequate spatial separation between sources of disease (and pollution) and receptors.
4. Assure that food processing, distribution, preparation, and service do not cause disease.
5. Control air, land, and water pollution, hazardous wastes, accidents, carcinogens, and toxics.
6. Prevent access to disease sources—polluted bathing waters and disease vector–infested areas.
7. Adopt and enforce environmental standards—air, water, land, noise, land use, housing.
8. Educate polluters, legislators, media, and the public to the need for regulation and funding where indicated.
9. Support comprehensive environmental health, engineering, and sanitation planning, protection, surveillance, and regulation programs at the state and local levels.
10. Adjust personal behavior to counteract cigarette smoking, poor nutrition, stress, overeating, and lack of exercise. Promote personal hygiene and handwashing to prevent person-to-person transmission of pathogenic or toxic agents.

Control of Susceptibles (Host Factors)

The more susceptible individuals are the very young, the elderly, those with cardiovascular and respiratory disease, the immunocompromised, those occupationally exposed to air and other pollutants, those who smoke heavily, the obese, and those who underexercise. There are many diseases to which all persons are considered to be generally susceptible. Among these are measles, streptococcal diseases caused by group A streptococci, the common cold, ascariasis, chickenpox, amebic dysentery, bacillary dysentery, cholera, malaria, trichinosis, and typhoid fever. There are other diseases, such as influenza, meningococcus meningitis, pneumonia, human brucellosis (undulant fever), and certain water- and foodborne illnesses, to which some people apparently have an immunity or resistance. To these should be added the noninfectious diseases such as diseases of the heart, malignant neoplasms, and cerebrovascular diseases.

In order to reduce the number of persons who may be susceptible to a disease at any one time, certain fundamental disease prevention principles are followed to improve the general health of the public. This may be accomplished by instructions in personal hygiene and immunization; avoidance of smoking; maintenance of proper weight; minimal liquor consumption; and conserving or improving the general resistance of individuals to disease by a balanced diet and nutritious food, fresh air, moderate exercise, sufficient sleep, rest, and the avoidance of stress, fatigue, and exposure. In addition, all individuals should be educated and motivated to protect themselves to the extent feasible from biological, physical, chemical, and radiation hazards and environmental pollutants.

Immunization can be carried out by the injection of vaccines, toxoids, or other immunizing substances to prevent or lessen the severity of specific diseases. Typhoid and paratyphoid fevers, poliomyelitis, and tetanus are some of the diseases against which all in the armed forces are routinely immunized. Children are generally immunized against diphtheria, tetanus, pertussis (whooping cough), poliomyelitis, rubeola (measles), mumps, and rubella (German measles). Revaccination of students and others born after January 1, 1957, against measles is recommended and may be required prior to school admission. It is now possible to discontinue smallpox vaccination as a routine measure in view of the global eradication of smallpox.[18]* Individuals at increased risk of hepatitis A and B, rabies, influenza, tuberculosis, and pneumococcal disease can also be immunized. Vaccination with BCG can prevent serious forms of tuberculosis in children with an efficacy of up to 80%, but the effectiveness in adolescents and adults has not been shown to be as high, and it interferes with the most used clinical test for the presence of tuberculosis, the tuberculin test. Therefore, the Centers for Disease Control and Prevention (CDC) only recommends its use in children and adults who are living or working in conditions that expose them to the disease.[19] A meningococcal vaccine in single-dose vials is available for travelers to areas with excessive

*WHO Director-General Gro Harlem Brundtland is asking the WHO Smallpox Advisory Group to review guidelines on smallpox vaccination in light of the current concern that populations might be deliberately infected with the smallpox virus. The guidelines recommend that only individuals at risk of exposure (e.g., laboratory researchers working on smallpox) should be vaccinated. Brundtland has asked the advisory group to consider whether WHO should modify this guidance to take account of any potential situation in which the smallpox virus is deliberately used to cause infection (WHO press release October 19, 2001).

or epidemic meningococcal disease and for persons at high risk. It replaces a previously available 10-dose vial. The vaccine has a protective efficacy of 85 to 95 percent for serogroups A, C, Y and W-135.[20]

Typhoid bacilli may be found in the feces and urine of cases and carriers. Individuals who have or had schistosomiasis (bilharziasis) are more likely to have a urinary infection. Leptospires may be found in the urine of those suffering from leptospirosis.

Typhoid immunization is reported to be about 70 to 90 percent effective, depending on degree of exposure,[21,22] and then only against small infective doses. Routine typhoid vaccination is indicated only when a person is in intimate contact with a known carrier or travels in areas where there is a recognized risk of exposure, but precautions should still be taken with water and food. Routine vaccination of sewage sanitation workers is warranted only in areas with endemic typhoid fever. There is no reason to use typhoid vaccine for persons in areas of natural disaster such as floods or for persons attending rural summer camps.[21,22] There are currently two typhoid vaccines available in the United States, an oral live-attenuated vaccine (Vivotif Berna) and an injected capsular polysaccharide vaccine (Typhim Vi). Both vaccines have been shown to protect 50 to 80 percent of recipients Boosters are required, every five years for the oral vaccine and every two years for the injected form.[23]

Cholera vaccine is not available in the United States. It has not been recommended for travelers because of the brief and incomplete immunity it offers. No cholera vaccination requirements exist for entry or exit of any country. Yellow fever vaccine offers protection for at least 10 years and possibly up to 35 years. A certificate of vaccination is required for entry into some countries.[23] The WHO is recommending the use of five anthelmintic agents—albendazole, mebendazole, diethylcarbamazine, ivermectin, and praziquantel—to control parasitic worm infections that affect over 25 percent of the world's population.[24]

Good housing, sanitation (water, sewerage, solid wastes, and vermin control), and personal hygiene provide long-term protection against many diseases whereas an immunization protects only against a specific disease and must be repeated to remain effective. Individual and community performance, environmental hygiene, and economic levels are also improved,[25] in addition to the quality of life. This is not to minimize the importance of immunization against the childhood diseases and epidemic control where indicated.

Typical Epidemic Control

Outbreaks of illnesses such as influenza, measles, dysentery, poliomyelitis, and other diseases can still occur. At such times the people become apprehensive and look to the health department for guidance, assurance, and information to calm their fears.

An example of the form health department assistance can take is illustrated in the precautions released June 1, 1951, in the *Illinois Health Messenger* for the control of poliomyelitis. These recommendations are quoted here, even though the disease now can be controlled, for the principles are generally applicable to outbreaks of other disease.

General Precautions during Outbreaks

1. The Illinois Department of Public Health will inform physicians and the general public as to the prevalence or increase in the incidence of the disease.
2. *Early diagnosis* is extremely important. Common early signs of polio are headache, nausea, vomiting, muscle soreness or stiffness, stiff neck, fever, nasal voice, and difficulty in swallowing, with regurgitation of liquids through the nose. Some of these symptoms may be present in several other diseases, but in the polio season they must be regarded with suspicion.
3. All children with any of these symptoms should be isolated in bed, pending diagnosis. Early medical care is extremely important.
4. Avoid undue fatigue and exertion during the polio season.
5. Avoid unnecessary travel and visiting in areas where polio is known to be prevalent.
6. Pay special attention to the practices of good personal hygiene and sanitation:
   a. Wash hands before eating.
   b. Keep flies and other insects from food.
   c. Cover mouth and nose when sneezing or coughing.

Surgical Procedures Nose, throat, or dental operations, unless required as an emergency, should not be done in the presence of an increased incidence of poliomyelitis in the community.

General Sanitation (*Including Fly Control*)

1. Although there has been no positive evidence presented for the spread of poliomyelitis by water, sewage, food, or insects, certain facts derived from research indicate that they might be involved in the spread.
   a. *Water*. Drinking water supplies can become contaminated by sewage containing poliomyelitis virus. Although no outbreaks have been conclusively traced to drinking water supplies, only water from an assuredly safe source should be used to prevent any possible hazards that might exist.
   b. *Sewage*. Poliomyelitis virus can be found for considerable periods of time in bowel discharges of infected persons and carriers and in sewage containing such bowel discharges. Proper collection and disposal facilities for human wastes are essential to eliminate the potential hazard of transmission through this means.
   c. *Food*. The infection of experimental animals by their eating of foods deliberately contaminated with poliomyelitis virus has been demon-

strated in the laboratory, but no satisfactory evidence has ever been presented to incriminate food or milk in human outbreaks. Proper handling and preparation of food and pasteurization of milk supplies should reduce the potential hazard from this source.

d. *Insects*. Of all the insects studied, only blowflies and houseflies have shown the presence of the poliomyelitis virus. This indicates that these flies might transmit poliomyelitis. It does not show how frequently this might happen; it does not exclude other means of transmission; nor does it indicate how important fly transmission might be in comparison with other means of transmission.

2. Fly eradication is an extremely important activity in maintaining proper sanitation in every community.
3. Attempts to eradicate flies by spraying effective insecticides have not shown any special effect on the incidence of polio in areas where it has been tried. Airplane spraying is not considered a practical and effective means in reducing the number of flies in a city. The best way to control flies and prevent them from spreading any disease is to eliminate fly breeding places. Eradicate flies by:
   a. Proper spreading or spraying of manure to destroy fly breeding places.
   b. Proper storage, collection, and disposal of garbage and other organic waste.
   c. Construction of all privies with fly- and rodent-proof pits.

Proper sanitation should be supplemented by use of effective insecticide around garbage cans, manure piles, privies, etc. Use effective insecticide spray around houses or porches or paint on screen to kill adult flies.

Swimming Pools

1. Unsatisfactorily constructed or operated swimming pools should be closed whether or not there is poliomyelitis in the community.
2. On the basis of available scientific information, the State Department of Public Health has no reason to expect that closure of properly equipped and operated swimming pools will have any effect on the occurrence of occasional cases of poliomyelitis in communities.
3. In communities where a case of poliomyelitis has been associated with the use of a swimming pool, that pool and its recirculation equipment should be drained and thoroughly cleaned. (The State Department of Public Health should be consulted about specific cleansing procedures.) After the cleaning job is accomplished, the pool is ready for reopening.
4. Excessive exertion and fatigue should be avoided in the use of the pool.
5. Swimming in creeks, ponds, and other natural waters should be prohibited if there is any possibility of contamination by sewage or too many bathers.

Summer Camps Summer camps present a special problem. The continued operation of such camps is contingent on adequate sanitation, the extent of crowding in quarters, the prevalence of the disease in the community, and the availability of medical supervision. Full information is available from the Illinois Department of Public Health to camp operators and should be requested by the latter.

1. Children should not be admitted from areas where outbreaks of the disease are occurring.
2. Children who are direct contacts to cases of polio should not be admitted.
3. The retention of children in camps where poliomyelitis exists has not been shown to increase the risk of illness with polio. Furthermore, return of infected children to their homes may introduce the infection to that community if it is not already infected. Similarly, there will be no introduction of new contacts to the camp and supervised curtailment of activity will be carried out, a situation unduplicated in the home. This retention is predicated upon adequate medical supervision.
4. If poliomyelitis occurs in a camp, it is advisable that children and staff remain there (with the exception of the patient, who may be removed with consent of the proper health authorities). If they do remain:
   a. Provide daily medical inspection for all children for two weeks from occurrence of last case.
   b. Curtail activity on a supervised basis to prevent overexertion.
   c. Isolate all children with fever or any suspicious signs or symptoms.
   d. Do not admit new children.

Schools

1. Public and private schools should not be closed during an outbreak of poliomyelitis, nor their opening delayed except under extenuating circumstances and then only upon recommendation of the Illinois Department of Health.
2. Children in school are restricted in activity and subject to scrutiny for any signs of illness. Such children would immediately be excluded and parents urged to seek medical attention.
3. Closing of schools leads to unorganized, unrestricted, and excessive neighborhood play. Symptoms of illness under such circumstances frequently remain unobserved until greater spread of the infection has occurred.
4. If poliomyelitis occurs or is suspected in a school:
   a. Any child affected should immediately be sent home with advice to the parents to seek medical aid, and the health authority notified.
   b. Classroom contacts should be inspected daily for any signs or symptoms of illness and excluded if these are found.

Hospitals

1. There is no reason for exclusion of poliomyelitis cases from general hospitals if isolation is exercised; rather, such admissions are necessary because of the need for adequate medical care of the patient.
2. Patients should be isolated individually or with other cases of poliomyelitis in wards.
3. Suspect cases should be segregated from known cases until diagnosis is established.
4. The importance of cases to hospitals in a community where poliomyelitis is not prevalent has not been demonstrated to affect the incidence of the disease in the hospital community.

Recreational Facilities

1. Properly operated facilities for recreation should not be closed during outbreaks of poliomyelitis.
2. Supervised play is usually more conducive to restriction of physical activities in the face of an outbreak.
3. Playground supervisors should regulate activities so that overexertion and fatigue are avoided.

RESPIRATORY DISEASES

Definition

The respiratory diseases are a large group of diseases spread by discharges from the mouth, nose, throat, or lungs of an infected individual. The disease-producing organisms are spread by coughing, sneezing, talking, spitting, dust, and direct contact, as in kissing, eating contaminated food, and using contaminated eating and drinking utensils or common towels, drinking glasses, and toys. Included are the diseases associated with the contaminants in indoor and outdoor polluted air.

A historical note is of interest. Robert Koch (1843–1910), who discovered the cause of anthrax, is perhaps best known for his work on tuberculosis (TB). On March 24, 1882, Koch announced that he had discovered the tubercle bacillus, the cause of TB. In 1884 he expounded *Koch's postulates*, which were basic to the studies of all infectious diseases in helping prove the cause.[26] He had

1. observed the bacillus in association with all cases of the disease,
2. grown the organism outside the body of the host, and
3. reproduced the disease in a susceptible host inoculated with a pure culture of the isolated organism.

Although the postulates helped advance the cause of public health for many years, it is now recognized that there are usually multiple factors involved before disease occurs, such as dose and natural resistance.

Treatment for TB has progressed from bed rest, special diets and fresh air, through pneumothorax and other lung-collapse procedures and surgical resection, to specific chemotherapy. With combinations of modern drugs properly administered, TB is now virtually 100 percent curable, although cases with multidrug-resistant strains of TB (MDR-TB) are rising. The death rate was 202 per 100,000 in 1900, 46 in 1940, and 0.8 in 1980.[27] However, the number of new cases increased from 1985 to 1992 by 20 percent as funding for TB control was reduced and cases of human immunodeficiency virus/

acquired immunodeficiency syndrome (HIV/AIDS) were rising along with drug-resistant strains of TB.[27] In developing countries, it is estimated that as many as 10 million cases occur annually, 2 to 3 million resulting in death.[27] The CDC's goal is the elimination of TB in the United States by the year 2010.

Group

A list of respiratory diseases and their incubation periods is provided in Table 1-6. Many are transmitted in ways other than through the respiratory tract. Scarlet fever, streptococcal sore throat, and diphtheria, for example, may also be spread by contaminated milk, particularly raw milk. Smallpox, chickenpox,

TABLE 1-6 Respiratory Diseases

Disease[a]	Communicability (days)[b]	Incubation Period (days)
Chickenpox (v)	−2–6	14–21
Coccidioidomycosis (f)	No direct transmission	7–28
Common cold (v)	1–5	$\frac{1}{2}$–3
Diphtheria (b)	14	2–5
German (rubella) measles (v)	−7–4+	14–23
Histoplasmosis (f)	No direct transmission	5–18
Infectious mononucleosis (v)	Prolonged	28–42
Influenza (v)	3	2–3
Legionellosis (b)	None	2–10
Measles (rubeola) (v)	2–4	8–13
Meningococcal meningitis (b)	—	2–10
Mumps (v)	−6–9	14–21
Pertussis (whooping cough) (b)	Inflammation–21	7–10
Plague, pneumonic (b)	During illness	2–6
Pneumonia, pneumococcal (b)	—	1–3
Poliomyelitis (v)	Days before and after onset	7–14
Psittacosis (r)	In illness possibly	4–15
Q fever (r)	Transmission rare	14–21
Scarlet fever and streptococcal sore throat (b)	10–21	1–3
Smallpox (v)[c]	1–21	7–17
Tuberculosis (b)	Extended	28–84

[a] Abbreviations: b, bacteria; f, fungus; r, rickettsias, airborne; v, virus. For details, see A. S. Benenson, *The Control of Communicable Diseases in Man,* 15th ed., American Public Health Association, Washington, DC, 1990.

[b] Period from onset of symptoms.

[c] Declared by WHO officially "eradicated" in 1978, if no new cases discovered.

mumps, infectious mononucleosis, meningococcal meningitis, and others may also be transmitted by contact with infected persons or items they have used. Eye irritations and emphysema are associated with air pollution.

Control

When the source of a respiratory disease is an infected individual, control would logically start with that person. The individual should be taught the importance of personal hygiene and cleanliness, particularly when ill, to prevent the spread of disease. Such practices as avoiding spitting, covering up a cough or sneeze with paper tissue, washing hands frequently, and staying away from people while ill are some of the simple yet important precautions that are not always followed. Every effort should be made to detect and treat the carriers and promptly hospitalize the seriously ill. Identification of the reservoir or agent of disease and its control or elimination should be the goal. When this is impractical or not completely effective, attention should be given to control of the mode of transmission and the susceptible persons.

Measures for the prevention of respiratory diseases include avoidance of crowds and places of public assembly when indicated and immunization of susceptible persons, with care to exclude those to whom administration of a particular vaccine is contraindicated. Schedules for the use of specific vaccines are available from the Public Health Service (PHS), CDC, and state and local health departments. See Control of Susceptibles in this chapter. In the mid-1970s, vaccination programs for children's communicable diseases had succeeded so well that an antivaccine movement arose that maintained that vaccines were dangerous and unnecessary. In countries where this movement was successful, incidence of disease was 10 to 100 times higher with corresponding incidence of serious complications than countries that sustained their vaccination programs.[28] The record for adult vaccinations is even worse. At least 40,000 American adults die each year from diseases that can be prevented by vaccination.[29] The CDC is working hard to increase vaccination rates and eliminate these diseases in the United States. Travelers to areas where certain diseases are epidemic or endemic are also advised to check their immunization record with their physician.

WATER- AND FOODBORNE DISEASES

General

The disease agents spread by water and food not only incapacitate large groups of people but also sometimes result in serious disability and death. The diseases are caused by the disregard of known fundamental sanitary principles and hence are in most cases preventable. In some instances, as among the very young, the very old, and those who are critically ill with some other illness, the added strain of a water- or foodborne illness can be fatal.

The water- and foodborne diseases are sometimes referred to as the intestinal or filth diseases because they are frequently transmitted by food or water contaminated with feces. Included as foodborne diseases are those caused by poisonous plants and animals used for food, toxins produced by bacteria, and foods accidentally contaminated with chemical poisons. They are usually, but not always, characterized by diarrhea, vomiting, nausea, or fever. Symptoms may appear in susceptible persons within a few minutes, several hours, several days, or longer periods, depending on the type and quantity of deleterious material swallowed and the resistance of the individual.

Water may be polluted at its source by excreta or sewage, which is almost certain to contain pathogenic microorganisms and cause illness by draining into an improperly protected and treated surface or groundwater supply. Food may also be contaminated by unclean foodhandlers who can inoculate the food with infected excreta, pus, respiratory drippings, or other infectious discharges by careless or dirty personal habits. In addition, food (raw poultry, beef, pork) can be contaminated in processing and preparation, by unclean equipment and practices, and by flies carrying the causative organisms of such diseases as salmonellosis, dysentery, or gastroenteritis from a septic tank system or overflowing cesspool to the kitchen. The role that the fly plays, and the roach may play, in disease transmission is treated separately in Chapter 10. Briefly, then, the intestinal diseases can be transmitted by feces, fingers, insects, food, equipment, and wastewater.

Survival of Pathogens

The survival of pathogens is affected by the type of organism, the presence of other antagonistic organisms, the soil characteristics, temperature, moisture, nutrients, pH, and sunlight. Since these factors are quite variable, the survival data in Tables 1-7 and 1-8 should be used only as a guide. The amount of clay and organic matter in the soil affect the movement of pathogens, but porous soils, cracks, fissures, and channels in rocks permit pollution to travel long distances. See Chapter 3, Travel of Pollution through the Ground.

Some organisms are more resistant than others. Soil moisture of about 10 to 20 percent of saturation appears to be best for survival of pathogens; drier conditions increase die-off. Nutrients increase survival. The pH is not a major factor. Exposure to sunlight increases the death rate. Low temperatures favor survival.[30,31] The survival of pathogens in soil, on foods, and following various wastewater unit treatment processes as reported by various investigators is summarized by Bryan[32] and others.[33] Most enteroviruses pass through sewage treatment plants, survive in surface waters, and may pass through water treatment plants providing conventional treatment. But water treatment plants maintaining a free residual chlorine and low turbidity [less than 1 nephelometric turbidity unit (NTU)] in the finished water, as noted under Chlorine Treatment for Operation and Microbiological Control in Chapter 3, or using other approved disinfection treatment can accomplish satisfactory virus destruction.

TABLE 1-7 Survival of Certain Pathogens in Soil and on Plants

Organism	Media	Survial Time (days)
Ascaris ova	Soil	Up to 7 years
	Vegetables and fruits	27–35
Coliforms	Soil surface	38, greater in soil
	Vegetables	35
	Grass and clover	6–34
Cryptosporidium oocyst[a]	Moist environment	60–180
Entamoeba histolytica cysts	Soil	6–8
	Vegetables	1–3
	Water	8–40
Enteroviruses	Soil	8 or longer[b]
	Vegetables	4–6 or longer
Salmonella	Soil	1–120
	Vegetables and fruits	1–68
Salmonella typhosa	Peat soils	Up to 85, 2 years at 0°C
Shigella	Grass (raw wastewater)	42
	Vegetables	2–10
	Water containing humus	160
Tubercle bacilli	Soil	180
	Grass	10–49

Source: D. Parsons et al., "Health Aspects of Sewage Effluent Irrigation," Pollution Control Branch, British Columbia Water Resources Services, Victoria, 1975, cited by E. Epstein and R. L. Chancy, "Land Disposal of Toxic Substances and Water-Related Problems," *J. Water Pollut. Control Fed.,* August 1978, pp. 2037–2042.

Note: The survival of pathogens can be quite variable.

[a] A. S. Benenson (Ed.), *Control of Communicable Diseases in Man,* 15th ed., American Public Health Association, Washington, DC. 1990, p. 113.
[b] One or two years at 40°F (4°C).

Substance Dose to Cause Illness

The development of illness is dependent on the toxicity or virulence of a substance, the amount of the substance or microorganisms ingested (at one time or intermittently), and the resistance or susceptibility of the individual. The result may be an acute or long-term illness. Sometimes two or more substances may be involved to produce a synergistic, additive, or antagonistic effect. The microbial modes of disease transmission include ingestion of a pathogen or toxin in contaminated water or food, contact with an infected person or animal, or exposure to an aerosol containing the viable pathogen.

When the dose of a chemical substance administered to a series of animals is plotted against the effect produced, such as illness, if increased doses produce no increases in illnesses, the substance is said to cause "no effect." If increased doses cause increasing illnesses, the substance has "no threshold." If increased doses cause no apparent increases in illnesses at first but then

TABLE 1-8 Survival of Certain Pathogens in Water

	Survival Time[a]	
Organism	In Surface Water	In Groundwater
Coliform bacteria	—	7–8 days[b]
Cryptosporidium spp. oocyst	18+ months at 4°C	2–6 months, moist[c]
Escherichia coli	—	10–45 days[b]
Entamoeba histolytica	1 month[d]	
Enteroviruses	63–91+ days[e]	
Giardia lamblia cyst	1–2 months, up to 4[f]	
Leptospira ichterohemorrhagiae	3–9 days[g]	
Pasteurella tularensis	1–6 months[g]	
Rotaviruses and reoviruses	30 days–1+ years[e]	
Salmonella faecalis	—	15–50 days[b]
Salmonella paratyphi	—	60–70 days[b]
Salmonella typhi	1 day–2 months[g]	8–23 days[b]
Salmonella typhimurium	—	140–275 days[b]
Shigella	1–24 months[g]	10–35 days[b]
Vibrio cholerae	5–16 days[g] 34 days at 4°C[g] 21+ days frozen[g] 21 days in seawater[d]	
Viruses (polio, hepatitis, entero)	—	16–140 days[b]
Enteroviruses[h]	38 days in extended aeration sludges at 5°C, pH 6–8; 17 days in oxidation ditch sludges at 5°C, pH 6–8	
Hepatitis A[i]	1+ years at 4°C in mineral water, 300+ days at room temperature	
Poliovirus[i]	1+ years at 4°C in mineral water, not detected at room temperature	

[a] Approximate. See also refs. 27–30.

[b] *Guidelines for Delineation of Wellhead Protection Areas,* Office of Ground-Water Protection, U.S. Environmental Protection Agency, Washington, DC, June 22, 1987, pp. 2–18. *Source:* Matthess et al., 1985.

[c] A. S. Benenson (Ed.), *Control of Communicable Diseases in Man,* 15th ed., American Public Health Association, Washington, DC, 1990, p. 113.

[d] B. K. Boutin, J. G. Bradshaw, and W. H. Stroup, "Heat Processing of Oysters Naturally Contaminated with *Vibrio cholerae,* Serotype 01," *J. Food Protection,* **45**(2), 169–171 (February 1982).

[e] G. Joyce and H. H. Weiser, *J. Am. Water Works Assoc.,* April 1967, pp. 491–501 (at 26° C and 8° C).

[f] S. D. Lin, "*Giardia lamblia* and Water Supply," *J. Am Water Works Assoc*., February 1985, pp. 40–47.

[g] A. P. Miller, *Water and Man's Health,* U. S. Administration for International Development, Washington, DC, 1961, reprinted 1967.

[h] G. Berg et al., "Low-Temperature Stability of Viruses in Sludges," *Appl. Environ. Microbiol.,* **54,** 839 (1988); *J. Water Pollut. Control Fed.,* June 1989, p. 1104.

[i] E. Biziagos et al., "Long-Term Survival of Hepatitis A Virus and Poliovirus Type 1 in Mineral Water," *Appl. Environ. Microbiol.,* **54,** 2705 (1988); *J. Water Pollut. Control Fed.,* June 1989, p. 1104.

continuing increased doses show increasing illnesses, the dose at which illnesses begin to increase is referred to as the substance "threshold." Below that dose is the "no-observed-effect" range. Variations between animal species must be considered.

Table 1-9 lists various microorganisms and the approximate number (dose) of organisms required to cause disease. Bryan[32] has summarized the work of numerous investigators giving the clinical response of adult humans to varying challenge doses of enteric pathogens. For example, a dose of 10^9 *Streptococcus faecalis* was required to cause illness in 1 to 25 percent of the volunteers, 10^8 *Clostridium perfringens* type A (heat resistant) to cause illness in 26 to 50 percent of the volunteers, and 10^9 *C. perfringens* type A (heat sensitive) to cause illness in 76 to 100 percent of the volunteers.

It is believed that ingestion of one pathogenic virus particle can cause infection in a susceptible host. In that case, it would appear that viral infections should be readily spread through drinking water, food, shellfish, and water contact recreational activities. Fortunately, the tremendous dilution that wastewater containing viruses usually receives on discharge to a watercourse

TABLE 1-9 Substance Dose to Cause Illness

Microorganism	Approximate Number of Organisms (Dose) Required to Cause Disease
Campylobacter jejuni[a]	10^2 or less
Coxiella burneti[b]	10^7
Cryptosporidium[c]	10^1–10^2 oocysts
Dracunculus, Ascaris, Schistosoma	1 cyst, egg, or larva
Entamoeba histolytica[d]	10–20 cysts, one in a susceptible host
Escherichia coli[b]	10^8
Giardia lamblia[c–f]	5–10^2 cysts
Salmonella typhi[b,g]	10^5–10^6
Salmonella typhimurium[g]	10^3–10^4
Shigella[b,g]	10^1–10^2
Staphylococcus aureus[b]	10^6–10^7 viable enterotoxin-producing cells per gram of food or milliliter of milk
Vibrio cholerae[b,g]	10^6–10^9
Virus, pathogenic	1 plaque-forming unit (PFU) or more

[a] Robert V. Tauxe et al., "*Campylobacter* Isolates in the United States, 1982–1986," *MMWR CDC Surveillance Summaries,* June 1988, p. 9.
[b] H. L. Dupont and R. B. Hornick, "Infectious Disease from Food," in *Environmental Problems in Medicine,* W. C. McKee (Ed.), Charles C. Thomas, Springfield, IL, 1974.
[c] R. M. Clark et al., "Analysis of Inactivation of *Giardia lamblia* by Chlorine," *J. Environ. Eng.,* February 1989, pp. 80–90.
[d] *Guidelines for Drinking Water Quality,* Vol. 2, World Health Organization, Geneva, 1984, p. 44.
[e] Up to 10 cysts from beaver to human and one to 10 cysts to cause human to human infection.
[f] R. C. Rendtorff, "Experimental Transmission of *Giardia lamblia,*" *Am. J. Hyg.,* **59,** 209 (1954).
[g] Eugene J. Gangarosa, "The Epidemiologic Basis of Cholera Control," *Bull. Pan Am. Health Org.,* **8**(3), 1974.

and the treatment given drinking water greatly reduce the probability of an individual receiving an infective dose. However, some viruses do survive and present a hazard to the exposed population. Not all viruses are pathogenic. An indication of the difficulty involved in testing for the effect of chemicals is given by Kennedy[34]: "A typical chronic toxicology test on compound X, done to meet a regulatory requirement with an adequate number of animals and an appropriate test protocol, costs $250,000 to 300,000" and requires two to three or more years to complete.

Information concerning the *acute* effect of ingestion of toxic substances is available in toxicology texts.[35]

Summary of Characteristics and Control of Water- and Foodborne Diseases

In view of the fact that the water- and foodborne diseases result in discomfort, disability, and even death, a better understanding of their source, method of transmission, control, and prevention is desirable. A concise grouping and summary of the characteristics and control of a number of these diseases are given in the summary sheets (Figure 1-2) for easy reference. Although extensive, it should not be accepted as complete or final but should be used as a starting point for further study.

Gastroenteritis is a vague disease that has also been listed. The term is often used to designate a water- or foodborne disease for which the causative agent has not been determined. Much remains to be learned about this broad catch-all classification. As the term implies, it is an inflammation of the stomach and intestines, usually with resultant diarrhea, nausea, vomiting, abdominal cramps, low-grade fever, and extreme discomfort. The purging of the gastrointestinal (GI) tract that takes place removes or inactivates the normal barriers to infection and changes the unshielded epithelium that alters the host defenses, causing malabsorption and nutrient loss. The occurrence of a large number of diarrheal cases indicates that there has been a breakdown in hygiene or in the sanitary control of water or food and may be followed by cases of salmonellosis, typhoid fever, dysentery, or other illness. There are undoubtedly many bacterial toxins, bacteria, viruses, protozoa, helminths, chemicals, and others that are not suspected or that are not examined for or discovered by available laboratory methods.

The headings in Figure 1-2 are defined here briefly. *Bacteria* are microscopic plants having round, rodlike, spiral or filamentous single-celled or noncellular bodies often aggregated into colonies or motile by means of flagella.[36] Their sizes average 0.5 to 1 μm in diameter by 4 to 20 μm in length. *Vibrios* and *spirochetes* are forms of bacteria. *Viruses* are parasitic organisms that pass through filters that retain bacteria, can only be seen with an electron microscope, and grow and multiply only inside living cells but can survive outside the host. Not all viruses are pathogenic. They are not readily detected by generally available laboratory methods. Animal enteric viruses do not ap-

Figure 1-2 Characteristics and control of water- and foodborne diseases.

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Bacterial Toxins	Botulism food poisoning	*Clostridium botulinum* and *C. parabotulinum* that produce toxin	Soil, dust, fruits, vegetables, foods, mud, fish, animal and human feces	Improperly processed canned and bottled foods containing the toxin, also other foods	Gastrointestinal pain, diarrhea or constipation, prostration, difficulty in swallowing, double vision, difficulty in respiration	2 hr–8 days, usually 12–36 hr	Boil home canned nonacid food 5 min; thoroughly cook meats, fish, foods held over. Do not taste suspected food. Store fish at ≤38°F.
	Staphylococcus food poisoning	Staphylococci that produce enterotoxin, *Staphylococcus aureus*. (Toxin is stable at boiling temperature.)	Skin, mucous membranes, pus, dust, air, sputum, and throat	Contaminated custard pastries, cooked or processed meats, poultry, dairy products, hollandaise sauce, salads, milk	Acute nausea, vomiting, and prostration; diarrhea, abdominal cramps. Usually explosive in nature, followed by rapid recovery of those afflicted.	1–6 hr or longer, average 2–4 hr	Refrigerate promptly prepared food in shallow containers at a temperature below 45°F. Discard leftover food. Avoid handling food. Educate foodhandlers in personal hygiene and sanitation.
	Clostridium perfringens food poisoning	*Clostridium perfringens* (*C. welchi*), a sporeformer. (Certain spores are heat resistant.)	Soil, gastrointestinal tract of man and animals, cattle, poultry, pigs, vermin, and wastes	Contaminated food, inadequately heated meats, including roasts, stews, beef, poultry, gravies, improperly held or cooled food	Sudden abdominal pain, then diarrhea and nausea Ingestion of large numbers of vegetative cells that grow in intestine and form spores. Cast off cell releases toxin causing symptoms.	8–22 hr, usually 10–12 hr	Cook foods thoroughly, cool rapidly, and refrigerate promptly foods not consumed. Cool foods in shallow containers, cut up large pieces. Reheat thoroughly to 165°F before reserving. Educate cooks.
	Bacillus cereus food poisoning—diarrheal type	*Bacillus cereus*, toxin heat labile	Spores found in wide variety of cereals, spices, vegetables, and milk	Inadequately refrigerated cooked foods and subsequently inadequately reheated	Diarrhea, cramps; vomiting sometimes	6–16 hr	Prevent food contamination. Cool food rapidly in shallow containers, reheat rapidly.
	Bacillus cereus food poisoning—vomiting type	*Bacillus cereus*, toxin heat stable	Same as diarrheal	Boiled and fried rice	Vomiting, diarrhea, nausea, sometimes	1–6 hr	Same as diarrhea. Some spores, if present in large numbers may survive UHT and HTST pasteurization.
Bacteria	Salmonellosis (*Salmonella* infection)	*Salmonella typhimurium*, *S. newport*, *S. enteritidis*, *S. montevideo*, others	Hogs, cattle, and other livestock, poultry, pets, eggs, carriers, powdered eggs, turtles, animal feed, and rodents	Contaminated sliced cooked meat, salads, uncooked meats, equipment, warmed-over foods, milk and milk products, water, eggs	Abdominal pain, diarrhea (persists several days), chills, fever, vomiting, and nausea	6–48 hr, usually 12–24 hr	Protect storage of food. Thoroughly cook food. Eliminate rodents, pets, and carriers. Similar measures as in *Straphylococcus*. Poultry, water, and meat sanitation. Do not eat raw eggs or ground beef. Refrigerate foods.

Bacteria

Typhoid fever	Typhoid bacillus, *Salmonella typhosa*	Feces and urine of typhoid carrier or patient	Contaminated water, milk and milk products, shellfish, and foods; flies	General infection characterized by continued fever, usually rose spots on the trunk, diarrheal disturbances	Average 14 days, usually 7-21 days	Protect and purify water supply. Pasteurize milk and milk products. Sanitary sewage disposal. Educate food-handlers. Food, fly, shellfish control. Supervise carriers. Personal hygiene. Isolate patients.
Paratyphoid fever	*Salmonella paratyphi* A, *S. schottmulleri* B, *S. hirschfeldii* C	Feces and urine of carrier or patient	Contaminated water, milk and milk products, shellfish, and foods; flies	General infection characterized by continued fever, diarrheal disturbances, sometimes rose spots on trunk, other symptoms	1-10 days for gastroenteritis; 1-3 weeks for enteric fever	Similar preventive and control measures as in typhoid fever and salmonellosis
Shigellosis (Bacillary dysentery)	Genus, *Shigella*, i.e., *flexneri, sonnei, boydii, dysenteriae*	Feces of carriers and infected persons	Contaminated water or foods, milk and milk products, flies, person-to-person	Acute onset with diarrhea, fever, tenesmus, frequent stools containing blood and mucus	1-7 days, usually less than 4 days	Food, water, sewage sanitation as in typhoid. Pasteurize milk (boil for infants). Control flies; supervise carriers. Personal hygiene.
Cholera	*Vibrio cholera, Vibrio comma*	Feces, vomitus; carriers	Contaminated water, raw foods, flies, shellfish	Diarrhea, rice-water stools, vomiting, thirst, pain, coma	A few hours–5 days, usually 3 days	Similar to typhoid. Quarantine. Isolate patients. Vaccine of limited value.
Melioidosis	*Pseudomonas pseudomallei*	Rats, guinea pigs, cats, rabbits, dogs, horses	Contact with or ingestion of contaminated excreta, soil, or water	Acute diarrhea, vomiting, high fever, delirium, mania	Less than 2 days or longer	Destroy rats. Protect food. Thoroughly cook food. Control biting insects. Personal hygiene.
Brucellosis (Undulant fever)	*Brucella melitensis*-goat, *Br. abortus*-cow, *Br. suis*-pig	Tissues, blood, milk, urine, infected animals	Raw milk from infected cows or goats; also contact with infected animals	Insidious onset, irregular fever, sweating, chills, pains in joints and muscles	5-21 days or longer	Pasteurize all milk. Eliminate infected animals. Handle infected carcasses with care.
Streptococcal infections	*Streptococcus pyogenes*	Nose, throat, mouth secretions	Contaminated salads or milk products	Sore throat and fever, sudden in onset, vomiting	1-3 days	Pasteurize all milk. Inspect contacts. Same as staphylococcus
Diphtheria	*Corynebacterium diphtheriae*	Respiratory tract, patient, carrier	Contact and milk or milk products	Acute febrile infection of tonsils, throat, and nose	2-5 days or longer	Pasteurize all milk. Disinfect utensils. Inspect contacts. Immunize.
Tuberculosis	*Mycobacterium tuberculosis* (hominis and bovis)	Respiratory tract of man, rarely cattle	Contact, also eating and drinking utensils, food, and milk	Cough, fever, fatigue, pleurisy	4-6 weeks	Pasteurize all milk, eradicate TB from cattle. Skin test. Control contacts and infected persons. Selective use of BCG.

Figure 1-2 *(Continued)*

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Bacteria	Tularemia	*Pasteurella tularensis* (*Bacterium tularense*)	Rodents, rabbits, horseflies, wood ticks, dogs, foxes, hogs	Meat of infected rabbit, contaminated water, handling wild animals	Sudden onset, with pains and fever, prostration	1–10 days, average of 3	Thoroughly cook meat of wild rabbits. Purify drinking water. Use rubber gloves (care in dressing wild animals).
	Campylobacter enteritis	*Campylobacter jejuni*	Chickens, swine, dogs, cats, man, raw milk, contaminated water	Undercooked beef, chicken, also pork Raw milk, contaminated water	Watery diarrhea, abdominal pain, fever, chills, nausea, vomiting, blood in stool	1–10 days 2–5 days average	Thoroughly cook chicken and pork and properly refrigerate. Treat water. Prevent cross-contamination.
	Vibrio parahaemolyticus gastroenteritis	*Vibrio parahaemolyticus*	Marine fish, shellfish, mud, sediment, salt water, brackish and fresh water	Raw seafoods or seafood products; inadequately cooked seafoods, and cross-contamination between raw and cooked products and sea water	Nausea, headache, chills, fever, vomiting, severe abdominal cramps, watery diarrhea, sometimes with blood	2–48 hr, usually 12–24 hr	Properly cook all seafood (shrimp 7 to 10 min). Avoid cross-contamination or contact with sea water or preparation surfaces used for uncooked foods. Refrigerate prepared seafoods promptly if not immediately served.
	Diarrhea enteropathogenic (Traveler's diarrhea)	Enteropathogenic *Escherichia coli* invasive and enterotoxigenic strains	Infected persons	Food, water, and fomites contaminated with feces, raw or undercooked meat	Fever, mucoid, occasionally bloody diarrhea; or watery diarrhea, cramps, acidosis, dehydration	12–72 hr	See Typhoid. Scrupulous hygiene and formula sanitation in hospital nursery. Food sanitation, thorough cooking.
	Yersiniosis	*Yersinia entercolitica, Yersinia pseudotuberculosis*	Wild and domestic animals, birds, man, surface water	Raw milk and milk products, seafoods, raw and rare meats, infected foodhandlers, contaminated water	Diarrhea, cramps, fever, headache, vomiting, skin rash, pseudo-appendicitis	3–7 days, usually 2–3 days	Sanitary disposal of human, dog, and cat feces. Safe water. Pasteurize milk. Food sanitation. Wash hands. Organism grows at 40°F. Thoroughly cook food.
	Listeriosis	*Listeria monocytogenes*	Goats, cattle, man, fowl, soil, water, sewage	Raw milk, contaminated pasteurized milk and milk products, contaminated vegetables	Fever, headache, nausea, vomiting, meningeal symptoms	Probably a few days–3 weeks	Avoid contact with infected persons and aborted animal fetuses, raw milk and meats. Listeria grows at 37° to 113°F.
	Vibrio vulnificus gastroenteritis	*Vibrio vulnificus*	Oysters, sea water, sediment, plankton	Raw or lightly cooked seafood, i.e., oysters	Fever, chills, vomiting, nausea, diarrhea	16 hr	Same as *Vibrio parahaemolyticus* gastroenteritis.
Rickettsias	Q Fever	*Coxiella burneti*	Dairy cattle, sheep, goats, ticks	Slaughterhouse, dairy employees, handling infected cattle; raw cow and goat milk, dust and aerosols from urine and feces	Heavy perspiration and chills, headache, malaise	2–3 weeks, average 20 days	Pasteurize milk and dairy products. Eliminate infected animal reservoir. Clean slaughterhouse and dairies. Keep down dust from dried wastes.

Viruses	Choriomeningitis, lymphocytic	*L. choriomeningitis* virus	House mice urine, feces, secretions	Contaminated food	Fever, grippe, severe headache, stiff neck, vomiting, somnolence	8–13 days	Eliminate or reduce mice. General cleanliness. Sanitation.
	Infectious hepatitis	Hepatitis A virus	Feces from infected persons	Water, food, milk, oyster, clams, contacts, person-to-person, fecal-oral	Fever, nausea, loss of appetite; possibly vomiting, fatigue, headache, jaundice	10–50 days, average 30–35 days	Sanitary sewage disposal, food sanitation, personal hygiene. Coagulate and filter water supply, and plus 0.6 mg/l free Cl_2. Obtain shellfish from certified dealers. Steam clams 4 to 6 min. Exclude ill workers.
	Gastroenteritis, viral	Rotaviruses, Norwalk agent, echo- and coxsackie-viruses, and others	Man, feces from infected foodhandler or sewage	Water, food including milk, possibly fecal-oral or fecal-respiratory route, ice, clams	Nausea, vomiting, diarrhea, abdominal pain, low fever	24–72 hr, 24–48 hr, 3–15 days	Same as Hepatitis A.
Protozoa	Amebiasis (Amebic dysentery)	*Entamoeba histolytica*	Bowel discharges of carrier, and infected person; possibly also rats	Cysts, contaminated water, foods, raw vegetables and fruits, flies, cockroaches	Insidious and undetermined onset, diarrhea or constipation, or neither; loss of appetite, abdominal discomfort; blood, mucus in stool	5 days or longer, average 2–4 weeks	Same as Shigellosis. Boil water or coagulate, set, filter through diatomite 5 gpm/ft^2, Cl_2. Usual Cl_2 and high-rate filtration not 100% effective. Slow sand filtration plus Cl_2, or conventional RSF OK. Pressure sand filtration ineffective. Also sanitation and personal hygiene.
	Giardiasis	*Giardia lamblia*	Bowel discharges of carrier and infected persons; dog, beaver	Cysts, contaminated water, food, raw fruits; also hand-to-mouth route	Prolonged diarrhea, abdominal cramps, severe weight loss, fatigue, nausea, gas, fever is unusual	6–22 days, average 9 days	Same as Amebiasis.
	Cryptosporidiosis	*Cryptosporidium* spp	Farm animals, man, fowl, cats, dogs, mice	Contaminated water, food, fecal-oral, person-to-person	Mild flulike symptoms, diarrhea, vomiting, nausea, stomach pain	2–21 days, average 2–10 days	Avoid untreated water, also ice, unpasteurized milk, salads in areas of poor hygiene.
	Balantidiasis	*Balantidium coli*	Swine, man, and other animals	Ingestion of cysts in infected feces	Mild diarrhea, nausea, dysentery, vomiting	Unknown, a few days	Same as Cryptosporidiosis, and Shigellosis.

Figure 1-2 *(Continued)*

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Spirochetes	Leptospirosis (Weil's disease) (Spirochetosis icterohemorrhagic)	*Leptospira icterohaemorrhagiae, L. hebdomadis, L. canicola, L. pomona*, others	Urine and feces of rats, swine, dogs, cats, mice, foxes, sheep	Food, water, soil contaminated with excreta or urine of infected animal, contact	Fever, rigors, headaches, nausea, muscular pains, vomiting, thirst, prostration, jaundice	4–19 days, average 9 to 10 days	Destroy rats. Protect food. Avoid polluted water. Treat abrasion of hands and arms. Disinfect utensils, treat infected dogs.
Helminths	Trichinosis (Trichiniasis)	*Trichinella spiralis*	Pigs, bears, wild boars, rats, foxes, wolves	Infected pork and pork products, bear and wild boar meat	Nausea, vomiting, diarrhea, muscle pain, swelling of face and eyelids, difficulty in swallowing	2–28 days, usually 9 days	Thoroughly cook pork (150°F), pork products, bear and wild boar meat. Destroy rats. Feed hogs boiled garbage or discontinue feeding. Store meat 20 days at 5°F or 10 days at −10°F.
	Schistosomiasis (Bilharziasis)[a] (blood flukes)	*Schistosoma haematobium, S. mansoni, S. japonicum, S. intercalatum*	Venous circulation of man; urine, feces, dogs, cats, pigs, cattle, horses, field mice, wild rats, water buffalo	Cercariae-infested drinking and bathing water (lakes and coastal sea waters)	Dysenteric or urinary symptoms, rigors, itching on skin, dermatitis; carrier state 1 to 2 years and up to 25 years. Swimmer's itch schistosomes do not mature in man.	4–6 weeks or longer	Avoid infested water for drinking or bathing; coagulation, sedimentation, and filtration plus Cl_2 1 mg/l; boil water; impound water 48 hr, Cl_2. Slow sand filtration plus Cl_2. 1 mg/l $CuSO_4$ to kill cercariae and 20 mg/l to kill snails. Drug treatment available.
	Ascariasis (intestinal roundworm)	*Ascaris lumbricoides*	Small intestine of man, gorilla, ape	Contaminated food, water; sewage	Worm in stool, abdominal pain, skin rash, protuberant abdomen, nausea, large appetite	About 2 months	Personal hygiene, sanitation.[b] Boil drinking water in endemic areas. Sanitary excreta disposal.
	Echinococcosis (Hydatidosis)	*Echinococcus granulosus*, dog tapeworm	Dogs, sheep, wolves, dingoes, swine, horses, monkeys	Contaminated food and drink; hand to mouth; contact with infected dogs	Cysts in tissues: liver, lung, kidney, pelvis, may give no symptoms, may cause death	Variable, months to several years	Keep dogs out of abattoir and do not feed raw meat. Mass treatment of dogs. Educate children and adults in the dangers of close association with dogs.
	Taeniasis (pork tapeworm) (beef tapeworm)	*Taenia solium* (pork tapeworm), *T. saginata* (beef tapeworm)	Man, cattle, pigs, buffalo, possibly rats, mice	Infected meats eaten raw, food contaminated with feces of man, rats, or mice	Abdominal pain, diarrhea, convulsions, insomnia, excessive appetite	8–10 weeks	Thoroughly cook meat. Control flies. Properly dispose of excreta. Foodhandler hygiene. Use only inspected meat. Store meat as for trichinosis.
	Fish Tapeworm (broad tapeworm)	*Diphyllobothrium latum*, other	Man, frogs, dogs, cats, bears	Infected freshwater fish eaten raw	Abdominal pain, loss of weight, weakness, anemia	3–6 weeks	Thoroughly cook fish, roe, (caviar). Proper excreta disposal.
	Dracontiasis (Guinea worm disease)	*Dracunculus medinensis*, a nematode worm	Man	Water contaminated with copepods-*Cyclops*; larvae from infected persons	Blistering of feet, legs, and burning and itching of skin; fever, nausea, vomiting, diarrhea; worms from skin	About 12 months	Use only filtered or boiled water in endemic areas for drinking, or a safe well-water supply. Treat water from unsafe source with temephos, Abate®. Health education.

Helminths	Paragonimiasis (lung flukes)	*Paragonimus ringeri, P. westermani, P. kellicotti*	Respiratory and intestinal tract of man, cats, dogs, pigs, rats, wolves	Contaminated water, freshwater crabs or crayfish	Chronic cough, clubbed fingers, dull pains, diarrhea	Variable	Boil drinking water in endemic areas. Thoroughly cook freshwater crabs and crayfish.[b]
	Clonorchiasis[a] (liver flukes)	*C. sinensis, Opisthorchis felineus*	Liver of man, cats, dogs, pigs	Contaminated freshwater fish	Chronic diarrhea, night blindness	Variable	Boil drinking water in endemic areas. Thoroughly cook fish.[b]
	Fascioliasis (sheep liver flukes)	*Fasciola hepatica*	Liver of sheep	Sheep liver eaten raw	Irregular fever, pain, diarrhea	Several months	Thoroughly cook sheep liver.[b]
	Trichuriasis (whipworm)	*Trichuris trichiura*	Large intestine of man	Contaminated food, soil	No special symptoms, possibly stomach pain	Long and indefinite	Sanitation, boil water, cook food well, properly dispose feces.[b]
	Oxyuriasis (pinworm, threadworm, or enterobiasis)	*Oxyuris vermicularis*, or *Enterobius vermicularis*	Large intestine of man, particularly children	Fingers, ova-laden dust, contaminated food, water, sewage; clothing, bedding	Nasal and anal itching, diarrhea	3–6 weeks; months	Wash hands after defecation. Keep fingernails short. Sleep in cotton underwear. Sanitation.
	Fasciolopsias[a] (intestinal flukes)	*Fasciolopsis buski*	Small intestine of man, dogs, pigs	Raw freshwater plants, water, food	Stomach pain, diarrhea, greenish stools, constipation, edema	6–8 weeks	Cook or dip in boiling water roots of lotus, bamboo, water chestnut, caltrop.
	Dwarf tapeworm (rat tapeworm)	*Hymenolepis nana (diminuta)*	Man and rodents	Food contaminated with ova, direct contact	Diarrhea or stomach pain, irritation of intestine	1 month	Sanitary excreta disposal, personal hygiene, food sanitation, rodent control. Treat cases.
	Anisakiasis	Nematodes of Anisakides family	Marine mammals and fish: rockfish, salmon, cod, tuna	Contaminated fish eaten raw or undercooked	Stomach pain, nausea, vomiting, confused with appendicitis	Hours	Do not eat raw fish. Cook fish to 140°F or freeze to −4°F for 60 hr to kill larvae.
	Ergotism[c]	*Ergot*, a parasitic fungus (*Claviceps purpurea*)	Fungus of rye and occasionally other grains	Ergot-fungus contaminated meal or bread	Gangrene involving extremities, fingers, and toes; or weakness and drowsiness, headache, giddiness, painful cramps in limbs	Gradual, after prolonged use of diseased rye in food	Do not use discolored or spoiled grain (fungus grows in the grain). Meal is grayish, possibly with violet-colored specks.
	Rhubarb poisoning	Probably oxalic acid	Rhubarb	Rhubarb leaves	Intermittent cramplike pains, vomiting, convulsions, coma	2–12 hr	Do not use rhubarb leaves for food.

Figure 1-2 *(Continued)*

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Poisonous Plants and Animals	Mushroom poisoning	Phalloidine and other alkaloids; also other poisons in mushroom	Mushrooms—*Amanita phalloides* and other Amanita	Poisonous mushrooms (*Amanita phalloides*, *Amanita muscaria*, others)	Severe abdominal pain, intense thirst, retching, vomiting, profuse watery evacuations	6–15 hr or 15 min–6 hr with muscaria	Do not eat wild mushrooms; warn others. *Amanita* are very poisonous, both when raw or cooked.
	Favism[a]	Poison from *Vicia faba* bean, pollen	*Vicia faba* Plant and bean	The bean when eaten raw, also pollen	Acute febrile anemia with jaundice, passage of blood in urine	1–24 hr	Avoid eating bean, particularly when green, or inhalation of pollen. Toxin not destroyed by cooking.
	Fish poisoning	Poison in fish, ovaries and testes, roe (heat stable)	Fish: pike, carp, sturgeon roe in breeding season	Fish: tedrodon, meletta, clupea, pickerel eggs, mukimuki	Painful cramps, dyspnea, cold sweats, dilated pupils, difficulty in swallowing and breathing	30 min–2 hr or longer	Avoid eating roe during breading season. Heed local warnings concerning edible fish.
	Ciguatera poisoning	Toxin concentrated in tropical reef fish flesh, possibly from toxic dinoflagellate; also roe	Warm-water fish, possibly barracuda, snapper, grouper, amberjack, sea bass	Warm-water fish caught near shore from Pacific and Caribbean, coral reef fish	Progressive numbness, tetanuslike spasms, heavy tongue, facial stiffness; also nausea, vomiting, diarrhea, dryness of the mouth, abdominal cramps	1–8 hr, usually 3–5 hr	Avoid warm-water fish caught near shore in Pacific and Caribbean. The toxin ciguatera is not destroyed by cooking; toxin is not poisonous to fish.
	Shellfish poisoning (Paralytic)	Neurotoxin produced by *Gonyaulax catenella* and *G. tamarensis*	Clams and mussels feeding on specific dinoflagellates	Mussels and clams, associated with so-called "red tides"	Respiratory paralysis; in milder form, trembling about lips to loss of control of the extremities and neck. Fish kills and mass deaths in seabirds.	5–30 min and longer, up to 12 hr	Obtain shellfish from certified dealers and from approved areas. Monitor plankton in coastal waters. Toxin not destroyed by routine cooking.
	Scombroid fish poisoning	Scombrotoxin (histamine-like toxin)	Scombridea family primarily tuna, bluefish, amberjack	Fish that have been held at room temperature forming toxic histamine in muscle	Headache, burning mouth, nausea, vomiting, diarrhea, tingling of fingers, fever, cramps	Several minutes to 1 hr	Gut fish immediately after catch and refrigerate at 32°F or on ice. Toxin heat stable.
	Snakeroot poisoning	Trematol in snakeroot (*Eupatorium urticaefolium*)	White snakeroot jimmy weed	Milk from cows pastured on snakeroot	Weakness or prostration, vomiting, severe constipation and pain, thirst; temperature normal	Variable, repeated with use of the milk	Prevent cows from pasturing in wooded areas where snakeroot exists.
	Potato poisoning	*Solanum tuberosum*; other *Solanum*	Sprouted green potatoes	Possibly green sprouted potatoes	Vomiting, diarrhea, headache, abdominal pains, prostration	A few hours	Do not use sprouts or peel of sprouted green potatoes.
	Water-hemlock poisoning	Cicutoxin or resin from hemlock (*Cicuta maculata*)	Water hemlock	Leaves and roots of water hemlock	Nausea, vomiting, convulsions, pain in stomach, diarrhea	1–2 hr	Do not eat roots, leaves, or flowers of water hemlock.
	Antimony poisoning	Antimony	Gray-enameled cooking utensils	Foods cooked in cheap enameled pans	Vomiting, paralysis of arms	5 min–1 hour	Avoid purchase and use of poor quality gray-enameled, chipped enamel utensils.

Chemical Poisons

Arsenic poisoning	Arsenic	Arsenic compounds	Arsenic-contaminated food or water	Vomiting, diarrhea, painful tenesmus (a cumulative poison)	10 min and longer	Keep arsenic sprays, etc., locked; wash fruits, vegetables. Avoid substances with concentrations greater than 0.05 mg/l.
Cadmium poisoning	Cadmium	Cadmium-plated utensils	Acid food prepared in cadmium utensils	Nausea, vomiting, cramps, diarrhea	15–30 min	Watch for cadmium-plated utensils, racks, and destroy. Inform manufacturer.
Cyanide poisoning	Cyanide, sodium	Cyanide silver polish	Cyanide-polished silver	Dizziness, giddiness, dyspnea, palpitation, unconsciousness	Rapid	Select silver polish of known composition. Prohibit sale of poisonous polish.
Fluoride or sodium fluoride poisoning	Fluoride or sodium fluoride	Roach powder	Sodium fluoride taken for baking powder, soda, flour	Acute poisoning, vomiting, abdominal pain, convulsions; paresis of eye, face, finger muscles, and lower extremities; diarrhea	Few minutes–2 hr	Keep roach powder under lock and key; mark "Poison"; color the powder, apply with care, if use is permitted.
Lead poisoning	Lead	Lead pipe, sprays, oxides, and utensils, lead-base paints	Lead-contaminated food or acid drinks; toys, fumes, paints, drinking water	Abdominal pain, vomiting, and diarrhea (a cumulative poison), mental retardation, birth defects, fatigue, anemia	30 min and longer	Do not use lead pipe; Pb < 0.015 mg/l. Wash fruits. Label plants. Avoid using unglazed pottery. Test imported pottery. Screen child. Remove lead paint.
Mercury poisoning	Mercury—methyl mercury and other alkyl-mercury compounds	Contaminated silt, water, aquatic life	Mercury-contaminated food, fish	Fatigue, mouth numbness, loss of vision, poor coordination and gait, tremors of hands, blindness, paralysis	2–30 min or longer	Keep mercuric compound under lock and key. Do not consume: fish with concentrations of mercury more than 0.5 ppm, water with more than 0.002 ppm, food with more than 0.05 ppm. Eliminate discharges to the environment.
Methyl chloride poisoning	Methyl chloride	Refrigerant, methyl chloride	Food stored in refrigerator having leaking unit	Progressive drowsiness, stupor, weakness, nausea, vomiting, pain in abdomen, convulsions	Variable	Use nontoxic refrigerant, or ice, water, brine, dry ice.
Selenium poisoning	Selenium	Selenium-bearing vegetation	Wheat from soil containing selenium, also other plants and water	Gastrointestinal, nervous, and mental disorders; dermatitis in sunlight	Variable	Avoid semiarid selenium-bearing soil for growing of wheat, or water with more than 0.05 mg/l Se.

Figure 1-2 *(Continued)*

	Disease	Specific Agent	Reservoir	Common Vehicle	Symptoms in Brief	Incubation Period	Prevention and Control
Chemical Poisons	Zinc poisoning	Zinc	Galvanized iron	Acid food made in galvanized iron pots and utensils	Pain in mouth, throat, and abdomen followed by diarrhea	Variable, short	Do not use galvanized utensils in preparation of foods or drink, or water with more than 5.0 mg/l zinc.
	Methemo-globinemia	Nitrate nitrogen, plus nitrite	Groundwater; shallow dug wells, also drilled wells	Drinking water from wells high in nitrates	Vomiting, diarrhea, and cyanosis in infants	2–3 days	Use water with less than 45 mg/l NO_3 for drinking water and in infant formula. Properly develop and locate wells.
	Sodium nitrite poisoning	Sodium nitrite	Impure sodium nitrate and nitrite	Sodium nitrate taken for salt, cured meats	Dizziness, weakness, stomach cramps, diarrhea, vomiting, blue skin	5–30 min	Use USP sodium nitrate in curing meat. Nitrite is poisonous, keep locked.
	Copper poisoning	Copper	Copper pipes and utensils	Carbonated beverages and acid foods in prolonged contact with copper	Vomiting, weakness, diarrhea	1 hr or less	Do not prepare or store acid foods or liquids or carbonated beverages in copper containers. Cu should not exceed 0.3 mg/l. Prevent CO_2 backflow into copper lines in soft drink machines.

Source: This figure represents a summary of information selected from: 1. G. M. Dack, *Food Poisoning*, 251 pp., University of Chicago Press, 1956. 2. C. E. Dolman, "Bacterial Food Poisoning," 46 pp., *Canad. Pub. Health J. Assoc.*, 1943. 3. V. A. Getting, "Epidemiologic Aspects of Food-Borne Disease," 75 pp., *New Eng. J. Med.*, 1943. 4. F. A. Korff, "Food Establishment Sanitation in a Municipality," *Am. J. Pub. Health* **32,** 740 (1952). 5. P. Manson-Bahr, *Synopsis of Tropical Medicine*, 224 pp., Williams & Wilkins Co., Baltimore, 1943. 6. New York State Department of Health, *Health News*. 7. Miscellaneous military and civilian texts and reports. 8. R. P. Strong, *Stitt's Diagnosis, Prevention and Treatment of Tropical Diseases*, 2 vols., Blakiston Co., Philadelphia, 1942. 9. *The Control of Communicable Diseases in Man*, American Public Health Association, Washington, D.C., (Sept. 1944, Revised May 1945, 1946, 1952, 1971, 1980, 1990.) Copyright 1946, Joseph A. Salvato, Jr., MCE.) More complete characteristics, preventive and control measures, and modes of transmission, other than food and water, have been omitted for brevity as has been the statement "epidemiological study" and "education of the public" opposite each disease under the heading "Prevention and Control." Milk and milk products are considered foods. Under "Specific Agent" and "Common Vehicle" above, only the more common agents are listed.

[a] Does not originate in the U.S.

[b] Take same precautions with drinking, culinary, and bathing water as in Schistosomiasis.

[c] Many other fungi that produce toxin are associated with food and feedstuffs. The mycotoxins cause illness in humans and animals; see text. For more information see F. L. Bryan, *Diseases Transmitted by Foods*. DHEW, PHS, Atlanta, Ga., 1971, 58 p., *Procedure for the Investigation of Foodborne Disease Outbreaks*, and *Procedures to Investigate Waterborne Illness*, International Association of Milk, Food, and Environmental Sanitarians, P.O. Box 701, Ames, Ia. 50010, 1988, and Morbidity and Mortality Weekly Report(s), U.S. DHHS, PHS, CDC, Atlanta, Ga.

pear to be transmissible to humans. Their sizes average 10 to 100 nm. There are more than 100 types of human enteric viruses excreted in large numbers and released from the respiratory tract. There are at least four groups: enteroviruses (polioviruses, echoviruses, coxsackie viruses A and B, also classified as picornaviruses), adenoviruses, reoviruses, and agents of infectious hepatitis. Other types are Norwalk agent, rotaviruses, papoviruses, and astroviruses. The viral gastroenteritis organism size is 27 to 35 nm.[37] A bacteriophage is a virus that lives upon or is parasitic to bacteria. *Rickettsias* are intermediate between bacteria and viruses. They differ from bacteria in that they are obligate parasites requiring living cells for growth and differ from viruses in that they are retained by the Berkefield filter (ref. 7, p. 1498). Their sizes average about 0.45 μm. *Protozoa* are usually single-cell aerobic animal-like organisms that have a true nucleus, reproduce usually by fission, and feed mostly on microscopic plants (bacteria). Protozoa are approximately 5 to 100 μm in size. *Giardia* cysts are 8 to 18 μm in length and 5 to 12 μm in width and *Cryptosporidium* 3 to 5 μm in size. *Helminths* include intestinal worms and wormlike parasites: the roundworms (nematodes), tapeworms (cestodes), and flatworms or flukes (trematodes). The eggs are about 40 μm or larger in size.

Poisonous plants contain toxic substances that, when consumed by humans or other animals, may cause illness or even death. Poisonous animals include fish whose flesh is poisonous when eaten in a fresh and sometimes cooked state. (Poisonous flesh is not to be confused with decomposed food.) The toxic substance in some poisonous fish flesh appears to be heat stable. Chemical poisons are certain elements or compounds, usually metallic, that may cause illness or death when consumed by humans or other animals in food and water. Fungi are small plantlike organisms devoid of chlorophyll that are found in soil, rotting vegetation, and bird excreta. They include molds, mildews, yeasts, and plant pathogens called rusts (see Mycotoxins in this chapter). Fungi can utilize almost all organic matter found in nature as a food. They grow aerobically. Some are facultative anaerobes and reproduce by spore formation. (Their sizes average 10 to 100 μm.) Systemic fungal diseases are transmitted through soil, vegetation, or excreta, by contact or ingestion, and by mycotoxins produced by minute fungi (molds). Illnesses associated with the consumption of poisonous plants and animals, chemical poisons, and poisonous fungi are strictly not communicable diseases but more properly noninfectious or noncommunicable diseases. They are listed and discussed here for convenience.

Food poisoning, or foodborne intoxication, is the ingestion of toxins found in plants or animals, metabolic products produced by microorganisms, and certain chemical food additives that result in illness. *Food infection* is the ingestion of bacteria or other microorganisms and the resultant bodily response that occurs either to the organism or to the toxin generated within the body by the organism.[38]

Reservoir or Source of Disease Agents

Humans as Reservoirs Intestinal diseases occur more frequently where there are low standards of hygiene and sanitation and where there is poverty and ignorance. Contamination of food and drink either directly with human or domestic animal feces or indirectly by flies that have had contact with infected waste is usually necessary for disease transmission. A high incidence of these diseases in developed areas of the world is an indication of the lack of or faulty sanitation and shows a disregard of fundamental hygienic practices.

The feces of infected persons may be the reservoir of a broad group of intestinal diseases. (Urine is usually sterile, except for urinary schistosomiasis, typhoid, and leptospirosis carriers (ref. 33, pp. 16, 17) which are not common in developed countries.) A certain percentage of the population is always infected with one or more of the intestinal diseases. For example, the prevalence of amebic dysentery in the native populations of tropical countries varies between 10 and 25 percent and may be as high as 60 percent; shigellosis may be higher. Stoll has ventured to hazard a guess of the prevalence of helminthic infections in the world.[39] He estimates that at least 500 million persons harbor ascarids, 400 million other worms.* Actually, a person who is ill with a helminthic disease probably is infected with more than one parasite since the conditions conducive to one infection would allow additional species to be present.

The WHO estimates that 600 million people are at risk and 300 million are afflicted by schistosomiasis (bilharziasis), usually spread by wading in cercariae-infested water. In addition, it is estimated that almost a quarter of the world's population suffers from one of four water-related diseases: gastroenteritis, malaria, river blindness (onchocerciasis), or schistosomiasis.[40]

A survey of U.S., state, and territorial public health laboratories by the CDC in 1976 for frequency of diagnosis of intestinal parasitic infections in 414,820 stool specimens showed 15.6 percent contained one or more pathogenic or nonpathogenic intestinal parasites, 3.8 percent were positive for *Giardia lamblia,* 2.7 percent for *Trichuris trichiura,* 2.3 percent for *Ascaris lumbricoides,* 1.7 percent for *Enterobius vermicularis,* and 0.6 percent for *Entamoeba histolytica*.[41]

A study made at a missionary college in east central China showed that 49 percent of the students harbored parasitic worms, and a survey made in an elementary school in New Jersey showed that 23 percent of the children were infected. In 1970, Lease[42] reported on the study of day care and ele-

*WHO estimates that there were 10 to 48 million cases of dracunculiasis (guinea worm) in rural regions of Southeast Asia, Africa, and the Eastern Mediterranean in the early 1980s. This was reduced to less than 80,000 cases mostly in Africa by 1997 (WHO Fact Sheet, "Dracunculiasis Eradication," No. 98, revised March 1998, available http://www.who.int/inffs/en/fact098.html, December 2001).

mentary school programs in four counties in South Carolina involving 884 children. He found that 22.5 percent of black children harbored *Ascaris* intestinal roundworms and, of the 52 white children in the group, 13.5 percent had worms. Central sewage and water supply was lacking. The rural infection rate was higher and the infected rural child had twice the number of worms as the infected city child. A study involving 203 children six months to six years of age in St. Lucia in the Caribbean showed that infection with *T. trichiura* was 84 percent, *A. lumbricoides* 62 percent, hookworm 7 percent, and *Toxocara canis* 86 percent.[43] Since parasitic infection plus poor diet may result in serious debility and perhaps death, preventive measures, including better sanitation and hygienic practices, are essential.

The mouth, nose, throat, respiratory tract, and skin of humans are also reservoirs of microorganisms that directly cause a large group of illnesses. Staphylococci that produce enterotoxin are also found on the skin and mucous membranes, in pus, feces, dust, and air, and in unsanitary food-processing plants. They are the principal causes of boils, pimples, and other skin infections and are particularly abundant in the nose and throat of a person with a cold. It is no surprise, therefore, that staphylococcus food poisoning is one of the most common foodborne diseases. Scrupulous cleanliness in food-processing plants, in the kitchen, and among foodhandlers is essential if contamination of food with salmonellas, staphylococci, clostridia, and other microorganisms is to be prevented.

Animals as Reservoirs Swine and other animals may be reservoirs of the organisms, causing the following:

1. brucellosis (undulant fever),
2. clonorchiasis,
3. fascioliasis (intestinal fluke) and fasciolopsiasis,
4. leptospirosis,
5. paragonimiasis (lung fluke),
6. salmonella infection (salmonellosis),
7. schistosomiasis,
8. taeniasis (pork or beef tapeworm) and cysticercosis,
9. toxoplasmosis,
10. trichinosis (trichiniasis),
11. trichuriasis (whipworm),
12. tularemia, and
13. yersiniosis.

In 1948 the prevalence of trichinosis in grain-fed hogs was 0.95 percent and in garbage-fed hogs 5.7 percent.[44] Surveys in New England and the Mid-Atlantic States in 1985 found infection rates of 0.73 and 0.58 percent, respectively, in pigs compared to an estimated national rate of 0.1 percent.[45] Wild animals, including bears, boars, martens, wolverines, bobcats, and coyotes, are also carriers. Horsemeat has also been implicated as a source of infection.[46] The incidence of adult *Trichinella* infection in the United States has been declining, with only 129 cases reported in 1990.[47]

Processed meats may be considered acceptable when stamped "U.S. inspected for wholesomeness," but this is no guarantee that the product is absolutely safe; it signifies the product was processed in accordance with U.S. Department of Agriculture (USDA) specifications. This is also true of raw meat and poultry, which frequently contain salmonellas and other pathogenic organisms, even though stamped "inspected." Such raw products require hygienic handling and adequate cooking. Uncooked summer sausage (fresh ground pork, beef, and seasoning plus light smoking) and raw or partially cooked pork products should be avoided.[48]

The excreta or urine of rats or mice may include the causative organisms of the following:

1. choriomeningitis, lymphocytic;
2. *Escherichia coli* diarrhea;
3. leptospirosis (Weil's disease);
4. salmonella infection (salmonellosis);
5. staphylococcus infections and food poisoning; and
6. yersiniosis.

Because of the practical difficulty of permanently eliminating all mice and rats, the threat of contaminating food with the organisms causing the foregoing diseases is ever present. This emphasizes the additional necessity of keeping all food covered and protected.

Dust, eggs, poultry, pigs, sheep, cattle and animal feed, rabbits, rats, cats, and dogs may harbor salmonella and other causative organisms. Shelled eggs and egg powder may also contain salmonella. Salmonella food infection is common.

Food Spoilage

When fresh foods are allowed to stand at room temperature, they begin to deteriorate. The changes in the composition of the food are brought about by the action of enzymes and microorganisms, including molds and yeasts. Such factors as oxygen, sunlight, warmth, dehydration, insects, and other vermin accelerate decomposition. This shows up in the unpleasant appearance and taste of the food, the loss of freshness, and changes in the color and odor. Food that has been permitted to decompose loses much of its nutritive value. Atmospheric oxidation causes a reduction of the vitamin content and quality, a breakdown of the fats, then the proteins, to form hydrogen sulfide, ammonia, and other products of decay. Antioxidants are sometimes used to slow down food deterioration, rancidity, or discoloration due to oxidation. These include ascorbic acid, butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), citric acid, and phosphates. The Food and Drug Administration (FDA) requires that ingredient labels carry and list the antioxidants as well as their carriers.[49] Contamination, which almost always accompanies putrefaction, is dangerous. In certain instances, the microbiological activity will produce a toxin (*Staphylococcus aureus* strain) that even ordinary cooking cannot destroy. Most bacteria associated with food spoilage will grow within a wide pH range, 3.0 or 4.0 to 8.0 or 9.3. Yeasts and molds also grow within a very wide pH range, 1.5 to 8.5 or 11.0. Foods with pH values below 4.5 are usually not easily spoiled by bacteria but are more susceptible to spoilage by yeasts and molds.[50]

Ptomaine poisoning is a misnomer for food poisoning or food infection. Ptomaines are basic products of decay formed as the result of the action of bacteria on nitrogenous matter such as meat. Ptomaines in and of themselves are not considered dangerous unless toxic amines are formed due to the advanced decomposition of food. (See Table 8-3.)

Mycotoxins

Mycotoxins are poisonous chemicals produced by molds (minute fungi). High humidity and water activity (a_w) favor mycotoxin production; the amounts vary with the product. Molds and most yeasts require oxygen to grow. They grow over a very wide pH range, as noted above. Mycotoxins are hazardous to humans and animals; some are very resistant to heat and drying and can survive a temperature range of 14 to 131°F (−10–55°C). Ingestion of contaminated feed by farm animals may permit carryover of toxins into meat and milk. There are about 15 types of dangerous mycotoxins. One common type, aflatoxin, is produced by the mold *Aspergillus flavus* and other *Aspergillus* species generally found in feeds and food. It is a potential human carcinogen. Aflatoxin-producing mold growths occur at 53 to 110°F (12–43°C), although 92°F (33°C) is optimum. The mold has been detected in peanuts and peanut butter, corn, figs, cereals (wheat, barley, millet), cottonseed products, milk and milk products, and other foods that are not properly dried and stored, thereby favoring fungus contamination and growth on the food. The *Aspergillus* species may be airborne and inhaled, causing aspergillosis. Compost piles are common reservoirs and sources of infection. Fortunately, the mere presence of a mold does not automatically mean the presence of mycotoxins. Contamination may result also before harvest. Most fungal toxins, including aflatoxins, are not destroyed by boiling and autoclaving.[51] Oven roasting artificially contaminated peanuts for 30 min at 302°F (150°C) or microwave roasting for 8.5 min can destroy 30 to 45 percent of aflatoxin B_1.[52] Improperly stored leftover foods may also be a source of aflatoxins. Aflatoxins fluoresce under long-wave ultraviolet light.

Aflatoxin causes cancer in rats and is suspected to be a cause of liver cancer in humans. Mycotoxins can also damage the liver, brain, bones, and nerves with resultant internal bleeding.

A concise summary of mycotoxins and some mycotoxicoses of humans and animals is found in a report of a WHO Expert Committee with the participation of the Food and Agriculture Organization (FAO) of the United Nations,[53] a paper by Bullerman,[54] and a paper by Scott.[55] Some compounds and substances may inhibit, stimulate, or have no effect on the growth of aflatoxins.[56]

The FDA reports that it is not safe to scrape off mold and eat the remaining food, the toxins produced are not always destroyed by cooking, freezing prevents mold growth, and mold grows at refrigerator temperature although at a slower rate. The inside of refrigerators should be washed and dried regularly to keep down mold growths and musty odors; commercial deodorants are not a substitute for cleanliness. Some cheeses, such as Roquefort, Brie, Camembert, and Blue, are processed with special species of molds, similar to those from which penicillin is made, and have been consumed with safety for hundreds of years. Foods (vegetables, meats, fruits, and cheeses) with abnormal mold should be discarded.[57]*

Vehicle or Means by Which Water- and Foodborne Diseases Are Spread

The means by which water- and foodborne disease agents are transmitted to individuals include water, milk and milk products, and other foods. These vehicles are not, however, the only methods by which diseases are spread. Some, as previously discussed, are also spread through the air, some by contact with persons who are ill, some by insects, and others by contaminated hands or equipment. The discussions that follow will cover the role of water, milk and milk products, and other foods as bearers or carriers of disease-producing organisms and poisonous substances. The lack of potable water for bathing, household cleanliness, and food preparation also contributes to poor personal hygiene and sanitation and to the spread of disease.

The reporting of water- and foodborne illnesses has, with rare exceptions, been very incomplete. Various estimates have been made in the past indicating that the number reported represented only 10 to 20 percent of the actual number.

Hauschild and Bryan,[58] in an attempt to establish a better basis for estimating the number of people affected, compared the number of cases initially reported with either the number of cases identified by thorough epidemiologic investigations or the number estimated. They found that for 51 outbreaks of

*Cheese from which mold has been *properly* removed (including mold filaments deeply penetrating along the holes or eyes) is considered sound and safe.

bacterial, viral, and parasitic disease (excluding milk), the median ratio of estimated cases to cases initially reported to the local health authority, or cases known at the time an investigating team arrived on the scene, was 25 to 1. On this basis and other data, the annual food- and waterborne disease cases for 1974 to 1975 were estimated to be 1,400,000 to 3,400,000 in the United States and 150,000 to 300,000 in Canada. The annual estimate for the United States for 1967 to 1976 was 1,100,000 to 2,600,000.[58] The authors acknowledge that the method used to arrive at the estimates is open to criticism. However, it is believed that the estimates come closer to reality than the present CDC reporting would indicate, particularly to the nonprofessional. The estimates would also serve as a truer basis for justifying regulatory and industry program expenditures for water- and foodborne illness prevention, including research and quality control. The total number of foodborne illnesses in the United States has been estimated at 5 million, with a total cost of $1 billion to $10 billion per year.[59]

Historical Waterborne Disease Background

Before the development of microbiology, the specific causes of diseases were unknown. Diseases such as cholera, typhoid, typhus, and dysentery were common in the United States, Europe, and other parts of the world. Three classical waterborne disease outbreaks, before the advent of the germ theory, are summarized below.

It was not until 1854 during an Asiatic cholera epidemic in London that some light was shed on the subject. After investigation of the Broad Street well in St. James Parish, Westminster, a physician, John Snow, suspected it was the cause of the cholera; 616 people had died during a 15-week period. The death rate for St. James Parish was 220 per 10,000, compared to 9 and 33 per 10,000 in adjoining subdistricts.

Snow found that a brewery on Broad Street employing 70 workmen had no deaths. The brewery had its own well and all the workers had a daily allotment of “malt liquor.” It can be reasonably assumed that these workers did not drink any water. In contrast, at a factory at 38 Broad Street where only water from the Broad Street well was available, 18 of 200 workers died (900 per 10,000). But in a nearby workhouse, which had its own water supply in addition to the city supply, there were only 5 deaths among 535 inmates.

Snow’s investigation included a follow-up on each death. He spotted the location of each on a map with relation to the Broad Street well and inquired of the work and activities of each person, their habits and customs, and source of drinking water. The one common factor was consumption of water from the Broad Street well. With this information in hand, he convinced the Board of Guardians of St. James Parish to have the handle of the pump removed and the epidemic was brought under control.

A survey was made to determine the cause and source of the epidemic. The house at 40 Broad Street nearest the well was suspected as the source;

there had been four fatal cases of cholera at the house. A privy emptying into a cesspool, which served more like a tank, overflowed to a drain passing close to the well.

On further investigation, including excavations, it was found that the Broad Street well was a brick-lined dug well with a domed brick top 3 ft, 6 in. below the street. The well was 28 ft, 10 in. deep and 6 ft in diameter and contained 7 ft, 6 in. of water. The house drain, 12 in. wide with brick sides 12 in. high and stone slab top and bottom, passed within 2 ft, 8 in. of the brick lining of the well. The drain, on a very flat grade, was 9 ft, 2 in. above the water level in the well and led to a sewer. The mortar joints* of the well lining and the drain were completely disintegrated. It was found on inspection after excavation that the drain was like a ''sieve and through which house drainage water must have percolated for a considerable period'' into the well, as indicated by black deposits and washout of fine sand. The drain received wastewater from 40 Broad Street in addition to the overflow from a cesspool in the basement, over which there was a privy.[60]

In another study in 1854, Snow found that people in one part of London supplied by water from the River Lea, more than 38 miles upstream from London, had a low incidence of cholera, whereas the people supplied by another water system taking water from the heavily sewage-polluted Thames River opposite the center of London had a very high incidence of cholera. He compared the income, living conditions, work, and other characteristics of the people in the two areas and found that source of water was the main variable and hence the cause of the illness. The study involved approximately 300,000 people and laid the basis for future epidemiologic studies.

In still another instance, Robert Koch (1843–1910), an eminent German microbiologist, investigated in 1892 the incidence of cholera in two adjacent cities in Germany that pumped drinking water out of the Elbe River. Hamburg pumped water from a point upstream and Altona, a suburb, took water downstream from the city sewer outfalls, but the outbreak occurred in Hamburg upstream. However, the water in Altona was filtered through a slow sand filter, whereas the water in Hamburg was not. Koch isolated *Vibrio cholerae* (1884) from the polluted Elbe River, proving the relationship between polluted water and disease.† There were 8605 deaths in Hamburg, a death rate of 1342 per 100,000. The death rate in Altona was 234 per 100,000.

Water treatment has practically eliminated cholera, typhoid, and dysentery in developed areas of the world. The conquest of these and other waterborne diseases parallels the development of microbiology and sanitary engineering as well as immunization; water treatment, including chlorination, proper excreta, and wastewater disposal; and education in hygiene and public health. However, waterborne diseases still occur with viral gastroenteritis (nonspecific

*Lime mortar was commonly used.

† Filippo Pacini (1812–1883) was the first to show that *V. cholerae* caused the disease.

gastroenteritis being more common), infectious hepatitis A, and giardiasis. The absence of potable water and latrines is associated with high diarrheal illness and mortality rates among children under five in developing countries. The major concerns in developed countries today are the chronic and degenerative diseases, including those associated with the ingestion of trace amounts of toxic organic and inorganic chemicals, but it is also essential that the safeguards found effective in preventing waterborne diseases be maintained and strengthened to prevent their recurrence.

Waterborne Disease Outbreaks

Although waterborne diseases account for only a very small percentage of all human illness in the United States and other industrialized countries, this advantage can only be maintained by the continued reduction in biological and chemical pollution of our surface and groundwaters and by complete and competent treatment of drinking water. Other water-related diseases caused by insects breeding in water (malaria, onchocerciasis), water contact (schistosomiasis), inadequate water, and poor personal hygiene (scabies, trachoma) are discussed separately.

Between 1946 and 1980 a total of 672 waterborne disease outbreaks were reported with 150,475 cases. Contaminated untreated groundwater accounted for 35.3 percent of the 672 outbreaks, inadequate or interrupted treatment for 27.2 percent, distribution or network problems 20.8 percent, contaminated untreated surface water 8.3 percent, and miscellaneous 8.3 percent. Forty-four percent of the outbreaks involved noncommunity water systems and accounted for 19 percent of the cases.[61]

Weibel et al. studied the incidence of waterborne disease in the United States from 1946 to 1960.[62] They reported 22 outbreaks (10 percent) with 826 cases due to use of untreated surface water; 95 outbreaks (42 percent) with 8811 cases due to untreated groundwater; 3 outbreaks (1 percent) with 189 cases due to contamination of reservoir or cistern; 35 outbreaks (15 percent) with 10,770 cases due to inadequate control of treatment; 38 outbreaks (17 percent) with 3344 cases due to contamination of distribution system; 7 outbreaks (3 percent) with 1194 cases due to contamination of collection or conduit system; and 28 outbreaks (12 percent) with 850 cases due to miscellaneous causes—a total of 228 outbreaks with 25,984 cases.

Weibel et al.[62] reported the greatest number of outbreaks and cases in communities of 10,000 population or less. Wolman and Gorman showed that the greatest number of waterborne diseases occurred among population groups of 1000 and under and among groups from 1000 to 5000, that is, predominantly in the rural communities.[63] Between 1971 and 1978, 58 percent of the outbreaks occurred at small noncommunity water systems. The need for emphasis on water supply control and sewage treatment at small existing and new communities, as well as at institutions, resorts, and rural places, is apparent and was again confirmed in the 1970 PHS study,[64] a 1978 summary,[65] and others.[61] From 1971 to 1982, a total of 399 waterborne outbreaks with 86,050 cases of illness were reported to the Public Health Service in the United States.* Forty percent of the outbreaks occurred at community water systems, 48 percent at noncommunity systems, and 12 percent at individual systems. Thirty-one percent involved groundwater systems serving motels, hotels, camps, parks, resorts, restaurants, country clubs, schools, day-care centers, churches, factories, offices, and stores. Thirty-one percent of the total waterborne outbreaks were caused by use of contaminated untreated groundwater (wells and springs); 20 percent by inadequate or interrupted disinfection of groundwater (wells and springs); 16 percent by distribution system deficiencies (cross-connection, storage facilities, and contamination of mains and through household plumbing); 14 percent by inadequate or interrupted disinfection of surface water; 8 percent by use of contaminated untreated surface water; 4 percent by inadequate filtration, pretreatment, or chemical feed; and 7 percent by miscellaneous deficiencies.[66] In another analysis of 484 waterborne outbreaks with 110,359 cases between 1971 and 1985, the agent was bacterial in 59, parasitic in 90, viral in 40, chemical in 51, and acute gastrointestinal in 244. Community systems caused 209 outbreaks, noncommunity systems 217, and individual systems 58. Untreated groundwater and treatment deficiencies were the major causes.[67] See also Chapter 3.

Drinking water contaminated with sewage is the principal cause of waterborne diseases. The diseases that usually come to mind in this connection are bacterial and viral gastroenteritis, giardiasis, hepatitis A, shigellosis, and typhoid and paratyphoid fevers. However, because of the supervision given public water supplies and control over a lessening number of typhoid carriers, the incidence of typhoid fever has been reduced to a low residual level. Occasional outbreaks, due mostly to carriers, remind us that the disease is still a potential threat. The outbreaks reported below are also instructive.

In 1940 some 35,000 cases of gastroenteritis and 6 cases of typhoid fever resulted when about 5 million gallons of untreated, grossly polluted Genesee River water were accidentally pumped into the Rochester, New York, public water supply distribution system. A valved cross-connection between the public water supply and the polluted Genesee River firefighting supply had been unintentionally opened. In order to maintain the proper high pressure in the fire supply, the fire pumps were placed in operation and hence river water entered the potable public water supply system. The check valve was also inoperative.

At Manteno State Hospital in Illinois, 453 cases of typhoid fever were reported, resulting in 60 deaths in 1939.[68] It was demonstrated by dye and salt tests that sewage from the leaking vitrified clay tile hospital sewer line passing within a few feet of the drilled well-water supply seeped into the well. The hospital water supply consisted of four wells drilled in creviced

*From 1971 to 1988 there were 545 outbreaks with 136,333 cases (*MMWR*, March 1990, p. 11).

limestone. The state sanitary engineer had previously called the hospital administrator's attention to the dangerously close location of the well to the sewer and made several very strong recommendations over a period of eight years, but his warning went unheeded until after the outbreak. Indictment was brought against three officials, but only the director of the Department of Public Welfare was brought to trial. Although the county court found the director guilty of omission of duty, the Illinois Supreme Court later reversed the decision.

An explosive epidemic of infectious hepatitis in Delhi, India, started during the first week of December 1955 and lasted about six weeks. A sample survey showed about 29,300 cases of jaundice in a total population of 1,700,000. (The authorities estimated the total number of infections at 1,000,000.) No undue incidence of typhoid or dysentery occurred. Water was treated in a conventional rapid sand filtration plant; but raw water may have contained as much as 50 percent sewage. Inadequate chlorination (combined chlorine), apathetic operation control, and poor administration apparently contributed to the cause of the outbreak, although the treated water was reported to be well clarified and bacteriologically satisfactory.[69]

An outbreak of gastroenteritis in Riverside, California, in the early 1960s affected an estimated 18,000 persons in a population of 130,000. Epidemiologic investigation showed that all cases were carriers of *Salmonella typhimurium,* serological type B and phage type II. The water supply was implicated. There was no evidence of coliform bacteria in the distribution system, although 5 of 75 water samples were found positive for *S. typhimurium,* type B, phage II. The cause was not found in spite of an extensive investigation.[70]

In 1974 to 1975 a waterborne outbreak of giardiasis occurred in Rome, New York. About 5357 persons out of a population of 46,000 were affected. The source of water was an upland surface supply receiving only chlorine–ammonia treatment, which confirmed the inadequacy of such treatment to inactivate the *Giardia* cyst. The coliform history was generally satisfactory. Giardiasis outbreaks have also been reported in Grand County and near Estes Park, Colorado; in Camas, Washington, in 1976[71,72]; in Portland, Oregon; in the Unita Mountains of Utah[73]; in Berlin, New Hampshire, in 1976[74]; in California, Pennsylvania[75]; and Baffin Island, Canada. Between 1969 and 1976 a total of 18 outbreaks with 6198 cases were reported. An additional 5 outbreaks with approximately 1000 cases were reported in 1977. There were 42 outbreaks reported with 19,728 cases between 1965 and 1980.[76] A total of more than 90 outbreaks occurred through 1984. Acceptable turbidity and coliform tests are important for routine water quality control, but they do not ensure the absence of *Giardia* or enteric viruses; complete water treatment is necessary.

The reporting of outbreaks of waterborne giardiasis has become more common in the United States, Canada, and other countries of the world. The source of the *G. lamblia* cyst is humans, and possibly the beaver, muskrat, and other wild and domestic animals probably infected from our waste. The *Giardia* stool positive rate may range from 1 to 30 percent depending on age and the indigenous level of personal hygiene and sanitation, with the higher rate in day-care centers and institutions (ref. 3, p. 183). Infected individuals may shed 10^6 cysts per gram of stool for many years. The cyst is resistant to normal chlorination, similar to the cyst of *E. histolytica*. Conventional rapid sand filtration of surface water—including coagulation, flocculation, and sedimentation, slow sand filtration, and diatomaceous earth filtration followed by disinfection—is considered effective in removing the *Giardia* cyst.[77] Prolonged protected sedimentation and a filter press using special cellulose sheets (reverse osmosis) to remove 1-μm-size particles is also reported to be effective.[78] Pressure sand filtration is not reliable and should not be used, as the cyst penetrates the filter. Experimental results[79] show that 2.5 mg/l (free) chlorine for 10 min killed all cysts at pH 6 at a water temperature of 60°F (15°C), but 60 min was required at pH 7 and 8, and 1.5 mg/l at 77°F (25°C) in 10 min at pH 6, 7, and 8; at 42°F (5°C), 2 mg/l killed or inactivated all cysts in 10 min at pH 7 and in 30 min at pH 8. A total chlorine residual of 6.2 mg/l after 30 min at pH 7.9 and 37°F (3°C) also inactivated *G. lamblia*. A temperature of 131°F (55°C) will destroy the cyst, but boiling is advised.

Cryptosporidium, a protozoan, ingested as an oocyst and excreted in the feces, is usually spread by the fecal-oral route but has also been implicated as the cause of food- and waterborne illness.[80] It is usually overlooked and not identified. The organism is found in the fecal discharges of humans and many wild and domestic animals, including cattle, deer, muskrats, raccoons, foxes, squirrels, turkeys, pigs, goats, lambs, cats, and dogs. The oocyst, 3 to 6 μm in diameter, survives 18 months or longer at 39°F (4°C). Conventional rapid sand filtration, including coagulation, should remove 90 to 100 percent of the *Cryptosporidium*. The oocysts survive very high chlorination, but boiling water destroys the organism. More confirmatory information is needed.[81]

Legionnaires' disease is caused by *Legionella pneumophila*. Another form is Pontiac fever, which has a shorter incubation period. The organism has been readily isolated from surface waters and adjacent soils. Other sources are cooling towers and evaporative condensers, hospital hot-water systems, whirlpools, showerheads, domestic hot-water tanks, hot- and cold-water distribution systems, humidifiers, and open water storage tanks. The organism is believed to be spread by aerosols and water ingestion. It is a major problem in hospitals. Person-to-person spread has not been documented.[82] A water temperature of 68 to 114°F (20–45°C) or 104 to 122°F (40–50°C)[83] appears to be most favorable for organism survival. The critical temperature is believed to be 97°F (36°C). The organism has been found in hot-water tanks maintained at 86 to 129°F (30–54°C) but not at 160 to 172°F (71–77°C).[84] The FDA recommends a minimum temperature of 166°F (75°C).

Suggested *Legionella* control measures include 1 to 2 ppm free residual chlorine at water outlets, including daily testing; maintenance of continuous chlorination and hot water temperature; annual cleaning and disinfection of the cold-water system.[85,86] A hot water temperature at 149 to 158°F (65–70°C) has been found effective in controlling *L. pneumophila,* although a temperature of 140°F (60°C) or greater was found sufficient to kill the organism. Scalding is a potential hazard at the suggested water temperature. Four to 6 mg/l residual chlorine in the distribution system for 6 hr has been suggested, but this is difficult to maintain in hot water and may cause problems with patients having transplant surgery.[87] In view of the different findings, laboratory monitoring of the water in the distribution system for *L. pneumophila* is also suggested.

Foodborne Disease Outbreaks

Milk Raw milk (including certified) or improperly pasteurized milk, poor milk-handling and processing practices, carriers, postpasteurization contamination, and improper refrigeration have been the principal causes of the milkborne diseases.

From 1923 to 1937, inclusive, 639 milkborne disease outbreaks were reported, involving 25,863 cases and 709 deaths.[88] There was an average of 43 outbreaks involving 1724 cases and 47 deaths reported each year. Between 1938 and 1956 an average of 24 milkborne disease outbreaks per year, with 980 cases and 5 deaths, were reported to the PHS. Between 1957 and 1960 the outbreaks averaged 9 and the cases 151 per year.

There were no deaths reported between 1949 and 1960. In 1978, the PHS/FDA reported that milk and fluid milk products were associated with less than 1 percent of all foodborne disease outbreaks.[89] The dramatic decrease in the number of outbreaks, cases, and deaths was due to better equipment and more effective control over the pasteurization of milk and milk products. However, illnesses can recur if controls are relaxed, particularly if the sale of raw or improperly pasteurized milk is permitted.

Raw milk was incriminated in an outbreak of gastroenteritis involving over 500 persons in Australia in February 1976.[90] *Salmonella typhimurium* was isolated from 78 of the 273 persons investigated. Two of the cows and one of the employees were found to be excreting the same phage-type *S. typhimurium*. Certified raw milk was found to be responsible for *Salmonella dublin* infection in 70 persons in California 1981 and 1982. It is associated with a higher mortality rate than other salmonellae.[91] Chronic diarrhea in 122 persons was associated with raw milk consumption in Minnesota.[92] Three salmonella episodes of milkborne infections caused by the consumption of raw milk were reported in England during 1974 and 1975.[93] *Campylobacter jejuni* illness was associated with raw milk consumption by 23 school children.[94] Present technology cannot produce raw milk (including that listed as certified) that can be assured to be free of pathogens; only with pasteurization is there this assurance.[95] Some of the other microorganisms implicated in outbreaks caused by the consumption of raw milk or milk products are *Listeria monocytogenes, Staphylococcus aureus* (staphylococcal enterotoxin), *Streptococcus* *agalactiae, Mycobacterium tuberculosis,* and *Yersinia enterocolitica. Listeria* grows at below refrigeration temperature, making it hazardous in raw milk products (cheeses), unpasteurized milk, and pasteurized products that have been contaminated after pasteurization. *Yersinia* linked to postpasteurization contaminated milk produced in Memphis affected 17,000 people in 1982.[96]

Pasteurized milk has also been involved in outbreaks primarily due to postcontamination. *Salmonella typhimurium* was associated with post contamination of pasteurized milk in Arizona in 1978.[97] Salmonellosis has also been associated with the consumption of nonfat powdered milk.[98] The largest milk-borne outbreak on record occurred in the Chicago area in March and April of 1985. Two brands of 2 percent low-fat pasteurized milk were implicated. *Salmonella typhimurium* was found in 16,284 culture-confirmed cases resulting in at least 2 deaths and probably 12 related deaths. It was estimated that 183,000 or more persons were actually stricken. The outbreak had been preceded by at least three smaller outbreaks. Evidence pointed to milk blending via a cross-connection between a pasteurized milk transfer line and a raw milk line. Other causes such as a suction in a milk line that could draw raw milk past two valves could not be ruled out. The cross-connection was an in-plant modification. Outbreaks such as this emphasize the complexity of modern processing equipment, the importance of plan approval, the continual necessity for evaluation of plant piping systems and controls, education and training of personnel, and constant supervision and surveillance. According to a class-action suit reported in the *Baltimore Sun,* the milk company must offer 2100 people who "represent about 15 percent of all those involved in the lawsuit . . . up to $1000 plus medical and employment compensation."[99]

One of the first outbreaks of yersiniosis was reported in 1976. It was caused by milk to which chocolate syrup had been added after pasteurization.

Food Between 1938 and 1956, 4647 foodborne outbreaks with 179,773 cases and 439 deaths were reported to the PHS CDC. In 1967, 273 outbreaks were reported, with 22,171 cases and 15 deaths.

Another analysis of foodborne illnesses based on 1969 and 1970 CDC/Department of Health, Education, and Welfare (DHEW) information reported 737 outbreaks with 52,011 cases. It was found that 33.0 percent of the outbreaks occurred at restaurants, cafeterias, and delicatessens; 39.1 percent at homes; 8.7 percent at schools; 5.2 percent at camps, churches, and picnics; and 14 percent at other places. However, 48 percent of the *cases* were at schools and 28 percent at restaurants, cafeterias, and delicatessens.[100]

Bryan,[101] in a summary of foodborne diseases in the United States from 1969 to 1973, reported 1665 outbreaks with 92,465 cases. During this same period it was found that food service establishments accounted for 35.2 percent of the outbreaks; homes 16.5 percent; food-processing establishments 6.0 percent; and unknown places 42.1 percent.

In 1982, 656 foodborne outbreaks with 19,380 cases and 24 deaths were reported to the U.S. PHS CDC. The most frequently isolated bacterial pathogens were salmonella, *Staphylococcus aureus, Clostridium perfringens, Campylobacter jejuni, Clostridium botulinum,* hepatitis A virus, and Norwalk virus. The latter two viruses accounted for 21 outbreaks and 5325 cases. The most common contributing factors were (1) improper holding temperature, (2) food from an unsafe source, (3) inadequate cooking, (4) poor personal hygiene on the part of foodhandlers, and (5) contaminated equipment.[102]

In 1999, Mead et al.[103] reported on new estimates of foodborne illnesses in the United States. They found that there are several factors that complicate the surveillance of foodborne illness. First is underreporting, even of severe cases, but most especially of mild cases. Second, they found that because many pathogens can be spread by means other than food, their role in foodborne illness is often obscured. Third, some illness is caused by pathogens that have not yet been identified and so cannot be diagnosed. They point out that many of the pathogens that are tracked today, such as *Campylobacter jejuni, Escherichia coli* O157:H7, *Lysteria monocytogenes,* and *Cyclospora cayetanensis,* were not recognized as causes of foodborne illness just 22 years ago. They estimate that foodborne diseases cause approximately 76 million illnesses, 325,000 hospitalizations, and 5000 deaths in the United States each year. Known pathogens account for an estimated 14 million illnesses, 60,000 hospitalizations, and 1800 deaths each year. *Salmonella, Listeria,* and *Toxoplasma* cause more than 75 percent of deaths by known pathogens. Overall, they state that foodborne diseases appear to cause more illnesses but fewer deaths than previously reported.

An analysis of 1586 foodborne outbreaks reported to the CDC from 1977 through 1984 most frequently implicated fish and shellfish in 24.8 percent of the outbreaks; beef and pork in 23.2 percent; turkeys and chickens in 9.8 percent; potato, chicken, and other salads in 8.8 percent; and other foods in 5 percent.[104]

An analysis in Canada for the year 1979 of 825 incidents implicated meat in 23.5 percent, marine foods in 6.2 percent, poultry in 9.8 percent, dairy foods in 5.3 percent, bakery products in 8.4 percent, vegetables and fruits in 9.1 percent, Chinese foods in 5.9 percent, with 15.3 percent unknown and the remaining, other foods.[105]

Common Agent or Vehicle and Outbreak Costs *Campylobacter jejuni* is a common contaminant in a poultry-processing plant and is frequently found with salmonella.[106] Contaminated chicken has been found to be the source or vehicle of over 50 percent of the cases of *C. jejuni* enteritis.[106,107] The organism is also found in raw milk and contaminated water. *Salmonella enteriditis* outbreaks have been related to the use of raw or undercooked eggs.[108] Contaminated feed is believed to cause animal infection leading to contamination of meat and poultry products.[109]

Todd,[110] in an analysis of foodborne diseases in Canada, reported 1440 outbreaks with 14,573 cases in 1973 to 1975, 1292 outbreaks with 11,463 cases in 1978 to 1979, 791 outbreaks with 7187 cases in 1982, 752 outbreaks with 5744 cases in 1983, and 116 outbreaks with 9788 cases in 1984.[111] There were 1199 outbreaks with 49,214 cases in the United States between 1973 and 1975, 1957 outbreaks with 14,246 cases in England and Wales between 1973 and 1975, 6109 outbreaks with 182,900 cases in Japan between 1968 and 1972, and 48 outbreaks with 2500 cases in Australia between 1967 and 1971. The numbers are considered more a reflection of the efficiency of reporting rather than an indication of the problem in each country.[58] An analysis of 415 reported disease incidents with 3618 cases in the Netherlands for 1981 showed *C perfringens* as the most common agent followed by *S aureus* and salmonella.[112]

Between 1963 and 1975 there were 651 reported outbreaks of salmonellosis with 38,811 cases in the United States. Poultry, meat (beef, pork), and eggs were the three most common vehicles. Eggs were not incriminated in 1974 and 1975, probably due to hygienic processing, pasteurization,* and quality control,[113] but bulk and cracked eggs are a recurring problem as vehicles for foodborne salmonella.[108] However, more recently, it has been found that eggs can be and are contaminated in the mother hen as the egg is being formed. The FDA is now recommending that all products containing eggs are cooked or made with a pasteurized liquid egg product.[114] Gangarosa[115] reported that 23,300 cases of salmonella food poisoning (infection) were reported to the Communicable Disease Center in 1976 but that the actual number of affected Americans was about 2.5 million. Hauschild and Bryan[58] found that for a total of 26 outbreaks of salmonellosis the median ratio of estimated cases to initial human isolations of salmonella was 29.5. On this basis, the actual number of cases of human salmonellosis for the period 1969 to 1978 was estimated to be 740,000 in the United States and 150,000 in Canada annually.[58] Although estimates differ, they do show the seriousness of the problem and the need for more effective control methods. The overall national salmonellosis morbidity has remained relatively constant.[116] The average number of isolates has actually increased since 1976 except for the years 1980 and 1984.[117] Salmonellosis control involves use of salmonella-free feeds; strict hygiene in the handling and preparation of food for human consumption; education of managers, inspectors, and foodhandlers; time–temperature control in food preparation; and prohibition of antibiotics in animal feed (cattle, hogs, poultry), which may promote the growth of drug-resistant organisms that can spread to humans.

In a situation involving 142 cases of listeriosis in 1985, including 48 deaths, contaminated soft cheese was found to be the cause. Victims filed damage claims for $100 million. The manufacturer of the cheese went out of business. A jury found the manufacturer responsible, but the supplier of raw milk was exonerated. The federal investigators could not determine whether

*Pasteurization of liquid whole egg at 140°F (60.0°C) for 3.5 min and salted egg products at 146°C (63°C).

the raw milk, improper pasteurization, or postpasteurization contamination was the cause.[118] *Listeria monocytogenes* has also been found in seafood and turkey franks. Other outbreaks have been reported in Canada, Massachusetts, Los Angeles, California, and Switzerland.[119]

Four separate outbreaks of typhoid fever in England in 1963 and 1964 were traced to canned corn beef processed in Argentina in which the cans were cooled in sewage-polluted river water.[120]

The total cost of a disease outbreak is usually overlooked. For example, typhoid fever in 80 restaurant patrons consuming food contaminated by a carrier was estimated to cost $351,920. The total cost consists of patient-related medical expenses and loss of income or productivity.[121] One estimate of the annual economic impact of foodborne disease in the United States is $1 to $10 billion. If there are 5 million cases each year, the average cost per case would range from $200 to $2000.[122] The economic loss from 17 foodborne disease outbreaks and three non-illness-related food recalls was estimated at $586,752,708 (direct and indirect) with a median total cost per case of $43,667.[123] The FDA estimated (1985) that 21 to 81 million cases of diarrhea yearly are caused by foodborne pathogens. The out-of-pocket costs were estimated to be $560 million for the quarter million hospitalized and $690 million for those who saw a doctor.[124] More recently, the FDA Food Code 2001 estimates that the annual cost of foodborne illness is $10 to $83 billion annually.[125] This figure is calculated considering the increased estimation of foodborne illness by Mead et al.[103]

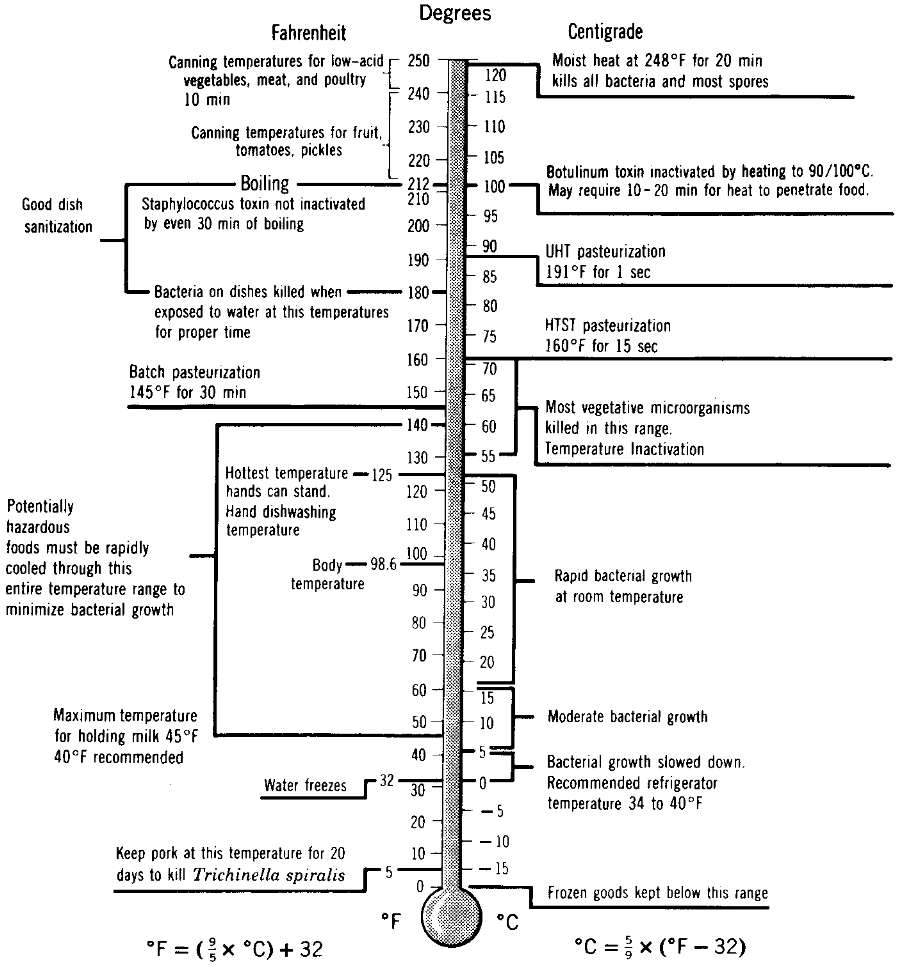
Control and Prevention of Water- and Foodborne Diseases

Design, operation, and control measures dealing with food protection are covered in Chapter 8. Water system control and details are covered in Chapter 3. A summary of water- and foodborne diseases is given in Figure 1-2.

Many health departments, particularly on a local level, are placing greater emphasis on water quality and food protection at food-processing establishments, catering places, schools, restaurants, institutions, and the home and on the training of food management and staff personnel. An educated and observant public, a systematic inspection program with established management responsibility, coupled with a selective water and food quality laboratory surveillance system and program evaluation can help greatly in making health department food protection programs more effective. It is necessary to remain continually alert as water- and foodborne diseases have not been completely eliminated; we just continue to find new ones.

Prevention of Foodborne Diseases

The application of known and well-established microbiological and sanitary principles has been effective in keeping foodborne diseases under control, but it is apparent that more effective measures are needed. Refrigeration, hygienic practices including prevention of cross-contamination with raw foods or contaminated surfaces, food preparation planning, hot or cold holding of potentially hazardous food, identification and assurance of critical temperatures for proper cooking and reheating, and general sanitation are most important. These precautions apply also to prepared frozen dinners, reconstituted foods, and drinks. See Figure 1-3 and Table 1-10. Leaving food at room temperature, inadequate cooking, and storing food in a large container account for most outbreaks. Continuous and competent surveillance is necessary to identify and eliminate procedures that might permit contamination of food or the growth



Note: Increase boiling time 5 min for each 1000 ft above sea level.
H.T.S.T. = high temperature, short time. UHT = ultra high temperature.

Figure 1–3 Food sanitation temperature chart.

TABLE 1-10 Pathogen Time–Temperature Inactivation[a]

Organism	Temperature °C	Temperature °F	Time	Source
Ascaris lumbricoides eggs	50	122	60 min	2, 4
Brucella abortus	62–63	144–145	3 min	2
Brucella suis	61	142	3 min	3
Campylobacter jejuni	60	140	10 min	
Clostridium botulinum	100	212	5 hr	2
Spores	105	221	40 min	2
	110	230	15 min	2
	120	248	6 min	2
Toxin	70–73	158–163	10 min	2
	80	176	2 min	2
	72	162	10 min	2
	65	149	30 min	2
Clostridium burnetii				
In ice cream	66	150	30 min	5
In chocolate milk	74	165	15 sec	5
In milk	63	145	30 min	5
	72	161	15 sec	5
Clostridium perfringens				
Enterotoxin		140+	80 min	6
Spores	100	212	1 hr or more	6
Vegetative cells	65	150	A few seconds	
Corynebacterium diphtheriae	55	131	45 min	3, 4
	60	140	20 min	2
Coxsackie viruses	71	160	15 sec	
	62	143	30 min	
Entamoeba histolytica	49	120	60 min	1
	45	113	A few minutes	4
	55	131	A few seconds	2
	68	154	10 min	3
Enteric viruses	63	145	60 min	1
	71	160	30 min	
Escherichia coli	60	140	15–20 min	3
	55	131	60 min	4
Giardia lamblia	55	131	A few minutes	
Micrococcus pyogenes var.	50	122	10 min	3, 4
Mycobacterium tuberculosis				
var. hominis	66	151	15–20 min	3
	60	140	20 min	2
	67	153	A few minutes	3, 4
Necator americanus	45	113	50 min	3
Salmonella spp.	60	140	15–20 min	3
	57	135	60 min	1
	55	131	60 min	4
Salmonella typhosa	55–60	131–140	30 min	3, 4
	60	140	20 min	2

TABLE 1-10 (*Continued*)

Organism	Temperature °C	Temperature °F	Time	Source
Shigella spp.	60	140	20 min	2
	55	131	60 min	3, 4
	58	136	60 min	1
Staphylococcus aureus	71	160	15 sec	
	60	140	30 min	
Streptococcus pyogenes	54	129	10 min	3
	60	140	5 min	2
Taenia saginata	55	131	A few minutes	2, 4
	71	160	5 min	3
	51	124	60 min	1
Toxoplasma gondii	70	158	A few seconds	
Trichinella spiralis larvae	55	131	A few minutes	2, 4
	60	140	A few seconds	2, 4
	62–70	144–158	10 min	3
Vibrio cholerae	45	113	60 min	1

Sources:

1. R. G. Feachem et al., *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management,* World Bank Studies in Water Supply and Sanitation, No. 2, World Bank, Washington, DC, 1978.
2. K. F. Maxcy, *Rosenau Preventive Medicine and Hygiene,* Appleton-Century-Crofts, New York, 1951, pp. 230, 255, 874, 877, 897, 901.
3. C. G. Golueke, *Composting A Study of the Process and Its Principles,* Rodale, Emmaus, PA, 1972.
4. R. Rickles, *Pollution Control,* Noyes Development, Park Ridge, NJ, 1965, p. 143.
5. J. M. Last (Ed.), *Maxcy-Rosenau Public Health and Preventive Medicine,* 11th ed., Appleton-Century-Crofts, New York, 1980, p. 937.
6. H. S. Naik and C. L. Duncan, "Thermal Inactivation of *Clostridium perfringens* Enterotoxin," *J. Food Protection,* February 1978, pp. 100–103.

[a] In the presence of moisture. To compensate for elevation, increase heating time 5 min for each 1000 ft above sea level. There is a lack of agreement among experts regarding some time—temperature relationships.

of microorganisms or the accidental addition of toxic substances from the point of preparation to the point of consumption to prevent foodborne illnesses.

The approximate optimal temperature for growth of the principal organisms associated with foodborne illnesses are salmonella 99°F (37°C) (maximal 114°F), *Staphylococcus aureus* 99°F (maximal 114°F), *Clostridium perfringens* 115°F (46°C) (maximal 112°F), and enterococci (maximal 126°F).[126]

Salmonellae are widely distributed in nature and found in many raw food products, especially poultry, beef, and swine. Pets are also sources of salmonellae. Tables and surfaces used in preparing raw poultry and other meats can serve as vehicles for the spread of salmonellae and other pathogens unless they are thoroughly cleaned and sanitized between each use. *Clostridium perfringens, Campylobacter jejuni,* and *Staphylococcus aureus* are also frequently found in samples of raw beef and on workers' hands, knives, and cutting boards as well as in soil, dust, and the intestinal tracts of humans and other warm-blooded animals.

Salmonellae may survive up to 10 months in cheddar cheese. Aging of salmonella-infected cheese 60 days, manufactured from heat-treated (nonpasteurized) milk, is therefore ineffective to prevent human illness. The use of pasteurized milk can ensure the marketing of safe milk and milk products, including elimination of *Salmonella* sp., *Listeria, Yersinia, Campylobacter,* hemorrhagic *E. coli,* and other pathogens.[127] Thorough cooking [165°F (74°C)] of raw shell eggs, raw meat and poultry, raw clams, and other foods of animal origin before consumption will prevent salmonellae infections, as will the use of pasteurized egg products in preparing eggnog, Caesar salad, hollandaise sauce, and homemade mayonnaise and ice cream.[128] Eggs should not be used raw and should be cooked thoroughly before service. Flocks and eggs have been found infected.[129] Avoid cross-contamination in food preparation.

Fish that has been fried, baked, or broiled until it flakes when pried with a fork can be assumed to be free of viable parasites. Freezing fish at −4°F (−20°C) for three to five days will also prevent illness. A temperature of 145°F (63°C) will kill parasites.[130,131]

Campylobacter jejuni is responsible for numerous foodborne outbreaks, many of which are not recognized. Infection probably starts during animal slaughtering and processing and with the concentration of animals in feedlots and brooding houses. Poor food handling, storage, and sanitation facilitate the transmission of the organism.[132]

All cooked and precooked beef and beef roasts must be heated to a minimum internal temperature of 145°F (62.7°C) to comply with USDA regulations to ensure destruction of all salmonellae. At this temperature, it would not be possible to make available "rare" roast beef. However, the USDA permits other time–temperature relations for processing of water- or steam-cooked and dry-roasted beef.[133] Studies show that salmonella-free rare roast beef can be produced, for example, at internal temperature–times ranging from 130°F (54.4°C) for 121 min to 136°F (58°C) for 32 min. The elimination of salmonella from the surface of dry oven-roasted beef (at least 10 lb uncooked in size) requires a minimum internal temperature of 130°F (54.4°C) in an oven set at 250°F (121.0°C) or above.[134,135] It should be understood that these time–temperatures are under controlled laboratory conditions, which normally do not prevail in the average restaurant. The higher time–temperatures should be used in practice to prevent possible disease transmission and ensure heat penetration.

Cooked beef roasts and turkeys, because of their size, are rarely rapidly cooled to 45°F (7°C) or less. If not consumed or sold immediately, they should be reheated as noted before use. Cooked roasts that have been rolled or punctured should be reheated to 160°F (71.1°C).* Cooked roasts that have been cut up into small pieces should be reheated to 165°F (73.9°C) because the handling introduces greater possibility of contamination. Cooked roasts that are solid muscle should be reheated to assure pasteurization of the surface of the roast.[136]

There is a danger of cooking large masses of raw meat on the outside but leaving the interior of the food underdone, thereby permitting survival of salmonellae,[137] spores introduced in handling, or those intrinsically present that can germinate and cause *C. perfringens* food poisoning.[138] However, if the meat is cooked as noted above and eaten immediately after cooking, there is usually no risk of bacterial foodborne illness.[136]

Incomplete cooking of stews, meats, gravies, and large cuts of meat that have been rolled or penetrated with skewers and failure to provide prompt and thorough refrigeration can lead to contamination with *C. perfringens. Clostridium perfringens* vegetative cells in food are destroyed by heat and thorough cooking, but spores are not completely destroyed by normal cooking. Therefore, foods contaminated with spores that are cooked and not promptly cooled can permit the germination of spores and the multiplication of vegetative cells with the danger of food poisoning on consumption. Heating *C. perfringens* enterotoxin at 140°F (60°C) in cooked turkey showed a gradual decrease in serologic activity with no detectable toxin being present after 80 min.[139]

Clostridium perfringens type A food poisoning is caused by the ingestion of foods containing large numbers of vegetative cells of enterotoxigenic strains. Many (not all) of these cells pass through the human stomach into the intestines where they are able to grow and eventually sporulate. During sporulation, the enterotoxin responsible for food-poisoning symptoms is synthesized and released. The toxin does not normally develop in the food, as in staphylococcus food poisoning and botulism, but rather forms in the intestinal tract. Adequate cooking alone will not always prevent *C. perfringens* food poisoning because the spores are resistant to heat and may survive, multiply during slow cooling, and produce a toxin under anaerobic conditions, unless the food is eaten immediately or *promptly* cooled to 45°F (7°C) or less and reheated to 165°F (74°C) for safety to destroy the vegetative cells in the food.

The enterotoxin is produced in the intestinal tract after ingestion or in food under suitable temperatures [60–120°F (16–49°C), 110–117°F (43–47°C) for optimum growth] in the absence of air. This enterotoxin is destroyed above 140°F (60°C). Bacteria in spore form are more difficult to destroy than when in vegetative form. The vegetative cell is killed at a temperature of 150°F (66°C); spores survive 212°F (100°C) for 1 hr or more. Spores are dormant, that is, inactive or not growing; they must germinate and become vegetative cells to grow. The term germination refers to the process involved when a spore changes into a vegetative cell.

*The FDA recommends 165°F (73.9°C).

Illness may also result from the presence of a bacterial toxin in the food. Certain specific strains of staphylococcis (*S. aureus*) commonly found in skin infections, hands, feces, and discharges from the nose and throat are frequently associated with food poisoning. Such staphylococci multiply under favorable temperature conditions and produce enterotoxins that are highly resistant to heat, cold, and chemicals. Common vehicles are contaminated ham, potato and chicken salads, sauces, poultry, and custard or cream-filled bakery products. The consumption of food containing sufficient toxin, therefore, even after refrigeration and reheating, may cause food poisoning.

The *C. botulinum* in improperly canned or bottled low-acid food and in improperly cooled food will also produce a toxin (neurotoxin), but this poison is destroyed by boiling and cooking. *Clostridium botulinum* is rarely found in commercially canned foods but can be a risk in home-canned foods. Between 1899 and 1981, 522 botulism outbreaks were associated with home-canned foods and 55 with commercially canned foods.[140] Botulism is also a hazard in prepared foods in which oxygen has been driven off in cooking and in which the food is shielded from oxygen and kept warm, permitting surviving spores to germinate and produce toxin, such as in potato salad, beef stew, meat pie, sauteed onions, and garlic in olive oil. *Clostridium botulinum* is reported not to grow at an a_w less than 0.93.*

Infant botulism can result from *intraintestinal* production and absorption of botulinum toxin, which is thought to result from the colonization of spores found in foods and dust and entering the gastrointestinal tract of the infant (2 to 38 weeks of age). One source of these spores is honey. Therefore, the CDC has recommended that honey not be fed to infants under 1 year of age.

The spread of diseases such as trichinosis, taeniasis, and salmonellosis associated with the consumption of foods of animal origin can be prevented by thorough cooking. Using only inspected meats, prohibiting the feeding of uncooked garbage or offal to hogs, and good sanitation will also help.

Storage of pork 10 days at −13°F (−25°C), or 20 days at −13°F if the meat is more than 6 in. thick, is adequate to kill trichina larvae. Cooking to an internal temperature of 150°F (66°C) is also adequate, although 165°F (74°C) is recommended for safety. The National Pork Producers Council recommends, and the USDA requires, that pork and pork products labeled ready to eat be frozen as noted above or cooked to 170°F (76°C). Fewer than 100 cases of trichinosis are being reported annually to the CDC. Cooking in a microwave oven does not ensure destruction of trichinae. Trichinae in polar bear meat remained viable after 24 months at 0°F (−18°C) and bear meat 81 days at 0°F.[141] See also Zoonoses and Their Spread in this chapter.

The FDA requires that ''fishery products which are not cooked throughout to 140°F (60°C) or above, must have been or must, before service or sale in

*Reduced water activity level (a_w) is the ratio of the water vapor pressure of the food to the vapor pressure of pure water at the same temperature. It is a measure of the relative availability of water (not amount) in a food on a scale of 0 to 1.00 (ref. 23, Chapter 8).

ready-to-eat form, be blast frozen to −31°F (−35°C) or below for 15 hours or regularly frozen to −10°F (−23°C) or below for 168 hours (7 days). Records which establish that fishery products were appropriately frozen on-site must be retained by the operator for 90 days.'' These temperatures assure that tapeworms, roundworms, flukes, and other parasites are killed. Fish menu items that have not been fully cooked may harbor pathogenic bacteria or viruses (FDA Code Interpretations, No. 2-403, August 21, 1987).

The essential elements of health protection in food establishments are as follows[142,143]:

1. Cooking to proper internal temperature (minimum); beef roasts 145°F (63°C), pork 165°F (74°C), eggs, fish, and lamb (145°F), poultry and all stuffed meats (165°F); holding of hot foods at 140°F (60°C), thorough reheating to 165°F of precooked or leftover (refrigerated) potentially hazardous foods, and holding potentially hazardous foods at or above 140°F or refrigerating at 45°F (7°C) or less in shallow pans (less than 4 in. food depth) until served; heating of custard and pastry filling to 165°F and cold holding at 45°F. Bring stock to a boil and keep at 140°F or above. Serve prepared foods promptly. Do not reuse leftover food that has been served. Microwave cooking of pork is not reliable, as microwave cooking can leave cold spots.
2. Adequate refrigeration capacity and prompt and proper refrigeration at 45°F or less of potentially hazardous leftover and prepared foods in shallow pans, with food thickness or depth not greater than 4 in. Cool foods to 45°F or less within 4 hrs, but do not allow foods to remain at room temperature longer than 2 hrs. A refrigeration temperature of 38 to 40°F (3–4°C) is recommended and refrigerators should have indicating thermometers.
3. Planning of food preparation to coincide as closely as possible with serving time. Serve food immediately after cooking.
4. Cleanliness and good personal hygiene habits of employees (who should be free of communicable disease or infection transmissible through food or food service). Wash hands before and after preparing each food; avoid or prevent handling of food; use utensils or plastic gloves to mix or serve food. Avoid cross-contamination; thoroughly clean and sanitize cutting boards used for raw poultry, beef, pork, lamb, or fish before using for other foods; also clean meat grinders, knives, saws, and mixing bowls.
5. Use of wholesome food and food ingredients; purchase and use of shellfish from approved safe sources. Discard swollen, leaking, deeply rusted, and seam-dented cans. Do not use raw or certified raw milk or home-canned foods. Use only pasteurized milk and milk products and commercially canned food. See Table 8-1.

6. Clean dishware, utensils, equipment, and surfaces used for food preparation; use adequate, properly constructed equipment that is easily cleaned and sanitized and is kept clean.
7. An adequate supply of potable water (hot and cold), detergents, and equipment for cleaning and sanitization of dishes and utensils; elimination of cross-connections or conditions that may permit backflow or backsiphonage of polluted or questionable water into the water supply piping or equipment.
8. Proper storage and disposal of all liquid and solid wastes.
9. Control of rodents, flies, cockroaches, and other vermin and proper use and storage of pesticides, sanitizers, detergents, solvents, and other toxic chemicals. Exclude dogs, cats, birds, and turtles from kitchen.
10. Protection of dry food stores from flooding, sewage backup, drippage, and rodent and insect depredations. Store all foods at least 6 in. above the floor. Rotate stock—first in, first out.
11. Structurally sound, clean facilities in good repair and adequately lighted and ventilated premises that can be properly cleaned.

According to *Food Code 2001* (ref. 143, Ch. 1, sec. 201.10):

> Potentially hazardous food means any food or ingredient, natural or synthetic, in a form capable of supporting (1) the rapid and progressive growth of infectious or toxigenic microorganisms or (2) the slower growth of *C. botulinum*. Included is any food of animal origin, either raw or heat-treated, and any food of plant origin which has been treated or which is raw, e.g. seed sprouts. Excluded are the following:
>
> - Air-dried hard-boiled eggs with shells intact [the FDA has classified raw shell eggs as a potentially hazardous food];
> - Foods with a water activity (a_w) value of 0.85 or less;
> - Foods with a pH level of 4.6 or below;
> - Foods, in unopened hermetically sealed containers, which have been commercially processed to achieve and maintain commercial sterility under conditions of nonrefrigerated storage and distribution; and
> - Foods for which laboratory evidence (acceptable to the regulatory authority) demonstrates that rapid and progressive growth of infectious and toxigenic microorganisms or the slower growth of *C. botulinum* cannot occur."

Open self-service food counters, salad bars, or buffets require a physical barrier such as a canopy or guard that will effectively prevent or minimize contamination by persons assisting themselves to the displayed food. In any case, the potentially hazardous food should be held either at or above 140°F (60°C) or at or below 45°F (7°C) at all times. Displayed foods remaining should not be reused.[143] (See Chapter 8.)

Since food service in private institutions, including churches and nonprofit and fraternal organizations, have been implicated in numerous foodborne outbreaks, special educational material should be developed incorporating the principles listed above and distributed to affected organizations. Caterers should be under special surveillance and permit.

Sandwiches containing potentially hazardous foods that remain unrefrigerated for more than 2 or 3 hr at room temperature can support the growth of bacteria that could lead to a foodborne disease outbreak. Prior refrigeration, or freezing where appropriate, and consumption within 4 hr will minimize the hazard. Cheese, peanut butter and jelly sandwiches, salami, bologna, and hard-boiled eggs will keep better. Canned meats and poultry also keep well. Commercial mayonnaise (pH below 4.1–4.6) will inhibit the surface growth of salmonellae and staphylococci on food, but the pH of all the ingredients or mass of the food, such as egg, meat, chicken, or potato salad, must be reduced to inhibit bacterial growth in the food. Vinegar and lemon juice can accomplish the same objective, provided the food ingredients do not neutralize the acidity of the mixture. The salads should be kept refrigerated. Hygienic food preparation practices, proper cooking, and *prompt refrigeration* of potentially hazardous foods if the food is not immediately consumed should be the guiding principles.

Prevention of Waterborne Diseases

A primary requisite for the prevention of waterborne disease is the ready availability of an adequate supply of water that is of satisfactory sanitary quality—microbiological, chemical, physical, and radiological. It is important that the water be convenient, attractive, and palatable to induce its use, for otherwise, water of doubtful quality from some nearby unprotected stream, well, or spring may be used. Where a municipal supply is available, it should be used, as such supplies are usually of satisfactory quality, ample in quantity, and under competent supervision. However, this is not always the case. Because of the excellent water service generally available in the United States and in many developed areas of the world, the people and public officials have tended to become complacent and take for granted their water supply. As a result, in some instances, funds have been diverted to other more popular causes rather than to the maintenance, operation, and upgrading of the water supply system. Safeguards to protect and maintain the integrity of a public water supply system are necessary in such instances. It is also sometimes forgotten that in developing areas of the world a convenient, safe, and adequate water supply does more than protect against numerous waterborne diseases. It also makes possible good personal hygiene, including hand washing, sanitation, household cleanliness, and clean food preparation. In addition, wading in schistosome snail infested streams is avoided as is the laborious and time-consuming task of carrying water.

Adequate drinking water statutes and regulations and surveillance of public water supply systems are necessary for their regulatory control. This is usually a state responsibility, which may be shared with local health or environmental regulatory agencies. The EPA recommendations for a minimum state program include the following[144]:

1. A drinking water statute should define the scope of state authority and responsibility with specific statutory regulations and compliance requirements. Regulations should be adopted for drinking water quality standards; water supply facility design and construction criteria; submission, review, and approval of preliminary engineering studies and detailed plans and specifications; approval of a water supply source and treatment requirements; establishment of a well construction and pump installation code; operator certification; provision for state laboratory services; and cross-connection and plumbing control regulations.
2. The surveillance of public water supply systems should involve water quality sampling—bacteriological, chemical, and radiological, also turbidity and residual chlorine; supervision of operation, maintenance, and use of approved state, utility, and private laboratory services; cross-connection control; and bottled and bulk water safety.
3. Surveillance and disease prevention are recommended with periodic, onsite fact finding as part of a comprehensive sanitary survey of each public water supply system, from the source to the consumer's tap, made by a qualified person to evaluate the ability of the water supply system to *continuously* produce an adequate supply of water of satisfactory sanitary quality. The qualified person may be a professionally trained public health, sanitary, or environmental engineer, or a sanitarian, to make sanitary surveys of the less complex water systems such as well-water supplies. The EPA suggests that the sanitary survey, as a minimum, cover quality and quantity of the source; protection of the source (including the watershed and wellhead drainage area); adequacy of the treatment facilities; adequacy of operation and operator certification; distribution storage; distribution system pressure; chlorine residual in the distribution system; water quality control tests and records; cross-connection control; and plans to supply water in an emergency. The WHO has similar suggestions.[145]

Details concerning water supply quality and quantity, source protection, design, and treatment are given in Chapter 3.

Schistosomiasis If known preventive precautions are not taken, the global prevalence of schistosomiasis, spread by freshwater snails and estimated at 300 million or more cases, is expected to increase as new impoundments and irrigation canal systems are built. Cooperation in the planning through the construction phases in endemic areas, or potentially endemic areas, between the health and water resources agencies can help reverse this trend. Water contact through swimming, wading, laundering, bathing, and collecting infested water and poor sanitation and hygiene are the major causes for the persistence and spread of schistosomiasis. Long-term schistosomiasis control would involve an appropriate combination of chemotherapy; mollusciciding; basic sanitation, including biological intervention and the supply of potable water at the village level; and socioeconomic development.[146] Mollusciciding is impractical where the water is used as a direct source of drinking water or where the water body and its tributaries are inaccessible or beyond control. In such cases chemotherapy is considered the most cost-effective control and, particularly for those environmentally and occupationally exposed, coupled with safe drinking water and sanitation facilities to minimize indiscriminate urination and defecation. In any case, education to prevent reinfection is necessary.[147,148] Heating water to 122°F (50°C) for 5 min or treating with chlorine or iodine as in drinking water and filtration through tightly woven cloth or paper (coffee) filter will remove the cercaria. Settling water for three days is also effective as cercaria survives only 48 hr, but reinfestation must be prevented. See also Control of Swimmer's Itch, Chapter 9.

BIOTERRORISM

Following the attacks in New York and Washington on September 11, 2001, letters containing *Bacillus anthracis* (anthrax) spores were mailed to various locations in the United States. This led to the deaths of at least five individuals due to inhalation anthrax and to several other cases of the less severe cutaneous form of the disease. While it remains to be determined whether these terrorist attacks were related and to identify the perpetrators, they signaled a new era in the use of biological agents as a real and present threat to mankind. The CDC and other federal agencies currently list *Bacillus anthracis* (anthrax), *Variola major* (smallpox), *C. botulinum* toxin (botulism), *Yersinia pestis* (plague), *Franciscella tularensis* (tularemia), and viral hemorrhagic fevers (Ebola virus, lassa virus) as category A agents—those that are the most likely to be used as potentially lethal weapons.[149] This section will briefly discuss two of the major agents, smallpox and anthrax. Due to the significant pathogenicity of each of these agents, individuals seeking to employ their use, especially in large amounts, would require substantial knowledge, expertise, and laboratory equipment as well as protection against accidental exposure (e.g., vaccination or antibiotics).

Smallpox

Smallpox, a disease that has killed approximately 300 million people worldwide in the twentieth century alone, may have been one of the first microbial agents to be used as a weapon. During the 1800s North American Indians were deliberately given blankets contaminated with the virus[150] by European settlers. The only remaining stocks of smallpox are currently being held in secure locations in the United States and Russia. The WHO has recently voted to delay destruction of the remaining smallpox stocks, raising the possibility of their misappropriation and use as weapons. Since immunization against smallpox was halted in 1976 following a successful worldwide eradication program, a significant number of the U.S. population would be at risk from a bioterrorism attack. Although individuals vaccinated prior to 1976 may retain immunity to smallpox, the level of protection is currently unknown (smallpox is generally fatal in about 30 percent of infections of unvaccinated individuals).[149] Given these uncertainties and the significant health risk of smallpox, the United States and other countries are currently increasing the production of smallpox vaccine. However, approximately 1 in 1 million people exhibit serious and potentially fatal complications following vaccination. Thus if the entire U.S. population were to be vaccinated, we might expect 100 to 300 deaths from the vaccine. To avoid this situation, one strategy that is being considered for a bioterrorism attack is to limit vaccination to individuals that have come in contact with the initial (index case) infected individual. Vaccination and training of primary health care workers and physicians who are most likely to see the first cases in an attack will also be an important aspect for countering the use of viruses and bacteria as weapons.

Anthrax

As noted above, anthrax is also a major concern for use in bioterrorism. Inhalation of anthrax spores is fatal in approximately 75 percent of untreated cases. Anthrax consists of several major virulence factors: a polysaccharide capsule and three separate proteins (toxins) that act in concert to disrupt immune defense systems. An anthrax vaccine is available and is generally effective, although it is currently in limited supply (and mostly dedicated to military rather than civilian use). It has also been observed to cause side effects. Antibiotics such as amoxicillin, ciprofloxacin, and doxycycline are effective against the inhalation form of anthrax; however, they must be administered prior to spore germination, which can occur within 48 to 72 hr following exposure and must be continued for several months. One particular concern is that terrorists may genetically alter common strains of anthrax to encode antibiotic resistance genes, a situation that could pose significant problems for current treatment protocols. Thus, it will be important to be able to rapidly monitor and analyze the genetic properties of different anthrax strains and to develop new antibiotics. Another promising avenue stems from the recent identification of the receptor for anthrax lethal factor toxin[151] as well as high-resolution structural determination of lethal factor[152] and edema factor.[153] These molecules represent potential targets for rational drug design of new antibacterial compounds to combat this disease.

The use of pathogens as weapons is no longer theoretical, and thus, strategies to counteract their use are currently in place or under discussion. Efforts in this arena will likely stimulate the development of improved treatments for infectious diseases in general, which will likely plague mankind for the foreseeable future.

INSECTBORNE DISEASES AND ZOONOSES

General

The diseases transmitted by arthropods, commonly known as insectborne diseases, are those diseases that are usually transmitted by biting insects from person to person or from animal to person. The ordinary housefly and roach, mechanical carriers of many disease agents, are discussed separately in Chapter 10 of the fourth edition. Zoonoses are defined as ''those diseases and infections which are naturally transmitted between vertebrate animals and man.''*[154]

Insectborne Diseases

A list of insectborne diseases together with their important reservoirs is given in Tables 1-11, 1-12, and 1-13. The list is not complete but includes some of the common as well as less known diseases. Tick- or fleaborne diseases may be spread directly by the bite of the tick or flea and indirectly by crushing the insect into the wound made by the bite. Usually mosquitoes, lice, ticks,

TABLE 1-11 Some Exotic Insectborne Diseases (Not Normally Found in the United States)

Disease	Incubation Period	Reservoir	Vector
Bartonellosis	16–22 days	Man	Sandflies (*Phlebotomus*)
Leishmaniasis			
cutaneous	Days to months	Animals, dogs	Sandflies (*Phlebotomus*)
Visceral	2–4 months	Man, dogs, cats, wild rodents	Sandflies (*Phlebotomus*)
Loiasis (*Loa loa*)	Years	Man	Chrysops. blood-sucking flies
Sandfly fever	3–4 days	Man, sandfly	Sandfly (*Phlebotomus*)
Relapsing fever	5–15 days	Man, ticks, rodents	Lice, crushed in wound; ticks
Trench fever	7–30 days	Man	Lice, crushed in wound (*Pediculus humanus*)

Source: Ref. 3.

WHO Tech. Rep. Ser.*, **378, 6 (1967) considers the definition too wide but recommends no change.

TABLE 1-12 Characteristics of Some Insectborne Disease

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control[a]
Endemic typhus (murine) (fleaborne)[b]	*Rickettsia typhi* (*R. mouseri*) also possibly *Ctenocephalides felis*	Infected rodents, *Rattus rattus* and *Rattus norvegicus,* also fleas, possibly opossums	Bite or feces of rat flea *Xenopsylla cheopis*; also possibly ingestion or inhalation of dust contaminated with flea feces or urine.	7–14 days, usually 12 days	First, elimination of rat flea by insecticide applied to rat runs, burrows, and harborages, then rat control. Spray kennels, beds, floor cracks.
Epidemic typhus (louseborne)	*Rickettsia prowazeki*	Infected persons and infected lice	Crushing infected body lice *Pediculus humanus* or feces into bite, abrasions, or eyes. Possibly louse feces in dust.	7–14 days, usually 12 days	Insecticidal treatment of clothing and bedding; personal hygiene, bathing, elimination of overcrowding. Immunization. Delousing of individuals in outbreaks.
Bubonic plague	*Pasteurella pestis,* plague bacillus (*Yersinia pestis*)	Wild rodents and infected fleas	Bite of infective flea *X. cheopis,* scratching feces into skin, handling wild animals, occasionally bedbug and human flea; pneumonic plague spread person to person.	2–6 days	Immunization. Surveys in endemic areas. Chemical destruction of flea. Community hygiene and sanitation; rat control. (Plague in wild rodents called sylvatic plague.)
Q fever	*Coxiella burneti* (*Rickettsia burneti*)	Infected wild animals (bandicoots); cattle, sheep, goats, ticks, carcasses of infected animals	Airborne rickettsias in or near premises contaminated by placental tissues; raw milk from infected cows, direct contact with infected animals or meats	2–3 weeks	Immunization of persons in close contact with rickettsias or possibly infected animals. Pasteurization of all milk at 145°F for 30 min or 161°F for 15 sec.
Rocky Mountain spotted fever	*Rickettsia rickettsii*	Infected ticks, dog ticks, wood ticks, Lone Star ticks	Bite of infected tick or crushed tick blood or feces in scratch or wound.	3–10 days	Avoid tick-infested areas and crushing tick in removal; clear harborages; insecticides.
Colorado tick	Colorado tick fever virus	Infected ticks and small animals	Bite of infected tick, *Dermacentor andersoni*	4–5 days	See Rocky Mountain spotted fever.
Tularemia	*Franciscella tularensis* (*Pasteurella tularensis*)	Wild animals, rabbits, muskrats; also wood ticks	Bite of infected flies or ticks, handling infected animals. Ingestion of contaminated water or insufficiently cooked rabbit meat.	1–10 days, usually 3 days	Avoid bites of ticks, flies. Use rubber gloves in dressing wild animals; avoid contaminated water; thoroughly cook rabbit meat.
Rickettsial-pox	*Rickettsia akari*	Infected house mice; possibly mites	Bite of infective rodent mites	10–24 days	Mouse and mite control. Apply miticides to infested areas; incinerators.

TABLE 1-12 (*Continued*)

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control[a]
Scabies	*Sarcoptes scabiei,* a mite	Persons harboring itch mite; also found in dogs, horses, swine (called mange); do not reproduce in skin of humans	Contact with persons harboring mite and use of infested garments or bedding; also during sexual contact	Several days or weeks	Personal hygiene, bathing, chemical treatment, clean laundry; machine laundering. Exclude children from school until treated. Prevent crowded living.
Trypanosomiasis, American	*Trypanosoma cruzi*	Infected persons, dogs, cats, wood rats, opossums	Fecal material of infected insect vectors, conenosed bugs in eye, nose, wounds in skin	5–14 days	Screen and rat proof dwellings; destroy vectors by insecticides and on infested domestic animals.
Scrub typhus	*Rickettsia tsutsugamushi*	Infected larval mites, wild rodents	Bite of infected larval mites	10–12 days	Eliminate rodents and mites; use repellents; clear brush.
Trypanosomiasis, African (sleeping sickness)[c]	*Trypanosoma gambiense*	Humans, wild game, and cattle	Bite of infected tsetse fly	2–3 weeks	Fly control; treatment of population; clear brush; education in prevention.
Lyme disease	*Borrella burgdorferi*	White-footed field mice in eastern United States and lizards and jack-rabbits in the West; ixodid tick feeds on and survives on white-tailed deer	Bite of infected deer tick nymph and adult	3–32 days, average 7 days	Identify and post infested areas and educate public to avoid ticks. Use repellent—deet or pemethrin. Inspect for presence of ticks, also cats and dogs, and remove without crushing. Early treatment if bitten. See Ticks, Chapter 10.

Source: Various sources and ref. 3.

[a] Investigation and survey usually precede preventive and control measures. See also Chapter 10.

[b] ‘‘The association of seropositive opossums with human cases of murine (endemic) typhus in southern California and the heavy infestation of the animals with *Ctenocephalides felis* which readily bite man, suggest that opossums and their ectoparasites are responsible for some of the sporadic cases of typhus in man.’’ W. H. Adams, R. W. Emmons, and J. E. Brooks, ‘‘The Changing Ecology of Murine (Endemic) Typhus in Southern California,’’ *Am. J. Trop. Med. Hyg.,* March 1970, pp. 311–318.

[c] African trypansomiasis, or Chagas disease, affects 16–18 million people with 90 million at risk according to the WHO, *Nation's Health,* July 1990, p. 9.

TABLE 1-13 Mosquitoborne Diseases

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Dengue or Break-bone fever[a]	Viruses of dengue fever	Infected vector mosquitoes, humans, and possibly animals, including the monkey	Bite of infected *Aedes aegypti, A. albopictus, A. scutellaris* complex	3–15 days, commonly 5–6 days.	Eliminate *Aedes* vectors and breeding places; screen rooms; use mosquito repellents.
Encephalitis, anthropodborne viral	Virus of Eastern equine, Western, St. Louis, Venezuelan equine, Japanese B, Murray Valley, West Nile, and others	Possibly wild and domestic birds and infected mosquitoes, ring-necked pheasants, rodents, bats, reptiles	Bite of infected mosquito, probably *Culiseta melanura* and *Aedes* for Eastern; *Culex tarsalis* for Western; *Culex tritaeniorhynchus* for Japanese; *Culex pipiens-quinquefasciatus* for St. Louis, also *Culex nigripalpus*	Usually 5–15 days	Destruction of larvae and breeding places of *Culex* vectors. Space spraying, screening of rooms; use mosquito bed-nets where disease present. Avoid exposure during biting hours or use repellents. Public education on control of disease. Vaccination of equines.
Filariasis[a] (elephantiasis after prolonged exposure)	Nematode worms, *Wuchereria bancrofti* and *W. malayi*	Blood of infected person bearing microfiliariae, mosquito vector	Bite of infected mosquito: *Culex fatigans, C. pipiens; Aedes polynesiensis* and several species of anopheles	3 months; microfilariae do not appear in blood until at least 9 months	Antimosquito measures. Determine insect vectors, locate breeding places, and eliminate. Spray buildings. Educate public in spread and control of disease.
Malaria[a]	*Plasmodium vivax, P. malariae, P. falciparum, P. ovale*	Humans and infected mosquitoes, found between 45° N and 45° S latitude and where average summer temperature is above 70°F or the average winter temperature is above 48°F or the average winter temperature is above 48°F	Bite of certain species of infected anopheles and injection or transfusion of blood of infected person	Average of 12 days for falciparum, 14 for vivax, 30 for malariae; sometimes delayed for 8–10 months	Residual insecticide on inside walls and places where anopheles rests. Community spraying. Screen rooms and use bed-nets in edemic areas. Apply repellents to skin and clothing. Eliminate breeding places by drainage and filling; use larvicides: oil and Paris green. Suppressive drugs, treatment, health education. *Gambusia affinis* fish for larvae control.

TABLE 1-13 (*Continued*)

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Rift Valley fever[a]	Virus of Rift Valley fever	Sheep, cattle, goats, monkeys, rodents	Probably through bite of infected mosquito or other blood-sucking arthropod; laboratory infections and butchering	Usually 5–6 days	Precautions in handling infected animals. Protection against mosquitoes in endemic areas. Care in laboratory.
Yellow fever[a]	Virus of yellow fever	Infected mosquitoes, persons, monkeys, marmosets, and probably marsupials	Bite of infected *A. aegypti*. In South Africa, forest mosquitoes, *Haemagogus spegazzinii,* and others; in East Africa, *Aedes simpsoni, A. africanus,* and others; in forests of South America, by bite of several species of *Naemagogus* and *Aedes leucocelaenus; Aedes albopictus* in Asia, Pacific, also southern United States and Brazil[b]	3–6 days	Control of *Aedes* breeding places in endemic areas. Intensive vaccination in South and East Africa. Immunization of all persons exposed because of residence or occupation. In epidemic area spray interior of all homes, apply larvicide to water containers; mass vaccination, evaluation surveys.

Source: Various sources and ref. 3.

[a] Normally not found in United States. The WHO estimates that 90 million people have lymphatic filariasis with 900 million at risk: *The Nation's Health,* July 1990, pp. 8–9.

[b] *PAHO Bulletin,* **21**(3), 314 (1987).

and other blood-sucking insects spread disease from person to person, or animal to human by biting a person or animal carrying the disease-causing organisms. By taking blood containing the disease-producing organisms, the insect is in a position to transmit the disease organism when biting another person or animal. Lately, insectborne diseases that had been confined to Africa or South America are now showing up in the United States. A good example of this is West Nile Virus. This virus, a flavivirus, causes encephalitis in susceptible individuals. It was formerly found in Africa, Southeast Asia, and the Middle East, but how now been detected in the United States. It is spread by *Culex* mosquitoes, and usually is not spread from person to person. However, there are documented cases of people obtaining the virus from an organ donor. The donor was apparently healthy before a fatal accident and the donor's organs were transplanted into four individuals who became ill with a febrile illness progressing to encephalitis 7–17 days posttransplantation. Their cerebral spinal fluid was tested and found positive for West Nile Virus. The donor's serum was also tested by a PCR test and found positive for West Nile Virus.[155] This indicates that transmission routes can change, and unusual transmissions should be considered when investigating the cause of insectborne diseases.

Since many diseases are known by more than one name, other nomenclature is given to avoid confusion. As time goes on and more information is assembled, there will undoubtedly be greater standardization of terminology. In some cases there is a distinction implied in the different names that are given to very similar diseases. The names by which the same or similar diseases are referred to are presented below.

Bartonellosis includes oroya fever, Carrion's disease, and verruga peruana. Dengue is also called dandy fever, breakbone fever, bouquet, solar, or sellar fever. Endemic typhus, fleaborne typhus, and murine typhus are synonymous. Epidemic typhus is louseborne typhus, also known as classical, European, and Old-World typhus. Brill's disease is probably epidemic typhus. Plague, black death, bubonic plague, and fleaborne pneumonic plague are the same. Filariasis or mumu, an infestation of *Wuchereria bancrofti,* may after obstruction of the lymph channels and cause elephantiasis. Loa loa and loiasis are the same filarial infection. Cutaneous leishmaniasis, espundia, uta, bubas and forest yaws, aleppo, Baghdad or Delhi boil, chiclero ulcer, and oriental sore are synonyms. Visceral leishmaniasis is also known as kala azar. Malaria, marsh miasma, remittent fever, intermittent fever, ague, and jungle fever are synonymous. Blackwater fever is believed to be associated with malaria. Onchocerciasis is also known as blinding filarial disease. Sandfly fever is the same as phlebotomus fever, three-day fever, and pappataci fever. Q fever is also known as nine-mile fever. Febris recurrens, spirochaetosis, spirillum fever, famine fever, and tick fever are terms used to designate relapsing fever. Rocky Mountain spotted fever, tick fever of the Rocky Mountains, tick typhus, black fever, and blue disease are the same. Tsutsugamushi disease, Japanese river fever, scrub typhus, and miteborne typhus are used synonymously. Trench fever is also known as five-day fever, Meuse fever, Wolhynian fever, and skin fever. Plaguelike diseases of rodents, deer-fly fever, and rabbit fever are some of the other terms used when referring to tularemia. Other forms of arthropodborne infectious encephalitis in the United States are the St. Louis type, the Eastern equine type, and the Western equine type; still other types are known. Nasal myiasis, aural myiasis, ocular myiasis or myiases, cutaneous myiases, and intestinal myiases are different forms of the same disease. Sleeping sickness, South American sleeping sickness, African sleeping sickness, Chagas' disease, Negro lethargy, and trypanosomiasis are similar diseases caused by different species of trypanosomes. Tick-bite fever is also known as Boutonneuse fever, Tobia fever, and Marseilles fever; Kenya typhus and South African tick fever are related. Scabies, "the itch," and the "seven-year itch" are the same disease.

The complete elimination of rodents and arthropods associated with disease is a practical impossibility. Humans, arthropods, and rodents, therefore, offer ready foci for the spread of infection unless controlled.

Zoonoses and Their Spread

The Pan American Health Organization lists as the major zoonoses in the Americas encephalitis (arthropodborne), psittacosis, rabies, jungle yellow fever, Q fever, spotted fever (Rocky Mountain, Brazilian, Colombian), typhus fever (murine), leishmaniasis, trypanosomiasis (Chagas' disease), anthrax, brucellosis, leptospirosis, plague, salmonellosis, tuberculosis (bovine), tularemia, hydatidosis, taeniasis (cysticercosis), and trichinosis. Others are ringworm, crytococcosis, toxoplasmosis, yersiniosis, cat scratch fever, tetanus, and tapeworm, hookworm, and roundworm infections;[156] as well as histoplasmosis, equine encephalitis, cryptosporidiosis, campylobacter infection, and Lyme disease. It will be recognized that some of these diseases are also classified with water-, food-, or insectborne diseases. A very comprehensive summary of zoonoses was prepared by Steele[156] and the Pan American Health Organization.[157]

The rodentborne diseases include rat-bite fever, Haverhill fever, leptospirosis, choriomeningitis, salmonellosis, tularemia, possibly amebiasis or amebic dysentery, rabies, trichinosis (indirectly), and tapeworm. Epidemic typhus, endemic or murine typhus, Rocky Mountain spotted fever, tsutsugamushi disease, Hantavirus[158], and others are sometimes included in this group. Although rodents are reservoirs of these diseases (typhus, spotted fever, etc.), the diseases themselves are actually spread by the bite of an infected flea, tick, or mite or the blood or feces of an infected flea or tick on broken skin, as previously discussed. Immunization with plague vaccine reduces the incidence and severity of disease.[159] Rats are also carriers of *S. aureus, E. coli, Y. enterocolitica,* and *Yersinia pseudotuberculosis*[160] as well as leptospirae and other pathogens.

Sodoku and Haverhill fevers are two types of rat-bite fever. The incubation period for both is 3 to 10 days. Contaminated milk has also been involved as the cause of Haverhill fever. The importance of controlling and destroying rats, particularly around dwellings and barns, is again emphasized.

The causative organism of leptospirosis, also known as Weil's disease, spirochetosis icterohemorrhagic, leptospiral jaundice, spirochaetal jaundice, hemorrhagic jaundice, canicola fever, mud fever, and swineherd's disease, is transmitted by the urine of infected rodents, cattle, dogs, swine, and wild animals. Direct contact or the consumption of contaminated food or water or direct contact with waters containing the leptospira may cause the infection after 4 to 19 days.

Dogs are carriers of many microorganisms and parasites that are discharged in the feces and urine and that may be transmitted to humans, particularly children. These include *G. lamblia* and *T. canis,* an ascarid roundworm (the larval stage in humans is called visceral larva migrans, a rare but serious disease if the larval stage lodges in the brain, eyes, heart, or liver). *Toxocara cati* and *Ancylostoma brazillense* are found in cats. *Ancylostoma caninum* is a canine hookworm that may affect humans. *Dipylidium caninum* and *Taenia pisiformis* are two common canine tapeworms; *Toxoplasma gondii,* a protozoa causing toxoplasmosis is also carried by cats, goats, pigs, rats, pigeons, and humans.[161] Salmonella and campylobacter bacteria can also be transmitted to humans and from humans to dogs. Dogs are the reservoir of many other diseases. Stray and pet dogs are carriers of *Brucella canis;* stray dogs have a higher rate of infection, 9 percent as compared to 1 percent for pet dogs.[162] A significant number of dogs and cats excrete the toxocara ova, and the hazard to human health is reported to be considerable.[163] General control measures include proper disposal of dog feces; avoidance of contact with the feces, such as in children's play areas; deworming of dogs; regulation of dogs in urban areas; and personal hygiene. In addition, there are the hazards associated with fleas, ticks, and rabies as well as play areas and street pollution from feces and urine. Pregnant women should exercise extreme sanitary precautions and avoid any contact.

The virus causing lymphocytic choriomeningitis (LCM) is found in the mouth and nasal secretions, urine, and feces of infected house mice, which in turn can infect guinea pigs and hamsters. The virus is probably spread by contact, bedding, or consumption of food contaminated by the discharges of an infected mouse. The disease occurs after an incubation period of 8 to 21 days. Precautions include destruction of infected mice, hamsters, and guinea pigs and burning their bodies and bedding. This is followed by cleansing of all cages with water and detergent, disinfection, rodent-proofing pet stores and animal rooms in laboratories and hospitals, and waiting one week before restocking with LCM-free animals.[164]

During 1968 to 1977, wild and domestic pigeons were associated with 13 percent (88 of 657) of the psittacosis cases in humans reported in the United States.[165]

Rodents, poultry, meat, eggs, dairy products, and livestock are sources of salmonella infection in addition to human carriers, as previously noted. It has been demonstrated that salmonellosis can be transmitted from humans to cattle and then from cattle to humans. An intensive investigation in Yorkshire, England, showed that a human carrier of *Salmonella paratyphi B* discharged his wastes via septic tank effluent to a stream that flowed through a pasture. Cows grazing in the pasture became infected, and subsequently 7 of 13 persons living or working on the farm became infected with the same organism.[166]

Melioidosis is an uncommon disease in humans. It is a disease primarily of rodents and small animals. The rat, cat, dog, horse, rabbit, and guinea pig are reservoir hosts of the disease-producing organisms. The incubation period is less than 10 days.

Tularemia may be transmitted by handling infected rodents with bruised or cut hands, particularly rabbits and muskrats, by the bite of infected deerflies, ticks, and other animals, and by drinking contaminated water. Freezing may not destroy the organism.

Trichinosis is ordinarily spread by the consumption of undercooked or raw infected pork, pork products, and, less frequently, bear or wild boar meat. The National Pork Products Council recommends that pork roasts be cooked to an internal temperature of 170°F (77°C); 165°F (74°C) has been proposed to also kill *T. gondii*.

Taeniasis includes beef tapeworm (beef measles) and pork tapeworm (pork measles). The infective larva is found in beef (*Taenia saginata*) and pork (*Taenia solium*); when consumed in the raw or partially cooked state, it develops into the beef tapeworm and pork tapeworm, respectively, in two to three months. Cysticercosis is caused by eating or drinking the pork tapeworm egg. Larval forms of the pork tapeworm develop into cysts that may locate in any organ of the human body and cause serious disability. Eating raw or undercooked beef or pork is dangerous. Cattle can contract the disease (*T. saginata*) if permitted to pasture in fields upon which human feces containing tapeworm segments or eggs have been spread. Prevention and control measures include protection of animal feed, pasture, and drinking water from human feces and wastewater (sewage) effluent. Freezing of beef carcasses at 15°F (−10°C) for 10 days and cooking beef to above 133°F (56°C) [the USDA recommends cooking to at least 140°F (60°C)] inactivates the *T. saginata* (beef tapeworm) cysticerci larvae.[167] See also Prevention of Foodborne Diseases in this chapter.

Dwarf tapeworm (*Hymenolepis nana*) is found in humans, rats, and mice and has worldwide distribution. Consumption of food and drink contaminated with their feces is the major cause of infection. The CDC reports that about 0.4 percent of over 216,000 stool samples tested in 1987 were found to contain evidence of tapeworm.[168]

In addition to the human diseases mentioned above, rats may transmit hog cholera, swine erysipelas, fowl tuberculosis, and probably hoof-and-mouth disease to livestock or domestic animals.

Anthrax, also known as woolsorter's disease, malignant pustule, and charbon, is an infectious disease principally of cattle, swine, sheep, and horses that is transmissible to humans. Many other animals may be infected. (See Table 1-14.)

TABLE 1-14 Some Characteristics of Miscellaneous Disease

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Ringworm of scalp (tinea capitis)	*Microsporum* and *Trichophyton*	Infected dogs, cats, cattle	Contact with contaminated barber clippers, toilet articles or clothing, dogs, cats, cattle, backs of seats in theaters, planes, and railroads	10–14 days	Survey of children with Wood lamp; education about contact with dogs, cats, infected children; reporting to school and health authorities; treatment of infected children, pets, and farm animals; investigation of source.
Ringworm of body (tinea corporis)	*Epidermophyton floccosum, Microsporum, Trichophyton*	Skin lesions of infected humans or animal	Direct contact with infected person or contaminated floors, shower stalls, benches, towels, etc.; lesions of infected persons or animals	4–14 days	Hot water laundering of towels; fungicidal treatment of floors, benches, mats, shower stalls with creosol or equal. Exclusion of infected persons from pools and gyms. Treatment of infected persons, pets, and animals. Cleanliness, sunlight, dryness.
Ringworm of foot (tinea pedis) (athlete's foot)	*Trichophyton rubrum, T. mentagrophytes*	Skin lesions of infected humans	Contact with skin lesions of infected persons, contaminated floors, shower stalls, benches, mats, towels	Unknown	In addition to above, drying feet and between toes with individual paper towels; use of individual shower sandals, foot powder, and clean sterilized socks. Well-drained floors in bathhouses, pools, etc.
Ringworm of nails (tinea unguium)	Epidermophyton and *Trichophyton*	Skin or nails of infected persons, soil, animals	Probably from infected feet, contaminated floors, shower stalls	Unknown	Same as above.
Ancylostomiasis (hookworm disease)	*Necator americanus* and *Ancylostoma duodenale*	Feces of infected persons; soil containing infective larvae; cats and dogs	Larvae hatching from eggs in contaminated soil penetrate foot; larvae also swallowed	Weeks to months	Prevention of soil pollution; sanitary privies or sewage disposal systems; wearing shoes; education in method of spread; treatment of cases; sanitary water supply.

TABLE 1-14 (*Continued*)

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Rabies (hydrophobia)	Virus of rabies	Infected dogs, foxes, cats, squirrels, cattle, horses, swine, goats, wolves, bats, skunks, wild and domestic animals	Bite of rabid animal or its saliva on scratch or wound	2–8 weeks, as little as 5 days, or more than 1 year	Detention and observation for 10 days of animal suspected of rabies. Immediate destruction or 6 months detention of animal bitten by a rabid animal. Vaccination of cats and dogs, dogs on leashes; dogs at large confined. Education of public. Avoid killing animal; if necessary, save head intact. Reduce wild life reservoir in cooperation with conservation agencies. If bitten, wash wound immediately and obtain medical attention.
Tetanus	*Clostridium tetani,* tetanus bacillus	Soil, street dust, animal feces containing bacillus	Entrance of tetanus bacillus in wound, puncture wound, burn, or minor wound	3 days–3 weeks, average of 10 days	Immunization with primary series of three doses of tetanus toxoid plus reinforcing dose and booster every 10 years. Allergic persons should carry record of sensitivity. Thorough cleansing of wounds. Safety program.
Anthrax	*Bacillus anthracis*	Cattle, sheep, goats, horses, swine, skins and hides of infected animals	Contaminated hair, wool, hides, shaving brushes, ingestion or contact with infected meats; inhalation of spores; flies possibly; laboratory accidents (Shaving brushes are under PHS regulations. Bristles soaked 4 h in 10% formalin at a temperature of at least 110°F destroys anthrax spores.)	7 days, usually less than 4 days.	Isolation and treatment of suspected animals. Postmortem examination by veterinarian of animals suspected of anthrax and deep burial of carcass, blood, and contaminated soil at a depth of at least 6 ft or incineration. Spores survive a long time. Vaccination of workers handling animals, hair, hides, or meats; personal hygiene; prompt treatment of abrasions. Treatment of trade wastes. Disinfection of wool, hide, animal food. Dust control.

Myiasis	*Cochliomya hominivorax* fly larva (screwworm)	Humans and vertebrate animals	Fly (dipterous) infestation of humans and vertebrate animal tissue with fly larvae	Variable	Prevent fly larvae or egg infestation of wounds, skin, eye, ear, nasopharynx, food, and genitourinary tract. Manual removal of larvae. Personal hygiene, medical treatment. Release of artificially sterilized male flies. Apply insecticide (dichlorvos).
Yaws	*Treponema pertenue*	Humans and possibly higher primates	Direct contact with exudates of early skin lesions of infected persons; also contamination from scratching and flies on open wounds	2 weeks–3 months	Better sanitation, availability of clean water, personal hygiene, screening and mass treatment, including contacts.
Onchocerciasis[a] (river blindness)	*Onchocerca volvulus,* a nematode	Infected humans, gorillas rarely	Female black fly *Simulium* genus carrying *Onchocerca* bites human, causing infection with parasite; another fly bites victim	1 year or less, sometimes more	Protective clothing. Use repellent (deet). Selected spraying of fast-flowing (oxygen) rivers harboring the larvae and treatment of individuals annually with drug invermectin,[b] which kills the microfilariae but not the worm.
Trachoma	*Chlamydia trachomatis*	Tears, secretions, discharges of nasal mucous membranes of infected persons	Direct contact with infected persons and towels, fingers, handkerchiefs, clothing soiled with infective discharges	5–12 days	Routine inspections and examinations of school children. Elimination of common towels and toilet articles and using sanitary paper towels. Education in personal hygiene and keeping hands out of eyes.
Psittacosis (Ornithosis)	*Chlamydia psittaci*	Infected parrots, parakeets, love birds, canaries, pigeons, poultry, other birds	Contact with infected birds or inhalation of their desiccated wastes; agent is airborne	4–15 days	Importation of birds from psittacosis-free areas. Quarantine of pet shops having infected birds until thoroughly cleaned. Education of public to dangers of parrot illnesses.
Staphylococcal disease in the community	*Staphylococcus aureus*	Humans	Direct contact with infected skin lesions or articles such as towels and pencils soiled by discharges	Usually 4–10 days	Personal hygiene, avoidance of common use of toilet articles; prompt recognition and treatment of illness. Inspection of children at camps, nurseries, institutions, schools. Frequent handwashing.

TABLE 1-14 (*Continued*)

Disease	Etiologic Agent	Reservoir	Transmission	Incubation Period	Control
Chancroid (soft chancre)	*Haemophilus ducreyi, Ducrey bacillus*	Discharges from open lesions and pus from buboes from infected persons	Prostitution, indiscriminate sexual promiscuity and uncleanliness; sexual contact with open lesions and pus; direct contact with infectious discharges in sexual intercourse; transfusion of infected blood	3–5 days or longer	Character guidance, health and sex education, premarital and prenatal examinations. Improvement of social and economic conditions; elimination of slums, housing rehabilitation and conservation, new housing, neighborhood renewal. Suppression of commercialized prostitution, personal prophylaxis, facilities for early diagnosis and treatment, public education concerning symptoms, modes of spread, and prevention. Case finding, patient interview, contact-tracing and serologic examination of groups known to have a high incidence of venereal disease, with follow-up. Report to local health authority.
Gonorrhea (clap, dose)	*Neisseria gonorrhoeae,* gonococcus *C. trachomatis*	Infected persons, particularly females	Sexual intercourse; contact with open lesions of infected persons	2–7 days; sometimes longer, 3–30 days	
Lymphogranuloma venereum (tropical bubo)					
Syphilis (pox, lues)	*Treponema pallidum*	Exudates from lesions of skin, mucous membrane, body fluids, and secretions of infected persons; exudate from mucous membranes of infected persons	Sexual intercourse, contact with mucous membranes of infected persons	10 days–10 weeks, usually 3 weeks	Use of condom. Control of drugs.

Granuloma inguinale (tropical sore)	*Donovania granulomatis,* (presumed agent)	Infected persons	Presumably by sexual intercourse, direct contact with lesions	Unknown, probably 8 days–12 weeks

Other sexually transmitted diseases include chlamydial infections, nongonococcal urethritis, trichomoniasis, herpes simplex (genital herpes), genital warts, viral hepatitis B, human immunodeficiency virus (HIV) infection, and acquired immunodeficiency syndrome (AIDS). Control measures are similar to above.

[a]The WHO estimates that there are 17 million cases of onchocereciasis, or river blindness, mostly in Africa, and 326,000 people have been blinded by it. About 90 million are at risk. *Nation's Health,* July 1990, pp. 8–9.

[b]E. Eckholm, ''River Blindness, Conquering an Ancient Scourge,'' *New York Times Mag.,* Jan. 8, 1989, p. 20. For further information the reader is referred to specialized sources such as ref. 3; P. N. Acha and B. Szyfres, *Zoonoses and Communicable Diseases Common to Man and Animals,* 2nd ed., Pan American Health Organization, WHO, Washington, DC, 1987; and ''Guidelines for Prevention of Transmission of Human Immunodeficiency Virus and Hepatitis B Virus to Health-Care and Public-Safety Workers,'' U.S. Department of Health and Human Services, PHS, CDC, Atlanta, GA, February 1989, reprinted in *MMWR,* **38**(25), 446 (June 30, 1989).

Animal Rabies Control

Rabies is a disease of many domestic and wild animals and biting mammals, including bats. In 1988, 4724 laboratory-confirmed cases were reported to the CDC[169] in the United States and its territories. The distribution in 1988 was 38 percent in skunks, 31 percent in raccoons, 14 percent in bats, and 4 percent in foxes. Other animals accounted for 12 percent of the cases, mostly cats, dogs, and cattle.[169] Every sick-looking dog or other animal that becomes unusually friendly or ill-tempered and quarrelsome should be looked on with suspicion. One should not place one's hand in the mouth of a dog, cat, or cow that appears to be choking. The animal may be rabid. A rabid animal may be furious or it may be listless; it may salivate heavily or have spasms, paralysis, and a hung jaw, depending on the form of the disease. A person bitten or scratched by a rabid animal, or an animal suspected of being rabid, should immediately wash and flush the wound and surrounding area thoroughly with soap and warm water, a mild detergent and water, or plain water if soap or detergent is not available and seek immediate medical attention. The physician will notify the health officer or health department of the existence of the suspected rabid animal and take the required action. Airborne spread of the virus has been demonstrated in the laboratory and in the air of heavily bat infested caves.

The animal (usually a pet) should be caged or tied up with a strong chain and isolated for 10 days; if any of the above symptoms appear, a veterinarian should evaluate the animal. An animal suspected of being rabid that has not been vaccinated will have to be confined for four months or be killed. A dog or cat bitten by or exposed to a rabid animal should be confined for 6 months and vaccinated one month before release or be destroyed. Consult the local health department.[170] Any domestic animal that is bitten or scratched by a bat or a wild, carnivorous mammal that is not available for testing should be regarded as having been exposed to a rabid animal.[171] A wild animal, if suspected, should be killed without unnecessary damage to the head. Gloves should be worn when handling the carcass of a suspected rabid animal since rabies virus can be introduced through saliva or a cut or scratch on the hands. The dead animal should be wrapped in newspaper or other covering and taken to a veterinarian or local health department. The head should be immediately delivered or packed in ice (not frozen) and shipped to the nearest equipped health department laboratory where the brain can be examined for evidence of rabies.

Several immunization products, vaccines and globulins, are available and used for postexposure prophylaxis. If treatment has been initiated and subsequent testing of the animal shows it to be negative, treatment can be discontinued. Preexposure prophylaxis is also practical for persons in high-risk groups. These include veterinarians, animal handlers, certain laboratory workers, and persons, especially children, living or visiting countries where rabies is a constant threat. Persons whose vocational or avocational pursuit brings them into contact with potentially rabid dogs, cats, foxes, skunks, or other species at risk of having rabies should also be considered for preexposure prophylaxis.[172] The CDC, Department of Health and Human Services (DHHS), PHS, and local and state health departments provide detailed recommendations for rabies prevention and treatment including pre- and post-prophylaxis.

Vaccination of dogs and cats in affected areas, stray animal control, and public information are important for a good control program. In areas where rabies exists, mass immunization of at least 70 percent of the dog and cat population in the county or similar unit within a two- or three-week period is indicated. Where rabies exists or where it might be introduced, a good program should include vaccination of all dogs and cats at three months of age and older. Vaccines are available for dogs, cats, and cattle; special vaccines can be used in certain animals. A booster is recommended annually or triennially, depending on the vaccine used.[173] All animal rabies vaccines should be administered by or under the supervision of a veterinarian. See also Table 1-14.

Bat Rabies Rabid bats have been reported from every state except Hawaii and have caused human rabies infections in the United States.[174] The vampire bat (*Desmodus rotundus*) is a rabies carrier spreading death and disease among cattle and other livestock and endangering humans in Latin America from Mexico to northern Argentina. The anticoagulant diphenadione is effective against the vampire bat species. The chemical may be injected directly in cattle and then taken by the bat when it gets its blood meal or spread as a petroleum jelly mixture on captured bats, which when released spread the chemical by contact throughout a bat colony. In either case the diphenadione enters the bloodstream and the bat bleeds to death.[175] Annual livestock production losses are estimated at $250 million.

DDT formally was used as a control measure but has been banned since 1972. Currently, the most effective means of bat control is to screen all openings or build them out insofar as possible.[174] Fiberglass insulation will keep bats out of spaces so insulated.

Any person bitten or scratched by a bat should receive antirabies therapy without delay unless the bat (head) is found negative by laboratory test. Any person who has handled a bat, dead or alive, may also have to undergo antirabies therapy as the bat saliva, containing the rabies virus, may enter a patient's body through open cuts in the skin or mucous membranes.[176]

Control of Zoonoses and Insectborne Diseases

To eliminate or reduce the incidence of zoonoses and insectborne diseases, it is necessary to control the environment and reservoirs and the vehicles or vectors. This would include control of water and food, carriers of disease agents, and the protection of persons and domestic animals from the disease (immunization). Where possible and practical, the reservoirs and vectors of disease should be destroyed and the environment made unfavorable for their propagation. Theoretically, the destruction of one link in the chain of infection should be sufficient. Actually, efforts should be exerted simultaneously toward elimination and control of all the links, since complete elimination of one link is rarely possible and protection against many diseases is difficult, if not impossible, even under ideal conditions. Personnel, funds, and equipment available will frequently determine the action taken to secure the maximum results or return on the investment made. The control of insects and rodents is discussed in some detail in Chapter 10 of the fourth edition.

MISCELLANEOUS DISEASES AND ILLNESSES

This is a divergent group of diseases, not all communicable in the usual sense and discussed separately below.

Ringworm

This disease includes a group of fungus infections that develop on the surface of the skin and may involve the nails, scalp, body, and feet. See Table 1-14. Practically all persons have or have had one or more of the fungus infections. Thickening and scaling of the skin, raw inflamed areas, cracked skin, and blistering accompanied by severe itching are usual symptoms of dermatophytosis. (Bacteria predominate at this point.) The microscopic fungi grow best under conditions of warmth, darkness, and moisture. Damp floors and cracks in floors, mats, benches and chairs at swimming pools, shower rooms, bathrooms, and locker rooms present ideal conditions for the incubation and spread of the fungi that come into contact with the bare skin if not controlled.

The provision of smooth, nonslip, impervious floors constructed to remain well drained and facilitate quick drying is recommended. The direct entrance of sunlight that has not passed through window glass to take advantage of the sterilizing properties of solar ultraviolet rays and the provision of ample window area with a southern exposure for adequate ventilation should be given serious consideration in swimming pool, shower, and bathhouse design. This will encourage prompt drying of the floor and destruction of fungi and their spores. Indoor floors and benches can be disinfected with a solution of sodium hypochlorite (500 mg/l available chlorine), but the strong odor may discourage its use unless followed by rinsing with clear water. Daily scrubbing with a strong detergent in hot water followed by a rinse containing a quaternary ammonium compound (0.1 percent) would seem to be the most practical fungicide treatment where material might be attacked by chlorine. A strong hot alkaline solution is also effective. Hexachlorophene solution should not be used where skin contact and absorption are possible.

Simple laundering of stockings or towels is not effective in destroying the pathogenic fungi responsible for athlete's foot; sterilization is necessary. This can be accomplished by boiling cotton socks 15 min. Air drying in sunlight may also be effective. Emphasis should be placed on keeping the feet dry and clean, especially between the toes. The use of cotton or wool and cotton socks, antifungal foot powder, and leather shoes will help keep the feet dry. A regimen of daily washing of the feet, careful drying between the toes, application of baby or foot powder, clean socks, and alternate-day use of shoes is good to follow. See also Prevention of Ringworm and Other Skin Infections, Chapter 9.

Hookworm Disease or Ancylostomiasis

Hookworm disease is most common in tropical and subtropical areas. The parasite develops best at a temperature of around 81°F (27°C), although it will live at temperatures between 57 and 100°F (38°C). It has a complex life cycle that begins and ends in the small intestine. The eggs hatch in moist, warm, shaded soil and the larvae infect people by penetrating the skin, usually the soles of the feet. They are then carried to the lungs, go through the respiratory tract to the mouth, are swallowed, and eventually reach the small intestine. They attach to the intestinal wall and suck blood. The adult worm produces thousands of eggs that are shed in the feces. If the feces contaminates soil, the cycle begins again.[177] A hard frost will kill the eggs and larvae. See Table 1-14.

Strongyloidiasis is an infection of the nematode *Strongyloides stercoralis*. It is similar to hookworm disease. Hookworm is a cause of anemia.

Tetanus or Lockjaw

This is a disease caused by contamination of a wound or burn with soil, street dust, or animal excreta containing the tetanus bacteria, *Clostridium tetani*. The bacillus lives in the intestines of domestic animals. Gardens that are fertilized with manure, barnyards, farm equipment, and pastures are particular sources of danger. The tetanus germ produces a toxin that affects the nervous system, causing spasms, convulsions, and frequently death. It is a spore former that survives in soil and is resistant to ordinary boiling. Deep puncture-type wounds are most dangerous, regardless of whether they are made by clean or rusty objects. The mortality rate is 40 percent for untreated infections. There is a tetanus antitoxin that can be used after infection, however, preventative vaccination is much more effective. Older adults (over 50) especially should be revaccinated against tetanus. See Table 1-14.

NONINFECTIOUS AND NONCOMMUNICABLE DISEASES AND CONDITIONS ASSOCIATED WITH THE ENVIRONMENT, INCLUDING AIR, WATER, AND FOOD

Background

The terms noncommunicable and noninfectious are used interchangeably. The noncommunicable diseases are the major causes of death in developed areas of the world, whereas the communicable diseases are the major causes of death in the developing areas of the world. The major noncommunicable disease deaths in the United States in 1988 were due to diseases of the heart, malignant neoplasms, cerebrovascular diseases, accidents, atheriosclerosis, diabetes mellitus, and chronic liver disease and cirrhosis (accounting for 73 percent of all deaths). An analysis of mortality due to noncommunicable diseases in five subregions of the Americas in 1980 showed 75 percent of the total mortality attributed to noncommunicable diseases in North America (United States and Canada); 60 percent in Temperate South American countries (Argentina, Chile, and Uruguay); 57 percent in the Caribbean area (including Cuba, the Dominican Republic, and Haiti); 45 percent in Tropical South America (including the Andean countries, Brazil, French Guiana, Guyana, Paraguay, and Suriname); and 28 percent in Continental Middle America (Central America, Mexico, and Panama).[29] The mortality can be expected to shift more to noncommunicable causes in the developing countries as social and economic conditions improve and communicable diseases are brought under control. Major diseases of developing countries are gastrointestinal, schistosomiasis, malaria, trachoma, and malnutrition.

Treatment of the environment supplements treatment of the individual but requires more effort and knowledge. The total environment is *the most important determinant of health.* A review of more than 10 years of research conducted in Buffalo, New York, showed that the overall death rate for people living in heavily polluted areas was twice as high, and the death rates for tuberculosis and stomach cancer three times as high, as the rates in less polluted areas.[179] Rene Dubos points out that "many of man's medical problems have their origin in the biological and mental adaptive responses that allowed him earlier in life to cope with environmental threats. All too often the wisdom of the body is a shortsighted wisdom."[180] In reference to air pollution, he adds that "while the inflammatory response is protective (adaptive) at the time it occurs, it may, if continuously called into play over long periods of time, result in chronic pathological states, such as emphysema, fibrosis, and otherwise aging phenomena."

Human adjustment to environmental pollutants and emotional stresses due to crowding and other factors can result in later disease and misery with reduced potential for longevity and a productive life.[181]

In an address to the Sierra Club, EPA Administrator Barbara Blum stated (ref. 182):

> Inner-city people—white, yellow, brown and black—suffer to an alarming degree from what are euphemistically known as diseases of adaptation. These are not healthy adaptations, but diseases and chronic conditions resulting from living with bad air, polluted water, excessive noise, and continual stress. Hypertension, heart disease, chronic bronchitis, emphysema, sight and hearing impairment, cancer, and congenital anomalies are all roughly fifty percent higher (for inner-city people) than the level for suburbanites. Behavioral, neurological and mental disorders are about double.

Whereas microbiological causes of most communicable diseases are known and are under control or being brought under control in many parts of the world (with some possible exceptions such as malaria and schistosomiasis), the physiologic and toxicologic effects on human health of the presence or absence of certain chemicals in air, water, and food in trace amounts have not yet been clearly demonstrated. The cumulative body burden of all deleterious substances, especially organic and inorganic chemicals, gaining access to the body must be examined both individually and in combination. The synergistic, additive, and neutralizing effects must be learned in order that the most effective preventive measures may be applied. Some elements, such as fluorine for the control of tooth decay, iodine to control goiter, and iron to control iron deficiency anemia, have been recognized as being beneficial in proper amounts. But the action of trace amounts ingested individually and in combination of the pollutants shown in Figure 1-4 and other inorganic and organic chemicals is often insidious. Their probable carcinogenic, mutagenic, and teratogenic effects are extended in time, perhaps for 10, 20, or 30 years, to the point where direct causal relationships with morbidity and mortality are difficult if not impossible to conclusively prove in view of the many possible intervening and confusing factors. Nevertheless, sufficient information about many noninfectious diseases, including the chronic diseases, is available to make possible the mounting of an attack to *prevent* or at least minimize the debilitating effects. Some will say that we do not have sufficient preventive information and should devote our attention only to screening and treatment. Where would we be today if the same philosophy prevailed in our attack on the infectious diseases?

An interesting analysis was made by Dever[183] for use in policy analysis of health program needs. He selected 13 causes of mortality and allocated a percentage of the deaths, in terms of an epidemiologic model, to four primary divisions, namely, system of health care organization, life-style (self-created risks), environment, and human biology. He envisioned the environment as comprised of a physical, social, and psychologic component. Environmental factors were considered to be associated with 9 percent of the mortality due to diseases of the heart, with the rest due to causes associated with health care, life-style, or human biology. Similarly, environmental factors were considered the cause of 24 percent of the cancer deaths, 22 percent of the cerebrovascular deaths, and 24 percent of the respiratory system deaths.

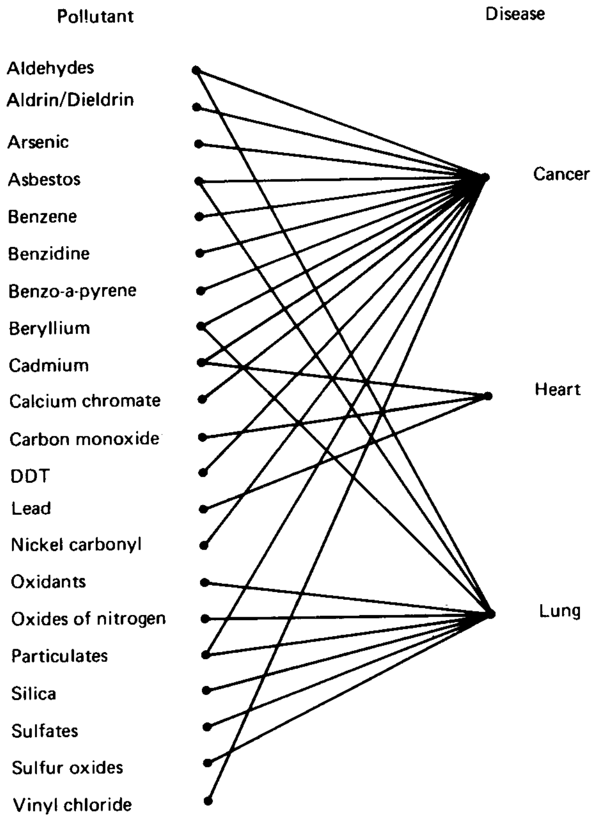


Figure 1-4 Known or suspected links between selected pollutants and disease. (*Source: First Annual Report by the Task Force on Environmental Cancer and Heart and Lung Disease,* Printing Management Office, U.S. Environmental Protection Agency, Washington, DC, August 7, 1978, p. 9.)

Of added interest is Dever's analysis showing that environmental factors were considered to be the cause of 49 percent of all deaths due to accidents, 20 percent of the influenza and pneumonia deaths, 41 percent of the homicides, 15 percent of the deaths due to birth injuries and other diseases peculiar to early infancy, 6 percent of the deaths due to congenital anomalies, and 35 percent of the deaths due to suicides.

Another study by Clough[184] compares two investigations showing the impact of environmental factors on cancer mortality. The term "environment" has different meanings to the epidemiologist and to the general public. To the epidemiologist, "it refers to everything that humans encounter: everything that is eaten, drunk, and smoked; drugs, medicine, and occupational exposures; and air, water, and soil. In this context it means everything outside the body as distinct from a person's genetics."[184] The environment can also be defined as the aggregate of all the external conditions and influences affecting the life and development of humans. Included is the air, water, land, and climate and the interrelationship that exists between them and all living things.

Clough made a comparison of the annual cancer mortality as estimated by Doll and Peto[185] and by the EPA[186] and found a surprising agreement. Tables 1-15 and 1-16 place in perspective environmental problems and mortality and risk of cancer mortality. It is of significance to note that Doll and Peto[185] attributed 30 percent of all cancer mortality to smoking and 35 percent probably to diet, whereas only 2 percent was attributed to pollution, 3 percent to geophysical factors, 4 percent to occupation, and less than 1 percent to consumer products. The EPA attributed 1 to 3 percent to pollution, 3 to 6 percent to geophysical factors, 1 to 4 percent to occupation, and less than 1 percent to consumer products. Although these latter percentages are small, they become significant when considered in the context of 485,000 cancer deaths per year (in 1987). However, this analysis does not reflect deaths and illnesses due to pollution from other causes or the harm done by pollution to the physical environment, including acid rain, carbon dioxide buildup, and ozone depletion in the upper atmosphere, or to the quality of life. Nevertheless, priorities in the allocation of government resources seem to be governed more by the public's perception of the significance of environmental problems rather than by the recorded deaths and health effects. Obviously, a more balanced approach is needed.

There are an estimated 2 million recognized chemical compounds with more than 60,000 chemical substances in past or present commercial uses. Approximately 600 to 700 new chemicals are introduced each year, but only about 15,000 have been animal tested with published reports. Limited trained personnel and laboratory facilities for carcinogenesis testing in the United States by government and industry will permit testing of no more than 500 chemicals per year. Each animal experiment requires three to six years and a cost of more than $300,000.[187] Another estimate is $500,000 just to establish the carcinogenicity of one compound with the National Cancer Institute test protocol requiring at least two species of rodents and three years' time.[188] A full toxicologic test, including those for carcinogenicity, can take five years and cost in excess of $1.25 million for each compound. The chemicals are viewed by Harmison[189] as falling into four groups:

1. Halogenated hydrocarbons and other organics; polychlorinated biphenyls (PCBs); chlorinated organic pesticides such as DDT, Kepone, Mirex, and endrin; polybrominated biphenyls (PBBs); fluorocarbons; chloroform; and vinyl chloride. These chemicals are persistent, often bioac-

TABLE 1-15 Comparable Environmental Problem Categories and Cancer Risks

Doll and Peto Category[a]	EPA (Rank) Category[b]	Estimated Annual Risk of Cancer Mortality
Pollution	(1) Indoor air pollutants	
	(tobacco smoke)	5000[c]
	Organic chemicals	1240
	(3) Pesticides on food	3000–6000[d]
	(6) Hazardous, toxic air pollutants	1027–2054[d]
	(8) Inactive, hazardous waste sites	500–1000[d]
	(9) Drinking water, chemicals only	215–430[d]
	(12) Other pesticide risks	75–150[d]
	(13) Active, hazardous waste sites	100[e]
	(14) Nonhazardous, industrial waste sites	100[e]
	(16) Nonhazardous, municipal waste sites	20–40[d]
	(17) Contaminated sludge	20–40[d]
	(11) Radiation from industrial emissions	12
	(18) Mining wastes	10–20[d]
	Total EPA pollution category	6214–1054
Geophysical factors	(7) Current sunlight exposures	10,000
	(1′) Indoor radon	5000–20,000
	(9) Drinking water, radiation only	37–730
	Total EPA geophysical category	15,037–30,730
Occupation	(11) Radiation, workplace[f]	46
	(10) Pesticide application	50–100[d]
	(1) Workplace chemicals[f]	125–250
	Total for EPA occupation category	221–396
Industrial (consumer) products	(11) Radiation from building materials	196–280
	(11) Radiation from televisions, other consumer products[f]	64
	(4′) Consumer products[e]	47–136[d]
	Total EPA consumer products category	307–480

Source: M. Gough, "Estimating Cancer Mortality," *Environ. Sci. Technol.,* **23**(8), 928, Table 3 (1989). Copyright 1989 by the American Chemical Society. Reprinted with permission.

Note: Parentheses represent EPA scientists' and managers' relative ranking of environmental problem areas on the basis of cancer risk.

[a] Ref. 185.
[b] Ref. 186.
[c] This number is not included in the total or in the percentage of cancers ascribed in this category in Table 1–6 because it was considered by Doll and Peto as part of the mortality caused by tobacco.
[d] For this category, the EPA estimated annual number of cancer cases rather than deaths. The fraction of deaths was assumed to range from 0.5 to 1.0 (see text).
[e] For EPA estimates less than a certain number, a value equal to one-half the number was used in calculating the total on this table or the percentages that appear in Table 1–6. For instance, EPA estimate below 100 became 50 in calculating percentages.
[f] The EPA acknowledges it considered only a few agents in computing the number of cancers associated with this exposure. Consideration of more agents would increase the estimate. This exposure is also not usually thought of as falling within the EPA's purview.

TABLE 1-16 Percentage of Annual Cancer Mortality Associated with Environmental Exposures

Source of Exposure Estimate	Exposure Categories			
	Pollution	Geophysical Factors	Occupation	Consumer Products
Doll and Peto[a]	2; 1–5	3; 2–4	4; 2–8	1; 1–2
EPA Unfinished Business[b]	1–3	3–6	1; 1–4	1

[a]Ref. 185.
[b]Ref. 186.

Source: M. Gough, "Estimating Cancer Mortality," *Environ. Sci. Technol.,* **23**(8), 929, Table 4 (1989).

cumulate in food organisms, and may in small quantities cause cancer, nervous disorders, and toxic reactions.

2. Heavy metals: lead, mercury, cadmium, barium, nickel, vanadium, selenium, beryllium. These metals do not degrade; they are very toxic and may build up in exposed vegetation, animals, fish, and shellfish.
3. Nonmetallic inorganics: arsenic and asbestos, for example, are carcinogens.
4. Biological contaminants such as aflatoxins and pathogenic microorganisms; animal and human drugs such as diethylstilbestrol (DES) and other synthetic hormones; and food additives such as red dye No. 2.

Evaluation of the toxicity of existing and new chemicals on workers, users, and the environment and their release for use represent a monumental task, as noted above. Monitoring the total effect of a chemical pollutant on humans requires environmental monitoring and medical surveillance to determine exposure and the amount absorbed by the body. The sophisticated analytical equipment available can detect chemical contaminants in the parts-per-billion or parts-per-trillion range. However, mere detection does not mean that the chemical substance is automatically toxic or hazardous. But detection does alert the observer to trends and the possible need for preventive measures. Short-term testing of chemicals, such as the microbial Ames test, is valuable to screen inexpensively for carcinogens and mutagens. The Ames test determines the mutagenic potential of a chemical based on the mutation rate of bacteria that are exposed to the chemical. However, positive results suggest the need for further testing and negative results do not establish the safety of the agent. Other tests use mammalian cell cultures and cell transformation to determine mutagenicity.

Selected chemical pollutants known or suspected of causing or aggravating certain noninfectious diseases are shown in Figure 1-4. Environmental pollutants subject to federal regulation are given in Table 1-17. Agents, pollutants, or sources having definite and possible health effects are summarized in Table 1-18 and suggest possible environmental preventive program activities.

Prevention and Control

Prevention of the major causes of death, such as diseases of the heart, malignant neoplasms, cerebrovascular disease, accidents, and other noninfectious chronic and degenerative diseases, should now receive high priority. Prevention calls for control of the source, mode of transmission, and/or susceptibles

TABLE 1-17 Federal Regulation of Levels of Environmental Pollutant

	Ambient Air Quality Standards	
Particulates	Lead (proposed)	Hydrocarbons
Sulfur dioxide	Nitrogen dioxide	
Carbon monoxide	Photochemical oxidants	
	Air Emission Standards	
Acid mist	Nitrogen dioxide	Sulfur dioxide
Carbon monoxide	Particulates	Total reduced sulfur
Fluorides	Beryllium	Mercury
Hydrocarbons	Vinyl chloride	Asbestos
	Toxic Substances Control	
Several substances have been recommended to the EPA by the TSCA Interagency Testing Committee for further testing.		
	Occupational Standards	
Permissible exposure limits for approximately 400 toxic and hazardous substances Occupational Safety and Health Standards for 20 designated carcinogens		
	Drinking Water Standards	
Arsenic	Cyanide	Nitrate
Barium	Fluoride	Selected pesticides
Cadmium	Lead	Selenium
Chromium	Mercury	Silver
	Others—Regulatory Actions to Limit Environmental Damage from	
Effects of food additives	Pesticides	Solid waste
Radioactive materials	Noise	Effects of smoking

Source: First Annual Report by The Task Force on Environmental and Heart and Lung Disease, Printing Management Office, U.S. Environmental Protection Agency, Washington, DC, August 7, 1978, p. 9.

TABLE 1-18 Definite and Possible Health Effects of Environmental Pollutants and Exposures

Agent, Pollutant, or Source	Definite Effect	Possible Effect
	Community Air Pollution	
Sulfur dioxide (effects of sulfur oxides may be due to sulfur, sulfur trioxide, sulfuric acid, or sulfate salts)	1. Aggravation of asthma and chronic bronchitis	
	2. Impairment of pulmonary function	
	3. Sensory irritation	
Sulfur oxides and particulate matter from combustion sources	4. Short-term increase in mortality	
	5. Short-term increase in morbidity	
	6. Aggravation of bronchitis and cardiovascular disease	
	7. Contributory role in etiology of chronic bronchitis and emphysema	
	8. Contributory role to respiratory disease in children	
		9. Contributory role in etiology of lung cancer
Particulate matter (not otherwise specified)		10. Increase in chronic respiratory disease
Oxidants	11. Aggravation of emphysema, asthma, and bronchitis	
	12. Impairment of lung function in patients with bronchitis-emphysema	
	13. Eye and respiratory irritation and impairment in performance of student athletes	
		14. Increased probability of motor vehicle accidents

TABLE 1-18 (***Continued***)

Agent, Pollutant, or Source	Definite Effect	Possible Effect
Ozone	15. Impairment of lung function	16. Acceleration of aging, possibly due to lipid peroxidation and related processes
Carbon monoxide	17. Impairment of exercise tolerance in patients with cardiovascular disease	
		18. Increased general mortality and company mortality rates
		19. Impairment of central nervous system function
		20. Causal factor in atherosclerosis
Nitrogen dioxide		21. Factor in pulmonary emphysema
		22. Impairment of lung defenses such as mast cells and macrophages or altered lung function
Lead	23. Increased storage in body	
		24. Impairment of hemoglobin and porphyrin synthesis
Hydrogen sulfide	25. Increased mortality from acute exposure	
	26. Sensory irritation	
Mercaptans		27. Headache, nausea, and sinus infections
Asbestos	28. Pleural calcification	
	29. Malignant mesothelioma, asbestosis	
		30. Contributory role in chronic pulmonary disease (asbestos and lung cancer)

Organophosphorus pesticides	31. Acute fetal poisoning	
	32. Acute illness	
	33. Impaired cholinesterase activity	
Other odorus compounds		34. Headache and sinus affections
Beryllium	35. Berylliosis with pulmonary impairment	
Airborne microorganisms	36. Airborne infections	
	Food and Water Contaminants	
Bacteria	1. Epidemic and endemic gastrointestinal infections (e.g., typhoid, cholera, shigellosis, salmonellosis, leptospirosis)	
		2. Secondary interaction with malnutrition and with nitrates in water (cf. no. 13)
Viruses	3. Epidemic hepatitis and other viral infections	
		4. Eye and skin inflammation from swimming
Protozoa and metazoa	5. Amoebiasis, schistosomiasis, hydatidosis, and other parasitic infections	
Metals	6. Lead poisoning	
	7. Mercury poisoning (through food chains)	
	8. Cadmium poisoning (through food chains)	
	9. Arsenic poisoning	
	10. Chromium poisoning	
		11. Epidemic nephropathy
		12. "Blackfoot" disease

TABLE 1-18 (*Continued*)

Agent, Pollutant, or Source	Definite Effect	Possible Effect
Nitrates	13. Methemoglobinemia (with bacterial interactions)	
"Softness" factor		14. Increase in cardiovascular disease
Sulfates and/or phosphates	15. Gastrointestinal hypermotility	
Fluorides	16. Fluorosis of teeth when in excess	
	Land Pollution	
Human excreta	1. Schistosomiasis, taeniasis, hookworm, and other infections	
Sewage		2. Infectious diseases
Industrial and radioactive waste	3. Storage and effects from toxic metals and other substances through food chains	
Pesticides: lead arsenate	4. Increased storage of heavy metals in smokers of tabacco grown on treated areas	
	Thermal Exposures	
Cold damp	1. Excess mortality from respiratory disease and fatal exposure	
		2. Contribution to excess mortality and morbidity from other causes
	3. Excess morbidity from respiratory and related diseases and morbidity from exposure	
		4. Rheumatism

Cold dry	5. Mortality from frostbite and exposure	
		6. Impaired lung function
	7. Morbidity from frostbite and respiratory disease	
Hot dry	8. Heat stroke mortality	
	9. Excess mortality attributed to other causes	
	10. Morbidity from heat stroke and from other causes	
	11. Impaired function; aggravation of renal and circulatory diseases	
Hot damp	12. Increase in skin affections	
		13. Increase in prevalence of infectious agents and vectors
	14. Heat-exhaustion mortality	
	15. Excess mortality from other causes	
	16. Heat-related morbidity	
	17. Impaired vigor and circulatory function	
	18. Aggravation of renal and circulatory disease	
	Radiation and Microwaves	
Natural sunlight	1. Fatalities from acute exposure	
	2. Morbidity due to "burn"	
	3. Skin cancer	
	4. Interaction with drugs in susceptible individuals	
		5. Increase in malignant melanoma

TABLE 1-18 (*Continued*)

Agent, Pollutant, or Source	Definite Effect	Possible Effect
Diagnostic X-ray	6. Skin cancer and other skin changes	
		7. Contributing factors to leukemia
		8. Alteration in fecundity
Therapeutic radiation	9. Skin cancer	
	10. Increase in leukemia	
		11. Increase in other cancers
		12. Acceleration of aging
		13. Mutagenesis
Industrial uses of radiation and mining of radioactive ores	14. Acute accidental deaths	
	15. Radiation morbidity	
	16. Uranium nephritis	
	17. Lung cancer in cigarette-smoking miners	
		18. Increase in adjacent community morbidity or mortality
Nuclear power and reprocessing plants		19. Increase in cancer incidence
		20. Community disaster
		21. Alteration in human genetic material
Microwave		22. Tissue damage
	Noise and Vibrations	
Traffic		1. Progressive hearing loss
Aircraft (including sonic boom)	2. Permanent hearing loss	
		3. Aggravation or cause of mental illness

Vibrations		4. Articular and muscular disease 5. Adverse effects on nervous system
	Housing and Household Agents	
Heating, cooking, and refrigeration	1. Acute fatalities from carbon monoxide, fires and explosions, and discarded refrigerators	2. Increase in diseases of the respiratory tract in infants
Fumes and dust	3. Acute illness from fumes 4. Aggravation of asthma	5. Increase in chronic respiratory disease
Crowding	6. Spread of acute and contribution to chronic disease morbidity and mortality	
Structural factors (including electrical wiring, stoves, and thin walls)	7. Accidental fatality 8. Accidental injury 9. Morbidity and mortality from lack of protection from heat or cold 10. Morbidity and mortality due to fire or explosion	
Paints and solvents	11. Childhood lead-poisoning fatalities, associated mental impairment, and anemia 12. Renal and hepatic toxicity 13. Fatalities	

TABLE 1-18 (*Continued*)

Agent, Pollutant, or Source	Definite Effect	Possible Effect
Household equipment and supplies (including pesticides)	14. Fatalities from fire and injury	
	15. Morbidity from fire and injury	
	16. Fatalities from poisoning	
	17. Morbidity from poisoning	
Toys, beads, and painted objects	18. Mortality and morbidity	
Urban design	19. Increased accident risks	
		20. Contribution to mental illness

Source: Vital and Health Statistics, Series 4, No. 20, DHEW Publication No. (HRA) 77–1457, National Center for Health Statistics, Hyattsville, MD, July 1977, pp. 27–29.

Note: Items in parentheses refer to effects other than those directly affecting human health status.

as appropriate and as noted in Figures 1-1, 1-2, and 1-4 through 1-6 and Table 1-18.

The prevention and control of environmental pollutants generally involves the following:

1. Elimination or control of the pollutant at the source: minimize or prevent production and sale; substitute nontoxic or less toxic chemical; materials and process control and changes; recover and reuse; waste treatment, separation, concentration, incineration, detoxification, and neutralization. See Chapters 4 and 5.
2. Interception of the travel or transmission of the pollutant: air and water pollution control and prevention of leachate travel. See Chapters 4 to 6.
3. Protection of humans to eliminate or minimize the effects of the pollutant: water treatment, air conditioning, land-use planning, and occupational protection. See Chapters 2, 3, and 6.

At the same time the air, sources of drinking water, food, aquatic plants, fish and other wildlife, surface runoff, leachates, precipitation, surface waters, and humans should be monitored. This should be done for potentially toxic and deleterious chemicals as indicated by specific situations. Figure 1-2 also lists characteristics of noninfectious diseases due to the ingestion of poisonous plants and animals and chemical poisons in contaminated water or food.

Environmental Control Legislation

Many of the laws establishing national standards and controls for the discharge of pollutants to the environment and consumer and worker protection are listed below*:

- *Asbestos Hazard Emergency Response Act of October 22, 1986* (Amends Toxic Substances Control Act (TSCA).] Requires the EPA to regulate the inspection of schools, identify asbestos-containing materials, monitor the development of asbestos management plans by schools, and oversee corrective measures. The Occupational Safety and Health Administration (OSHA) is to establish asbestos regulations in the workplace and for asbestos removal. The *Asbestos School Hazard Abatement Act of 1984* authorizes the EPA to provide grants and loans if justified.

*A very good resource for examining public laws is the Thomas search engine of the Library of Congress web site. This is a searchable database of all laws in Congress, whether passed or not, from the 93rd Congress (1973-1974) through the current one. (http://thomas.loc.gov/home/thomas.html, December 2001).

- *Atomic Energy Act of 1954* P.L. 83–703 (as amended). Regulates the discharge of radioactive waste into the environment. Gives the EPA authority to set standards for the disposal of radioactive materials to be implemented by the National Research Council (NRC).
- *Clean Air Act of 1970* P.L. 91–604 (as amended 1990, 1996, 1998, 1999). To improve the quality of the nation's air, the EPA is to establish national air quality standards to protect the public health and welfare from the harmful effects of air pollution and ensure that existing clean air is protected from significant deterioration by controlling stationary and mobile sources and preventing harmful substances from entering the ambient air; also to review and regulate hazardous and toxic air pollutants.
- *Coastal Zone Management Act of 1972* P.L. 92–583 (as amended). Requires consideration of environmental and economic factors in the planning and efficient development of coastal areas. State receives financial and technical assistance.
- *Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980* P.L. 96–510 (as amended). (Superfund.) Establishes a trust fund financed by taxes on oil and certain chemical compounds and authorizes federal action in cleaning up hazardous waste sites (especially soil and water contaminated sites), responds to spills of hazardous substances that present danger to public health and welfare, and prepares guidelines for coordinating federal and state responses. Short-term response may include provision of bottled water and temporary evacuation. Sites are ranked for priority action.
- *Consumer Product Safety Act of 1972* P.L. 92–573. The Consumer Product Safety Commission (CPSC) is responsible for reducing injuries associated with consumer products, including the development of safety standards and the investigation of product-related morbidity and mortality.
- *Emergency Planning and Community Right-to-Know Act of 1986* Also called *Superfund Amendments and Reauthorization Act (SARA) Title III.* Employers must report and advise employees of hazardous substances handled and their potential effects. The act also requires that information about toxic chemicals stored or permitted to be released during operation of commercial and manufacturing facilities be made available to the public. State and local governments and facilities using or storing hazardous chemicals must have emergency plans for notification and response. Facilities must report annually the amount and characteristics of certain toxic chemicals on premises and released to the environment.
- *Federal Food, Drug, and Cosmetic Act of 1938* (As amended.) The FDA is responsible for the safety and effectiveness of foods, drugs, medical devices, and cosmetics; it is also responsible for radiologic health and toxicologic research, enforces compliance with EPA-established al-

lowable limits for pesticides on food and feed crops, and prohibits use of any carcinogenic additives.

- *Federal Insecticide, Fungicide, and Rodenticide Act of 1972* P.L. 92–516 (as amended). Requires that all pesticides be registered and used strictly in accordance with label instructions; gives government (EPA) authority to prohibit or restrict a pesticide to special uses for application only by a person trained in an approved program; extends control to intrastate products, container storage and disposal methods, and direct or indirect discharge of pesticides to surface waters and groundwaters; also requires proof that pesticides will cause no harm to people, wildlife, crops, or livestock when used as directed.
- *Federal Water Pollution Control Acts of 1971, 1972* P.L. 83–660, P.L. 92–500, and P.L. 95–217 (*Clean Water Act of 1977* as amended by the *Water Quality Act of 1987* and further amended in 2000). Controls water pollutants and other related factors to make surface waters fishable and swimmable. Intended to restore and maintain the chemical, physical, and biological integrity of the nation's surface and groundwaters. Also water quality planning, wetlands protection, research, and regulation of toxic water pollutants.
- *Food Security Act of 1985* (As amended by the 1990 Farm Bill.) To control degradation of wildlife habitat, water quality, and inland waters due to cultivation of marginal farmlands; preservation of wetlands; minimizing of agricultural pollutant releases.
- *Hazardous Materials Transportation Act of 1974* P.L. 93–633. U.S. Department of Transportation regulates the transportation in commerce of hazardous materials or hazardous wastes by all means of transportation.
- *Irrigation Mitigation and Restoration Partnership Act of 2000* P.L. 106-502. Directs the development and implementation of projects to mitigate impacts to fisheries resulting from the construction and operation of water diversions by local governmental entities in the Pacific Ocean drainage area (areas of Washington, Oregon, Montana, and Idaho from which water drains into the Pacific Ocean).
- *Lead Contamination Control Act of 1988* Requires that lead be removed from school and day-care center drinking water supplies, especially water coolers. The CDC is authorized to provide funds to states for screening of children and their treatment and to remove sources of lead. The CPSC is required to recall drinking water coolers that are not lead free, if not repaired or replaced.
- *Low Level Radioactive Waste Policy Act of 1980* Declares that the disposal of low-level radioactive waste is a state responsibility. Permits states to make agreements for joint use of a site if approved by Congress.
- *Marine Protection, Research, and Sanctuaries Act of 1972* P.L. 92–532 (as amended). Controls the dumping of materials, including sewage sludge and toxic substances, into the oceans, and EPA responsibility.

- *Medical Waste Tracking Act of 1988* The EPA is to establish requirements for medical and infectious waste management, including control of waste generators, transporters, and disposal facility operators. The CDC and OSHA are also involved.
- *National Environmental Policy Act of 1969* P.L. 91–190 (as amended). Encourages productive and enjoyable harmony between human and environment; promotes efforts that will prevent or eliminate danger to the environment and biosphere and stimulates the health and welfare of humans; enriches the understanding of the ecologic systems and natural resources important to the nation; and establishes a Council on Environmental Quality.
- *National Flood Insurance Act of 1968* P.L. 90–448, P.L. 93–234. A program administered by the Federal Emergency Management Agency for land management in flood-prone areas. Supplies funds to states for planning and regulation, restricting certain uses in flood-prone areas, with community participation.
- *National Gas Pipeline Safety Act of 1968* (As amended 1992, 1996.) Requires federal pipeline safety standards to meet the need for protection of the environment and demands corrective action when any pipeline facility is hazardous to the environment.
- *National Invasive Species Act of 1996* P.L. 104-332. Orders the prevention of the introduction and spread of aquatic nuisance species into the Great Lakes and other U.S. waters through the discharge of ballast water.
- *Noise Control Act of 1972* P.L. 92–574 (as amended). Makes the federal government responsible for setting standards for noise detrimental to the human environment from a broad range of sources.
- *Nuclear Waste Policy Act of 1982* Requires the Department of Energy (DOE) to prepare guidelines for and select a geologic site for the storage of high-level waste by 1998 and a second site at a later date. The DOE is also responsible for waste management, including interim storage and transportation.
- *Occupational Safety and Health Act of 1970* P.L. 91–956. To prevent occupational disease and accidents and to establish workplace standards as well as national standards for significant new pollution sources and for all facilities emitting hazardous substances.
- *Ports and Waterways Safety Act of 1972* P.L. 92–340. Regulates, through the Coast Guard, the bulk of shipment of oil and hazardous materials by waters, also under the authority of the *Tanker Act* and the *Dangerous Cargo Act*.
- *Public Utility Regulatory Policy Act of 1979* Requires utilities to purchase energy produced by small power generators at a set cost.
- *Radiation Control for Health and Safety Act of 1968* Controls performance standards for electronic products and notification of defects, also repair or replacement.

- *Resource Conservation and Recovery Act of 1976* P.L. 94–580 (as amended). (Revised by the Hazardous and Solid Waste Amendments of 1984, P.L. 98–616.) Requires a regulatory system for the generation, treatment, transport, storage, and disposal of hazardous wastes—that is, hazardous to human health or to the environment, including a manifest system, from the ''cradle to the grave.'' Conserves natural resources directly and through resource recovery from wastes. Protects groundwater from contamination. Controls landfills and underground storage tanks for hazardous materials and lagoons. Land disposal, landfilling, placement in salt domes, beds, or underground mines, and injection of hazardous wastes into or above underground drinking water source are banned. Small generators, transporters, and disposers are also regulated.
- *River and Harbor Act of 1899* Prohibits discharge of refuse to navigable waters. Also *Oil Pollution Control Act of 1924*. U.S. Army Corps of Engineers is the responsible agency.
- *Safe Drinking Water Act of 1974* P.L. 93–523 (as amended 1986). Authorizes the EPA to establish regulations for drinking water in public water systems, including microbiological, radiologic, organic and inorganic chemical standards, and turbidity levels in drinking water, to protect the public's health. Also controls underground injection of hazardous waste and lead in drinking water, permits sole-source aquifer designation, and provides for water supply source and wellhead protection.
- *Solid Waste Disposal Act of 1965* P.L. 89–272 (as amended 1992, 1996). To initiate and accelerate a national research and development program for new and improved methods of proper and economic solid waste disposal and to provide technical and financial assistance to appropriate agencies in the planning, development, and conduct of solid waste disposal programs. The Secretary of Health, Education, and Welfare (program transferred to the EPA) was responsible for the administration of the act with respect to solid waste problems of communities and their environments, including those solid waste residues that result from business, agricultural, and industrial activities. The Department of the Interior was responsible for solving industrial solid waste problems within facilities engaged in extraction, processing, or utilization of minerals and fossil fuels.
- *Surface Mining Control and Reclamation Act of 1977* P.L. 95–87. The U.S. Department of the Interior sets standards to control disturbance of the land from mining and to assure reclamation afterward. The act also deals comprehensively with specific types of pollution affecting groundwaters.
- *Toxic Substances Control Act of 1976* P.L. 94–569. Grants the EPA authority to control manufacture, distribution, and use of new and existing chemical substances that present an unreasonable risk of injury to health or the environment, except for pesticides, foods, drugs, cosmetics, tobacco, liquor, and several additional categories of chemicals regulated

under other federal laws; develop adequate data and knowledge on the effects of chemical substances and mixtures on health and the environment; establish an inventory and selectively act on those that appear to pose potential hazard; and devise a system to examine new chemicals before they reach the marketplace.

- *Uranium Mill Tailings Radiation Control Act of 1978* (As amended.) Requires the cleanup of radioactive contamination, including groundwater, remaining from inactive processing sites.

Lead Poisoning

Lead is a cumulative poison ending up in the bones, blood, and tissue. Lead is also found in the urine. It is not readily excreted by children. It may cause mental retardation, blindness, chronic kidney diseases, fatigue, anemia, gastroenteritis, muscular paralysis, behavioral changes, high blood pressure, birth defects, and other impairments. Lead poisoning is commonly associated with children living in old and substandard housing built before 1950 who eat lead-based paint on woodwork and paint that peels or flakes from walls (both inside and outside of buildings), ceilings, and other surfaces. However, other sources of lead, as discussed below, may contribute to or be the major cause of high blood lead levels.

Removal of lead-based paint requires special precautions to protect children, adults, and workers from inhaling dust and fumes. Sanding causes the release of lead-laden dust, and open-flame burning or torching releases lead fumes. A heat gun is preferred. Precautions include enclosure of the work area to prevent spread of the dust to other apartments or public areas; protection of furnishings and clothing in the apartments; worker protection, including proper respirator and clothing; complete dust removal and collection using a vacuum with a high-efficiency particle air filter; and proper disposal of the dust and debris, all in accordance with building code, the Department of Housing and Urban Development (HUD), the EPA, and related regulations. The effectiveness of dust removal and cleanup should be determined by surface sampling (floors, walls, window sills) before and after paint removal. Encapsulating the lead-based paint may be a preferred and acceptable alternative to removal if approved by the regulatory agency. Easily accessible locations, such as window sills, should be given priority.

Lead was banned from housepaint in 1978. Food canners stopped using lead solder in the manufacture of tin cans in 1991 and lead in gasoline was phased out in 1995. Thus the number of children with potentially harmful levels of lead in the blood ($>10\ \mu g/dl$) has dropped by 85 percent in the last 20 years. However, there are still many older homes with lead paint, which has further deteriorated and presents a great risk to children and adults who live in or near those homes. Lead is still in the soil, especially near major freeways and highways, at some worksites, and occasionally in drinking water, ceramics, and a number of other products.[190]

Children two to three years old absorb 30 to 75 percent of their lead from ingesting substances, as compared to 11 percent for adults.[191,190] Adults excrete up to 95 percent of ingested lead, whereas children may absorb half of it. Other sources of lead are lead fumes and ashes produced in battery repair and burning lead battery casings, inadequately ventilated indoor firing ranges,[192] emissions from industrial processes, soft corrosive water standing and flowing in lead pipe, pipe with lead-soldered joints, some bronze and brass faucets, and chrome-plated fixtures; natural or added lead in food and drink; lead in dust and soil[193,194]; making lead type; handling lead scrap; lead in lead arsenate pesticides; radiator repair; pottery and ceramics manufacture; lead crystal decanters; lead-soldered cans; colored newsprint; household dust in urban areas; and lead in some household products, all of which contribute to the body burden.

The phasing out of tetraethyl lead from gasoline has introduced a potential and unknown problem associated with manganese compounds used as a replacement for lead, which are emitted at low levels in various forms, including the toxic manganese tetroxide.[195] On the other hand, a HUD study between 1970 and 1976 in New York City showed a drop in blood lead levels in children from 30 to 21 μg/100 ml (same as 30–21 μg/dl) of blood. The drop paralleled a recorded decrease of lead in the ambient air, suggesting a significant relationship.[196] A report from the National Center for Health Statistics found that 90 percent of all lead in the air came from leaded gasoline and that the blood lead level of the average U.S. resident between 1976 and 1980 dropped 38 percent, from 14.9 to 9.2 μg/100 ml,[197] and continued through 1986. This drop in blood lead level reinforces previous findings and the relationship to greater use of unleaded gasoline.

Serious illness and death have been attributed to the use of earthenware pottery with improperly heated lead-based glaze. Such glaze dissolves in fruit juice, acid salad dressing, tomato sauce, coffee, wine, soda pop, and other soft acid drinks.[198–200] Most of the glaze applied to pottery contains lead. When pottery, dinnerware, and other ceramics are not fired long enough at the correct temperature or the glaze is not properly formulated, the glaze will not fuse and seal completely and its lead (and possibly cadmium) component can be leached or released. Moonshine whiskey made in stills containing lead has also been implicated. The FDA has set a limit of 0.5 ppm lead leachate for ceramics used to store acid liquids (including large bowls) and 7.0 ppm for ceramics used for liquid or food service (dishes), with 5.0 ppm for small bowls. Commercial laboratories can analyze dishes, bowls, pitchers, and cups for improper lead glaze. A home test kit found in hardware stores[190] is available to check the detection level.[200,201]* The FDA and U.S. Potters Association

*For information on the home test kit, write to Frandon Enterprises, Inc., 511 N. 48th Street, Seattle, Wa. 98103. Also HybriVet Systems, P.O. Box 1210, Framingham, MA. 01701; Verify, Inc., 1185 Chess Drive, Suite 202, Foster City, CA 94404; and Michigan Ceramic Supplies, 4048 Seventh St., P.O. Box 342, Wyandotte, MI 48192. See *Consumer Reports,* June 1990, p. 378.

check on production and import of ceramic dinnerware. Ornamental pottery should not be used for food or drink.

Control of lead poisoning is approached through identification and removal of lead sources and through mass screening of ghetto children and workers and their families where exposure has occurred. It is ''recommended[202] that children at high risk for lead poisoning be screened as frequently as every 3 to 6 months, using a two-step screening process consisting of an initial erythrocyte protoporphyrin (EP) test followed by a second EP test and a blood lead (BL) test if the initial test indicated an EP level ≥35 μg/dl'' (ref. 202, p. 649). It is also ''recommended that children <6 years of age with BL concentrations ≥25 μg/dl and EP concentrations ≥35 μg/dl be considered to have lead toxicity and to require medical follow-up'' (p. 649). Blood-lead levels of 10 to 15 μg/dl are also cause for concern. WHO recommends 20 μg/dl.[203]*

Environmental follow-up to eliminate the source should also be made. A New York State Supreme Court justice directed New York City to expand its program to eliminate lead-based paint from apartments. He stated that ''patching or removal only of obviously peeling paint is inadequate.'' In effect, the municipality cannot wait for a report from the health department that lead poisoning has occurred before making an inspection and ordering removal of lead-based paint if found.[204] Screening of one- to three-year-olds should be given priority. The average blood lead level in adults not exposed to lead at work is 15 μg/dl or less. Higher levels should therefore be cause for concern. Blood levels of 40 to 60 μg/dl have caused medical problems in adults.[194] Lead is of no known value in the diet. The public health program goal for children ages six months through five years should be the reduction of blood lead level to less than 10 μg/dl, as proposed by CDC.

Additional controls include identification through selective systematic inspection of housing, mostly built before 1950 or 1960, and removal of lead-based paint containing more than 0.05 percent lead by weight; prohibition of sale of toys or baby furniture containing lead paint; removal of dust from floors by wet mop or vacuum; and promotion of hygiene and handwashing by children and adults; education of parents, social workers, public health professionals, health guides, owners of old buildings, and those occupationally exposed to the hazard and its control. The X-ray fluorescence lead paint analyzer has improved hazard identification. Paint analysis by a laboratory is necessary for lead concentrations below the fluorescence analyzer sensitivity. Building codes should prohibit the use of lead solder, pipe, and fittings. The

*35 μg/100 ml maximum in European Economic Community. There is evidence that newborn babies have accumulated lead poisoning from their mothers due to ingestion of lead from very soft water supplies in old lead pipes (''Lead threat to new-born babies,'' *World Water*, January 1981, p. 9).

sale of drinking water coolers with lead-lined tanks or piping is also prohibited. Lead water service lines should be replaced.

In 1986, HUD was required to publish rules and regulations for the systematic inspection and abatement of lead paint hazard in housing it owned or supported. This includes public housing and Federal Housing Administration single-family and multifamily housing. In addition, HUD must notify tenants of low-income public housing constructed before 1978 that may contain lead-based paint of the necessary precautions, of the symptoms of and treatment for lead poisoning, and of the need for blood lead screening for children under seven years of age and where to go for screening.[205]

The national ambient air quality standard for airborne lead is 1.5 $\mu g/m^3$ of air averaged over a three-month period. The OSHA permissible lead exposure level averaged over an 8-hr work day is 50 $\mu g/m^3$, but if the airborne lead concentration averages 30 $\mu g/m^3$ during a work shift, a control program and medical surveillance are required.[206] Persons who work in lead smelters, brass foundries, storage battery–manufacturing plants, and plastic-compounding factories and persons cutting through metal structures coated with lead-based paint or who remove such paints from tanks or other structures are at high risk for lead toxicity.[207]

The national primary drinking water regulation for lead is proposed to be lowered to 0.01 mg/l.* See Lead, Chapter 3. The FDA sets a "tolerable" daily diet level of 6 μg/day for children under age 6, 25 μg/day for pregnant women, and 75 μg/day for other adults. However, they state that some risk exists with any level of lead exposure.[190] It is estimated that the average lead intake from food is 200 to 300 μg/day; air may average 15 to 20 μg/day. Dust and soil may contribute an additional 10 μg/day or more. Water at 50 μg/l would contribute 22 percent of the blood lead level.[203]

It is believed that lead poisoning contributed to the decline of the Roman Empire and the associated deaths, disease, and sterility. The poisoning was due to water distribution in lead pipes and the widespread practice of cooking in lead-based utensils (old pewter), particularly the cooking of a syrup used to preserve and enhance the taste of wine.

There is evidence that there is no acceptable level of lead in humans. Even low levels (below 25 μg/dl) may cause brain damage. It is theorized "that lead, as well as other toxic pollutants may interfere with calcium flow into neurons, thereby disrupting the learning process" in children.†

The CDC guideline for blood lead level has been lowered to 10 μg/dl. This will increase the number of children under age 6 at risk by 10 times according to CDC estimates.

*An action level of 0.015 mg/l in not more than 10 percent of tap samples was subsequently established by the EPA.

†See D. Carpenter, *The Public Health Memo,* School of Public Health, Albany, NY, December 1989.

Carbon Monoxide Poisoning

Carbon monoxide poisoning is sometimes confused with food poisoning as nausea and vomiting are common to both. In carbon monoxide poisoning, the additional symptoms include headache, drowsiness, dizziness, flushed complexion, and general weakness, and carbon monoxide is found in the blood. Excessive exposure results in reduced oxygen availability to the heart, brain, and muscles, leading to weakness, loss of consciousness, and possible death. Persons with cardiovascular diseases are very sensitive to carbon monoxide in low concentrations.

Carbon monoxide combines readily with blood hemoglobin to form carboxyhemoglobin (COHb), thereby reducing the amount of hemoglobin available to carry oxygen to other parts of the body. Hemoglobin has a greater affinity for carbon monoxide than for oxygen—about 210 to 1. Fortunately, the formation of COHb is a reversible process. Death can occur when blood contains 60 to 80 percent COHb.[208]

Carbon monoxide is an odorless, tasteless, and colorless gas. It is a product of incomplete combustion of carbonaceous fuels. Poisoning is caused by leaks in an automobile exhaust system; running a gasoline or diesel engine indoors or while parked; unvented or defective kerosene, gas,* fuel oil, coal, or wood-burning space or water heater, gas range-oven, or gas-fired floor furnace; use of charcoal grill indoors; clogged or leaking chimney or vent; inadequate ventilation and fresh air for complete combustion; improperly operating gas refrigerator; and incomplete combustion of liquefied petroleum gas in recreational and camping units. The indoor work environment (use of a fork lift or other motorized equipment) may also be a hazardous source of carbon monoxide.

Motor vehicle exhausts are the principal source of carbon monoxide air pollution; however, federal standards and emission controls on new automobiles are reducing the ambient-air carbon monoxide levels. Room space heaters are a major potential hazard indoors. Cigarette smoke is also a significant source of carbon monoxide to the smoker. See Venting of Heating Units, Chapter 11.

Education of the public and medical care personnel, standards for appliances, and housing code enforcement can reduce exposure and death from this poisoning.[209] Homes in low-socioeconomic areas can be expected to have the highest carbon monoxide levels.[210]

Concentrations of 70 to 100 ppm carbon monoxide are not unusual in city traffic. The federal ambient-air-quality standard maximum 8-hr concentration is 10 mg/m^3 (9 ppm); the maximum 1-hr concentration is 40 mg/m^3 (35 ppm). These levels can reduce mental efficiency. The standard recommended by the National Institute for Occupational Safety and Health is (NIOSH) 55

*Including methane, butane, and propane.

mg/m^3 (50 ppm) 8-hr time-weighted average.[211] Carbon monoxide levels of 200 to 400 ppm may cause headache and levels of 800 to 1600 ppm unconsciousness; even 50 ppm for 120 min has been shown to reduce exercise tolerance in subjects with angina.[212] Persons with cardiovascular diseases are sensitive to concentrations of 35 ppm and as low as 10 ppm for extended periods.

Mercury Poisoning

Mercury poisoning in humans has been associated with the consumption of methylmercury-contaminated fish, shellfish, bread, and pork and, in wildlife, through the consumption of contaminated seed. Fish and shellfish poisoning occurred in Japan in the Minamata River and Bay region and at Niigata between 1953 and 1964. Bread poisoning occurred as a result of the use of wheat seed treated with a mercury fungicide to make bread in West Pakistan in 1961, Central Iraq in 1960 and 1965, and Panorama, Guatemala, in 1963 and 1964. Pork poisoning took place in Alamagordo, New Mexico, when methylmercury-treated seed was fed to hogs that were eaten by a family. In Sweden, the use of methylmercury as a seed fungicide was banned in 1966 in view of the drastic reduction in the wild bird population attributed to treated seed. In Yakima, Washington, early recognition of the hazard prevented illness when 16 members of an extended family were exposed to organic mercury poisoning in 1976 by the consumption of eggs from chickens fed mercury-treated seed grain. The grain contained 15,000 ppb total mercury, an egg 596 and 1902 ppb, respectively, of organic and inorganic mercury. Blood levels in the family ranged from 0.9 to 20.2 ppb in a man who ate eight eggs per day. A whole-blood level above 20 ppb may pose a mercury poisoning hazard.[213]

It is also reported that crops grown from seed dressed with minimal amounts of methylmercury contain enough mercury to contribute to an accumulation in the food chain reaching humans. The discovery of moderate amounts of mercury in tuna and most freshwater fish and relatively large amounts in swordfish by many investigators in 1969 and 1970 tended to further dramatize the problem.[214]

The organic methylmercury and other alkylmercury compounds are highly toxic. Depending on the concentration and intake, they can cause fever, chills, nausea, unusual weakness, fatigue, and apathy followed by neurologic disorders. Numbness around the mouth, loss of side vision, poor coordination in speech and gait, tremors of hands, irritability, and depression are additional symptoms leading possibly to blindness, paralysis, and death. Methylmercury also attacks vital organs such as the liver and kidney. It concentrates in the fetus and can cause birth defects.[215]

Methylmercury has an estimated biological half-life of 70 to 74 days in humans, depending on such factors as age, size, and metabolism, and is excreted mostly in the feces at the rate of about 1 percent per day. Mercury persists in large fish such as pike from one to two years.

Elemental metallic mercury volatilizes on exposure to air, especially if heated, and in that state poses a distinct hazard. Mercury spills and the mercury from broken thermometers and barometers must be meticulously cleaned and the space ventilated and isolated until the mercury vapor level is no longer detectable by a ''mercury sniffer'' or similar device. Metallic mercury should never be incinerated; toxic gases would be released. Mercury should normally be stored and handled in an airtight enclosure with extreme care. Laboratory use must be carefully controlled and monitored.[216] Certain compounds of mercury may be absorbed through the skin, gastrointestinal tract, and respiratory system (up to 98 percent), although elemental mercury and inorganic mercury compounds are not absorbed to any great extent* through the digestive tract because they do not remain in the body.

Mercury is ubiquitous in the environment. The sources are both natural and man made. Natural sources are leachings, erosion, and volatilization from mercury-containing geologic formations. Carbonaceous shales average 400 to 500 ppb Hg, up to 0.8 ppm in soil. Man-made sources are waste discharges from chlor-alkali and paper pulp manufacturing plants, mining and extraction of mercury from cinnabar, chemical manufacture and formation, the manufacture of scientific instruments, mercury seals and controls, treated seeds, combustion of fossil fuels, atmospheric deposition, and surface runoff. The mercury ends up in lakes, streams, tidal water, and the bottom mud and sludge deposits.

Microorganisms and macroorganisms in water and bottom deposits can transform metallic mercury, inorganic divalent mercury, phenylmercury, and alkoxyalkylmercury into methylmercury. The methylmercury thus formed and perhaps other types, in addition to that discharged in wastewaters, are assimilated and accumulated by aquatic and marine life such as plankton, small fish, and large fish. Alkaline waters tend to favor production of the more volatile dimethylmercury, but acid waters are believed to favor retention of the dimethyl form in the bottom deposits. Under anaerobic conditions, the inorganic mercury ions are precipitated to insoluble mercury sulfide in the presence of hydrogen sulfide. The process of methylation will continue as long as organisms are present and have access to mercury. It is a very slow process, but exposure of bottom sediment such as at low tide permits aerobic action causing methylation of the inorganic mercury.[217]

The form of mercury in fish has been found to be practically all methylmercury, and there are indications that a significant part of the mercury found in eggs and meat is in the form of methylmercury.

The concentration of mercury in fish and other aquatic animals and in wildlife is not unusual. Examination of preserved fish collected in 1927 and

*Seven to 8 percent from food and 15 percent or less from water (*Guidelines for Drinking Water Quality,* Vol. 2, World Health Organizatioin, Geneva, 1984, p. 122).

1939 from Lake Ontario and Lake Champlain in New York has shown concentrations up to 1.3 ppm mercury (wet basis). Fish from remote ponds, lakes, and reservoirs have shown 0.05 to 0.7 ppm or more mercury, with the larger and older fish showing the higher concentration.

In 1970 the amount of mercury in canned tuna fish averaged 0.32 ppm; in fresh swordfish, 0.93 ppm; in freshwater fish, 0.42 ppm (up to 2.0 and 3.0 ppm in a few large fish such as walleyed pike); and in fish taken from heavily contaminated waters, as high as 8 to 23 ppm. The mercury in urban air is generally in the range of 0.02 to 0.2 $\mu g/m^3$; in drinking water, less than 0.001 ppm; in rainwater, about 0.2 to 0.5 ppb ($\mu g/1$); in ocean water, 0.12 ppb; in Lake Superior water, 0.12 ppb; in Lake Erie water, 0.39 ppb; and in soil, 0.04 ppm.[218] Reports from Sweden and Denmark (1967–1969) indicate a mercury concentration of 3 to 8 ppb (ng/g) in pork chops, 9 to 21 ppb in pig's liver, 2 to 5 ppb in beef filet, 9 to 14 ppb in hen's eggs, and 0.40 to 8.4 ppm in pike.

In view of the potential hazards involved, steps have been taken to provide standards or guidelines for mercury. The maximum allowable concentration for 8 hr occupational exposure has been set at 0.05 mg metallic vapor and inorganic compounds of mercury per cubic meter of air.* For organic mercury the threshold limit is 0.01 mg/m^3 of air. The suggested limit for fish is 0.5 ppm; for shellfish, it is 0.2 ppm. The primary standard for drinking water is 0.002 mg/l (2 ppb) as total mercury. A standard of 0.05 ppm has been suggested for food.

A maximum ADI of 0.03 mg for a 70-kg (154-lb) man would provide a safety factor of 10. If fish containing 0.5 ppm mercury were eaten daily, the limit of 0.03 mg would be reached by the daily consumption of 60 g (about 2 oz) of fish.[219] The safe levels would be 2 $\mu g/100$ ml for whole blood and 6 ppm for hair.[220]

There is no evidence to show that the mercury in the current daily dietary intake has caused any harm, although this does not rule out possible nondetectable effects on brain cells or other tissues. The general population should probably not eat more than one freshwater-fish meal per week.

Since mercury comes from man-made and natural sources, every effort must be made to eliminate mercury discharges into the environment. The general preventive and control measures applicable to chemical pollutants were summarized previously under Background, but the goal should be "zero discharge."

Habashi[221] has summarized techniques for the removal of mercury at metallurgical plants in the United States, Europe, and Japan. The author reports that "the removal and recovery of traces of mercury from SO_2 gases or from sulfuric acid has been proved to be technically and economically feasible."

*The OSHA permissible exposure for inorganic mercury is 0.1 mg/m^3 acceptable ceiling. The NIOSH 8-hr time-weighted average exposure limit is 0.05 mg/m^3. See *MMWR*, August 26, 1988, vol. 37, pp. 5–7. The EPA has banned mercury from interior latex paints.

Insofar as water supply is concerned, approximately 98 percent inorganic mercury may be removed by coagulation and settling at a pH of 9.5 followed by filtration through a granular activated carbon filter.

Illnesses Associated with Air Pollution—Lung Diseases

The particulate and gaseous contaminants in polluted air may irritate the eyes and respiratory system or damage the clearance mechanism of the lungs, thereby increasing susceptibility to upper respiratory diseases and aggravating existing chronic illnesses. Diseases mentioned as *also* being associated with air pollution include bronchial asthma (restriction of the smaller airways or bronchioles and increase in mucous secretions), chronic bronchitis (excessive mucus and frequent cough), pulmonary emphysema (shortness of breath), lung cancer, heart diseases, and conjunctivitis (inflammation of the lids and coatings of the eyeballs) (also with lead and carbon monoxide poisoning as previously discussed). It has been estimated that 80 to 90 percent of the emphysema, asthma, and chronic bronchitis is due to cigarette smoking. See Figure 1-4, Table 1-16, and Table 2-2.

A direct single cause-and-effect relationship is often difficult to prove because of the many other causative factors and variables usually involved. Nevertheless, the higher morbidity and mortality associated with higher levels of air pollution and reported episodes (Table 6-2) are believed to show a positive relationship.

Certain air contaminants, depending on the body burden, may produce systemic effects. These include arsenic, asbestos, cadmium, beryllium compounds, mercury, manganese compounds, carbon monoxide, fluorides, hydrocarbons, mercaptans, inorganic particulates, lead, radioactive isotopes, carcinogens, and insecticides. They require attention and are being given consideration in the development of air quality criteria. See Chapter 6.

Bronchial asthma affects susceptible sensitive individuals exposed to irritant air contaminants and aeroallergens. The aeroallergens include pollens, spores, rusts, and smuts. There also appears to be a good correlation between asthmatic attacks in children and adults and air pollution levels.

Chronic bronchitis has many contributing factors, including a low socioeconomic status, occupational exposure, and population density; smoking is a major factor. Air pollution resulting in smoke, particulates, and sulfur dioxide is an additional factor.

Emphysema mortality rates in U.S. urban areas are approximately twice the rural rates, indicating an association with air pollution levels (sulfur oxides). Asthma and bronchitis often precede emphysema.

Lung cancer rates are reported to be higher among the urban populations than the rural. The dominant factor in lung cancer is smoking. Air pollution plays a small but continuous role.

Some generalized effects of common air pollutants and their possible relationship to the above are of interest. Sulfur dioxide and sulfuric acid in low concentrations irritate the lungs, nose, and throat. This can cause the membrane lining of the bronchial tubes to become swollen and eroded, with resultant clotting in the small arteries and veins. Children are more susceptible to coughs, colds, asthma, bronchitis, and croup. Carbon monoxide can affect the cardiovascular system; in high concentrations, the heart, brain, and physical activity can be impaired. It can reach dangerous levels where there is heavy auto traffic and little wind. Smokers are at greater risk. Acute carbon monoxide poisoning causes a lowered concentration of oxygen in the blood and body tissues. (See the discussion on carbon monoxide poisoning earlier in this chapter.) Ozone and other organic oxidants, known as photochemical oxidants, are produced by the reaction of hydrocarbons and nitrogen oxides in sunlight. Ozone is believed to be responsible for a large portion of the health problems associated with photochemical oxidants.[222] Ozone and other chemicals formed in smog irritate the eyes and air passages, causing chest pain, coughing, shortness of breath, and nausea. Ozone can cause aging and severe damage to the lung tissues and interference with normal functioning of the lungs at levels of 0.12 ppm to greater than 0.20 ppm.[223] Nitrogen dioxide in high concentrations can result in acute obstruction of the air passages and inflammation of the smaller bronchi. Nitrogen dioxide at low levels causes eye and bronchial irritation. In the presence of strong sunlight, nitrogen dioxide breaks down into nitric oxide and atomic oxygen, and this then combines with molecular oxygen in air to form ozone. Particulate matter can cause eye and throat irritation, bronchitis, lung damage, and impaired visibility. Benzopyrene and related compounds are known to cause some types of cancer under laboratory conditions and have been incriminated as carcinogens. Olefins have an injurious effect on certain body cells and are apt to cause eye irritation.[224] Beryllium concern relates primarily to lung disease, although it also affects the liver, spleen, kidneys, and lymph glands. Vinyl chloride is related to lung and liver cancer. Mercury may affect several areas of the brain as well as the kidneys and bowels. Lead is associated with retardation and brain damage, especially in children (see separate discussion earlier). The EPA National Emission Standards for Hazardous Air Pollutants identify vinyl chloride, lead, benzene, asbestos, beryllium, and mercury as hazardous. Considerable evidence has been assembled linking air pollution with adverse health effects.[225,226]

Asbestos Diseases

Asbestosis is caused by fine silicate fibers retained in the lungs. There are six grades of asbestos: The most common are crocidolite (blue asbestos), amosite (brown asbestos), and chrysotile (white asbestos), which come from serpentine, and the less common are actinolite, tremolite, and anthrophyllite. Fibers are 0.1 to 10 μm in length, a size not generally visible. Positive identification requires laboratory analysis. The crocidolite fibers, the most hazardous, are straight and stiff (crocidolite has rarely been used since World War II), the amosite are less so; the chrysotile are curly. Fibers that are stiff and elongated lodge across the bronchi and eventually pass into the lung tissue and pleural cavity. Hence, more of the crocidolite is retained in the lungs and may be the cause of most asbestosis.[227] However, chrysotile* is as likely as crocidolite and other fine silicate fibers to induce mesotheliomas after intrapleural entry and also as likely to induce lung neoplasms after inhalation exposures, although it is of less risk than crocidolite. The most common diseases that might result from asbestos, usually after prolonged exposure, are listed below. The disease may appear 10 to 35 years after first exposure:

1. *asbestosis*—a diffuse interstitial nonmalignant, scarring of the lungs;
2. *bronchogenic carcinoma*—a malignancy of the interior of the lungs;
3. *mesothelioma*—a diffuse malignancy of the lining of the chest cavity (pleural mesothelioma) or of the lining of the abdomen (peritoneal mesothelioma); and
4. cancer of the stomach, colon, and rectum.[228]

A potential health risk exists when asbestos fibers become airborne, as in the deterioration and exposure of asbestos in old asbestos paper-lined air distribution ducts, acoustic plaster ceilings, decorative and textured-spray finishes or paints and fire-retardant coatings on steel beams, and the demolition of old buildings. Spackling and other patching compounds may contain asbestos, which would be released to the ambient air in mixing and sanding to prepare the surface for painting. Fireplaces that simulate live embers and ash usually contain asbestos in an inhalable form. Other sources include furnace patching compounds, old steam pipe covers, floor materials, brake linings, paints, and certain domestic appliances. Asbestos is also found in some surface waters, urban stormwaters, and soils and generally in urban areas.[229] However, occupational exposure is the major risk.

The EPA, under authority of the Toxic Substances Control Act of 1976, ruled on July 6, 1989, that all manufacture, import, or processing of felt products, asbestos–cement sheets, floor tiles, and clothing containing asbestos be ended by August 1990 and that distribution be ended in 1992; that disc brake linings and gaskets be ended by August 1993 and their distribution by 1994; and that the manufacture, import, or processing of asbestos–containing paper products, brake blocks and pads, and asbestos-cement pipe and shingles be ended by August 1996 and distribution ended in 1997.† The CPSC has

*Chrysotile fibers are estimated to make up 90 percent of all asbestos (‘‘The asbestos dilema,’’ *U.S. News & World Report*, January 14, 1990, pp. 57–58).

†The EPA ban on, e.g., pipe and pads was overturned by the U.S. Court of Appeals for the 5th Circuit in New Orleans. The ban on insulation, patching, and clothing remains in effect. (P. Zurer, *C&EN,* October 28, 1991, p. 5. Also, EPA Asbestos Materials Bans: Clarification May 18, 1999, EPA Office of Pollution Prevention and Toxics Web page, http://www.epa.gov/opptintr/asbestos/help.htm#Roles. December 2001.)

banned the use of sprayed-on asbestos insulation, spackling compound, and fireplace logs made with asbestos.

Airborne asbestos is potentially hazardous where asbestos-containing materials are loosely bound or deteriorating (friable, crumbly, or powdery when dry), including areas subject to vibration or abrasion, permitting fibers to be released. Control measures in buildings include removal, coating, or sealing (with butyl rubber in inaccessible locations) the surface; enclosure to prevent escape of fibers; surveillance; and affirmative action when the asbestos material begins to lose its integrity. *Existing asbestos that is sound is best left undisturbed*. Schools are required to be inspected to identify both deteriorating and solid asbestos. The coating or sealer used must be flame resistant, and must not release toxic gases or smoke when burned or contain asbestos. Coating or sealing must be considered an expedient requiring continual surveillance. Removal poses added risks to renovation, demolition, and other workers and occupants; it may also cause air pollution and dangers in handling (respirators, disposable garments, showering, complete enclosure of work area, and wetting down are needed) and disposal. Special precautions must be taken.[230] The EPA and OSHA regulations must be followed.[231] The local building department should be consulted and a permit obtained.

Barrett[232] reports that in the occupational field in England the standards are 2 fibers/ml of air for chrysotile asbestos and 0.2 fibers/ml of air for crocidolite. The acceptable level for ambient air would become 0.05 fibers/ml for chrysotile and 0.005 fibers/ml for crocidolite. This allows a safety factor of 4 to convert from occupational to whole-time exposure and a factor of 10 to allow for susceptible members of the population, for a total allowable of one-fortieth of the occupational standard. The EPA regulates asbestos that is released into air and water.[233] The FDA regulates asbestos in food and drugs. Asbestos fibers in drinking water are discussed under Asbestos, Chapter 3.

The Occupational Safety and Health Administration of the Department of Labor regulates exposure (except agricultural) of workers to asbestos[233]: the 8-hr time-weighted average (TWA) airborne concentration of asbestos fibers greater than 5 μm in length shall not exceed 0.2 fiber/cm^3 over an 8-hr workshift. The "action level" is 0.1 fiber/cm^3 as an 8-hr TWA. The NIOSH recommends the lowest feasible concentration with an exposure limit of 0.1 fiber/cm^3 (in a 400-liter air sample) as a TWA concentration for up to an 8-hr workshift, 40-hr workweek. The American Conference of Governmental Industrial Hygienists threshold limit values for fiber >5 μm/cm^3 are 2 fiber/cm^3 for chrysotile, 0.5 fiber/cm^3 for amosite, 0.2 fiber/cm^3 for crocidolite, and 2 f/cc for other forms.[234] Many countries have occupational exposure limits.[235] It is important to ensure that particles identified as asbestos are in fact asbestos fibers. Employ a certified consultant.

Malignant Neoplasms (Cancer)

Cancer is any malignant growth in the body. It is an uncontrolled multiplication of abnormal body cells. The cause of the various types of cancer is unknown, circumstantial, or unclear except for cigarette smoking and exposure to ionizing radiation. There does not appear to be a dosage or level of exposure to cigarette smoking or ionizing radiation below which there is *no* risk. Viruses, genetic background, poor health, and exposure to various agents in our air, water, food, drugs, and cosmetics are believed to contribute to the disease. According to Hamburg,[236] some environmental substances become carcinogenic only after metabolism within the body: "Individual differences in metabolism of these carcinogens may be influenced both by genetic factors and by interaction with other environmental influences" (p. 1026).

Figure 1-4 lists known or suspected links between selected pollutants and cancer as well as heart and lung diseases. Some of the cancers and their associated agents, in addition to cigarette smoking and exposure to radon and other ionizing radiations and sunlight, are tars in smoked fish (cancer of the stomach), asbestos, soot, and beryllium aspiration (cancer of the lungs), polyvinyl chloride (cancer of the liver), and aflatoxin.[237] Diet, life-style, and cultural habits may be contributing factors. Industrial pollutants and toxic chemicals cause a small percentage of all cancers. See Figures 1-5 and 1-6.

Mortality data for the United States show that the crude death rate due to malignant neoplasms in the year 1900 were 64 per 100,000 population, increasing to 147 in 1960, 163 in 1970, 172 in 1975, and 198 in 1988. The age-adjusted death rates increased from 125.4 in 1950 to 133.2 in 1986, remaining fairly constant between 1980 and 1986. Lung cancer was responsible for 27 percent of all human cancer deaths in the United States in 1986, increasing to 28 percent of all cancer deaths in the 1990s.[238] More than 90 percent of lung cancer deaths are estimated to be caused by cigarette smoking.[238,239] There are, however, geographic and demographic differences for different types of cancer, probably due to cultural patterns and environmental factors. The latency period for development of cancer may vary from 5 to more than 40 years. In any case, exposure to known or suspected man-made and natural carcinogenic chemicals should be eliminated or minimized to reduce the incidence of cancer.

Cardiovascular Diseases

The following are the major cardiovascular diseases.

Ischemic heart disease (coronary heart disease)—a deficiency of the blood supply; the principal disease of the heart.

Cerebrovascular disease (stroke)—an occlusion or rupture of an artery to the brain.

Arteriosclerosis—a thickening or hardening of the walls of the arteries, as in old age. Atherosclerosis is the most common form; fatty substances (containing cholesterol) deposited on the inner lining restrict the flow of blood in the arteries, causing coronary thrombosis (an occlusion of arteries supplying heart muscle).

DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL
ATLANTA, GEORGIA 30333

CDC USE ONLY ☐☐☐☐ (1-4)

FORM APPROVED
OMB NO. 0920-0004

INVESTIGATION OF A FOODBORNE OUTBREAK

1. Where did the outbreak occur ?

State ________ (5-6) City or Town ________ County ________

2. Date of outbreak: (Date of onset 1st case)

____
MO / DA / YR (7-12)

3. Indicate actual(a) or estimated (e) numbers:

Persons exposed ________ (13-17)

Persons ill ________ (18-22)

Hospitalized ________ (23-27)

Fatal case ________ (28-31)

4. History of Exposed Persons;

No. histories obtained ________ (32-35)

No. persons with symptoms ________ (36-39)

Nausea ________ (40-43) Diarrhea ________ (44-47)

Vomiting ________ (48-51) Fever ________ (52-55)

Cramps ________ (56-59) Other, specify ________

________ (60-79)

5. Incubation period (hours):

Shortest ________ (80-83) Longest ________ (84-87)

Approx. for majority ________ (88-91)

6. Duration of illness (hours):

Shortest ________ (92-95) Longest ________ (96-99)

Approx. for majority ________ (101-104)

7. Food - specific attack rates:

Food Items Served	Number of persons who ATE specified food				Number who did NOT eat specified food			
	Ill	Not Ill	Total	Percent Ill	Ill	Not Ill	Total	Percent Ill

8. Vehicle responsible (food item incriminated by epidemiological evidence): (105-106) ________

9. Manner in which incriminated food was marketed: (Check all Applicable)

	Yes 1	No 2	
(a) Food Industry			
Raw	☐	☐	(107)
Processed	☐	☐	(108)
Home Produced			
Raw	☐	☐	(109)
Processed	☐	☐	(110)
(b) Vending Machine	☐	☐	(111)
(c) Not Wrapped	☐	☐	(112)
Ordinary Wrapping	☐	☐	(113)
Canned	☐	☐	(114)
Canned – Vacuum Sealed	☐	☐	(115)
Other (specify)	☐	☐	(116)
________			(117-129)
(d) Room Temperature	☐	☐	(130)
Refigerator	☐	☐	(131)
Frozen	☐	☐	(132)
Heated	☐	☐	(133)

If a commerical product, indicate brand name and lot number

________ (134-150)

10. Place of Preparation of Contaminated Item: (151)

Restaurant ☐ 1
Delicatessen ☐ 2
Cafeteria ☐ 3
Private Home ☐ 4
Caterer ☐ 5
Institution:
School ☐ 6
Church ☐ 7
Camp ☐ 8
Other, specify ☐ 9

____
________ (152-171)

11. Place where eaten: (172)

Restaurant ☐ 1
Delicatessen ☐ 2
Cafeteria ☐ 3
Private Home ☐ 4
Picnic ☐ 5
Institution:
School ☐ 6
Church ☐ 7
Camp ☐ 8
Other, specify ☐ 9

____
________ (173-192)

This questionnaire is authorized by law (Public Health Service Act, 42 USC §241). Although response to the questions asked is voluntary, cooperation of the patient is necessary for the study and control of the disease. Public reporting burden for this collection of information is estimated to average 15 minutes per response. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to PHS Reports Clearance Officer; Rm 721-H, Humphrey Bg; 200 Independence Ave. SW; Washington, DC 20201; ATTN: PRA, and to the Office of Information and Regulatory Affairs, Office of Management and Budget, Washington, DC 20503.

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Figure 1-5 Investigation of foodborne outbreak.

LABORATORY FINDINGS (Include Negative Results)

12. Food specimens examined: (193)
Specify by "X" whether food examined was original (eaten at time of outbreak) or check-up (prepared in similar manner but not involved in outbreak).

Item	Orig.	Check up	Findings Qualitative	Findings Quantitative
Example: beef	X		C. perfringens Hobbs type 10	2 x 10^6/gm

13. Enviromental specimens examined: (194)

Item	Findings
Example: meat grinder	C. perfringens, Hobbs Type 10

14. Specimens from patients examined (stool, vomitus, etc.): (195)

Item	No. Persons	Findings
Example: stool	11	C. perfringens, Hobbs Type 10

15. Specimens from food handlers (stool, lesions, etc.): (196)

Item	Findings
Example: lesion	C. perfringens, Hobbs Type 10

16. Factors contributing to outbreak (check all applicable):

	Yes 1	No 2	Unk.	
1. Improper storage or holding temperature	☐	☐	☐	(197)
2. Inadequate cooking	☐	☐	☐	(198)
3. Contaminated equipment or working surfaces	☐	☐	☐	(199)
4. Food obtained from unsafe source	☐	☐	☐	(200)
5. Poor personal hygiene of food handler	☐	☐	☐	(201)
6. Other, specify	☐	☐	☐	(202)

17. Etiology: (203-204)

Pathogen ______________
Chemical ______________
Other ______________

Suspected ☐ 1 (205)
Confirmed ☐ 2
Unknown ☐ 3

18. Remarks: Briefly describe aspects of the investigation not covered above, such as unusual age or sex distribution: unusal circumstances leading to contamination of food, water, epidemic curve; etc. (Attach additional page if necessary)

(206-225)

Name of reporting agency: (226)

Investigating offical: | Date of Investigation:

NOTE: Epidemic and Laboratory Assistance for the investigation of a foodborne outbreak is available upon request by the State Health Department to the Centers for Disease control, Atlanta, Georgia 30333

To improve national surveillance, please send a copy of this report to: Enteric Diseases Branch
Bacterial Diseases Division
Center for Infectious Diseases
Centers for Disease Control
Atlanta, Georgia 30333

Submitted copies should include as much information as possible, but the completion of every item is not required.

CDC 52.13 (back)
REV. 9/88

Figure 1-5 (*Continued*)

Please answer the questions asked below to the best of your ability. This information is desired by the health department to determine the cause of the recent sickness and to prevent its recurrence. Leave this sheet, after you have completed it, at the desk on your way out. (If mailed, enclose self-addressed and stamped envelope and request return of completed questionnaire as soon as possible.)

1. Check any of the following conditions that you have had:

Nausea	Fever	Sore throat	Cough	Chills
Vomiting	Constipation	Headache	Pain in chest	Weakness
Diarrhea	Stomach ache	Dizziness	Laryngitis	Cramps
Thirst	Sweating	Paralysis	Bloody stool	Other

2. Were you ill .... Yes .... No.
3. If ill, first became sick on: Date.................Hour.................A.M./P.M.
4. How long did the sickness last?..
5. Check below (✓) the food eaten at each meal and (×) the food not eaten. Answer even though you may not have been ill.

Meal	Tuesday	Wednesday	Thursday
Breakfast	Apple juice, Corn flakes, Oatmeal, Fried eggs, Bread, Coffee, Milk, Water	Orange, Pancakes, Wheaties, Syrup, Coffee, Milk, Water	Grapefruit, Wheatina, Shredded wheat, Boiled egg, Coffee, Milk, Water
Lunch	Baked salmon, Creamed potatoes, Corn, Apple pie, Lemonade, Water	Roast pork, Baked potatoes, Peas, Rice pudding, Milk, Water, Chef salad	Swiss steak, Home fried potatoes, Turnips, Spinach, Chocolate pudding, Orange drink, Milk, Water
Dinner	Gravy, Hamburger steak, Mashed potatoes, Salmon salad, Cookies, Pears, Cocoa, Water	Roast veal, Rice, Beets, Peas, Jello, Coffee, Water	Fruit cup, Meat balls, Spaghetti, String beans, Pickled beets, Sliced pineapple, Tea, Coffee, Milk

6. Did you eat food or drink water outside?.......... If so, where and when?
....
7. Name.................................... Tel.................. Age.......... Sex..........
8. Remarks (Physician's name, hospital)...
.... Investigator ....

Figure 1-6 Questionnaire for illness from food, milk, or water.

Hypertension (high blood pressure) and hypertensive heart disease.
Rheumatic fever and rheumatic heart disease.

The risk factors associated with cardiovascular diseases include cigarette smoking, poor nutrition, socioeconomic status, age, sedentary way of life, family history, severe stress, personality type, and high blood pressure. Cardiovascular diseases have also been linked to high amounts of total fats, saturated fats, cholesterol, and sodium in the diet. Persons with cardiovascular diseases are more sensitive to carbon monoxide in low concentrations. Obesity and excessive alcohol intake are associated with hypertension.

The Council on Environmental Quality[240] confirmed reports showing that the death rates from cardiovascular diseases tend to decrease as the hardness of drinking water increases, but the factor is not considered to be hardness per se. The direct relationship between cardiovascular death rates and the degree of softness or acidity of water, according to Schroeder, points to cadmium as the suspect.[241] Large concentrations of cadmium may also be related to hypertension in addition to kidney damage, chronic bronchitis, and emphysema. Cadmium builds up in the human body. Low levels of magnesium in soft drinking water are also linked to sudden cardiac death. The indications are that the effects of soft water on cardiovascular diseases may be relatively small. Nevertheless, the water association deserves close attention since cardiovascular disease deaths account for about one-third of all deaths in the United States. Additional substances such as high lithium content in hard water are being correlated with low cardiovascular mortality.[242] See also Cadmium and Hardness, Chapter 3.

There is also evidence associating the ingestion of sodium with heart disease as well as with kidney disease and cirrhosis of the liver. Soft waters and reused waters generally contain higher concentrations of sodium than hard waters. Incidentally, diet drinks generally contain more sodium than regular soft drinks, as do sodium-containing dried milk preparations and cream substitutes. High sodium also contributes to disease in infants.[243,244] Home drinking water supplies softened by the ion exchange process (most home softeners) contain too much sodium for persons on sodium-restricted diets.* This can be avoided by having the cold-water line bypass the softener and using only the cold water for drinking and cooking. Other sources of sodium in drinking water are road salt contamination of surface and groundwater supplies; the sodium hydroxide, sodium carbonate, and sodium hypochlorite used in water treatment; sodium in distilled and bottled water; carbonated water in soft drinks; lime–soda ash and zeolite softened municipal water supplies; and natural minerals in sources of drinking water. The total body

*Each grain per gallon (17.1 mg/l) of hardness removed will add 8 mg/l sodium to the treated water.

burden including that from food and drink must be considered. The crude death rate has decreased from 366.4 per 100,000 population in 1960 to 314.2 in 1988. The age-adjusted rate decreased from a peak of 307.4 in 1950 to 134.6 in 1996, an overall decline of 56 percent. This decline is due to a number of factors, including a decrease in the number of adults who smoke cigarettes, better control of hypertension, less ingestion of cholesterol and control of cholesterol levels, and improvements in medical care.[245] See also Sodium, Chapter 3.

Methemoglobinemia

The presence of more than 45 mg/l nitrates (10 mg/l as N), the standard for drinking water, appears to be the cause of methemoglobinemia, or "blue baby." The disease is largely confined to infants less than three months old but may affect children up to age 6. It is caused by the bacterial conversion of the nitrate ion ingested in water, formula, and other food to nitrite (ref. 246, p. 218): Nitrite then converts hemoglobin, the blood pigment that carries oxygen from the lungs to the tissues, to methemoglobin. Because the altered pigment no longer can transport oxygen, the physiologic effect is oxygen deprivation, or suffocation. Methemoglobinemia is not a problem in adults as the stomach pH is normally less than 4, whereas the pH is generally higher in infants, allowing nitrate-reducing bacteria to survive.

The boiling of water containing nitrates would cause the concentration of nitrates to be increased. Parsons[247] presents evidence showing the standard is too low. Also, certain respiratory illnesses may in themselves cause an increase in methemoglobin levels in infants. A better epidemiologic basis for the standard is apparently needed. The inclusion of nitrite ion and nitrates ingested through food and air, in addition to those ingested through water, would give a more complete basis for evaluating dietary intake. Spinach, for example, is a high source of nitrate nitrogen.

See also Figure 1-2 and Nitrates, Chapter 3.

Dental Caries

Fluoride deficiency is associated with dental caries and osteoporosis.[248] Water containing 0.8 to 1.7 mg/l natural or artificially added fluoride is beneficial to children during the period they are developing permanent teeth. The incidence of dental cavities or tooth decay is reduced by about 60 percent. The maximum fluoride concentration permissible in drinking water is 4.0 mg/l. Optimum fluoride levels in drinking water for caries control, based on the annual average of the maximum daily air temperature for the location of the community water system, are as follows:

Temperature (°F)	Fluoride Level (mg/l)
53.7 and below	1.2
53.8–58.3	1.1
58.4–63.8	1.0
63.9–70.6	0.9
70.7–79.2	0.8
79.3–90.5	0.7

See also Fluoridation, Chapter 3.

An alternate to community water fluoridation is a 1-min mouth rinse by children once a week; it is reported to reduce tooth decay by about one-third or more. The mouth rinse also appears to be beneficial to adults in the prevention of dental caries. Other alternatives include fluoridation of school water supplies if there is an onsite water supply, use of fluoride toothpaste, drops and tablets, and topical application. Milk fluoridation has been shown to be effective in the prevention of dental caries, but to be clinically effective,[249] it must be freshly prepared and consumed immediately. The use of table salt containing fluoride has been proposed by the Pan American Health Organization in areas lacking fluoridated community water supplies.[250] Oral hygiene, including at least daily teeth brushing, consumption of fewer sweets, followed by water rinse or drink, is also basic to caries reduction.

A federal study involving almost 1 million people in 46 American cities showed virtually no difference in death rates, including from cancer, between 24 cities using fluoridated water and 22 without fluoridated water.[251]

The long-term consumption of water high in fluoride (8–20 mg/l) is reported to cause bone changes. An intake of 20 mg fluoride per day for 20 or more years may cause crippling fluorosis, and death can come from a single dose of 2250 to 4500 mg.[252] On the other hand, optimal concentrations of fluoride in drinking water and food appear to be beneficial in preventing osteoporosis.

Hypothermia

The maintenance of a normal body temperature at or near 98.4°F (37°C) is necessary for proper body function. When the body core temperature drops to 95°F (35°C) or below, the vital organs (brain, heart, lungs, kidneys) are affected, causing what is known as hypothermia. There were 7450 deaths from hypothermia reported between 1976 and 1985.[253] Rectal temperature measurement is necessary to get a correct reading. Special ‘‘hypothermia thermometers’’ for accurate reading are available. Predisposing conditions for hypothermia include old age, poor housing, inadequate clothing, poverty, lack of fuel, illness, cold weather, alcohol, and drugs.[254] Outdoor activities may lead to hypothermia.

Proper body temperature requires a balance between body heat generated and heat loss. Bald people lose a great deal of heat; fat people are better insulated and lose less heat on a weight–body surface basis. Disease and drugs, including alcohol, affect heat loss. Wind and dampness increase coldness. The maintenance of warmth and comfort is related to the prevailing temperature, building design and construction, clothing, heating and cooling facilities, and food consumed and also to air movement, radiant heat, relative humidity, the tasks performed, and the age and health status of individuals. At greater risk are babies and the elderly, particularly those already suffering from an acute or chronic illness. In view of the above, a minimum temperature of 70°F (21°C) may be required.[255] Provision for heating and cooling above and below that temperature is recommended. Lack of adequate housing and acute alcohol intoxication are the principal causes of death, as well as advanced age and adverse social and economic circumstances (homelessness).[256]

Signs of hypothermia are bloated face, pale and waxy skin or pinkish color, drowsiness, low blood pressure, irregular and slow heart beat, shallow very slow breathing, trembling of leg, arm, or side of body, and stiff muscles. People should stay indoors when the windchill index is −20°F (−29°C) and below.

High Environmental Temperatures

Heat waves have been associated with marked increases in morbidity and mortality in the United States, but these are largely preventable. Heat disorders include heatstroke, heat exhaustion, heat cramps, and heat rash. Heatstroke, when one's core temperature exceeds 105°F (40.5°C), is the most serious.[257] The measures that have been shown to be effective to reduce heat stress include the following:

1. Keep as cool as possible.
   a. Avoid direct sunlight.
   b. Stay in the coolest available location (it will usually be indoors).
   c. Use air conditioning, if available.
   d. Use electric fans to promote cooling.
   e. Place wet towels or ice bags on the body or dampen clothing.
   f. Take cool baths or showers.
2. Wear lightweight, loose-fitting clothing.
3. Avoid strenuous physical activity, particularly in the sun and during the hottest part of the day.
4. Increase intake of fluids, such as water and fruit or vegetable juices. Thirst is not always a good indicator of adequacy of fluid intake. Persons for whom salt or fluid is restricted should consult their physicians for instructions on appropriate fluid and salt intake.

5. Do not take salt tablets unless so instructed by a physician.
6. Avoid alcoholic beverages (beer, wine, and liquor).
7. Stay in at least daily contact with other people.

Special precautions should be taken for certain higher risk groups, including those occupationally exposed.[258] Safeguards may include increased efforts to keep cool and close observation by others for early signs of heat illness. The high-risk groups are infants and children less than 4 years of age, persons over 65 years of age, alcoholics, persons who are less able to care for themselves because of mental illness or dementia, persons with chronic diseases, especially cardiovascular or kidney disease, and those taking any of the three classes of medication that reduce the ability to sweat: diuretics (“water pills”), tranquilizers, and drugs used for the treatment of gastrointestinal disorders.[259] Building insulation and ventilation help control indoor temperature. Temperatures of 85°F (29°C) or less are usually no cause for worry. High humidity and temperatures near 100°F (38°C) for several days could be dangerous. Strenuous activity should be suspended when the wet bulb temperature index is 90°F (32°C) and above.*

Skin Damage from Sunlight[260]

The ultraviolet light in sunlight can injure the skin and cause skin cancer (melanoma), depending on the exposure. Melanoma appears as a pigmented mole or tumor that may or may not be malignant. Melanomas are almost always curable if detected early and can be usually removed by surgery or freezing with liquid nitrogen. Cataracts can also result from too much sun.

Anyone exposed to the sun should take precautions to avoid the most intense and most hazardous rays between 11 a.m. and 3 p.m. in the United States. A hat and clothing that covers the body are advised. Bathers should use an effective sunscreen lotion. The higher the sunscreen number, the higher the protection. The number selected should be based on skin type and expected exposure time. Individuals with light skin are especially vulnerable.

Tap Water Scalds

Residential hot-water heaters with temperature settings above 120°F (48.9°C) are the principal cause of tap water scalds. Young children, the elderly, and the handicapped are most frequently involved.[261] Showers are another potential hazard if capable of discharging water above 120°F. Hot-water heater thermostats should be lowered to 120°F to prevent scalding accidents.

*FM 21–10 *Field Hygiene and Sanitation*, HQ Department of the Army, November 1988.

Sporotrichosis

Conifer seedlings packed in sphagnum moss can cause papules or skin ulcers and inflammation on the hands and arms, which can then spread to other parts of the body. This disease is caused by a fungus, *Sporothrix schenckii,* found in moss, hay, soil, and decaying vegetation. Protective clothing, including gloves and long-sleeved shirts, should be worn when handling sphagnum moss or seedlings.[262]

Nutritional Deficiency and Related Diseases

Severe examples of diseases caused by deficiencies in the diet are not common in the United States and other developed countries; however, they do occur.[263] These deficiencies are found much more often in less developed countries of the world. There are, however, many people whose diet is slightly deficient in one or more nutrients but who show no clinically detectable symptoms for many years. Most malnutrition takes the form of protein deficiency. Social, biological, cultural, and emotional patterns as well as ignorance contribute to the problem, regardless of the economic status of individuals. Diarrheal diseases and consequent malabsorption compound nutritional deficiency; hence, basic environmental sanitation, including safe water, availability and use of latrines, clean food handling, hand washing, personal hygiene, and refrigeration of food, are essential elements of a comprehensive nutrition program. Deficiency of a nutrient does not by itself necessarily cause disease. Predisposing host and environmental factors as noted are also involved, and this must not be overlooked in the development of a control program.

The vague and insidious nature of these diseases is good reason to apply known preventive and control measures continuously. Recommended daily dietary allowances for the maintenance of good nutrition, to be consumed in a variety of foods to provide other less defined required nutrients, are shown in Table 1-19 (see page 166). Of the more than 60 mineral elements found in living things, 9 are considered essential to human life.[264] These are iron, iodine, fluoride, copper, manganese, zinc, selenium, chromium, and cobalt. The role of other minerals is not well established. Several of the nutritional diseases are mentioned below.

There has been a great deal of interest in the adoption of a balanced, healthy diet to hopefully help minimize deaths due to heart disease and cancer, which, together with stroke, accounted for 66 percent of the causes of deaths in 1986 (64 percent age-adjusted death rate in 1984). The general consensus seems to be that too much saturated fat and cholesterol, sugar, and sodium are unhealthy and that foods containing starch and fiber are good for one's health. Although there is not complete agreement, recommendations include greater consumption of chicken and turkey (with skin removed), fish, pasta, whole-grain products, vegetables, fruits, and vegetable oils (not palm or coconut oils) and less of meat, dairy products, and eggs. Avoid salt, salt- and smoke-preserved ham, bacon, and sausage. J. Michael McGinnis, Deputy Assistant Secretary for Health, U.S. Public Health Service, reported that more than 1.25 million heart attacks occur in the United States, and more than one-half million people die as a result. Although there are multiple risk factors involved, it is believed that 30 percent are related to the excess consumption of saturated fat and cholesterol. It is also reported that 475,000 Americans died of cancer in 1987, with 900,000 new cases. A best guess is that 35 percent were diet related.[265] See also Malignant Neoplasms (Cancer).

Scurvy This is a disease caused by a deficiency of vitamin C or ascorbic acid, which is found in citrus fruit, fresh strawberries, tomatoes, raw peppers, broccoli, kale, potatoes, and raw cabbage. Weakness, anemia, spongy and swollen gums that bleed easily, and tender joints are some of the common symptoms. Vitamin C also strengthens body cells and blood vessels and aids in absorption of iron and in healing wounds and broken bones.

Pellagra This disease is due to a prolonged deficiency of niacin (nicotinic acid) or tryptophan (amino acid). Niacin is found in eggs, lean meats, liver, whole-grain cereals, milk, leafy green vegetables, fruits, and dried yeast. Recurring redness of the tongue or ulcerations in the mouth are primary symptoms, sometimes followed by digestive disturbances, headache, and mental depressions.

Rickets This is a childhood disease (under two years) caused by the absence of vitamin D, which is associated with proper utilization of calcium and phosphorus. Vitamin D is found in liver, fortified milk, butter, eggs, and fish of high-body-oil content such as sardines, salmon, and tuna. An inadequate supply of vitamin D in the diet will probably show in knock-knees or bowed legs, crooked arms, soft teeth, potbelly, and faulty bone growth. Sunshine is a good source of Vitamin D, as are vitamin D–fortified foods. Vitamin D helps build strong bones and teeth.[263]

Beriberi A prolonged deficiency of thiamin or vitamin B_1, found in whole-grain cereals, dried beans, peas, peanuts, pork, fish, poultry, and liver, may cause changes in the nervous system, muscle weakness, loss of appetite, and interference with digestion. Change from unpolished to polished rice in the diet can cause the disease in some countries where the diet is not varied.

Ariboflavinosis This disease is due to a deficiency of riboflavin, known also as vitamin B_2 or G. Riboflavin is found in liver, milk, eggs, dried yeast, enriched white flour, and leafy green vegetables. An inadequate amount of this vitamin may cause greasy scales on the ear, forehead, and other parts of the body, drying of the skin, cracks in the corners of the mouth, anemia, and sometimes partial blindness. Riboflavin is essential for many enzyme systems.

Vitamin A Deficiency This disease causes night blindness, skin and mucous membrane changes, and dryness of the skin and eyeballs and is believed to increase susceptibility to colds. In severe deficiencies, children lose their eyesight and may die. Vitamin A is also needed for bone growth. The diet should be adjusted to include foods rich in vitamin A or carotene, such as dry whole milk and cheese, butter, margarine, eggs, liver, carrots, dandelion, kale, and sweet potatoes.

Liver Cirrhosis Chronic liver disease/cirrhosis is the 10th leading cause of death in the United States[266] Approximately 50 percent of the disease is caused by alcoholism, with 11 percent caused by infection with viruses and the remainder of unknown etiology.[267] Liver damage is also caused by exposure to pesticides and other chemicals. Protective clothing, personal hygiene, and education are essential. Alcoholism requires special treatment.

Iron Deficiency Anemia Lack of vitamin B_{12} or folic acid, repeated loss of blood, and increased iron need during pregnancy cause weakness, irritability, brittle fingernails, cuts and sores on the face at the mouth, and other debility. Prevention of blood loss and treatment with iron salts are suggested. Iron combines with protein to make the hemoglobin of the red blood cells that distribute oxygen from the lungs to body tissues. Consumption of liver, lean meats, poultry, shellfish, eggs, oysters, dried fruits, dark green leafy vegetables, iron-fortified flour, and cereal foods will contribute iron to the diet.

Goiter The WHO reports that an estimated 1000 million people, mostly in Asia and Africa, are at risk of goiter. This is a thyroid disorder usually caused by deficient iodine content in food and water and inadequate iodine absorption. Universal use of iodized or iodated salt has practically eliminated goiter in developed countries. Seafoods and ocean mist are good sources of iodine.

Kwashiorkor Kwashiorkor is one of a group of protein deficiency nutritional diseases common among children under about six years of age living in underdeveloped areas of the world. Others include marasmus and protein energy malnutrition (PEM). Kwashiorkor is usually defined as a sudden-onset malnutritional disease due to man-made or natural disasters. Changes in the color and texture of the hair, diarrhea, and scaling sores are some of the clinical signs. A diet rich in animal proteins, including dry skim milk, meat, eggs, fish, and cheese, and vegetables can control the disease. However, because of the scarcity or lack of these foods in some developing countries, special formulations have been prepared to provide the necessary nutrients. These include Incaparina,[268] a mixture of cornmeal, ground sorghum, cottonseed flour, torula yeast, and leaf meal, blended and fortified with calcium and vitamins; WSDM, consisting of 41.5 percent sweet whey, 36.5 percent full-fat soy flour, 12.2 percent soybean oil, 9 percent corn syrup, and vitamins and minerals; and CSM, corn soya-milk.

Dehydration The loss of body fluids faster than they can be replaced, as a result of diarrhea or other causes, can cause dehydration, debility, and death, especially in children in developing countries. Oral rehydration therapy (ORT), which includes the administration of a balanced mixture of salts, sugar, and water during and after the early stages of diarrhea, controls dehydration and saves many lives at a low cost. The oral rehydration solution consists of 1 liter of *potable* water, plus 3.5 g of sodium chloride, plus 2.5 g of trisodium citrate, plus 1.5 g potassium chloride, plus 20 g of glucose. Foods prepared at home containing cereals, soups, yogurtlike drinks, and other fluids that contain some salt, glucose, and carbohydrate or sucrose may be improvised where oral rehydration salts are not available. Education of users is necessary.[269]

However, affected children require ORT many times during their first five years. The treatment does *not* prevent recurrence of the diarrheal disease. The causes must be removed. Safe drinking water, environmental sanitation, and hygiene are essential to provide long-term protection against the causes of diarrheal diseases. More support and emphasis must be placed on prevention—making available safe and adequate water supplies and sanitation facilities. Doing so will reap multiple benefits, including protection against many diseases such as dracunculiasis (guinea worm disease), cholera, amebiasis, dysentery, typhoid, giardiasis, and a host of helminthic (worm) diseases. Safe drinking water will also promote sanitary food preparation, personal hygiene and household cleanliness, improved housing, a better quality of life, and more.[270]

Osteoporosis In osteoporosis there is a decrease in bone mass and a greater risk from fractures. The bone is decalcified and becomes porous and brittle, particularly in women after menopause, possibly due to dietary factors and a decrease in female hormones. Maintenance of an adequate level of calcium and vitamin D may offset the disease. Fluorides in proper amounts in drinking water and food also appear to help prevent osteoporosis. Calcium helps build teeth and bones, aids in blood clotting, and helps maintain muscles and nerves. Major sources of calcium are milk, cheese and other milk products, egg yolk, and dark green leafy vegetables. However, calcium assimilation by the human body may be quite variable. The administration of estrogens at the time of the menopause can offset the decrease in female hormones, but there are some risks.

Diseases of the Bowel Diets low in fiber have been associated with diseases of the bowel, including diverticulosis and cancer, but more confirmation information is needed. The consumption of more cereal products, potatoes, raw fruits, and vegetables has been suggested.

Overweight and Obesity Overweight has been defined as "a body mass index (BMI = weight [kg]/height [m]^2) $\geq$ 27.8 for men and $\geq$ 27.3 for women. These values represent the sexspecific 85th percentile of BMI for

U.S. adults aged 20–29 years" (ref. 271, p. 421). Initial results from the 1999 National Health and Nutrition Examination Survey (NHANES) indicate that the number of overweight/obese adults is on the rise. In 1999, 61 percent of adults surveyed were either overweight or obese. This is a 5 percent increase over the last survey (NHANES III, 1988–1994). This increase is almost entirely due to a doubling of the number of adults classified as obese (BMI > 30).[272]

Obesity may be due to genetic factors and poor metabolism; however, it is primarily the result of consuming large amounts of food containing high concentrations of sugar and fat, coupled with sedentary living. Possible contributing causes of overeating are stress and depression. Overweight is associated with heart disease, high blood pressure, stroke, respiratory problems, diabetes, and other degenerative diseases. A balanced nutritional diet low in calorie and fat intake that maintains proper weight should be everyone's goal together with moderate and regular exercise.

Marasmus Marasmus is a form of malnutrition caused by chronic lack of calories. It is usually associated with diarrheal diseases and loss of weight in young children. An inadequate diversified food intake can contribute to the problem. A gradual increase in food intake, including protein, carbohydrates, and fat, is the suggested treatment.[7]

Other Noncommunicable or Noninfectious Diseases and Conditions Associated with the Environment

For discussion of diseases associated with poison ivy, poison oak, poison sumac, and hayfever and their control, see Chapter 10 in the fourth edition.

For discussion of illnesses associated with indoor air pollution including biological contaminants, radon, formaldehyde, polychlorinated biphenyls, tobacco smoke, and other contaminants and their control, see Indoor Air Quality, Chapter 11.

For discussion of disease prevention, control, and health effects of chemical ingestion, see Figure 1-2 and Organic and Inorganic Chemicals in Drinking Water, Chapter 3.

For discussion of accidents and safety in swimming pools, beaches, septic tanks, manure pits, sewage treatment plants, sludge digesters, sewers, pumping stations, water tanks, trenches, and confined spaces, see *Accidents* in Index.

For discussion of Legionnaires' disease, see Waterborne Disease Outbreaks in this chapter. Person-to-person spread has not been demonstrated.

For effects of noise and its control, see Chapter 6.

For effects of radon in drinking water and in indoor air, see Chapters 3 and 11.

INVESTIGATION OF WATER- AND FOODBORNE DISEASE OUTBREAKS

General

The promptness with which an investigation is started will largely determine its success. In this way, the cause of the disease may be determined and precautions for the prevention of future incidents learned. One water- or foodborne outbreak at an institution, camp, hotel, or eating place or associated with a food-processing plant will cause severe repercussions and may result in great financial loss.

Upon learning of the existence of an unusual incidence of a disease, it is the duty of the owner or manager and physician called, the hospital and clinic admission office, or the water superintendent, as the case may be, to immediately notify the health department. They are required to cooperate with the investigating authority. The health department, in turn, should report to the owner or operator of the establishment and to the PHS upon completion of the investigation. Such notification and reporting, however, have been sporadic. The PHS CDC compiles statistical reports for the entire country from such information and provides special investigatory assistance on request.

A general knowledge of the cause, transmission, characteristics, and control of diseases is necessary in order to conduct an epidemiologic investigation. This is usually made under the direction of an epidemiologist and a public health engineer or sanitarian if available. The background material was discussed earlier in this chapter. Reference to Figure 1-2 will give, in easily accessible form, the characteristics of various water- and foodborne diseases and perhaps a clue as to what might be responsible for a disease outbreak. It is not a simple matter to quickly determine the cause of illness due to water, food, or other vehicle, but a preliminary study of the symptoms, incubation periods, food and water consumed, housing, bathing area, and sanitary conditions may give a lead and form a basis for the immediate control action to be instituted. Publications summarizing disease outbreak investigation procedures are very helpful.[273–276]

A common method of determining the probable offending food is a tabulation as shown in Figures 1-5, which is made from the illness questionnaire provided in Figure 1-6. Comparison of the attack rates for each food or water will usually implicate or absolve a particular food or water. The food or water implicated is that showing the highest percentage difference between those who ate the specified food or water and became ill and those who did not eat the specified food or water and became ill (see Figure 1-5 as well as Figure 1-8 below). The hazard analysis critical control point procedure should be an essential part of the facility comprehensive sanitary survey.

A summation can be made in the field to take the place of individual questionnaires when assistance is available. The tabulation horizontal headings would include the following:

1. names of persons served;
2. age;
3. ill—yes or no;
4. day and time ill;
5. incubation period in hours (time between consumption of food and first signs of illness);
6. foods served at suspected meals—previous 12 to 72 hr (foods eaten are checked); and
7. symptoms—nausea, vomiting, diarrhea, blood in stool, fever, thirst, constipation, stomach ache, sweating, sore throat, headache, dizziness, cough, chills, pain in chest, weakness, cramps, other.

A simple bar graph, with hours and days (possibly weeks) as the horizontal axis and number ill each hour or other suitable interval plotted on the vertical axis, can be made from the data. The time between exposure to or ingestion of contaminated food or water and illness or first symptoms or between peaks represents the incubation period. The average incubation period is the sum of the incubation periods of those ill (time elapsing between the initial exposure and the clinical onset of a disease) divided by the number of ill persons studied. The median, or middle, time may be preferable when incubation periods vary widely.

Other analyses may include a summary of persons showing a particular symptom such as vomiting, diarrhea, and nausea, as shown in Figure 1-6, or those using a specific facility or calculation of incidence rates. (See refs. 265–268 as appropriate for complete investigation details.)

Sanitary Survey

The sanitary survey should include a study of all environmental factors that might be the cause or may be contributing to the cause of the disease outbreak. These should include water supply, food, housing, sewage disposal, bathing, insects, rodents, pesticide use, foodhandlers and other workers, practices, procedures, and any other relevant factors. Each should be considered responsible for the illness until definitely ruled out. Figure 1-2 and Chapters 1, 3, 4, and 8 to 11 should be referred to for guidance and possible specific contributing causes to an outbreak and their correction. Figure 1-7 will be helpful. Water system, food service, housing, and swimming pool sanitary survey report forms are usually available from the state or local health department to assist in making a complete epidemiologic investigation. A WHO publication also has a water system reporting form[277,278] and the EPA an evaluation manual.[279] See Figure 1-8.

Date .... Investigator ....
Name of place .... Owner ....
Population .... Manager ....
Onsets—day and hours .... Incubation period ....
Number afflicted .... Number hospitalized .... Number deaths ....
Outbreak: explosive .... gradual .... undetermined ....
Samples collected ....

Underline symptoms most commonly reported:

Diarrhea, constipation, abdominal pains, stomach cramps, muscular cramps, prostration, high temperature, painful straining at stool or in urination, sore throat, chills, thirst, sweating, vomiting, nausea, swelling of face and eyelids, laryngitis, cough, pain in chest, enlarged tonsils or adenoids, pains in joints, eye movement difficult, swallowing difficult, headache, dizziness, other ....

Water

1. Water sources and treatment ....
2. Method of serving water ....
3. Interconnections: toilet .... washbasin .... bath tubs .... tubs .... other ....
4. Recent repairs ....
5. Cross-connections, with other supplies ....
6. Changes in water taste .... color .... odor ....

Milk and food

7. Source of milk (pasteurized) ....
8. Method of handling milk ....
9. Use of leftover foods ....
10. Source of fowl, meats, ice cream, shellfish, pastries ....
11. Food refrigeration and storage ....
12. Food handling and preparation ....
13. Ice source and handling ....
14. Thawing foods protected ....
15. Dressings, sauces, etc. ....

Food handlers

16. Recent illness in food handlers ....
17. Hand-washing facilities ....
18. No. pyogenic skin infections ....
19. Personal hygiene ....

Kitchen and dining hall

20. Storage and use of insecticides .... rat poison .... roach powder .... water paint .... silver polish ....
21. Garbage storage and disposal ....
22. Prevalence of rodents and insects ....
23. Fly breeding controlled ....
24. Dish cleansing and disinfection ....
25. Premises and equipment clean ....
26. Food service well organized ....

Other

27. Housing overcrowding ....
28. Bathing beach or swimming pool operation, water source ....
29. Medical and nursing care ....
30. Other ....

Remarks (Comment on unsatisfactory items and probable cause, general impressions, etc.):

Figure 1-7 Outbreak investigation field summary.

Medical Survey

The medical survey should develop a clinical picture to enable identification of the disease. Typical symptoms, date of onset of the first case, date of onset of last case, range of incubation periods, number of cases, number hospitalized, number of deaths, and number exposed are usually determined by the epidemiologist. To assemble this information and analyze it carefully, a ques-

DEPARTMENT OF
HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL
CENTER FOR INFECTIOUS DISEASES
ATLANTA, GEORGIA 30333

INVESTIGATION OF A WATERBORNE OUTBREAK

Form Approved
OMB No. 920-0004

1. Where did the outbreak occur?

________ (1-2) City or Town ________ County ________

2. Date of outbreak: (Date of onset of 1st case)

________ (3-8)

3. Indicate actual (a) or estimated (e) numbers:

Persons exposed ________ (9-11)
Persons ill ________ (12-14)
Hospitalized ________ (15-16)
Fatal cases ________ (17)

4. History of exposed persons:

No. histories obtained ________ (18-20)
No. persons with symptoms ________ (21-23)
Nausea ________ (24-26) Diarrhea ________ (33-35)
Vomiting ________ (27-29) Fever ________ (36-38)
Cramps ________ (30-32)
Other, specify (39) ________

5. Incubation period (hours):

Shortest ________ (40-42) Longest ________ (43-45)
Median ________ (46-48)

Shortest ________ (49-51) Longest ________ (52-54)
Median ________ (55-57)

7. Epidemiologic data (e.g., attack rates [number ill/number exposed] for persons who did or did not eat or drink specific food items or water, attack rate by quantity of water consumed, anecdotal information) * (58)

ITEMS SERVED	NUMBER OF PERSONS WHO ATE OR DRANK SPECIFIED FOOD OR WATER				NUMBER WHO DID NOT EAT OR DRINK SPECIFIED FOOD OR WATER			
	ILL	NOT ILL	TOTAL	PERCENT ILL	ILL	NOT ILL	TOTAL	PERCENT ILL

8. Vehicle responsible (item incriminated by epidemiologic evidence): (59-60)

9. Water supply characteristics

(A) Type of water supply (61)**

- ☐ Municipal or community supply (Name ________)
- ☐ Individual household supply
- ☐ Semi-public water supply
  - ☐ Institution, school, church
  - ☐ Camp, recreational area
  - ☐ Other, ________
- ☐ Bottled water

(B) Water source *(check all applicable)*:

(C) Treatment provided *(circle treatment of each source checked in B)*:

(B) Water source					
☐ Well	a	b	c	d	
☐ Spring	a	b	c	d	
☐ Lake, pond	a	b	c	d	
☐ River, stream	a	b	c	d	

a. no treatment
b. disinfection only
c. purification plant — coagulation, settling, filtration, disinfection *(circle those applicable)*
d. other ________

10. Point where contamination occurred: (66)

☐ Raw water source ☐ Treatment plant ☐ Distribution system

*See CDC 52.13 (Formerly 4.245) Investigation of a Foodborne Outbreak, Item 7.
**Municipal or community water supplies are public or investor owned utilities. Individual water supplies are wells or springs used by single residences. Semipublic water systems are individual-type water supplies serving a group of residences or locations where the general public is likely to have access to drinking water. These locations include schools, camps, parks, resorts, hotels, industries, institutions, subdivisions, trailer parks, etc., that do not obtain water from a municipal water system but have developed and maintain their own water supply.

CDC 52.12 (f. 4.461)
REV. 7-81

This report is authorized by law (Public Health Service Act, 42 USC 241).
While your response is voluntary, your cooperation is necessary for the understanding and control of the disease.

Figure 1-8 Investigation of waterborne outbreak.

tionnaire should be completed, by trained personnel if possible, on each person available or on a sufficient number to give reliable information. A typical simple, short question sheet is shown in Figure 1-6.

A very important part of the medical survey is examining all the foodhandlers and assembling a medical history on each one. Frequently, a carrier or a careless infected foodhandler can be found at the bottom of a foodborne

11. Water specimens examined: (67)
(Specify by "X" whether water examined was original (drunk at time of outbreak) or check-up (collected before or after outbreak occurred)

ITEM		ORIGINAL	CHECK UP	DATE	FINDINGS		BACTERIOLOGIC TECHNIQUE (e.g., fermentation tube, membrane filter)
					Quantitative	Qualitative	
Examples:	Tap water	X		6/12/74	10 fecal coliforms per 100 ml.		
	Raw water		X	6/2/74	23 total coliforms per 100 ml.		

12. Treatment records: *(Indicate method used to determine chlorine residual):*
Example: Chlorine residual — One sample from treatment plant effluent on 6/11/74 — trace of free chlorine
Three samples from distribution system on 6/12/74 — no residual found

13. Specimens from patients examined (stool, vomitus, etc.) (68)

SPECIMEN	NO. PERSONS	FINDINGS
Example: Stool	11	8 *Salmonella typhi*
		3 negative

14. Unusual occurrence of events:
Example: Repair of water main 6/11/74; pit contaminated with sewage, no main disinfection. Turbid water reported by consumers 6/12/74.

15. Factors contributing to outbreak *(check all applicable):*

- ☐ Overflow of sewage
- ☐ Seepage of sewage
- ☐ Flooding, heavy rains
- ☐ Use of untreated water
- ☐ Use of supplementary source
- ☐ Water inadequately treated
- ☐ Interruption of disinfection
- ☐ Inadequate disinfection
- ☐ Deficiencies in other treatment processes
- ☐ Cross-connection
- ☐ Back-siphonage
- ☐ Contamination of mains during construction or repair
- ☐ Improper construction, location of well/spring
- ☐ Use of water not intended for drinking
- ☐ Contamination of storage facility
- ☐ Contamination through creviced limestone or fissured rock
- ☐ Other (specify) ______

16. Etiology: (69-70)
Pathogen ______
Chemical ______
Other ______

(71)
Suspected 1
Confirmed . . . . 2 *(Circle one)*
Unknown 3

17. Remarks: *Briefly describe aspects of the investigation not covered above, such as unusual age or sex distribution; unusual circumstances leading to contamination of water; epidemic curve; control measures implemented; etc. (Attach additional page if necessary)*

Name of reporting agency: (72)

Investigating Official: | **Date of investigation:**

Note: Epidemic and Laboratory assistance for the investigation of a waterborne outbreak is available upon request by the State Health Department to the Centers for Disease Control, Atlanta, Georgia 30333.

To improve national surveillance, please send a copy of this report to: Centers for Disease Control
Attn: Enteric Diseases Branch, Bacterial Diseases Division
Center for Infectious Diseases
Atlanta, Georgia 30333

Submitted copies should include as much information as possible, but the completion of every item is not required.

CDC 52.12 (f. 4,461) (BACK)
7-81

Figure 1-8 (*Continued*)

outbreak. The importance of animal reservoirs of infection should not be overlooked. Figure 1-2 gives in condensed form symptoms and incubation period of many diseases that, when compared to a typical clinical picture, may suggest the causative organism and the disease. A high attack rate, 60 to 80 percent for example, would suggest a virus (Norwalk) as the cause of a foodborne outbreak.[280]

Samples and Specimens

The prompt collection of samples and specimens for laboratory examinations is a necessary part of the investigation of water- and foodborne disease outbreaks. Isolating the incriminating organism from the persons made ill and the allegedly responsible food or drink, producing the characteristic symptoms in laboratory animals or human volunteers, and then isolating the same organisms from human volunteers or laboratory animals will confirm the field diagnosis and definitely implicate the responsible vehicle. In the early stages of the field investigation, it is very difficult to determine just what samples to collect; yet if the samples of food, for example, are not collected at that moment, the chances are the samples will be gone when they are wanted. It is customary, therefore, to routinely collect samples of water from representative places and available samples of all leftover milk, drinks, and food that had been consumed and place them under seal and refrigeration. Sterile spatulas or spoons boiled for 5 min can be used to collect samples. Sterile widemouth water bottles and petri dishes make suitable containers. In all cases, a sterile technique must be used. Since examination of all the food may be unnecessary, it is advisable, after studying the questionnaires and accumulated data, to select the suspicious foods for laboratory examination and set aside the remaining food in protected sterile containers under refrigeration at a temperature of less than 40°F (4°C) for possible future use. Laboratory procedures should be followed for collection, preservation, and shipment of all specimens and samples.

Samples of water should be collected directly from the source, storage tanks, high and low points of the distribution system at times of high and low pressure, kitchens, and taps near drinking fountains for chemical and bacterial examinations. Samples of milk should be collected from unopened and opened bulk milk cartons or containers and leftover milk in pitchers or other containers for phosphatase tests, coliform tests, direct microscopic counts, standard plate counts, presence of streptococcus, and any other specific tests that may be indicated. Samples of food possibly incriminated should be collected from the refrigerator, storeroom, or wherever available. As a last resort, samples have been collected from garbage pails or even dumps; however, results on such samples must be interpreted with extreme caution. If commercial food has been used, the original container or package should be salvaged for future reference. Figure 1-2 will be of assistance in suggesting the common vehicle, and hence the foods to suspect, by using the incubation periods and symptoms of those ill as a guide. It should be remembered that the time elapsing before symptoms appear is variable and depends on the causative agent and size of dose, the resistance of individuals, and the amount and kind of food or drink consumed. For example, an explosive outbreak with a very short incubation period of a few minutes to less than an hour would suggest a chemical poisoning. Antimony, arsenic, cadmium, cyanide, mercury, sodium fluoride, sodium nitrate, or perhaps shellfish poisoning, favism, fish poisoning, and zinc poisoning are possibilities. An explosive outbreak with an incubation period of several hours would suggest botulism or fish, mushroom, potato, rhubarb-leaf, shellfish, chemical, or staphylococcus food poisoning. An incubation period of 6 to 24 hr would suggest botulism, mushroom poisoning, rhubarb poisoning, salmonella infection, or streptococcus food poisoning. An incubation period of one to five days would suggest ascariasis, botulism, diphtheria, amebic dysentery, bacillary dysentery, leptospirosis, paratyphoid fever, salmonella infection, scarlet fever, streptococcal sore throat, or trichinosis. For other diseases with more extended incubation periods, refer to Figure 1-2. The laboratory examinations might be biologic, toxicologic, microscopic, or chemical, depending on the symptoms and incubation period.

The CDC[281] classifies outbreaks of unknown etiology into four subgroups by incubation period of the illnesses: <1 hr (probable chemical poisoning), 1 to 7 hr (probable *Staphylococcus* food poisoning), 8 to 14 hr (probable *C. perfringens* food poisoning), and >14 hr (other infectious or toxic agents).

Specimens collected from foodhandlers may include stool, vomitus, blood, urine, skin, nose, throat, and other membrane specimens or swabs for biologic or microscopic examinations. Stool specimens can be collected even after symptoms subside. Disease agents can continue to be excreted in the feces for weeks or longer. Medical and laboratory study to determine the origin of the food contaminant may be carried over an extended period of time, since the absence of disease-producing organisms in three stools is generally required before a person is considered negative, although in screening, one stool specimen will reveal a high percentage of carriers.

Some of those ill with the severest symptoms, say about 10, should be selected for laboratory study to determine, if possible, the organism causing the illness. The specimens collected and the examinations made would be indicated by the symptoms and dates of onset displayed by the sufferers as explained above. Stool, urine (chemical poisoning), rectal, serum, vomitus, skin, nose, and throat swabs may be indicated.[276] Specimens from some not ill should also be taken.*

When chemical poisoning is suspected, samples of flour, sugar, and other foods that might have been contaminated in transportation, handling, and preparation should be considered. Galvanized or zinc-, cadmium-, and antimony-plated utensils and liquids prepared in such containers should be col-

*See J. F. Lew, C. W. LeBaron, R. I. Glass, T. Torok, P. M. Griffin, J. G. Wells, D. D. Juranek, and S. P. Wahlquist, "Recommendations for Collection of Laboratory Specimens Associated with Outbreaks of Gastroenteritis," *MMWR,* October 26, 1990 (PR-14), pp. 1–13, for instructions on the collection of stool and serum specimens.

lected for chemical and toxicologic tests. Also include samples of insecticides, rodenticides, ant powders or sprays, and silver polish.

The sanitary and medical surveys may involve the swimming pool or bathing beach. In that case, samples should be collected at the peak and toward the end of the bathing period for examinations.

Laboratory analyses for water samples should include the standard plate count (heterotrophic plate count), in addition to the test for coliform bacteria, since large bacterial populations may suppress the growth of coliform organisms. Where large volumes of water are needed, use 2- to 5-gal sterile containers and store at 41°F (5°C). Sampling for recovery of viruses and *Giardia* or *Entamoeba* cysts may require special on-site filters and equipment.[282] See (a) Sanitary Survey and Water Sampling, (b) Bacterial Examinations, (c) Virus Examination, and (d) Protozoa and Helminths Examination, Chapter 3.

It is customary to notify the laboratory in advance that an outbreak has occurred and that samples and specimens will be delivered as soon as possible. All should be carefully identified, dated, sealed, and refrigerated. A preliminary report with the samples and specimens, including the probable cause, number ill, age spread, symptoms, incubation period, and so on, will greatly assist the laboratory in its work.

Preliminary Recommendations

Before leaving the scene of an investigation, a preliminary study should be made of the data accumulated and temporary control measures instituted based on the findings summarized in Figures 1-6 and 1-7. Instructions should be left by the health officer, sanitary engineer, or sanitarian with the owner or manager regarding those who are ill, the housing, water supply, food and milk supply, foodhandlers, sewage disposal, swimming and bathing place, vectors, noxious weeds, safety hazards, pesticide use, and any other items that may be indicated. The purpose of an investigation should be not to go home and write a paper but to stop the outbreak or epidemic and prevent recurrences. This requires immediate follow-up.

Epidemiologic Report

The report of an investigation of a water- or foodborne disease outbreak should include the cause, laboratory findings, transmission, incidence, cases by dates of onset, average incubation period and range, typical symptoms, length of illness, age and sex distribution, deaths, secondary attack rate, and recommendations for the prevention and control of the disease. This can often be accomplished by careful study of the results of the sanitary and medical surveys and results of laboratory examinations, including the questionnaires and summaries given in Figures 1-5 to 1-8. Reports should be sent to the state health department and the PHS.

Reliable data from an accredited laboratory are essential to support administrative judgment. However, this is not the sole or necessarily the major factor in making an administrative decision. Equally important are proper container and specimen preparation, sample transportation and storage, proper collection of a representative sample, and a *comprehensive detailed sanitary survey* of the food service water system and other environmental facilities and services involved. The sanitary survey is as important to the interpretation of an environmental sample and determining a sound course of action as is a medical history to the interpretation of results of an examination of a diagnostic specimen in determining proper treatment of a patient. Laboratories must refrain from attempting, or succumbing to the temptation, to make a judgment based solely on the laboratory results.

Other

Although only water- and foodborne disease investigations have been discussed, other agents might be suspected. Respiratory disease as related to overcrowding; ringworm infections as related to shower rooms and bathhouses; lousiness, impetigo, and scabies as related to personal hygiene and close contact; vectorborne diseases as related to arthropod prevalence; and carbon monoxide poisoning as related to unvented heaters or poor ventilation are other examples of possible investigations.

The reader is referred to *Procedures to Investigate Arthropod-Borne and Rodent-Borne Illness,* prepared by the International Association of Milk, Food, and Environmental Sanitarians, for excellent detailed information when other avenues of disease transmission are suspected (see the Bibliography).

Useful Internet Web Sites

Most of the updating of this chapter was accomplished by using online references. When citing material from a web site, the authors have included a complete journal reference when possible and in any case have cited the month and year the web page was accessed in parentheses.

Centers for Disease Control: http://www.cdc.gov. Site includes Emerging Infectious Disease, National Vital Statistics, *MMWR* (*Morbidity and Mortality Weekly*), National Center for Environmental Health, and FoodNet,

World Health Organization: http://www.who.int/home-page.

Environmental Protection Agency: Including National Ambient Air Quality Standards, AIRNOW and Pollution Prevention.

U.S. Dept of Health and Human Services: http://www.dhhs.gov.

Food and Drug Administration: http://www.fda.gov. Including FDA Consumer Magazine and Center for Food Safety and Applied Nutrition.

Taber's Online: http://www.tabers.com. Medical definitions and periodicals.

American Journal of Public Health: http://www.ajph.org.

American Podiatric Medical Association: http://www.apma.org/index.html.

Library of Congress: http://thomas.loc.gov/home/thomas.html. Thomas Search Engine, which searches the database of the *Congressional Record* for any law or piece of legislation from the 93rd Congress (1973–1974) to the present Congress.

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TABLE 1-19 Food and Nutrition Board, National Academy of Sciences—National Research Council Recommended Dietary Allowances,[a] Revised 1989

		Weight[b]		Height[b]			Fat-Soluble Vitamins			
Category	Age (years) or Condition	(kg)	(lb)	(cm)	(in)	Protein (g)	Vitamin A (μg RE)[c]	Vitamin D (μg)[d]	Vitamin E (mg α-TE)[e]	Vitamin K (μg)
Infants	0.0–0.5	6	13	60	24	13	375	7.5	3	5
	0.5–1.0	9	20	71	28	14	375	10	4	10
Children	1–3	13	29	90	35	16	400	10	6	15
	4–6	20	44	112	44	24	500	10	7	20
	7–10	28	62	132	52	28	700	10	7	30
Males	11–14	45	99	157	62	45	1,000	10	10	45
	15–18	66	145	176	69	59	1,000	10	10	65
	19–24	72	160	177	70	58	1,000	10	10	70
	25–50	79	174	176	70	63	1,000	5	10	80
	51+	77	170	173	68	63	1,000	5	10	80
Females	11–14	46	101	157	62	46	800	10	8	45
	15–18	55	120	163	64	44	800	10	8	55
	19–24	58	128	164	65	46	800	10	8	60
	25–50	63	138	163	64	50	800	5	8	65
	51+	65	143	160	63	50	800	5	8	65
Pregnant						60	800	10	10	65
Lactating	1st 6 months					65	1,300	10	12	65
	2nd 6 months					62	1,200	10	11	65

Water-Soluble Vitamins							Minerals						
Vitamin C (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg NE)[f]	Vitamin B_6 (mg)	Folate (μg)	Vitamin B_{12} (μg)	Calcium (mg)	Phosphorus (mg)	Magnesium (mg)	Iron (mg)	Zinc (mg)	Iodine (μg)	Selenium (μg)
30	0.3	0.4	5	0.3	25	0.3	400	300	40	6	5	40	10
35	0.4	0.5	6	0.6	35	0.5	600	500	60	10	5	50	15
40	0.7	0.8	9	1.0	50	0.7	800	800	80	10	10	70	20
45	0.9	1.1	12	1.1	75	1.0	800	800	120	10	10	90	20
45	1.0	1.2	13	1.4	100	1.4	800	800	170	10	10	120	30
50	1.3	1.5	17	1.7	150	2.0	1,200	1,200	270	12	15	150	40
60	1.5	1.8	20	2.0	200	2.0	1,200	1,200	400	12	15	150	50
60	1.5	1.7	19	2.0	200	2.0	1,200	1,200	350	10	15	150	70
60	1.5	1.7	19	2.0	200	2.0	800	800	350	10	15	150	70
60	1.2	1.4	15	2.0	200	2.0	800	800	350	10	15	150	70
50	1.1	1.3	15	1.4	150	2.0	1,200	1,200	280	15	12	150	45
60	1.1	1.3	15	1.5	180	2.0	1,200	1,200	300	15	12	150	50
60	1.1	1.3	15	1.6	180	2.0	1,200	1,200	280	15	12	150	55
60	1.1	1.3	15	1.6	180	2.0	800	800	280	15	12	150	55
60	1.0	1.2	13	1.6	180	2.0	800	800	280	10	12	150	55
70	1.5	1.6	17	2.2	400	2.2	1,200	1,200	320	30	15	175	65
95	1.6	1.8	20	2.1	280	2.6	1,200	1,200	355	15	19	200	75
90	1.6	1.7	20	2.1	260	2.6	1,200	1,200	340	15	16	200	75

[a]The allowances, expressed as average daily intakes over time, are intended to provide for individual variations among most normal persons as they live in the United States under usual environmental stresses. Diets should be based on a variety of common foods in order to provide other nutrients for which human requirements have been less well defined. See text for detailed discussion of allowances and of nutrients not tabulated.

[b]Weights and heights of Reference Adults are actual medians for the U.S. population of the designated age, as reported by NHANES II. The median weights and heights of those under 19 years of age were taken from P. V. Hamill, T. A. Drizd, C. L. Johnson, R. B. Reed, A. F. Roche, and W. M. Moore, "Physical Growth: National Center for Health Statistics Percentiles," *Am. J. Clinical Nutrition,* March 1979, pp. 607–629 (see pp. 616–617). The use of these figures does not imply that the height-to-weight ratios are ideal.

[c]Retinol equivalents: 1 retinol equivalent = 1 μg retinol or 6 μg β-carotene. See text for calculation of vitamin A activity of diets as retinol equivalents.

[d]As cholecalciferol; 10 μg cholecalciferol = 400 IU of vitamin D.

[e]α-Tocopherol equivalents: 1 mg D-α-tocopherol = 1 α-TE. See text for variation in allowances and calculation of vitamin E activity of the diet as α-tocopherol equivalents.

[f]1 NE (niacin equivalent) is equal to 1 mg of niacin or 60 mg of dietary tryptophan.

2 Environmental Engineering Planning and Impact Analysis

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INTRODUCTION

Definitions

Comprehensive planning takes into account the physical, social, economic, environmental, and related factors of an area and attempts to blend them into a single compatible whole that will support a healthy and efficient society. A *comprehensive plan* has been defined as follows (ref. 1, p. 10)*:

> (a) A model of an intended future situation with respect to: (i) specific economic, social, political, and administrative activities; (ii) their location within a geographic area; (iii) the resources required; and (iv) the structures, installations, and landscape that are to provide the physical expression and physical environment for these activities; and (b) A program of action and predetermined coordination of legislative, fiscal, administrative, and political measures, formulated with a view to achieving the situation represented by the model.

The term *planning* is defined as follows (ref. 2, p. 2):

> [The] systematic process by which goals (policies) are established, facts are gathered and analyzed, alternative proposals and programs are considered and compared, resources are measured, priorities are established, and recommendations are made for the deployment of resources designed to achieve the established goals.

*This definition modifies that of E. Weissman, *Planning and Urban Design,* Bureau of Municipal Research, Toronto, 1967, p. 40.

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0-471-41813-7

There is great need for emphasis on the areawide, metropolitan, and regional approaches to planning and on the presentation of a total integrated and balanced appraisal of the essential elements for healthy living. The latter is difficult to achieve, as it requires a delicate synthesis of competing economic, social, and physical environmental goals. However, a reasonable balance must be sought, and these goals can only be approached if realistic objectives are set and *all* the facts are analyzed and presented with equal force. Regional planning should recognize and integrate national, interstate, state, county, and local planning. In some instances, no matter how logical and sound the regional planning, the most that can be achieved is local implementation, hopefully within the context of the regional plan. The complexity of modern society requires increased emphasis and attention to regional plans.

Environmental Engineering Multimedia Considerations

Some of the essential environmental health and environmental engineering objectives, frequently overlooked in planning, will be identified to show how they can be blended into the usual planning process to achieve more comprehensive community plans and integrated environmental management. People are demanding as a fundamental right, not only clean air and pure water and food, but also decent housing, an unpolluted land, freedom from excessive noise, adequate recreational facilities, and housing in communities that provide comfort, privacy, and essential services. The usual single-purpose planning for a highway, housing development, or solid waste facility must be broadened to consider the environmental, economic, and social purposes to be served and the effects (beneficial and adverse) produced by the proposed project. The planner must ensure that potential problems are avoided in the planning stages, that the solution of one pollution problem is not transferred from one medium to another (from air to land or water and vice versa), and that projects are so designed as to be pleasing and enhance the quality of life. This is discussed later in this chapter under Environmental Factors to Be Evaluated in Site Selection and in Environmental Impact Analysis.

For example, transportation planning must take into consideration the need for service and rest areas with picnic spaces, toilet facilities, drinking water, insect and weed control, wastewater disposal, and solid waste storage and disposal facilities. It must also consider, impervious surfaces, accident hazards, potential spills, landscaping, buffer zones, and the effects of terminals, ports, routes, entrances, and exits on adjoining communities. Environmental effects during and after construction must also be taken into consideration: erosion control during construction; travel of sediment, dust, and possible flooding; pollutional effects on water supply intakes, streams, lakes, fish, and wildlife; and the disposal of trees, stumps, and demolition material without causing air pollution. Problems to be resolved in the planning stages are control of noise, vibration, and air pollution; dust and weed suppression; and control of deicing chemicals, herbicides, and other pollutants, because they might affect nearby water wells, reservoirs, watersheds, and recreational areas as well as wildlife, vegetation, streams, and lakes.

Beyond these direct effects and services, transportation planning and implementation can leave a dominant impact on community cohesion, population density, infrastructure cost, urban design, and quality of life.

Another example is the design and construction of an incinerator. Many engineering and environmental considerations and interrelations, if recognized in the planning stage, can greatly minimize the design, social, political, and ecological problems that may delay or prevent project implementation. Figure 2-1 shows the process involved in the treatment and disposal of solid wastes by incineration, the potential liquid, solid, and gaseous waste products, energy and resource recovery, and the supporting needs. Listed below are factors that require integrated study and resolution, in addition to siting acceptance, to ensure final construction, operation, and minimal deleterious effects:

Environmental, Engineering, Planning, and Site Selection Factors

1. *Geology* Suitable foundation soils, safe from earthquake, active faults and slides; avoid channeled and creviced formations, that is, limestone, dolomite or gypsum, and shale.
2. *Drainage and Flooding* Site above 100-year flood level; access roads well drained and above flood level.
3. *Transportation* Access roads of proper design, safe entrance and exit lanes; noise, dust, and other air pollution on transportation routes minimal and compatible with adjacent land uses.
4. *Aesthetics* Site is screened and landscaped.
5. *Noise Control* At dumping platform, charging hopper, truck delivery and leaving; buffers.
6. *Water Supply* Drinking and sanitary purposes, cooling water, makeup water; cross-connection control. Also water resources; recreation, wildlife. Compliance with Safe Drinking Water Act; if source is onsite, also state and local regulations.
7. *Wastewater Disposal* From dumping platform, storage and charging areas, residue quenching, gas cooling, particulate removal; toilet, shower, and dressing rooms; receiving stream classification, treatment and permit required, wastewater reuse, cross-connection control. Compliance with Clean Water Act as amended; also state and local regulations.
8. *Solid Waste Disposal* Incinerator residue; fly ash from particulate removal; nonincinerable solid wastes; sludge from wastewater treatment; resource recovery and reuse of residue; sanitary landfill; air, surface,

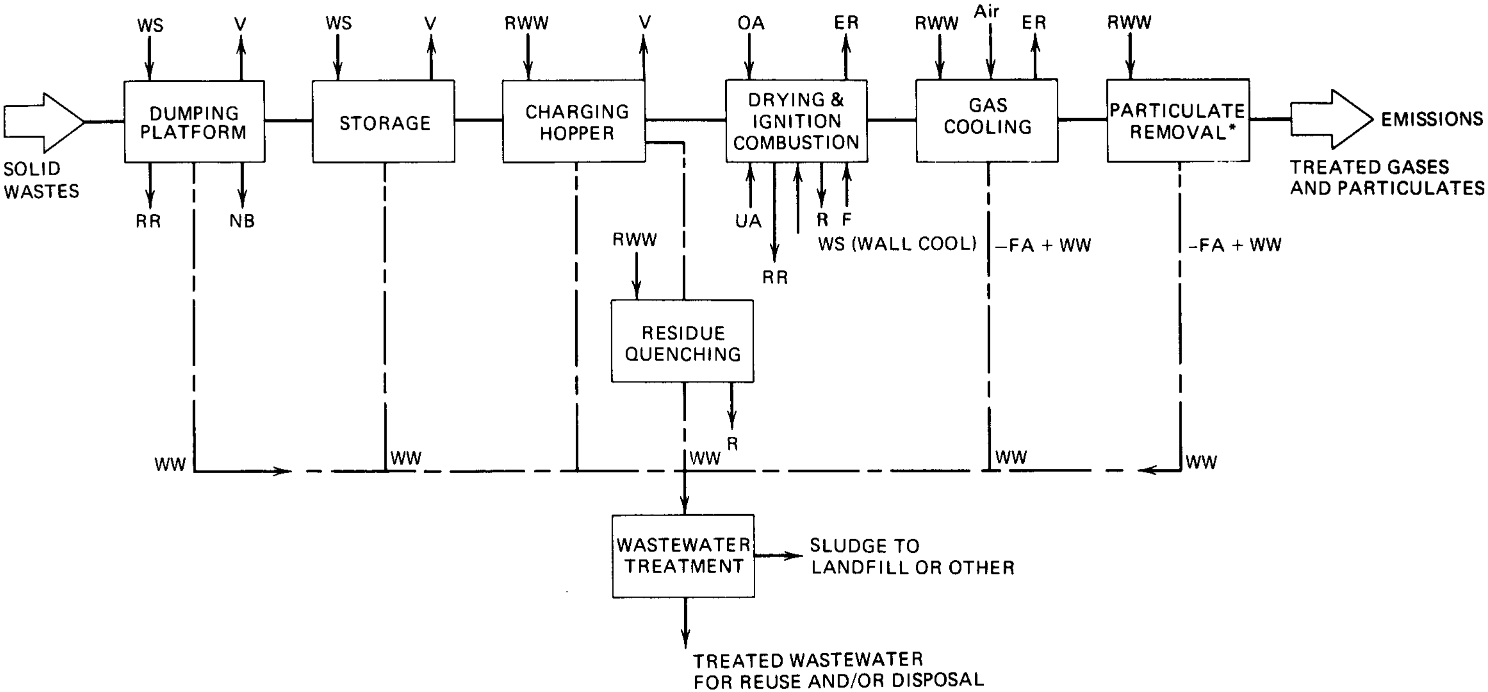

Figure 2-1 Incinerator processes and environmental engineering controls requiring integrated multimedia environmental planning and management: WS, water supply; WW, wastewater; RWW, reclaimed wastewater; OA, overfire air; UA, underfire air; F, fuel, if needed; R, residue, landfill, metal salvage; FA, fly ash; V, ventilation, odor, and dust control; NB, nonburnables; ER, energy recovery; RR, resource recovery. *Settling chamber, wetted baffles, fabric filters, cyclones, wet scrubbers, electrostatic precipitators. (Adapted from DeMarco et al., *Incinerator Guidelines—1969*, Pub. No. 2021, Department of Health, Education, and Welfare, Public Health Service, Washington, DC, p. 47.)

and groundwater pollution control. Compliance with Solid Waste Disposal Act and Resource Conservation and Recovery Act; also state and local regulations.

9. *Air Pollution Control* At dumping, storage, and charging areas; odors; air pollution control devices on stack; effect on surrounding areas; permits required. Compliance with Clean Air Act.
10. *Occupational Health* Safety, toilet, shower, and locker facilities, lunch room, clean air, safe water, accident and explosion hazards, pathogens and dust in work areas, ventilation, general sanitation. Compliance with Occupational Safety and Health Act.
11. *Vermin Control* Flies, roaches, rats, mice, inside and outside.
12. *Environmental Impact on Surrounding Area* Compliance with Endangered Species Act, National Environmental Policy Act, and other applicable laws.

The same principles would apply to other construction such as a landfill site, wastewater treatment plant, factory, shopping center, or real estate development.

In addition, communication should be maintained in the planning, design, construction, and operation stages with official agencies and the people affected to resolve actual and perceived concerns, ensure compliance with special regulations such as the National Environmental Policy Act (NEPA) (discussed later) and state equivalent, and obtain financial and other assistance that might be available. Federal agencies may include the U.S. Environmental Protection Agency (EPA), the Army Corps of Engineers, the Department of Labor, and the Department of Transportation. State agencies may include the EPA, the Health Department, the Labor Department, and the Department of Transportation. Local agencies may include planning and zoning, highway, building, and fire departments and the local county, city, village, or town government.

TYPES OF PLANNING

There are many kinds and levels of planning for the future. They may range from family planning to national planning. The discussion here will deal with *comprehensive* community planning,* also referred to as *general planning,* from which policy decisions can be made; *comprehensive functional planning,* also called *preliminary or feasibility studies* dealing with a single facility or service; and *definitive planning* for a specific project, which includes final

*The term "comprehensive" referred to here and in the discussion that follows is used with considerable reservation because truly comprehensive planning is an ideal rarely, if ever, achieved.

engineering and architectural reports, plans, contract drawings, and specifications leading to construction.

Figure 2-2 shows a typical planning–implementation framework that has emerged as a result of many new laws, particularly in the environmental field, that were adopted during the last four decades. These laws and programs were initiated independent of each other and of laws governing local planning processes. This framework has not attained the kind of harmony and linkage that are implicit in Figure 2-2. The kind of interrelationship and harmony suggested in the figure are goals the engineer and planner need to strive for to make progress in meeting future requirements of a complex society.

Comprehensive Community Planning

In this phase, an attempt is made to take an overall look at the region. If only a part of the total region is involved, the area, or community, is studied within the context of the larger region. This is described later as the process of comprehensive community planning. Report recommendations should lead to policy decisions or statements, including maps, that can be used to establish priorities to implement specific projects, with an estimate of their cost. At this stage, cost is a secondary consideration, although cost may become a major factor in the specific planning and implementation phase. A range of talents is needed to make a sound study. These may include the architect, artist, attorney, biologist, ecologist, civil engineer, economist, environmental engineer, geographer, geologist, hydrogeologist, hydrologist, landscape architect, mathematician, planner, political scientist, sociologist, soils scientist, systems engineer, and others.

Functional or Program Planning A large number of laws related to the environment and natural resources that have emerged at the federal and state levels have established planning requirements for water quality management planning such as required by section 208 of the Federal Water Quality Act, source protection planning, total maximum daily loads, and state implementation plans under the Air Quality Act. Similar state and federal planning requirements have been established in the fields of solid waste management, coastal zone management, energy, Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA) in the Air Quality Act, planning requirements existing under prevention of significant deterioration, nonattainment areas, acid deposition control, national air quality standards, transportation planning, state implementation plans, federal land policy and management, solid waste disposal, and in the case of interstate compacts, both in the air and water fields, planning requirements are part of the functional planning process. Unfortunately, these plans are not well integrated at federal or state level. Most state environmental laws include similar planning provisions. Both the state and federal functional planning requirements should ideally be coordinated through both state and regional levels. If they are not

Level of Governance	Types of Planning			Forms of Implementation			
					Approvals		
	Comprehensive	Functional or Program	Project	Regulation or Ordinance	Plans	Permits	Financial Assistance
Federal		√	√	√	√	√	√
Interstate		√	√	√	√	√	
State	√	√	√	√	√	√	√
Regional county	√	√	√	√	√	√	
Community	√	√	√	√	√	√	
Corporate-private		√	√				

Figure 2-2 Typical planning–implementation framework. Comprehensive planning normally occurs at the state, regional, and county levels. Functional program planning at the federal, state and regional levels occur as a result of requirements in law—for example, SIP planning required by the Federal Water Pollution Control Law. Project planning involves specific projects and can be carried out by any level or form of organization. Such standards are required normally by federal and state law in the field of air and water pollution; for example, implementation is normally required by federal and state law or local ordinance involving many thousands of pages of regulations in the environmental field alone. Approvals of plans and permits are normally required by federal and state law and interstate agencies such as the National Pollution Discharge Elimination System (NPDES) permit in the water pollution field, permits for solid waste sites, and so on. Financial assistance involves grants and loans from the federal and state levels.

so harmonized, the implementation steps identified in Figure 2-2 may turn out to be counterproductive or the source of considerable controversy.

Functional Regional Planning

If the priority project is a new or improved municipal water system (it could be a sewage system and treatment plant, park and recreation facilities, or a solid waste collection and disposal system), then the next step is a functional comprehensive engineering planning study to consider in some detail the several ways in which the regional or areawide service or facility can be provided together with approximate costs.*[3] Such a study is also referred to as a preliminary or feasibility report; it is discussed in greater detail under the heading Regional Planning for Environmental, Health, and Engineering Controls in this chapter. For example, the water system study alternatives for the region might include purchase of water to serve possible service areas and combinations; a well-water supply with water softening and iron removal; an upland lake or reservoir with multipurpose uses requiring land acquisition, water rights, and a conventional water treatment plant; or a nearby stream requiring a water treatment plant to adequately handle a surface-water source.

At this stage no detailed engineering or architectural construction plans are prepared. However, the engineering, environmental, legal, economic, financial, and social impact of each alternative is presented together with the advantages, disadvantages, environmental impact, recommendations, cost estimates, and methods of financing each alternative. The study report should be sufficiently complete and presented so that the officials can, after thoughtful public participations, make a policy decision and select one alternative for definitive planning.

Definitive or Project Planning

The next step for the example given (a new water system) would be the establishment of a legal entity to administer the project as provided for by state or local law, followed by the acquisition of necessary right-of-way and water rights, resolution of any legal constraints, establishment of service districts, approval of bond issues, rate setting and financing of operation, maintenance, and debt retirement. This step is followed by selecting a consulting engineer (it could be the same engineer who made the preliminary study); preparing plans, specifications, and contract drawings; advertising for bids; and awarding the contract to a contractor. Construction should be under the

*For a guide to the selection of a consulting engineer, see ref. 3. The same general principles would apply to the selection of an architect or other planning consultant.

supervision of the consulting engineer, and a resident engineer responsible to the consultant or municipality should be employed.

The consulting engineer should ensure that the owner of the system is provided with revised drawings showing the works and location of facilities as constructed and in place. The consultant would also normally be expected to provide operation manuals and guides, take responsibility for placing the plant in operation, and, during the first year, train personnel to take over full operation.

PROCESS OF COMPREHENSIVE COMMUNITY PLANNING

There are several choices with regard to the process of comprehensive community planning. Two are presented here: The first provides the more traditional process guided by a broad set of community aspirations and goals. The second emphasizes the environmental impact framework with emphasis on the scope of the process and alternatives to be examined.

Option 1: Traditional Process

***Statement of Goals and Objectives* (*Step 1*): Community Aspirations and Environmental Quality** A first step is the preparation of a tentative statement to guide the planning staff and the affected public that reflects the goals and objectives the community expects to be achieved through the planning process (Figure 2-3). Goals are the purpose or aim, the ideals and ends to which a design tends. Objectives are the realistically attainable ends. In any case, the goals and objectives should be continually adjusted as the planning study progresses and as the quality of life desired and demanded changes. Sometimes goals and objectives are formulated after basic studies. Public input is required. The statement should recognize the economic, social, and physical community aspirations, including the environmental health quality goals and objectives. Depending on the need, as confirmed or modified by Step 2, Basic Studies, these may be a water supply of satisfactory quality adequate for domestic, industrial, recreational, and firefighting purposes; clean air; sewage and other wastewater collection and disposal; water pollution abatement; proper solid waste collection, reduction, recycling, treatment, and disposal; adequate and safe parks and recreational facilities; noise abatement and control; a convenient and acceptable transportation system; elimination of accident hazards; preservation of open spaces, good housing, and residential areas; rehabilitation of sound substandard housing and construction of new sound housing in a healthy and pleasing environment; elimination of sources and causes of mosquitoes, ticks, blackflies, termites, rats, and other vectors; adequate schools; adequate hospitals, nursing homes, and other med-

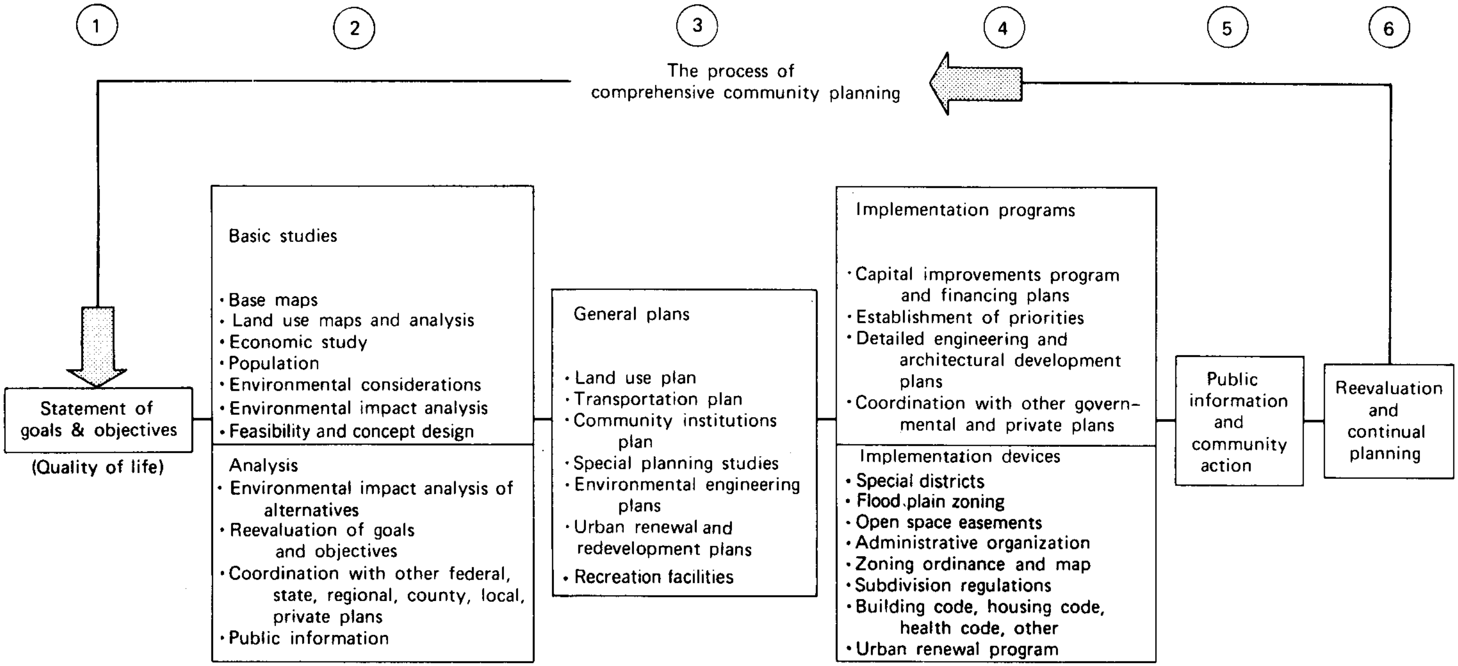

Figure 2-3 Example of option 1 of the planning process. [*Source:* J. A. Salvato, Jr., "Environmental Health and Community Planning," *J. Urban Plan. Dev. Div.*, **94**, 22–30 (August 1968). Reproduced by permission of the publisher, ASCE.]

ical care facilities; adequate gas and electricity; and public and cultural facilities.

Basic Studies, Mapping, and Data Analysis (Step 2): Research and Problem Identification Having tentatively agreed on a statement of goals and objectives, the next step is evaluation of the community. This is done by and includes the following.

1. *Mapping* Preparation of a base map, which will be the basis of other detail maps referred to below, and of land use maps, which can serve as policy references. Map scales found convenient for base maps are as follows: state or region 1:500,000; metropolitan area 1:250,000; county 1:100,000; detail and work maps 1:100,000 and 1:20,000 or 1:10,000 and 1:2400.
2. *Land-Use Analysis* Collection, plotting, and analysis of data on residential, commercial, industrial, public, agricultural, and recreational land uses; blighted and deteriorated structures, inefficient and conflicting land uses, and desirable land uses; areas available for future population growth and industrial development; and availability and adequacy of supporting services.
3. *Population and Demographic Studies* Present and future trends, locations, and amounts of populations; social composition and characteristics of the population; age distribution and changes.
4. *Economic Studies and Proposals* Existing sources of income, future economic base, labor force, markets, industrial opportunities, retail facilities, stability of economy, family income.
5. *Transportation Systems* Existing systems, their location and adequacy; effects of air and water pollution; aesthetic, zoning, noise, and vibration controls; population growth; industrial and recreational development of the systems; and modifications or protective features needed in existing and proposed systems.
6. *Community Institutions* Description, location, and adequacy of educational, recreational, and cultural facilities; medical, public health, and environmental protection facilities; religious and other institutions; and public buildings such as post offices, fire and police stations, auditoriums and civic centers, public markets, and government offices.
7. *Environmental Health and Engineering Considerations* Define and show on base maps and charts both favorable and unfavorable natural and man-made environmental conditions and factors such as meteorology, including wind and solar radiation studies; topography, hydrology, flooding, tidal effects, seismology, and geography, including soil drainage, soil characteristics such as percolation, and bearing characteristics; natural pollution of air, land, and water; background radiation and the flora and fauna of the area; man-made pollution of air, water,

and land; noise and vibrations, ionizing radiations, and unsightly condition of housing and community facilities and utilities. See Comprehensive Environmental Engineering and Health Planning, later in this chapter.

8. *Environmental Impact Assessment and Cost Benefit* Analyze the effects of the proposed action on the factors identified in item 7; also the alternative to eliminate or minimize deleterious effects and enhance beneficial effects. Environmental impact analyses are an integral part of project planning and preliminary design processes.[4] See Environmental Impact Analysis in this chapter.
9. *Coordinate with Other Planning* Federal, state, regional, county, and local agencies and municipalities usually have some plans already completed and certain plans under way or proposed. Private enterprises such as individuals, business establishments, industrial plants, and others are simultaneously making plans for renovation, expansion, or relocation and in many instances are in a position to support and implement the official planning. Hence, it is extremely important, insofar as is possible, to coordinate all the planning and obtain the participation essential to the realization of the planning goals and objectives.
10. *Public Information* Acquaint the public, specifically individual representatives of organizations that may be participating in the implementation of the comprehensive community plans, with the goals, objectives, scope of proposed studies, mapping and data analysis, and alternatives to be considered. Encourage and solicit feedback and carefully consider suggestions. Ask for supporting information to clarify suggestions made. At points during the planning process when important decisions are to be made, invite the public to focus groups or workshops to (a) discuss the issues and (b) participate in decisions.
11. *Infrastructure* Adequacy of the public infrastructure and the quality of maintenance and asset management to minimize future costs due to deferred maintenance, to provide the services and facilities such as water supply, wastewater disposal, transportation, solid waste management, schools, hospitals, housing, and recreation.
12. *Feasibility Studies and Concept Design* To study alternatives and costs.
13. *Reevaluate Goals and Objectives* Confirm or adjust as indicated by the basic studies, analyses, and feedback.
14. *Scope* Establish the scope of the preliminary plan preparation process and identify alternatives to be considered and criteria for the evaluation of alternatives.

***Plan Preparation* (*Step 3*)** General plans, including area wide and regional plans, that present alternatives and estimated costs to help people understand what is involved and help officials make policy decisions should be prepared.

The environmental, economic, and social effects of the actions proposed must also be considered. Detailed engineering and architectural drawings and specifications come later, when actual construction is scheduled as determined by implementation (Step 4). The plans should include the following.

1. *Land-Use Plan* This type of plan shows the existing uses to be retained and future patterns and areas for residential, commercial, industrial, agricultural, recreational, open space or buffer, and public purposes. Such plans are based on the findings in Steps 1 and 2 and are integrated with the plans that follow.

2. *Transportation or Circulation Plan* This shows major and minor highways and streets, transit systems, waterways, ports, marinas, airports, service areas, terminals, and parking facilities. The plan should clearly show facilities to be retained, those to be improved or altered, and new facilities proposed.

3. *Community Institutions Plan* This shows location of existing or proposed new, expanded, or remodeled educational and cultural facilities; health, welfare, religious, and other institutions; and public buildings and facilities. The plans for these institutions are considered in the light of their adequacy to meet present and future needs based on Steps 1 and 2.

4. *Special Planning Studies* These include neighborhood analyses and plans for urban renewal, neighborhood revitalization, clearance, rebuilding, rehabilitation, growth management, urban design, historic preservation, code enforcement, housing conservation, preservation of sites and structures, central businesses, parking, parks and recreational areas, as well as private enterprise plans and their integration with community plans.

5. *Environmental Engineering Plans* These plans are concerned with the adequacy and needs for water supply, sewage, stormwater management, solid waste disposal, air and water pollution control, housing and a healthy residential environment, realty subdivision and construction controls, gas, electricity, and nuisance control. They are also concerned with the environmental, economic, and social effects of industrial, agricultural, residential, commercial, highway, airport, recreational, and power development; stormwater, drainage, and flood control; forest, open-space, soil, estuary, and wildlife conservation; and planning for more aesthetic structures and public buildings. See Regional Planning for Environmental Health, and Engineering Controls.

The plans should take into consideration the environmental factors that need to be improved and those that can be developed to eliminate certain hazardous or annoying conditions while at the same time making a needed or desired improvement. At the same time, plans should identify environmental, scenic, cultural, historic, and natural resources to be protected. Incompatible or nonconforming structures or uses should be eliminated or adjusted to harmonize with the most desirable and obtainable environment. Additional details on environmental factors and controls are given later in this chapter under (a) Comprehensive Environmental Engineering and (b)

Health Planning and Environmental Factors to be Evaluated in Site Selection and Planning.

6. *Urban Renewal and Redevelopment Plans* Federal grants and assistance may be available to a municipality that formulates an acceptable ‘‘workable program’’ for community improvement.

A workable program is one that ‘‘will include an official plan of action . . . for effectively dealing with the problem of urban slums and blight within the community and for the establishment and preservation of a well-planned community with well-organized residential neighborhoods of decent homes and suitable living environment for family life’’ (ref. 5). A workable program includes the following seven elements. They are basic to the elimination of slums and blight and to the prevention of their spread in any city:

(a) Up-to-date codes and ordinances, including building, electrical, plumbing, fire prevention, housing, health codes and the like, and zoning and subdivision regulations, that provide sound standards governing land and building use and occupancy.
(b) A comprehensive community plan, often referred to as a general or master plan and made up of policy statements and plans to guide community growth and development (as outlined in this chapter). It includes three essential features: a land-use plan, a circulation plan, and a community facilities plan.
(c) Neighborhood analysis: An examination of the physical resources, a pinpointing of deficiencies, a notation of environmental problems of the area under study, and recommendations concerning the steps to be taken to eliminate physical and environmental shortcomings.
(d) Administrative organization: To ensure that codes and ordinances are enforced, the community must demonstrate that it has an effective organizational structure and adequate personnel to carry out these functions.
(e) Financing: The community must demonstrate that it has adequate financing and sound budgetary policies to ensure that public improvement projects related to urban renewal are carried out.
(f) Housing for displaced persons: Most projects result in temporary or permanent displacement, and relocation assistance must be available to residents requiring it. There is also need to assist businesses that have a relocation problem. Both of these problems must be faced by the community to prevent hardship to those who are displaced.
(g) Citizen participation: Broad citizen involvement, representative of all segments of community life, is required as part of the democratic process of program formulation.

Plan Implementation (Step 4): Construction; Problem Correction, Prevention, and Control Plans, to yield a return, must be implemented. Implementation involves political and governmental decisions and public acceptance:

1. *Capital Improvement Program and Financing Plans* Project priorities are established. Approximate costs, sources of revenue, and financing for 5 years or longer, up to 20 years, are determined. Existing and contemplated public and private planning and construction (including industrial, commercial, urban renewal, and slum clearance), local, state, and federal assistance programs, the feasibility of areawide or regional solutions, and the total tax burden are all recognized and coordinated. Careful attention should be given to the need to treat the public works infrastructure as an asset. Asset management tools assure timely maintenance to maintain service life and reduce annual costs. Opportunities for reducing or minimizing per-family service charges through regionalization should be considered. Careful attention needs to be given to the long-term infrastructure maintenance costs of low-density development as well as to the need for impact fees to make sure that existing residents are not forced to subsidize newcomers. The program as implemented will largely determine the future quality of the environment and the economic health of the community. Government action usually follows adoption of a capital improvement program. The program is reviewed and updated annually.

2. *Detailed Engineering, Architectural, and Development Plans* These are plans for specific projects as determined in item 1 and may be preceded by feasibility studies. In contrast to general plans, specific drawings, detail plans, and specifications are prepared from which accurate estimates or bids are obtained and construction contracts are let. Included are federal, state, urban renewal, and private construction projects such as a new city hall, school, shopping center, water system, sewage and treatment plant, marina, sanitary landfill, and housing and park and recreational area development.

3. *Regulations, Laws, Codes, and Ordinances* Zoning controls and subdivision regulations are commonly provided. Also considered are flooding and drainage controls, floodplain management, wetlands, prime agricultural lands, soils, steep slopes, designated natural areas, rare and endangered species, special districts, environmental protection regulations, agricultural zoning, and provision for long-term land leases, easement acquisition, purchase of development rights to land, and tax deferral for open-space preservation. There is a need for standards and regulations for water supply, sewage disposal, and house connections; water and energy conservation, air pollution control, and emission standards; control of noise and vibration nuisances; control of mining and excavations; regulations for residential and hazardous material and solid waste storage, collection, reduction, recycling, treatment,

and disposal. Also needed are a modern building code* (including plumbing, fire and safety, electrical, heating, and ventilation regulations), sanitary code,† and housing occupancy and maintenance code.‡ Legislation in developing areas must recognize indigenous needs and feasibility and promote orderly progress.

4. *Administrative Organization* The entire process of comprehensive community planning can at best be only of limited value unless provision is made for competent direction, personnel staffing, and administration, particularly during plan implementation following plan adoption. Adoption of an official map, land-use plans, improvement program, codes, ordinances, rules, and regulations has little meaning unless implemented by competent personnel who are adequately compensated.

***Public Information and Community Action* (*Step 5*)** For a community plan to be effective, it is necessary that public participation and information be involved at important stages in the planning process, such as selection and evaluation of alternatives and selection of criteria for evaluating alternatives. In keeping the public informed, it is also necessary to stimulate and provide channels for individuals and groups that have special concerns to respond with information and ideas. Public participation can result in plan improvement and programs that help achieve the public objectives.

On the subject of public participation, true participation of the public plays a critical role in the success of all forms of planning (comprehensive, community planning, functional regional planning, and project planning), and there is no simple formula for the process of making public participation useful, meaningful, and supportive. There are, however, a number of important points to include in the process:

* A building code deals primarily with, and contains standards for, the construction or alteration of buildings, structural and fire safety, light and ventilation, materials, electrical, air conditioning, and prevention of related hazards. The code authorizes plan and specification review functions, inspection for approval of the construction or alteration, and the issuance of permits.

† A sanitary code is concerned with environmental sanitation and safety and control and prevention of diseases for protection of the public health, safety, and general welfare. It may set standards and regulations for such matters as disease control; qualifications of personnel, including those responsible for the operation of certain facilities; water supply; wastewater disposal; air pollution prevention; solid wastes; food sanitation, including milk; radiation; noise; vectors; accident prevention; land subdivision and housing; hospitals, nursing homes, and institutions; recreational areas and facilities; schools, camps, and resorts; trailer and mobile home parks; bathing beaches and swimming pools; occupational health; emergency sanitation; and other preventive measures that may be required to ensure that the public health is protected.

‡ A housing code is concerned primarily with, and contains minimum standards for, the provision of safe, sanitary, decent dwellings for human habitation. It sets standards for the supplied utilities and facilities, occupancy, and maintenance. The code requires inspection to determine compliance and usually is applicable to all dwellings, regardless of when constructed. It is also a tool to obtain housing and community rehabilitation, conservation, and maintenance.

1. The process has to be such that it is easy for the affected public to participate. Hearings should not be held in places and at times that are difficult to attend.
2. Public participation must be organized around the manner in which the public relates to the plan or project. If there are five groups that have different goals, they should be worked with individually and separately. If there is no such grouping, workshops or focus groups that cover the entire project are often very useful. Every event relating to the field of public participation must be carefully planned in order to provide the public with the essential information and then allow much time for members of the public to react and provide their input to the process. That input should be displayed in newsletters, on web sites, and on other occasions when it is important to highlight the view of the public.
3. Feedback obtained at such public meetings needs to be summarized so that consultants, engineering firms, and others have clear instructions to try to build the public's desires into the project. While this is not always possible, it is often essential that an effort be made to address these issues.
4. When public workshops or focus groups or even public hearings are held, it is very important to make a special effort to bring important leaders in the community into the process. Merely sending out a notice or a newspaper ad is usually not enough. It is often very important to have planning and consulting staff call individuals and groups in order to encourage them to attend.
5. Public participation is most important when the following plan elements are in the process of development: planning and project goals, planning and project scope, preliminary selection of alternatives, and selection of criteria by which alternatives are evaluated; finally, public input is most important when recommendations and final plans are in the drafting stage.

***Reevaluation and Continual Planning* (*Step 6*)** Not to be forgotten is the continual need for public information, coordination, and administration of planning activities locally on a day-to-day basis and liaison with state and federal agencies. Studies and analyses in Step 2, the plans developed in Step 3, and the improvement program and controls in Step 4 must all be kept reasonably current. This is necessary to prevent obsolescence of the comprehensive community plan as well as the community.

Community objectives and goals can be expected to change with time. New and revised land-use concepts, means of transportation, housing needs and designs, public desires and aspirations, and economic, technological, and sociological developments will require periodic reevaluation of the general plan and revision as indicated. It should be kept in mind that human wants are insatiable; as soon as a goal or objective is approached, another will be sought. This is as it should be but must be kept in balance and within realistic bounds, which comprehensive planning should help accomplish.

Option 2: Process That Emphasizes Scope and Alternatives

Comprehensive community planning using this option is tailored to fit the characteristics and needs of the area under study (see Figure 2-4). *It considers social, environmental, economic, and infrastructure factors that have been identified for option 1 but are not repeated here*. The process is complex and, to be successful, should include a great deal of public participation.

It begins with statements (Step 1) by political leaders regarding their perceptions of the problems of the region and the values to be protected.

These statements are then modified through a focus group or public participation process (Step 2) that emerges with a set of goals and objectives for the planning process related to the problems and values to be protected.

From Step 2, we move to Step 3, in which the planning staff develops a draft scope of the study (“scope” meaning items and topics to be included), which again is subjected to public participation for review, and the recommended scope is accepted or revised.

Once that scope has been decided, basic studies that are relevant are initiated in Step 4. They would normally include base maps, geographic information system (GIS) data and overlays obtained from government programs at all levels (including land-use maps) and analysis of them, the study of the region’s economy, population and demographics, environmental inventory, including pollution problems, rare and endangered species, and other environmental values to be protected, together with linkages to federal, state, regional and county, local, and private plans as well as information regarding energy and natural and renewable resources.

In the study, Step 5 is an analysis of the initial goals and the data submitted and reviewed in Step 4. Problems to be solved and values to be protected are

Step 1	Political leaders identify problems to be corrected and values to be protected.
Step 2	Public participation to identify goals and objectives for plan.
Step 3	Planners develop draft scope of study. Public participation to review and approve or modify scope.
Step 4	Planners do basic studies and identify problems to be solved and values to be protected.
Step 5	Planners analyze goals, values, and data and identify preliminary alternatives and preliminary criteria for evaluation of alternatives.
Step 6	Public review of proposed alternatives and criteria approved or modified.
Step 7	Planners analyze approved alternatives using approved criteria.
Step 8	Public participation to select recommended alternatives.

Figure 2-4 The Option 2 process, which emphasizes scope and alternatives.

identified. Once that analysis is complete, the planning staff will identify alternatives to solve the problems and protect the values as well as criteria by which those alternatives will be evaluated.

Step 5 then is followed by Step 6, in which the public again is invited to participate and evaluate and revise both the alternatives and criteria that have been selected for study.

Step 7 is an analysis of the agreed-upon alternatives using the criteria that have been selected.

Step 8 is again a public participation process in which the recommended alternatives are selected in a public setting prior to implementation of the recommendations.

An important element of this process is the identification of planning processes in state and federal agencies that need to be linked with the community or regional plan in order to stimulate successful implementation.

Conclusion

There is a need for sound engineering in community planning and more sensitivity to comprehensive planning in engineering, with emphasis on areawide, metropolitan, and regional approaches. Environmental protection, conservation, natural resources, scenic landscape, architecture, and historic preservation need to be successfully integrated, and engineering factors that are essential for community survival and growth and the environmental, economic, and social benefits of any proposed projects must not be overlooked in planning and engineering.

Public awareness demands a quality of environment that provides such fundamental needs as pure water, clean air, unpolluted land, the absence of traffic congestion and the availability of convenient transit service, decent housing, privacy, safe recreational facilities, and preservation of open space and historic values. A balanced appraisal must be made, and the planning process must blend these goals in its objectives, analyses, plans, and capital budgeting.

State and local health and environmental protection departments have vital planning, plan approval, and regulatory responsibilities to ensure that the public health, environment, and welfare are protected. These responsibilities usually deal with water management and pollution abatement; wastewater treatment and disposal; safe and adequate water supply; air pollution control; solid hazardous and nonhazardous waste disposal; radiation protection; housing and realty subdivision development, including temporary residences such as motels, trailer parks, and resorts; vector control; safe use of pesticides; milk and food protection; medical care facilities; and recreational facilities, including bathing beaches and swimming pools. Responsibilities of the health and environmental protection departments extend to the issuance of permits and the continual monitoring of operational results to protect the public and enhance the home, work, and recreation environment. Hence, they have an important stake in all planning (preventive environmental sanitation and engineering) to ensure that the public does not inherit situations that are impossible or costly to correct.

Comprehensive community planning that gives proper attention to environmental health considerations, followed by phased detail planning and capital budgeting, is one of the most important functions a community can engage in for the immediate and long-term economy and benefit of its people.

The achievement of World Health Organization (WHO) health goals requires the control of all those factors in the physical environment that exercise or may exercise a deleterious effect on the physical, mental, or social well-being of humans. It is necessary, therefore, that single-purpose and general economic, social, and physical planning take into full consideration their effects on other environmental factors and media and the facilities and services required for healthy living.

The principles described in this chapter can also be applied to a voluntary environmental analysis or survey of a proposed or existing plant site and its internal and external operations. Self-appraisal or audit for compliance not only with environmental, health, and safety regulations but also with identification, elimination, and prevention of potentially hazardous conditions can avoid many problems, including regulatory actions and future liabilities.

REGIONAL PLANNING FOR ENVIRONMENTAL, HEALTH, AND ENGINEERING CONTROLS

General

Air, water, and land pollution, inefficient transportation facilities, urban and rural blight, and disease do not respect political boundaries. Adequate highways, mass transit options, walking and cycling opportunities, land-use management, parks and recreational facilities, water, sewers, solid waste disposal, and other services necessary for proper community functions are usually best designed within the context of a county or regional plan. Such planning, however, must recognize federal and state agency planning and local planning, including economic development. The cost-effective provision of the complex set of modern community services, can be hampered if legal impediments or sentiments of local prerogative prevent regional solutions. As long as a city, town, or village can unreasonably limit intermunicipal cooperation, planning for the future cannot be completely effective. Coordination of planning among smaller communities within the context of the applicable county, metropolitan, and regional plan is essential. The smallest practical planning unit for the development and administration of environmental controls should be the county.

Local governments normally do not have jurisdiction and resources to plan and budget for an entire region. The key to the solution of regional problems is to create a spirit of intermunicipal cooperation that sets aside the unreasonable exercise of local prerogatives and instead provides a sense of team-work to work toward establishment of an areawide organization that can investigate, plan, and act on an areawide basis. Such regional cooperation should never replace the spirit of community and attention to values that are unique to the community and may indeed differ from those of their neighbors. Unless this is done, regional plans that are developed will probably remain on the shelf for a long time.

Although planning the solution of regional problems on a regional basis is generally accepted as being basically sound, it does not necessarily follow that a special organization or authority must be established to carry out the actual construction, operation, and maintenance of the utility or facility. Local experiences and sentiment may dictate that the only way a regional project can be carried out, in whole or in part, is on an individual community basis regardless of the additional costs involved. Most important is that the particular project or facility be constructed in general conformance with the regional plan and that the additional cost be borne by the community that has opted for that choice. If this is done, it will be possible at a later date, when the ‘‘climate’’ is propitious, to realize the more efficient and economical consolidated arrangement.

Content of a Regional Planning Report

At the very least it would appear logical and economical to combine into one comprehensive environmental engineering study the evaluation of the regional water management, water supply, wastewater, solid wastes, air quality, and related land-use items. These all have in common the components listed below and are closely interrelated.

The ideal comprehensive regional plan would be one that combines all the project physical planning studies with a comprehensive economic and social development plan as well as watershed planning. In the absence of such a planning framework, the project or functional regional plans should take into consideration the economic, environmental, watershed, and social factors affecting the plans. In addition, comprehensive watershed and/or regional plans should be recognized and steps taken in the project planning to prevent or alleviate potential conflicts and deleterious side effects.

An outline of a regional or areawide planning study and report showing the elements that are common to most functional studies follows:

1. Letter of transmittal to the contracting agency
2. Acknowledgments
3. Table of contents
   a. List of tables
   b. List of figures
4. Executive summary, including findings, conclusions, and recommendations
5. Purpose and scope

6. Background data and analysis, as applicable, including base maps, reports, and special studies
   a. Geography, hydrology, meteorology, geology, groundwater availability, aquifer recharge areas
   b. Population density and characteristics: past, present, future
   c. Soil characteristics; flora and fauna
   d. Transportation and mobility; adequacy and effects produced: present and future multimodalism
   e. Residential, industrial, commercial, recreational, agricultural, and institutional development and redevelopment
   f. Land use: present and future; spread of blight and obsolescence; inefficient and desirable land uses designated growth and nongrowth areas, energy and energy efficiency
   g. Stormwater and flood control management; relationships between land and water management; wetlands
   h. Water resources, multiuse planning, and development with priority to water supply; environmental impact
   i. Air and water pollution, seweage, solid waste management
   j. Public utilities (electricity, gas, oil, heat) and their adequacy
   k. Educational and cultural facilities, size, location, effects, adequacy
   l. Economic studies: present sources of income, future economic base and balance, labor force, markets, economic development opportunities, retail facilities, stability
   m. Sociological factors: characteristics, knowledge, attitudes, behavior of the people and their expectations
   n. Local government, political organizations, and laws, codes, ordinances
   o. Special problems, previous studies and findings, background data, including tax structure and departmental budgets; also applicability of federal, state, and local environmental control legislation
7. *Project study.* This would be a regional or areawide-in-depth study of one or more projects or functions such as solid waste management, water supply, recreation, vector control, wastewater, or environmental health. Several examples of comprehensive project studies are outlined below under Project Study.
8. Comprehensive regional plan
   a. Alternative solutions and plans
   b. Economic, social, and environmental analysis and evaluation of alternatives, including adverse and beneficial environmental consequences

   c. Recommended regional plan
   d. Site development and reuse plans
9. Administration and financing
   a. Public information
   b. Administrative and institutional arrangements, management, and costs, including plans for infrastructure asset management
   c. Capital improvement program and financing methods: general obligation bonds, revenue bonds, special assessment bonds; also grants, incentives, federal and state aid
   d. Cost distribution, service charges and rates; capital costs: property, equipment, structures, engineering, legal services; nnual costs to repay capital costs, principal and interest, taxes; regular and special service charges and rates
   e. Legislation, standards, inspection, and enforcement
   f. Evaluation, research, and replanning
10. Appendices
   a. Applicable laws
   b. Special data
   c. Charts, tables, and illustrations
11. Glossary
12. References
13. Index

Project Study

Some examples of specific regional or areawide comprehensive single-purpose, functional, or project studies are outlined below. These expand on item 7 above, "project study." A complete project study and report would cover items 1 to 13, listed above, and one or more of the following.

Comprehensive Solid Waste Study (Expands on Project Study, Item 7 Above)

1. Additional background information and data analysis, including residential, commercial, industrial, and agricultural solid wastes
   a. Field surveys and investigations, including soils, hydrogeology, groundwater, land uses
   b. Existing methods and adequacy of collection, treatment, and disposal and their costs
   c. Characteristics of the solid wastes

   d. Quantities, summary tables, and projections
   e. Waste reduction at source; recycling, salvage and reuse
2. Solid waste collection, including transportation
   a. Present collection routes, restrictions, practices, and costs
   b. Equipment and methods used
   c. Handling of special wastes
   d. Recommended collection systems
3. Preliminary analyses for solid waste reduction, treatment, and disposal
   a. Resource recovery: salvaging, recycling, refuse derived fuel and energy conservation, economic viability
   b. Available treatment and disposal methods (advantages and disadvantages)—compaction, shredding, sanitary landfill, incinerator, high-temperature incinerator, pyrolysis, fluidized-bed oxidation, bulky waste incinerator, waste heat recovery, composting, garbage grinders
   c. Pretreatment devices: shredders, hammermills, hoggers, compaction, and their applicability, effectiveness, and hazards
   d. Disposal of special wastes: automobile, water and wastewater treatment plant sludges, scavenger wastes, commercial and industrial sludges and slurries, waste oils, toxic and hazardous wastes, rubber tires, agricultural wastes, pesticides, forestry wastes, construction and demolition wastes
   e. Treatment and disposal of commercial and industrial wastes. This would normally require independent study by the industry when quantities are large or when hazardous wastes and special treatment problems are involved
   f. Transfer stations, facilities, and equipment
   g. Rail haul; barge haul; other
   h. Alternative solutions, costs, advantages, and disadvantages
4. Review of possible solutions
   a. Social, political, and economic factors
   b. Beneficial and adverse environmental consequences of proposed actions
   c. Existing and potential best land use within 1500 ft of treatment and disposal site and aesthetic considerations
   d. Site development and reuse plans
   e. Special inducements needed
   f. Preliminary public information and education
5. Compliance with the Clean Air Act, Resource Conservation and Recovery Act, Clean Water Act, Safe Drinking Water Act, and state laws
6. Environmental impact analysis. See Environmental Engineering Multimedia Considerations in this chapter, Figure 2–1, and the National Environmental Policy Act or state equivalent. See also Chapter 5.

Comprehensive Wastewater Study (Expands on Project Study, Item 7 Above)

1. Additional background information and data analysis
   a. Field surveys and investigations, including physical, chemical, biological, and hydrological characteristics of receiving waters
   b. Existing methods of municipal and industrial wastewater collection, treatment, and disposal
   c. Characteristics of municipal wastes and wastewater volumes, strengths and flow rates
   d. Characteristics of industrial wastes, quantities, and amenability to treatment with municipal waste. Identify each.
   e. Water pollution control requirements; federal, state, and interstate receiving water classifications and effluent standards.
   f. Wastewater reduction, reclamation, reuse
   g. Extent of interim and private, on-lot sewage disposal (adequacy: present and future), including soil suitability
2. Wastewater collection
   a. Existing separate collection systems (condition and adequacy), including infiltration and exfiltration, surface, and stormwater flows.
   b. Existing combined sewer collection systems (condition and adequacy), including infiltration and exfiltration, surface, and stormwater flows
   c. Areas or districts needing collection systems and construction timetables
   d. Soils, rock, and groundwater conditions
   e. Routing and right-of-way
   f. Stormwater and/or combined sewer separation feasibility, holding tanks, special considerations, local ordinances, and enforcement
   g. Need for storm water drainage and collection systems
3. Preliminary analyses for wastewater treatment systems
   a. Treatment plant sites; pollution load; degree of treatment required; land requirements, including buffer zone; foundation conditions; outfall sewer; hydrologic and oceanographic considerations
   b. Areas served
   c. Trunk lines and pumping stations
   d. Property and easement acquisition problems
   e. Design criteria
   f. Industrial waste flows and pretreatment required, if any, at each industry

   g. Effect of stormwater flows on receiving waters and need for holding tanks or treatment
   h. Treatment plant and outfall sewer design considerations
   i. Grit, screening, and sludge disposal
   j. Alternative treatment and disposal solutions, total costs, and annual charges
4. Compliance with the Clean Water Act and state laws
5. Environmental impact analysis

Comprehensive Water Supply Study (Expands on Project Study, Item 7 Above)

1. Additional background information and data analysis
   a. Sanitary surveys and source protection investigations of public water source, treatment, wellhead area, distribution system, cross-connections, water pressure; breaks, water usage, storage adequacy, leaks, fire requirements; water quality
   b. Occurrence of waterborne diseases and complaints
   c. Leak survey of existing system, flow tests, condition of mains, and water use
   d. Existing and future land uses; service areas, domestic and industrial water demands
   e. Areas and number of people served by individual well-water systems, sanitary quality and quantity of water, chemical and physical quality, cost of individual treatment
   f. Recommendations of the Insurance Services Offices (formerly National Board of Fire Underwriters) and others
   g. Existing fire rates and reductions possible
2. Alternative sources of water
   a. Chemical, bacteriological, and physical quality ranges
   b. Average, minimum, and safe yields; source development
   c. Storage needed at source and on distribution system
   d. Flow requirements for fires
   e. Service areas, hydraulic analysis, and transmission system needs
   f. Preliminary designs of system and treatment required for taste, odor, turbidity, color, organic and inorganic chemicals control
   g. Right-of-way and water rights needed
   h. Preliminary study of total construction and operation cost of each alternative; advantages and disadvantages of each; annual cost to user and how apportioned
   i. Improvements needed in existing system: source, storage, transmission, treatment, distribution system, operation and maintenance,

costs, to meet state and federal requirements of the Safe Drinking Water Act

3. Environmental impact analysis

Comprehensive Environmental Engineering and Health Planning (Expands on Project Study, Item 7 Above)

1. Epidemiological and demographic survey, including mortality, morbidity, births and deaths, age and sex distribution, communicable, noninfectious and chronic diseases, incidence and prevalence of specific diseases by age groups; people most at risk; social, economic, and environmental relationships; respiratory and chemical sensitivity; water-, insect-, and foodborne diseases; domestic and wild animal and animal-related diseases; airborne and air-related diseases and illnesses; indices of disease vectors; pesticides and other chemical poisonings; congenital malformations; mental disorders; health services and their availability; adequacy of data and programs.
2. Public water supply, treatment and distribution, including watershed protection, population served, adequacy, operation, quality control, cross-connection control, storage and distribution protection, operator qualifications. For individual systems: population served, special problems, treatment and costs, adequacy, control of well construction. Extension of public water supply based on a comprehensive regional plan, including fire protection, to replace inadequate and unsatisfactory small community water systems and individual well-water supplies in built-up areas. See Chapter 3 and Comprehensive Water Supply Study above.
3. Wastewater collection, treatment, and disposal; adequacy of treatment and collection system, population served, operator qualifications, sewer connection control. For individual systems: population served, special problems, control of installations. Water pollution control. Provision of seweage meeting surface water and groundwater classifications based on a drainage area, watershed, or regional plan to eliminate pollution by existing discharges, including inadequate sewage and industrial waste treatment plants and septic tank systems. See Chapter 4 and Comprehensive Wastewater Study above.
4. Solid waste management: storage, collection, transportation, processing and disposal, adequacy. Resource recovery, salvaging and recycling, including municipal refuse, industrial and agricultural wastes; handling of hazardous wastes, their environmental impact, prevention of contact, and air, water, and land pollution. Use of solid wastes to accelerate construction of open-space buffer zones and recreational areas. See Chapter 5 and Comprehensive Solid Waste Study above.
5. Air resources management and air pollution control, including sources, air quality and emission standards, topographical and meteorological

factors; problems and effects on humans, livestock, vegetation, and property; regulation and control program. See Chapter 6.

6. Housing and the residential environment: control of new construction, modern building code, including plumbing, electrical, heating; housing conservation and rehabilitation and enforcement of housing occupancy and maintenance code; effectiveness of zoning controls, urban renewal, and redevelopment. Quality of housing, installed facilities, occupancy and overcrowding. Realty subdivision and mobile home park development and control, also effect of a development on the regional surroundings and effect of the region on the development, including the environmental impact of the development. See Chapter 10 and Fringe and Rural Area Housing Developments in this chapter.
7. Schools, public buildings, parks, and other recreation facilities and open-space planning, including suitability of water quality and adequacy of sewage, solid waste disposal, water supply, food service, restrooms, safety, pesticide use, prevention of indoor air pollution and protection of persons sensitive to pesticides and other air pollutants. See Chapter 9 and Environmental Factors to Be Evaluated in Site Selection and Planning in this chapter.
8. Food protection program: adequacy from source to point of consumption. See Chapter 8.
9. Nuclear energy development; radionuclide and radiation environmental control, including fallout, air, water, food, and land contamination; thermal energy utilization or dissipation and waste disposal; naturally occurring radioactive materials, including radon; air, water, plant, and animal surveillance; federal and state control programs; standards; site selection and environmental impact; plant design and operation control; emergency plans. See Chapters 2 and 7.
10. Planning for drainage, flood control, and land-use management. Surface-water drainage to eliminate localized flooding and mosquito breeding. Development of recreational sites, including artificial lakes, parks, swimming pools, bathing beaches, and marinas. See Chapters 9 and 10 (in the fourth edition).
11. Health care institutions and adequacy of medical care facilities such as hospitals; nursing homes; public health, mental health, and rehabilitation centers; clinics; service agencies; jails and prisons; day-care centers. Staffing, budgets, work load.
12. Noise and vibration regulations, abatement, and control. See Chapter 6.
13. Noxious weed, insect, rodent, and other vermin control, including disease vectors, nuisance arthropods; regulation, control, and surveillance, including pesticide regulation use for control of aquatic and terrestrial plants and vectors; federal, state, and local programs; effects on water,

recreation, housing, and other land resource development. See Chapter 10 (in the fourth edition).

14. Natural and man-made hazards, including slides, earthquakes, brush and forest fires, reservoirs, tides, sand storms, hurricanes, tornadoes, high rainfall, fog and dampness, high winds, gas and high-tension transmission lines, storage and disposal of explosive and flammable substances and other hazardous materials. See following pages.
15. Aesthetic and environmental considerations: wooded and scenic areas, prevailing winds and sunshine, solar energy utilization.
16. Laws, codes, ordinances, rules, and regulations, including environmental health criteria and standards, adequacy, enforcement, and education.

Financing

Financing of a municipal capital improvement is generally done by revenue bonds or general obligation bonds. Sometimes, as for small projects, funds on hand are used or special assessment bonds are issued to be paid by a special tax levy on properties directly benefited or a user service charge is levied. Other arrangements include a combination of revenue and general obligation bonding; the issuance of mortgage bonds using the physical utility assets as collateral; the creation of a nonprofit corporation or authority with the power to sell bonds; and operating and maintaining the facility, collecting revenues to pay for operation and capital, costs or contracting with a private investor to build a structure or facility or lease at an agreed-on cost, with ownership reverting to the municipality at the end of a selected time period.

Usually the constitution or other law of a state contains a specific limitation in regard to the amount of debt that a municipality may incur. The debt limit may be set at approximately 5 to 10 percent and the operating expenses at about 2 percent of the average full value of real estate. The debt margin established generally does not include bonded indebtedness for schools. In most cases, bond issues for capital improvements require approval of the state fiscal officer to determine if the proposed project is in the public interest and if the cost will be an undue burden on the taxpayer. The ability to pay or per-capita financial resources can be expected to vary from one municipality to another. Sometimes indebtedness for an essential revenue-producing service, such as water supply, is excluded from the constitutional limit.

Revenue bonds are repaid from a specific source of revenue, such as water sewer, toll road, and toll bridge charges. The service made possible by the bond issue is therefore directly related to the monthly, quarterly, or annual billing for a specific service. The bonds are not backed by the full credit of the municipality. Interest rates can therefore be expected to be somewhat higher than for general obligation bonds.

General obligation bonds are issued by a governmental agency such as a state or municipality. Their payment is guaranteed through its taxing powers. The money borrowed is repaid by all of the people in a community, usually as additions to the real property tax. The total amount of general obligation bonds that may be issued by a municipality is generally limited by law. Capital needs are usually met by general obligation bonds. General obligation bonds may also be used to pay off a revenue-producing capital improvement. Approval by the voters in a special referendum may be required. These bonds are considered among the safest of all tax-exempt bonds.

In the financing of capital improvements, one must not lose sight of the continuing cost of the operation and maintenance that is involved and the need for professional management that looks upon the facility as an asset to be preserved and maintained. The total annual cost must be considered. A municipality must also be wary of large governmental grants for capital improvements in which the cost of operation and maintenance for the life of the project may become unbearable to the taxpayer. In addition, the rising cost of regulatory requirements and suburban sprawl suggests that reliance on local financial resources and sound professional management is likely to obtain the lowest annual cost.

A *combination of revenue and general obligation bonds* would generally use revenue to pay off principal and interest but would also be paid from general tax funds to the extent needed if the revenues were inadequate. This can result in lower interest rates. Other arrangements and cost apportionment are possible.

Assessment of users to pay off bonds may be based on the property tax, known as an *ad valorem* tax; on the service provided, such as metered water; on the potential service provided, such as a trunk sewer line that may be connected to 10 or 20 years in the future; or some combination. The *ad valorem* tax is not a tax proportionate to the service received. For example, a home assessed at $200,000 would pay four times the tax paid by a home assessed at $50,000, but it would not normally receive four times the service. There are now increasing pressures to move away from this form of taxation.

Notes are short-term borrowings, that is, promises to pay, for a year or less, to tide a community over gaps in cash flow. They are issued in anticipation of taxes to be collected or revenues to be received from the state or federal government or of the proceeds of a long-term bond sale to be held at a later date.

Privatization Legal taxing and borrowing limitations may prohibit local governments from funding and providing a needed service or facility. In such instances, it may be possible to contract with a private organization, pay a fee, and transfer the responsibility, subject to conditions that will protect the public interest.

Increasingly investor-owned companies are purchasing or contracting for the operation of municipal, county, and regional water and wastewater

State and federal revolving loan funds are used to make low-interest loans to municipalities to construct, enlarge, or repair approved facilities. The repaid loan is then available for further loans. An example would be a loan to construct or modernize a wastewater treatment plant.

Other financing alternatives include use of bond banks, water banks, industrial development bonds, capital reserve, state corporations, lease purchase agreements, cost sharing with developer or user, private activity bonds, and federal and state government loans and grants. A county may sell bonds to purchase development rights to maintain and preserve existing land use. Financial planning assistance for small-town water systems may be available from the Farmers Home Administration (FHA) of the U.S. Department of Agriculture and the block grant program of the U.S. Department of Housing and Urban Development and the Environmental Protection Agencies. See Appendix, Finance or Cost Comparisons.

ENVIRONMENTAL FACTORS TO BE EVALUATED IN SITE SELECTION AND PLANNING

Certain general basic information should be known before a suitable site can be selected for a particular purpose. One should know the present and future capacity and the total land area desired. The type of establishment or facility to be maintained, the use to which it will be put—whether a new land subdivision, shopping plaza, adult or children's camp, park and picnic area, resort hotel, dude ranch, marina, trailer park, campground, country club, factory, industrial and scientific complexes, water treatment plant, wastewater treatment plant, solid waste resource recovery–treatment–disposal facility, power plant, school, institution, or private home—and the functions, activities, and programs to be carried on during each season or all year are to be decided before any property is investigated. In addition, one should know the radius in miles or time of travel within which the area must be located; the accessibility to roads, airports, waterways, or railroads; the availability of fire protection, utilities, and permanency of the project; the money and manpower available; whether lake, river, or stream frontage is necessary; and whether the site need be mountainous, hilly, flat, wooded, or open.

The prior use of the property should be investigated to determine if any hazardous dump sites, tanks, structures, or other hazardous conditions exist.[6] Interviews with former owners or users of the site and existing residents and a thorough first-hand inspection of the site would be preliminary steps. The presence of archeological and cultural artifacts and the laws governing their protection must be considered. Soil conservation survey soil maps, U.S. Geological Survey maps, aerial surveys, and other maps may show old mining, cemetery, dump, and landfill sites.

Not to be forgotten are evaluation of the environmental, safety, social, political, and economic impacts of the proposed project on the selected area; the numerous federal, state, and local environmental and land-use laws controlling development and construction; and minimization of the undesirable effects to acceptable levels. An environmental impact assessment is desirable and may be required by state or federal law (this is discussed below).

Desirable Features

It probably will not be possible to find a site that will meet all the conditions authorities recommend as being essential. Desirable features include the following.

1. It is best to have an adequate groundwater or surface-water supply not subject to excessive pollution that can be developed into a satisfactory supply at an accessible and convenient location on the property if an adequate public water supply is not available. The water supply source should meet federal and state standards.

2. A permeable soil that will readily absorb rainwater and permit the disposal of sewage and other wastewater by conventional subsurface means is most desirable, if not essential, for the smaller establishment where public sewage is not available. Such soil should contain relatively large amounts of sand and gravel, perhaps in combination with some silt, clay, broken stones, or loam. The underground water should not be closer than 4 ft to the ground surface at any time and there should be a porous earth cover of not less than 4 to 5 ft over impervious subsoil or rock. A suitable receiving stream or land area is needed if a sewage treatment plant is required.

3. Land to be used for housing or other structures must have suitable soil-bearing characteristics and be well above flood or high-water level. There should be no swamps nearby. The ground slope should normally not exceed 10 percent; slopes of 10 to 35 percent require careful soils and rock analysis for stability.

4. Elevated, well-drained, dry land open to the air and sunshine part of the day, on gently sloping, partly wooded hillsides or ridges, should be available for housing and other buildings. The cleared land should have a firm, grass-covered base to prevent erosion and dust. A slope having a southern or eastern exposure protected from strong winds on the north and west is generally desirable.

5. The area of the property should be large enough to provide privacy, avoid crowding, accommodate a well-rounded program of activities, and allow for future expansion. While the property should be accessible by automobile and bus and convenient to airports, local transit, highways, railroads, and waterways, if needed. Careful attention should be given to the traffic-

generating potential of the site and options for locating sites in the inner city or near community centers. Facilitating walking or biking areas should be emphasized.

An allowance of 1 acre per camper has been suggested as being adequate for children's camps. For elementary schools, 1 acre per 100 pupils and, for high schools, 10 acres plus 1 acre per 100 pupils are recommended. The play area should provide 1000 ft^2 per child using the area at any one time. For a residential area, ¾ acre of public playgrounds, 1¼ acres of public playfields, and 1 acre of public park land per 1000 population are considered minimums. Other suggested standards for parks are given in Table 2-1. Standards should be considered points of departure to be interpreted in the light of the economic and social structure of the people affected and adjusted accordingly. Consider also the recreation potential of abandoned railroad and barge canal rights-of-way for hiking, horseback trails, bicycle paths, snowmobile trails, and other recreation purposes.

6. A satisfactory area should be available for bathing and swimming and other water sports at recreational sites. This may be a clean lake, river, or stream or an artificial swimming pool. A river or stream should not have a strong current or remain muddy during its period of use. An artificial swimming pool equipped with filtration, recirculation, and chlorination equipment may be substituted to advantage.

7. Noxious plants, poisonous reptiles, harmful insects, excessive dust, steep cliffs, old dumps, chemical burial grounds, old mine shafts or wells, dangerous rapids, dampness, and fog should be absent. All this is not usually possible to attain; however, the seriousness of each should be evaluated.

8. A public water supply, sewage system, and solid waste disposal system, if available and accessible, would be extremely desirable.

9. For residential and industrial development, electricity, gas, cable, and telephone service; a sound zoning ordinance and a land-use plan that provides for and protects compatible uses; fire protection; and modern building construction and housing codes vigorously enforced by competent people should all be ensured.

10. Air pollution, noise, and traffic problems from the site and adjoining areas should not interfere with the proposed use.

Topography and Site Surveys

A boundary survey of the property with contours shown at 5-ft intervals, in addition to roads, watercourses, lakes, swamps, woodlands, structures, railroads, power lines, rock outcrops, and any other significant physical features indicated, would be of great value in studying a property. If such a map is not available, a U.S. Geological Survey (USGS) sheet (scale: 1 in. = ½ or 1 mi, contour interval = 10 ft) that has been blown up or an aerial photograph

TABLE 2-1 Park, Open-Space, and Pathway Classification

Classification	General Description	Location Criteria	Size Criteria	Application of LOS
		Parks and Open Spaces		
Minipark	Used to address limited, isolated or unique recreational needs	Less than a $\frac{1}{4}$ mile in residential setting	Between 2500 ft^2 and 1 acre in size	Yes
Neighborhood park	Neighborhood park remains the basic unit of the park system and serves as the recretional and social focus of the neighborhood. Focus is on informal active and passive recreaction.	$\frac{1}{4}$–$\frac{1}{2}$ mile and interrupted by nonresidential roads and other physical barriers	5 acres considered minimum size; 5–10 acres is optimal	Yes
School park	Depending on circumstances, combining parks with school sites can fulfill the space requirements for other classes of parks, such as neighborhood, community, sports complex, and special use.	Determined by location of school district property	Variable—depends on function	Yes—but should not count school only uses

Community park	Serves broader purpose than neighborhood park. Focus is on meeting community-based recreation needs as well as preserving unique landscapes and open spaces.	Determined by the quality and suitability of the site; usually serves two or more neighborhoods and $\frac{1}{2}$–3 miles	As needed to accommodate desired uses; usually between 30 and 50 acres	Yes
Large urban park	Large urban parks serve a broader purpose than community parks and are used when community and neighborhood parks are not adequate to serve the needs of the community. Focus is on meeting community-based recreational needs as well as preserving unique landscapes and open spaces.	Determined by the quality and suitability of the site; usually serves the entire community	As needed to accommodate desired uses; usually a minimum of 50 acres, with 75 or more acres being optimal	Yes
Natural resource areas	Lands set aside for preservation of significant natural resources, remnant landscapes, open space, and visual aesthetics/ buffering	Resource availability and opportunity	Variable	No

TABLE 2-1 (*Continued*)

Classification	General Description	Location Criteria	Size Criteria	Application of LOS
Greenway	Used to effectively tie park system components together to form a continuous park environment	Resource availability and opportunity	Variable	No
Sports complex	Consolidates heavily programmed athletic fields and associated facilities to larger and fewer sites strategically located throughout the community	Strategically located communitywide facilities	Determined by projected demand; usually a minimum of 25 acres, with 40–80 acres being optimal	Yes
Special use	Covers a broad range of parks and recreation facilities oriented toward single-purpose use	Variable—dependent on specific use	Variable	Depends on type of use
Private park/ recreation facility	Parks and recreation facilities that are privately owned yet contribute to the public park and recreation system	Variable—dependent on specific use	Variable	Depends on type of use

TABLE 2-1 Park, Open-Space, and Pathway Classification

Classification	General Description	Description of Each Type	Application of LOS
		Pathways	
Park trail	Multipurpose trails located within greenways, parks, and natural resource areas. Focus is on recreational value and harmony with natural environment.	Type I: Separate/single-purpose hard-surfaced trails for pedestrains or bicyclists/in-line skaters Type II: Multipurpose hard-surfaced trails for pedestrians and bicyclists/in-line skaters Type III: Nature trails for pedestrians; may be hard or soft surfaced	Not applicable
Connector trail	Multipurpose trails that emphasize safe travel for pedestrians to and from parks and around the community. Focus is as much on transportation as it is on recreation.	Type I: Separate/single-purpose hard-surfaced trails for pedestrians or bicyclists/in-line skaters *located in independent right of way (r.o.w.)* (e.g., old railroad r.o.w.) Type II: Separate/single-purpose hard-surfaced trails for pedestrains or bicyclists/in-line skaters; *typically located within road r.o.w.*	Not applicable

TABLE 2-1 **(*Continued*)**

Classification	General Description	Description of Each Type	Application of LOS
On-street bikeway	Paved se4gments of roadways that serve as a means to safely separate bicyclists from vehicular traffic	Bike route: designated portions of roadway for preferential or exclusive use of bicyclists	Not applicable
		Bike lane: Shared portions of roadway that provide separation between motor vehicles and bicyclists, such as paved shoulders	
All-terrain bike-trail	Off-road trail for all-terrain (mountain) bikes	Single-purpose loop trails usually located in larger parks and natural resource areas	Not applicable
Cross-country ski trail	Trails developed for traditional and skate-style cross-country skiing	Loop trails usually located in larger parks and natural resource areas	Not applicable
Equestrian trail	Trails developed for horseback riding	Loop trails usually located in larger parks and natural resource areas; sometimes developed as multipurpose with hiking and all-terrain biking where conflicts can be controlled	Not applicable

(approximately 1 in. = 1660 ft) from the U.S. Department of Agriculture or other agency may be used instead for the preliminary study.* The outline of the property should be marked on the map using deed descriptions. Old plot plans of the property that are available and distinctive monuments or other markings that can be found by site inspection would add valuable information. A long-time resident or cooperative neighbor may also be of assistance.

With the map as a beginning, one should hike over as much of the area as possible and carefully investigate the property. Complete notes should be kept that refer to numbers placed on the topographic map showing beautiful views and other desirable features as well as undesirable conditions. Supplementary freehand sketches and rough maps of possible camp, recreational, or building sites, with distances paced off, will be valuable details.

The bathing area should be sounded and slope of the bottom plotted. The need for cleaning and removal of mud, rocks, and aquatic growths should be noted. The drainage area tributary to a lake or stream to be used for bathing should be determined and the probable minimum contribution or flow computed to ascertain if an ample quantity of water will be available during the dry months of the year. Long-term hydrological data, such as at a USGS stream gauge station, would be very valuable.

In most cases, the watershed area tributary to a beach on a stream or lake will extend beyond the boundary of the land under consideration. Therefore, it is important to know what habitation, agriculture, and industry are on the watershed. The probable land usage, pollution of tributary streams, and probable water use should then be determined because persons owning land have the right to reasonable use of their property, including streams flowing through it. This will bring out whether the stream or lake is receiving chemical, bacterial, or physical pollution that would make it dangerous or unsuitable for bathing use or water supply purposes. In order to obtain this information, it is necessary to make a survey on foot of every stream and brook on the watershed and collect water samples at different times of the year for chemical, physical, and microbiological examinations. The local or state health, environmental, agriculture, or conservation department environmental engineer, agent, conservation officer, or sanitarian may be able to give assistance. In addition to satisfactory quantity and quality, the water should be relatively clear and slow moving. Study of the stream bottom and float or weir measurements to determine the velocity and quantity of water at different seasons of the year will provide supplemental information. Supplemental tests to determine type, concentration, and travel may also be indicated where organic or inorganic contamination is suspected.

While a foot survey is being made, one should look for signs indicating the high water level of the lake or stream. The topography of the ground; presence of a floodplain; stranded tree trunks and debris; discolorations on

*USGS plans to use the International System of Units (SI) for various map scales.

rocks and trees; width, depth, and slope of the stream channel, coupled with probable maximum flow; evaluation of nearby railroad beds and bridge elevations; and type of vegetation growing may give good clues. Old orchards might indicate pesticide-contaminated soil and groundwater. Local and state governmental agencies and individuals should be questioned regarding past history; agricultural, industrial, and commercial land uses; permits issued; accidental spills; old dumps; and illegal dumping. Valuable information can also be obtained by discussing these points with long-time residents.

Geology, Soil, and Drainage

The soil should be sampled at representative locations to determine its characteristics. Borings should be made to a depth of about 15 ft in order to record variations in the strata penetrated and the elevation of the groundwater level, if encountered, with respect to the ground surface. Borings, postholes, and earth auger tests will also indicate the depth to rock and the presence and thickness of clay or hardpan layers that might interfere with proper drainage or foundations for structures and old dump sites requiring further investigation.

In addition to borings, soil studies and soil percolation tests should be made in areas that, as indicated by the topography, are probably suitable for subsurface sewage disposal, if needed. Explanation of the soil's characteristics and percolation tests and application of the results are discussed in Chapter 4. Public sewage should be used if possible.

If a proposed development or building is to be located on the side of a long hill or slope, the necessity and feasibility of providing an earth berm or dam or deep surface-water drainage ditches to divert surface water around the site should be kept in mind. The possibility of earth slides, flooding, erosion, and washout should be given careful study. Slopes with a greater than 8 percent incline require special engineering study and treatment, such as water infiltration and percolation control to prevent slides, erosion control, drainage, and vegetative cover. All wetlands as defined by federal and state laws and regulations need to be identified, mapped, and protected. Where appropriate, wetland mitigation and banking should be considered.

Utilities

The existence of or need for a water supply system, a sewage treatment and disposal system, a solid waste collection and disposal system, roads, electricity or a generator of electricity, gas, oil, coal, wood, and telecommunications should be studied, for they will determine the type of establishment, services, and sanitary facilities that could be provided.

Needless to say, if an adequate, satisfactory, and safe water supply is not obtainable on- or off-site at a reasonable cost, with or without treatment, the site should be abandoned. This is particularly important to a factory or industry dependent on large volumes of water. See Chapter 3.

The probable cost of a wastewater collection and treatment system should be estimated before any commitments are made. Water classification, minimum stream flow, and effluent standards for water pollution abatement will govern the degree of treatment required and hence the cost of construction and operation. For a large project, an elaborate wastewater treatment plant may be required. For small establishments, a subsurface sewage disposal system may suffice if the soil conditions are satisfactory. An alternative at pioneer-type camps might be the use of privies. See Chapter 4.

Electricity for lighting or for the operation of water and wastewater pumps, kitchen equipment, refrigerator compressors, and other mechanical equipment is usually taken for granted. If the provision of electricity means the running of long lines, purchase of an electric-generating unit, or gasoline motor-driven equipment, then the first cost, cost of operation, maintenance, and replacement should be estimated.

Roads to the main buildings are needed for access and bringing in supplies. The distance from the main roads to the property and the length and condition of secondary roads within the property should be determined, as well as the need for road culverts and bridges. The traffic generation potential for the facility should be considered as well as the potential for generating costly suburban low-density, high-infrastructure-dependent development. Options for alternative sites in urban areas or community centers close to mass or other transit facilities should be given weight.

If a power plant or industrial process will cause air pollution, air pollution control requirements, prevailing winds, temperature, and related factors will have to be studied and the cost of treatment devices determined in evaluating the suitability of a proposed site. See Chapter 6. If a plant process will result in the production of large quantities of solid wastes, the treatment and disposal of the residue must also be considered. See Chapter 5.

Meteorology

Slopes having an eastern or southern exposure in the United States are preferred for building locations to get the benefit of the morning sun. This possibility can be ascertained by inspection of available topographic maps and field surveys. Information about the direction of prevailing winds is of value if a summer or winter place is proposed. An indication of the wind direction can be obtained by observing the weathering of objects and the lean of the trees. This information, plus average monthly temperature, humidity, snowfall, and rainfall data, may be available at local universities, nearby government weather stations, airfields, and some water or power company offices. Where these data are not available, it may be possible to utilize stream flow measurements to judge the general pattern of precipitation in the area. Consider also potential sources of air pollution, prevailing winds, and possible effects on the proposed land use.

Location

The relative location of the property can best be appreciated by marking its outline on a recent USGS sheet. In this way, the distance to airports, railroad and bus stations, first-class roads, shopping centers, neighbors, resort areas, schools, hospitals, and doctors is almost immediately apparent. State and county highway department road plans should also be investigated and proposed roads marked on the topographic plan to see what their probable effect will be.

Resources

To determine the resources on a property (when it is a large tract), one should seek the assistance of a person who is intimately familiar with wildlife, forestry, geology, hydrology, and engineering. Since this is not always possible, the next best thing would be for several persons having a broad knowledge to make the survey on foot. Much useful information can also be obtained from county, state, and federal GIS maps. The location, size, and type of woodland, pasture, rock, sand, and gravel should be carefully noted. The woodland may also serve as building material or firewood; the rock as roadbed or foundation material; the pasture as a recreational area or golf course; and the sand and gravel for concrete and cement work or road surfacing with admixtures if needed. The availability of such materials near the construction site will result in considerable savings. Other, less obvious resources are surface and underground water for domestic, recreational, and power purposes and unspoiled scenery.

Animal and Plant Life

A broad knowledge and extensive investigation are needed to properly evaluate the importance of animal and plant life and their conservation. The presence of poison ivy, for example, must be accepted as a potential source of skin irritations; ragweed and other noxious plants must be accepted as sources of hay fever. It is important to mark the location of any infested areas on a topographic map so that attention is directed to their existence in the construction and planning program. The same would apply to the presence of mosquitoes, flies, ticks, chiggers, rodents, poisonous reptiles, and dangerous animals. On the other hand, equal emphasis can be placed on the presence of wild flowers, useful reptiles and wild animals, and native trees. Rare and endangered species inventories can provide useful information.

Improvements Needed

Inasmuch as the ideal school, institution, industry, camp, or housing site is rarely if ever found, the work that needs to be done to make an ideal site should be determined. An undesirable feature may be a low swampy area. This may not be filled in, unless mitigation arrangements have been made with federal and state regulatory agencies. The swamp may be retained as a wildlife preserve. Each possibility and constraint should be examined and reviewed with the regulatory agency having jurisdiction, the cost of the work estimated, and the probable value of the improvement appraised. Needed clearing, seeding, or reforestation and the extent of poison ivy, ragweed, thistle, and other objectionable plants should also be considered. If a natural bathing area is not available on a lake or stream on the property, it is advisable to compare the cost of developing and maintaining one with the cost of an artificial swimming pool. If a lake is available, then thought must be given to clearing, the construction of a beach, and perhaps dredging and shore development to keep down heavy aquatic growths and plant life such as algae. The need for new roads inside the property connecting with town, county, or state roads is another consideration. In some cases, this may involve blasting, fill, bridges, and special construction, all of which could mean high costs. Other needed physical improvements may be surface-water diversion ditches, culverts, brush clearing, boat docks, parking areas, and the preparation of areas for recreational purposes. Also important is the environmental impact of the proposed land development and use.

Site Planning

After properties have been explored and studied and a site is selected, the next step is to prepare, if not already available, a complete large-scale topographic map of the purchased property to a scale of 1 in = 100 ft, with contours at least at 5-ft intervals, incorporating desirable and undesirable physical features and the details already discussed. After this, the elements of the ideal place should be put in writing. The approximate location of the proposed establishment should be indicated on the map, making maximum use of the natural advantages offered by the site.

Camps and resorts, for example, occupied during the summer months should have an eastern exposure. Camps and resorts are located on the west shore of a lake or stream to receive the benefit of early morning sun and afternoon shade. Then, without losing sight of the purpose the property is to serve and the program to be followed, cutouts are made to scale to represent plans of present and future buildings, roads, parking spaces, recreational areas, campsites, water supply, sewage and refuse disposal areas, bathing beaches, and other facilities. The preparation of a scale model also has great promotional possibilities. It will help others visualize the buildings and their relationship to each other and to roads, streams, lakes, hills, and neighboring communities. Changes can be easily made on paper. This method has been used successfully in obtaining funds for major improvements and new developments. Scheduled public information and participation sessions are essential components of the planning process.

It is advisable to seek the advice of a registered engineer, hydrogeologist, architect, planner, or other consultant to perform the preliminary planning, engineering design, and construction monitoring for compliance with plans and specifications. One should confer with the state and local planning, environmental, health, and building departments to learn of the regulations for the protection of the life, health, and welfare of the people and with environmental protection and conservation agencies for protection of the flora, fauna, and ecology and the need for an environmental impact assessment. This is particularly important when a housing development, industrial plant, incinerator, landfill, water treatment plant, wastewater treatment plants, office complex, camp, hotel, resort, shopping center, school, or other public place is contemplated. The agency staff may also be in a position to offer valuable assistance regarding former uses of the land and possible hazards not readily apparent. The plan should show, in addition to the items mentioned, such other details that may be required by the departments having jurisdiction to permit their staff to review the plans and pass on them favorably. After approved plans and permits are received, bids can be solicited, contracts let, a construction schedule established, and the work carried on in accordance with a preconceived, carefully thought-out plan. There will then be no looking back at useless, inefficient, wasteful structures or spaces; instead, the eventual realization of the "ideal" place by adding to what has already been accomplished can be anticipated.

The importance of obtaining competent professional advice cannot be emphasized too strongly. All too often charitable camps and institutions seek and expect free engineering and architectural services. This is unfair not only to the individuals consulted but also to the camp or institution. The consultants would unconsciously try to conclude the planning and design as rapidly as possible; and the recipient of the service would proceed on the basis of possibly incompletely studied and conceived plans, detailed drawings, specifications, and contract documents. A proper place for free expert advice would be in the process of selecting the engineer, architect, contractor, and equipment; reviewing plans, specifications, and contracts; and evaluating the bids received for the particular job. The fee for a consultant's services, in comparison to the cost of a project, is relatively small. The reduction of waste caused by incorrect size of buildings, improper materials, poor planning of equipment and facilities, foundation and structural weaknesses, and bad location or exposure of buildings, as well as savings in the selection of proper materials and equipment for minimum operating costs and the assurance that plans and specifications are being complied with, far outshadows the professional fee.

Environmental Assessment

An environmental assessment may relate to an existing or proposed site or plant. The environmental assessment attempts to identify all existing and past activities that may have a deleterious effect on human health, the environment, or safety. In so doing, compliance with all applicable federal, state, and local laws, rules, and regulations and required permit conditions are also determined.

An environmental assessment may be conducted for different purposes. It may emphasize compliance with existing regulations and permit requirements, respond to a spill, or relate to the potential or existing environmental risks and liabilities associated with the purchase or acquisition of a property.

An assessment to determine compliance with regulatory requirements is referred to as an *environmental audit*. It may be carried out by regulatory personnel, in-plant personnel, or a consultant. The audit may relate to a single-purpose facility, such as an incinerator, wastewater treatment plant, hazardous waste operation, or water system, or to all operations and procedures at a plant or site. An assessment that is concerned with a property or its acquisition is referred to as an *environmental property assessment*. It includes investigation for possible above-ground and subsurface contaminants and hazards, violations associated with structures on the property (including health and safety), and title searches.

At an existing operating site or facility, effluent, emission, water, waste, and soil samples may be collected, if indicated, for physical, chemical, and microbiological examinations and evaluation. Volume or weight measurements are made. Materials balances of input versus output are compared where possible. Raw-material and process changes to reduce and eliminate toxic or polluting discharges of product or wastes are considered. Deficiencies are identified and a correction and prevention program developed. In making an environmental property assessment, local residents, employees, and retirees may be interviewed regarding present and past products stored or manufactured, operations, practices, wastes produced, waste disposal methods, and previous land uses. Plant records, reports, and other documents would be useful.

A site investigation could include old and recent land deeds, zoning maps and codes, topographical maps and aerial surveys, historical reports and books, state archives records, regulatory agency and university reports, fire department and insurance files, and library files, Evidence of old mines, dumps, burial grounds, swamps, vegetation-free areas, wells, pipelines, buried tanks, impoundments, orchards, farmlands, laboratories, and factories may be found. Investigations and old reports and industrial directories may reveal types of waste materials generated and discarded at the site. Adjacent properties and uses may impact on the study site and should be explored. Site field surveys should be made at properties to be purchased and include, if indicated, soil, groundwater, waste, and possibly air sampling for physical, chemical, radiological, and microbiological analyses and evaluation. Caution must be exercised to protect personnel from exposure to hazardous wastes.

The value of an environmental assessment is dependent on the types and competencies of the professionals employed, the comprehensiveness of the survey, and the quality of the supporting laboratory results.

Professionals who may be involved include engineers, land surveyors, geologists, hydrogeologists, archaeologists, historical geographers, chemists, biologists, health physicists, attorneys, toxicologists, and others who have the proper, specialized training and experience. Professional organizations, governmental agencies, institutions, and others provide environmental assessment information, including guidelines, checklists, manuals, and books that can be of value. See Bibliography.

Purchasers of real estate, including plants and other properties, are advised to have an environmental site and facility assessment completed before purchase. The legal and financial liabilities assumed due to potentially hazardous contaminants on the site or building violations that may exist [structural, fire, asbestos materials, polychlorinated biphenyls (PCBs) leaking underground petroleum and chemical storage tanks] should be understood and evaluated before ownership is finalized. Consultants performing environmental site assessments and audits may become involved in legal actions as a result of their studies and reports. They may be sued for hazardous conditions or for having knowledge of such. A consultant should be careful not to guarantee that a property is free of all contamination or what level of cleanliness a regulatory agency may require. Therefore, it is prudent for a consultant to limit liability in an agreement with a client, as the extent of an ''adequate'' environmental assessment and audit needs to be defined.

See also previous discussions in this chapter; Environmental Factors to Be Evaluated in Site Selection and Planning later in this chapter; and the next section, Environmental Impact Analysis.

ENVIRONMENTAL IMPACT ANALYSIS

Concurrent with site selection and planning is the necessity to consider the effects of all proposed land uses, actions, and required services and facilities on the environment or geography of the area. It is extremely difficult to identify and evaluate in depth all possible factors that may affect and be affected by a particular project or action. Reference to the material that follows, the pertinent federal and state legislation, and source documents such as footnoted and listed in the References and Bibliography at the end of this chapter should assist in selecting items to be explored in greater depth in particular situations. A good regional plan, including the environmental, engineering, and health factors previously noted, will lead to the collection of pertinent data and greatly simplify preparation of an environmental impact assessment, and, if necessary, the environmental impact statement (EIS).

National Environmental Policy Act (NEPA)

Planning, design, and construction or implementation of a project, without regard to its environmental effects, not to mention the social, economic, and other consequences, calls attention to the custodial responsibility and moral obligation of society to protect the environment for future generations and ensure their survival. Public concern over environmental pollution, aided by scientific and professional prodding and support, has led to federal and state legislation mandating consideration and documentation of the beneficial and adverse effects of proposed actions in the project planning stage for official and public scrutiny and indicated adjustments. This concept was given national recognition by the National Environmental Policy Act (NEPA) of 1969,[7] as amended. It is quoted in part below. The reader should refer to the entire act and applicable state law[8] if involved in a project or action under such jurisdiction:

THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969, AS AMENDED*

An Act to establish a national policy for the environment, to provide for the establishment of a Council on Environmental Quality, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the ''National Environmental Policy Act of 1969.''

Purpose

SEC. 2. The purposes of this Act are: To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality.

Title I
Declaration of National Environmental Policy

SEC. 101. (a) The Congress, recognizing the profound impact of man's activity on the interrelations of all components of the natural environment, particularly the profound influences of population growth, high-density urbanization, industrial expansion, resource exploitation, and new and expanding technological advances and recognizing further the critical importance of restoring and maintaining environmental quality to the overall welfare and development of man, declares that it is the continuing policy of the Federal Government, in

*Public Law (P.L.) 91-190, 42 United States Code (U.S.C.) 4321–4347, January 1, 1970, as amended by P.L. 94-52, July 3, 1975, and P.L. 94-83, August 9, 1975. See also ref. 7.

cooperation with State and local governments, and other concerned public and private organizations, to use all practicable means and measures, including financial and technical assistance, in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans.

(b) In order to carry out the policy set forth in this Act, it is the continuing responsibility of the Federal Government to use all practical means, consistent with other essential considerations of national policy, to improve and coordinate Federal plans, functions, programs, and resources to the end that the Nation may—

(1) fulfill the responsibilities of each generation as trustee of the environment for succeeding generations;

(2) assure for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings;

(3) attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences;

(4) preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of individual choice;

(5) achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities; and

(6) enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

(c) The Congress recognizes that each person should enjoy a healthful environment and that each person has a responsibility to contribute to the preservation and enhancement of the environment.

SEC. 102. The Congress authorizes and directs that, to the fullest extent possible: (1) the policies, regulations, and public laws of the United States shall be interpreted and administered in accordance with the policies set forth in this Act, and (2) all agencies of the Federal Government shall—

(A) Utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decisionmaking which may have an impact on man's environment;

(B) Identify and develop methods and procedures, in consultation with the Council on Environmental Quality established by Title II of this Act, which will insure that presently unquantified environmental amenities and values may be given appropriate consideration in decisionmaking along with economic and technical considerations;

(C) Include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on—

(i) The environmental impact of the proposed action,

(ii) Any adverse environmental effects which cannot be avoided should the proposal be implemented,

(iii) Alternatives to the proposed action,

(iv) The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and

(v) Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

Prior to making any detailed statement, the responsible Federal official shall consult with and obtain the comments of any Federal agency which has jurisdiction by law or special expertise with respect to any environmental impact involved. Copies of such statement and the comments and views of the appropriate Federal, State, and local agencies, which are authorized to develop and enforce environmental standards, shall be made available to the President, the Council on Environmental Quality and to the public as provided by section 552 of title 5, United States Code, and shall accompany the proposal through the existing agency review processes;

(d) Any detailed statement required under subparagraph (c) after January 1, 1970, for any major Federal action funded under a program of grants to States shall not be deemed to be legally insufficient solely by reason of having been prepared by a State agency or official, if:

(i) the State agency or official has statewide jurisdiction and has the responsibility for such action,

(ii) the responsible Federal official furnishes guidance and participates in such preparation,

(iii) the responsible Federal official independently evaluates such statement prior to its approval and adoption, and

(iv) after January 1, 1976, the responsible Federal official provides early notification to, and solicits the views of, any other State or any Federal land management entity of any action or any alternative thereto which may have significant impacts upon such State or affected Federal land management entity and, if there is any disagreement on such impacts, prepares a written assessment of such impacts and views for incorporation into such detailed statement.

The procedures in this subparagraph shall not relieve the Federal official of his responsibilities for the scope, objectivity, and content of the entire statement or of any other responsibility under this Act; and further, this subparagraph does not affect the legal sufficiency of statements prepared by State agencies with less than statewide jurisdiction;

(e) Study, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources;

(f) Recognize the worldwide and long-range character of environmental problems and, where consistent with the foreign policy of the United States, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind's world environment;

(g) Make available to States, counties, municipalities, institutions, and individuals, advice and information useful in restoring, maintaining, and enhancing the quality of the environment;

(h) Initiate and utilize ecological information in the planning and development of resource-oriented projects; and

(i) Assist the Council on Environmental Quality established by Title II of this Act.

SEC. 103. All agencies of the Federal Government shall review their present statutory authority, administrative regulations, and current policies and procedures for the purpose of determining whether there are any deficiencies or inconsistencies therein which prohibit full compliance with the purposes and provisions of this Act and shall propose to the President not later than July 1, 1971, such measures as may be necessary to bring their authority and policies into conformity with the intent, purposes, and procedures set forth in this Act.

SEC. 104. Nothing in section 102 or 103 shall in any way affect the specific statutory obligations of any Federal agency (1) to comply with criteria or standards of environmental quality, (2) to coordinate or consult with any other Federal or State agency, or (3) to act, or refrain from acting contingent upon the recommendations or certification of any other Federal or State agency.

SEC. 105. The policies and goals set forth in this Act are supplementary to those set forth in existing authorizations of Federal agencies.

Title II of NEPA establishes a Council on Environmental Quality; requires the President to submit an annual Environmental Quality Report to Congress; authorizes personnel; states the duties, powers, and functions of the Council; and authorizes certain annual appropriations.

The Environmental Quality Improvement Act of 1970 was enacted

(1) To assure that each Federal department and agency conducting or supporting public works activities which affect the environment shall implement the policies under existing law; and

(2) To authorize an Office of Environmental Quality, which, notwithstanding any other provision of law, shall provide the professional and administrative staff for the Council on Environmental Quality established by Public Law 91–190.

By Executive Order Protection and Enhancement of Environmental Quality, March 5, 1970, as amended, the President directed federal agencies to provide leadership and meet the national environmental goals. The Council on Environmental Quality was made responsible for advising and assisting the President in leading this national effort.[7]

Other federal agencies and many states have also adopted rules or legislation and prepared procedures for environmental quality reviews of proposed actions and preparation of environmental impact statements.*

Terminology

Certain terms to aid in the interpretation of NEPA are explained below (ref. 7).

> Categorical exclusion means a category of actions which do not individually or cumulatively have a significant effect on the human environment and which have been found to have no effect in procedures adopted by a Federal agency in implementation of these regulations and for which, therefore, neither an environmental assessment nor an environmental impact statement is required. (Sec. 1508.4)
>
> Cumulative impact is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. (Sec. 1508.7)
>
> Effects include:
>
> (a) Direct effects, which are caused by the action and occur at the same time and place.
>
> (b) Indirect effects, which are caused by the action and are late in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.
>
> ‘‘Effects’’ and ‘‘impacts’’ as used in these regulations are synonymous. Effects include ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative. Effects may also include those resulting from actions which may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial. (Sec. 1508.8)
>
> Environmental Assessment†:

* Department of Housing and Urban Development (HUD), USGS, California, Illinois, Michigan, New York, Vermont, Virginia, Washington, others.

† An environmental impact assessment is similar to an environmental impact statement but not necessarily as comprehensive or in the same depth. It can determine if a negative declaration is indicated or if an environmental impact statement is required. An environmental assessment is not required if it has been decided to prepare an environmental impact statement (Sec. 1501.3).

(a) Means a concise public document for which a Federal agency is responsible that serves to:

(1) Briefly provide sufficient evidence and analysis for determining whether to prepare an environmental impact statement or a finding of no significant impact.

(2) Aid an agency's compliance with the Act when no environmental impact statement is necessary.

(3) Facilitate preparation of a statement when one is necessary.

(b) Shall include brief discussion of the need for the proposal, of alternatives as required by Sec. 102(2)(E), of the environmental impacts of the proposed action and alternatives, and a listing of agencies and persons consulted. (Sec. 1508.9)

Environmental document includes the documents specified in Secs. 1508.9 (environmental assessment), 1508.11 (environmental impact statement), 1508.13 (finding of no significant impact), and 1508.22 (notice of intent). (Sec. 1508.10)

Environmental Impact Statement means a detailed written statement as required by Sec. 102(2)(C) of the Act. (Sec. 1508.11)

Federal agency means all agencies of the Federal Government. It does not mean the Congress, the Judiciary, or the President, including the performance of staff functions for the President in his Executive Office. It also includes for purposes of these regulations States and units of general local government and Indian tribes assuming NEPA responsibilities under Sec. 104(h) of the Housing and Community Development Act of 1974. (Sec. 1508. 12)

Finding of No Significant Impact means a document by a Federal agency briefly presenting the reasons why an action, not otherwise excluded (1508.4), will not have a significant effect on the human environment and for which an environmental impact statement therefore will not be prepared. It shall include the environmental assessment or a summary of it and shall note any other environmental documents related to it. If the assessment is included, the finding need not repeat any of the discussion in the assessment but may incorporate it by reference. (Sec. 1508.13)

Human Environment shall be interpreted comprehensively to include the natural and physical environment and the relationship of people with that environment. [See the definition of "effects" (Sec. 1508.8).] This means that economic or social effects are not intended by themselves to require preparation of an environmental impact statement. When an environmental impact statement is prepared and economic or social and natural or physical environmental effects are interrelated, then the environmental impact statement will discuss all of these effects on the human environment. (Sec. 1508. 14)

Scoping may be used before Notice of Intent to prepare an environmental impact statement as long as there is appropriate public notice and enough information available on the proposal so that the public and relevant agencies can participate effectively. (CEQ 1981 Rpt., p.265)

Scoping

Scoping is a very important element of all planning processes because it explains what will and what will not be included in the process. It must be done early in the process and it should be at the beginning of the public participation process—here is what the federal regulations say about it:

(CEQ Regulations for implementing NEPA(http://ceq.eh.doe.gov/nepa/regs/ceq/1501.htm#1501.7)

> Sec. 1501.7 Scoping. There shall be an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to a proposed action. This process shall be termed scoping. As soon as practicable after its decision to prepare an environmental impact statement and before the scoping process the lead agency shall publish a notice of intent (Sec. 1508.22) in the Federal Register except as provided in Sec. 1507.3(e).
>
> (a) As part of the scoping process the lead agency shall:
>
> 1. Invite the participation of affected Federal, State, and local agencies, any affected Indian tribe, the proponent of the action, and other interested persons (including those who might not be in accord with the action on environmental grounds), unless there is a limited exception under Sec. 1507.3(c). An agency may give notice in accordance with Sec. 1506.6.
>
> 2. Determine the scope (Sec. 1508.25) and the significant issues to be analyzed in depth in the environmental impact statement.
>
> 3. Identify and eliminate from detailed study the issues which are not significant or which have been covered by prior nvironmental review (Sec. 1506.3), narrowing the discussion of hese issues in the statement to a brief presentation of why hey will not have a significant effect on the human environment or providing a reference to their coverage elsewhere.
>
> 4. Allocate assignments for preparation of the environmental impact statement among the lead and cooperating agencies, with the lead agency retaining responsibility for the statement.
>
> 5. Indicate any public environmental assessments and other environmental impact statements which are being or will be prepared that are related to but are not part of the scope of the impact statement under consideration.
>
> 6. Identify other environmental review and consultation requirements so the lead and cooperating agencies may prepare other required analyses and studies concurrently with, and integrated with, the environmental impact statement as provided in Sec. 1502.25.
>
> 7. Indicate the relationship between the timing of the preparation of environmental analyses and the agency's tentative planning and decision-making schedule.
>
> (b) As part of the scoping process the lead agency may:
>
> 1. Set page limits on environmental documents (Sec. 1502.7).

2. Set time limits (Sec. 1501.8).

3. Adopt procedures under Sec. 1507.3 to combine its environmental assessment process with its scoping process.

4. Hold an early scoping meeting or meetings which may be integrated with any other early planning meeting the agency has. Such a scoping meeting will often be appropriate when the impacts of a particular action are confined to specific sites.

(c) An agency shall revise the determinations made under paragraphs (a) and (b) of this section if substantial changes are made later in the proposed action, or if significant new circumstances or information arise which bear on the proposal or its impacts. (http://ceq.eh.doe.gov/nepa/regs/ceq/1501.htm#1501.7)

Recommended Format for Environmental Impact Statement (NEPA)

§ 1502.10 Recommended Format (ref. 7).

Agencies shall use a format for environmental impact statements which will encourage good analysis and clear presentation of the alternatives, including the proposed action. The following standard format for environmental impact statements should be followed unless the agency determines that there is a compelling reason to do otherwise:

(a) Cover sheet.

(b) Summary.*

(c) Table of Contents.

(d) Purpose of and Need for Action.

(e) Alternatives Including Proposed Action [Secs. 102(2)(C)(iii) and 102(2)(E) of the Act].

(f) Affected Environment.

(g) Environmental Consequences [especially Secs. 102(2)(C)(i), (ii), (iv), and (v) of the Act].

(h) List of Preparers.

(i) List of Agencies, Organizations, and Persons to Whom Copies of the Statement Are Sent.

(j) Index.

(k) Appendices (if any).

* See Section 1500.8 and Appendix 1 of NEPA.

An explanation of each section of the environmental impact statement is given in Sections 1502.11 to 1502.18 of the *Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act.*[7]

A suggested outline for the content of an environmental impact statement is shown in Figure 2-5. The content is explained in Section 1500.8, quoted below.

Environmental Impact Statement (EIS)

The EIS required under NEPA, Section 102(2)(C), is a detailed written statement by a responsible official on every proposal for legislation or other major federal action significantly affecting the quality of the human environment. It is to include the information required by Section 102(2)(C) quoted earlier.

Guidelines for the preparation of EIS published by the Council on Environmental Quality[9] are reported below in Section 1500.8. Many states have adopted similar guidelines. A draft EIS generally first prepared and circulated for comment. The EIS may be for a proposed concept or program, a planning study, and/or a proposed construction project. It must fulfill and satisfy the requirements established in Section 102(2)(C). The comments received are then evaluated and considered in the decision-making process.

Preparation of a generic environmental impact statement (GEIS) is advised during the project feasibility analysis. The GEIS is a means to consider the applicable regulatory controls and environmental impact of a project in a general, not necessarily site-specific manner. However, it would be desirable to consider site-specific factors to the extent available data permit. In any case, early and repeated public information and participation can help identify perceived and actual environmental issues to be addressed in the EIS, thus accommodating and minimizing objections. The GEIS and site-specific information evolving as the engineering planning proceeds are then combined to form the EIS.

§ 1500.8 CONTENT OF ENVIRONMENTAL STATEMENTS (ref. 10, pp. 405–407):

(a) The following points are to be covered:

(1) A description of the proposed action, a statement of its purposes, and a description of the environment affected, including information, summary technical data, and maps and diagrams where relevant, adequate to permit an assessment of potential environmental impact by commenting agencies and the public. Highly technical and specialized analyses and data should be avoided in the body of the draft impact statement. Such materials should be attached as appendices or footnoted with adequate bibliographic references. The statement should also succinctly describe the environment of the area affected as it exists prior to a proposed action, including other Federal activities in the area affected by the proposed action which are related to the proposed action. The interrela-

1. PROJECT DESCRIPTION
   a. Purpose of action
   b. Description of action
      (1) Name
      (2) Summary of activities
   c. Environmental setting
      (1) Environment prior to proposed action
      (2) Other related federal activities.
2. LAND-USE RELATIONSHIPS
   a. Conformity or conflict with other land-use plans, policies, and controls
      (1) Federal, state, and local
      (2) Clean Air Act and Federal Water Pollution Control Act Amendment of 1972
   b. Conflicts and/or inconsistent land-use plans
      (1) Extent of reconciliation
      (2) Reasons for proceeding with action
3. PROBABLE IMPACT OF THE PROPOSED ACTION ON THE ENVIRONMENT
   a. Positive and negative effects
      (1) National and international environment
      (2) Environmental factors
      (3) Impact of proposed action
   b. Direct and indirect consequences
      (1) Primary effects
      (2) Secondary effects
4. ALTERNATIVES TO THE PROPOSED ACTION
   a. Reasonable alternative actions
      (1) Those that might enhance environmental quality
      (2) Those that might avoid some or all adverse effects
   b. Analysis of alternatives
      (1) Benefits
      (2) Costs
      (3) Risks
5. PROBABLE ADVERSE ENVIRONMENTAL EFFECTS WHICH CANNOT BE AVOIDED
   a. Adverse and unavoidable impacts
   b. How avoidable adverse impacts will be mitigated
6. RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY
   a. Trade-off between short-term environmental gains at expense of long-term losses
   b. Trade-off between long-term environmental gains at expense of short-term losses
   c. Extent to which proposed action forecloses future options
7. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES
   a. Unavoidable impacts irreversibly curtailing the range of potential uses of the environment
      (1) Labor
      (2) Materials
      (3) Natural
      (4) Cultural
8. OTHER INTERESTS AND CONSIDERATIONS OF FEDERAL POLICY THAT OFFSET THE ADVERSE ENVIRONMENTAL EFFECTS OF THE PROPOSED PLAN
   a. Countervailing benefits of proposed action
   b. Countervailing benefits of alternatives

Figure 2-5 Outline for CEQ-prescribed EIS content. (*Source: Hanbbook for Environmental Impact Analysis,* Department of the Army, Superintendent of Documents, U.S. Government Printing Office, Washington, DC., April 1975, p. 20.)

tionships and cumulative environmental impacts of the proposed action and other related Federal projects shall be presented in the statement. The amount of detail provided in such descriptions should be commensurate with the extent and expected impact of the action, and with the amount of information required at the particular level of decisionmaking (planning, feasibility, design, etc.). In order to ensure accurate descriptions and environmental assessments, site visits should be made where feasible. Agencies should also take care to identify, as appropriate, population and growth characteristics of the affected area and any population and growth assumptions used to justify the project or program or to determine secondary population and growth impacts resulting from the proposed action and its alternatives [see paragraph (3)(ii), of this section]. In discussing these population aspects, agencies should give consideration to using the rates of growth in the region of the project contained in the projection compiled for the Water Resources Council by the Bureau of Economic Analysis of the Department of Commerce and the Economic Research Service of the Department of Agriculture (the "OBERS" projection). In any event it is essential that the sources of data used to identify, quantify, or evaluate any and all environmental consequences be expressly noted.

(2) The relationship of the proposed action to land use plans, policies, and controls for the affected area. This requires a discussion of how the proposed action may conform or conflict with the objectives and specific terms of approved or proposed Federal, State, and local land use plans, policies, and controls, if any, for the area affected, including those developed in response to the Clean Air Act or the Federal Water Pollution Control Act Amendments of 1972. Where a conflict or inconsistency exists, the statement should describe the extent to which the agency has reconciled its proposed action with the plan, policy, or control and the reasons why the agency has decided to proceed notwithstanding the absence of full reconciliation.

(3) The probable impact of the proposed action on the environment.

(i) This requires agencies to assess the positive and negative effects of the proposed action as it affects both the national and international environment. The attention given to different environmental factors will vary according to the nature, scale, and location of proposed actions. Among factors to consider should be the potential effect of the action on such aspects of the environment as those listed in Appendix II* of these guidelines. Primary attention should be given in

*Air quality, water quality, marine pollution, commercial fisheries, conservation, and shellfish sanitation; water regulation and stream modification, fish and wildlife, solid waste, noise, radiation, toxic materials, food additives and contamination of foodstuffs, pesticides, transportation and handling of hazardous materials, energy supply, and natural resources development; petroleum development, extraction, refining, transport, and use; natural gas development, production, transmission, and use; coal and minerals development, mining, conversion, processing, transport, and use; renewable resource development, production, management, harvest, transport, and use; energy and natural resource conservation; land use and management; public land management; protection of environmentally critical areas—floodplains, wetlands, beaches and dunes, unstable soils, steep slopes, aquifer recharge areas, etc.; land use in coastal areas; redevelopment and construction in built-up areas; density and congestion mitigation; neighborhood character and continuity; impact on low-income populations; historic, architectural, and archeological preservation; soil and plant conservation and hydrology; outdoor recreation.

the statement to discussing those factors most evidently impacted by the proposed action.

(ii) Secondary or indirect, as well as primary or direct, consequences for the environment should be included in the analysis. Many major Federal actions, in particular those that involve the construction or licensing of infrastructure investments (e.g., highways, airports, sewer systems, water resource projects, etc.), stimulate or induce secondary effects in the form of associated investments and changed patterns of social and economic activities. Such secondary effects, through their impacts on existing community facilities and activities, through inducing new facilities and activities, or through changes in natural conditions, may often be even more substantial than the primary effects of the original action itself. For example, the effects of the proposed action on population and growth may be among the more significant secondary effects. Such population and growth impacts should be estimated if expected to be significant [using data identified as indicated in § 1500.8(a)(1)] and an assessment made of the effect of any possible change in population patterns or growth upon the resource base, including land use, water, and public services, of the area in question.

(4) Alternatives to the proposed action, including, where relevant, those not within the existing authority of the responsible agency. [Section 102(2)(D) of the Act requires the responsible agency to "study, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources."] A rigorous exploration and objective evaluation of the environmental impacts of all reasonable alternative actions, particularly those that might enhance environmental quality to avoid some or all of the adverse environmental effects, is essential. Sufficient analysis of such alternatives and their environmental benefits, costs and risks should accompany the proposed action through the agency review process in order not to foreclose prematurely options which might enhance environmental quality or have less detrimental effects. Examples of such alternatives include: the alternative of taking no action or of postponing action pending further study; alternatives requiring actions of a significantly different nature which would provide similar benefits with different environmental impacts (e.g., nonstructural alternatives to flood control programs, or mass transit alternatives to highway construction); alternatives related to different designs or details of the proposed action which would present different environmental impacts (e.g., cooling ponds vs. cooling towers for a power plant or alternatives that will significantly conserve energy); alternative measures to provide for compensation of fish and wildlife losses, including the acquisition of land, waters, and interests therein. In each case, the analysis should be sufficiently detailed to reveal the agency's comparative evaluation of the environmental benefits, costs, and risks of the proposed action and each reasonable alternative. Where an existing impact statement already contains such an analysis, its treatment of alternatives may be incorporated provided that such treatment is current and relevant to the precise purpose of the proposed action.

(5) Any probable adverse environmental effects which cannot be avoided [such as water or air pollution, undesirable land use patterns, damage to life systems, urban congestion, threats to health or other consequences adverse to

the environmental goals set out in Section 101(b) of the Act]. This should be a brief section summarizing in one place those effects discussed in paragraph (a)(3) of this section that are adverse and unavoidable under the proposed action. Included for purposes of contrast should be a clear statement of how other avoidable adverse effects discussed in paragraph (a)(2) of this section will be mitigated.

(6) The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity. This section should contain a brief discussion of the extent to which the proposed action involves tradeoffs between short-term environmental gains at the expense of long-term losses, or vice versa, and a discussion of the extent to which the proposed action forecloses future options. In this context short-term and long-term do not refer to any fixed time periods, but should be viewed in terms of the environmentally significant consequent consequences of the proposed action.

(7) Any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented. This requires the agency to identify from its survey unavoidable impacts in paragraph (a)(5) of this section and the extent to which the action irreversibly curtails the range of potential uses of the environment. Agencies should avoid construing the term ‘‘resources’’ to mean only the labor and materials devoted to an action. ‘‘Resources’’ also means the natural and cultural resources committed to loss or destruction by the action.

(8) An indication of what other interests and considerations of Federal policy are thought to offset the adverse environmental effects of the proposed action identified pursuant to paragraphs (a) and (5) of this section. The statement should also indicate the extent to which these countervailing benefits could be realized by following reasonable alternatives to the proposed action [as identified in paragraph (a)(4) of this section] that would avoid some or all of the adverse environmental effects. In this connection, agencies that prepare cost-benefit analyses of proposed actions should attach such analysis, or summaries thereof, to the environmental impact statement, and should carefully indicate the extent to which environmental costs have not been reflected in such analyses.

(b) In developing the above points agencies should make every effort to convey the required information succinctly in a form easily understood, both by members of the public and by public decision-makers, giving attention to the substance of the information conveyed rather than to the particular form, or length, or detail of the statement. Each of the above points, for example, need not always occupy a distinct section of the statement if it is otherwise adequately covered in discussing the impact of the proposed action and its alternatives—which items should normally be the focus of the statement. Draft statements should indicate at appropriate points in the text any underlying studies, reports, and other information obtained and considered by the agency in preparing the statement including any cost-benefit analyses prepared by the agency, and reports of consulting agencies under the Fish and Wildlife Coordination Act, 16 U.S.C. 661 et seq., and the National Historic Preservation Act of 1966, 16 U.S.C. 470 et seq., where such consultation has taken place. In the case of documents not likely to be easily accessible (such as internal studies or reports), the agency should indicate how such information may be obtained. If such information is attached to the statement, care should be taken to ensure that the statement remains an essentially self-contained instrument, capable of being understood by the reader without the need for undue cross reference.

(c) Each environmental statement should be prepared in accordance with the precept in section 102(2)(A) of the Act that all agencies of the Federal Government "utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and decisionmaking which may have an impact on man's environment." Agencies should attempt to have relevant disciplines represented on their own staff; where this is not feasible they should make appropriate use of relevant Federal, State, and local agencies or the professional services of universities and outside consultants. The interdisciplinary approach should not be limited to the preparation of the environmental impact statement, but should also be used in the early planning stages of the proposed action. Early application of such an approach should help assure a systematic evaluation of reasonable alternative courses of action and their potential social, economic, and environmental consequences.

(d) Appendix I prescribes the form of the summary sheet which should accompany each draft and final environmental statement.

Selection and Analysis of Alternatives

The selection and analysis of alternatives is a very important element of all planning processes and the impact analysis process. It is important to make sure that the alternatives that are studied are reasonable. This means that the group of alternatives that will be considered is not picked so as to make a favored alternative look good. This is important and suggests that the "preferred" alternative not be identified as proposed in the regulation. It is also important that alternatives are discrete, which means that each alternative can on its own fulfill the objective of the project or plan. The analysis of the "null" or no-action alternative is also important from a policy point of view to show the value of the project or plan. Finally, it is important to identify the specific criteria, such as cost or environmental impact, by which each alternative will be analyzed. The proposed alternatives and the criteria for their analysis are important elements of the early public participation process.

Here is what the federal Regulations say about alternatives (ref. 9, p. 372):

Sec. 1502.14 Alternatives Including the Proposed Action

This section is the heart of the environmental impact statement. Based on the information and analysis presented in the sections on the Affected Environment (Sec. 1502.15) and the Environmental Consequences (Sec. 1502.16), it should present the environmental impacts of the proposal and the alternatives in comparative form, thus sharply defining the issues and providing a clear basis for choice among options by the decision maker and the public. In this section agencies shall:

(a) Rigorously explore and objectively evaluate all reasonable alternatives, and for alternatives which were eliminated from detailed study, briefly discuss the reasons for their having been eliminated.

(b) Devote substantial treatment to each alternative considered in detail including the proposed action so that reviewers may evaluate their comparative merits.

(c) Include reasonable alternatives not within the jurisdiction of the lead agency.

(d) Include the alternative of no action.

(e) Identify the agency's preferred alternative or alternatives, if one or more exists, in the draft statement and identify such alternative in the final statement unless another law prohibits the expression of such a preference.

(f) Include appropriate mitigation measures not already included in the proposed action or alternatives.

Some Methods of Comprehensive Analysis

Here is what the federal regulations say about the comprehensive analysis of environmental consequences (ref. 9, p. 372):

Sec. 1502.16 Environmental Consequences.

This section forms the scientific and analytic basis for the comparisons under Sec. 1502.14. It shall consolidate the discussions of those elements required by sections 102(2)(C)(i), (ii), (iv), and (v) of NEPA which are within the scope of the statement and as much of section 102(2)(C)(iii) as is necessary to support the comparisons. The discussion will include the environmental impacts of the alternatives including the proposed action, any adverse environmental effects which cannot be avoided should the proposal be implemented, the relationship between short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and any irreversible or irretrievable commitments of resources which would be involved in the proposal should it be implemented. This section should not duplicate discussions in Sec. 1502.14. It shall include discussions of:

(a) Direct effects and their significance (Sec. 1508.8).

(b) Indirect effects and their significance (Sec. 1508.8).

(c) Possible conflicts between the proposed action and the objectives of Federal, regional, State, and local (and in the case of a reservation, Indian tribe) land use plans, policies and controls for the area concerned. (See Sec. 1506.2(d).)

(d) The environmental effects of alternatives including the proposed action. The comparisons under Sec. 1502.14 will be based on this discussion.

(e) Energy requirements and conservation potential of various alternatives and mitigation measures.

(f) Natural or depletable resource requirements and conservation potential of various alternatives and mitigation measures.

(g) Urban quality, historic and cultural resources, and the design of the built environment, including the reuse and conservation potential of various alternatives and mitigation measures.

(h) Means to mitigate adverse environmental impacts [if not fully covered under Sec. 1502.14(f)]. 43 FR 55994, Nov. 29, 1978; 44 FR 873, Jan. 3, 1979]

Various methods and techniques have been devised to assist in making a comprehensive impact analysis. Each method needs to be adapted to the particular plan, project, or action under consideration to properly reflect the action and assess its impact. It is unlikely that any analysis, no matter how carefully made, will satisfy everyone, but it is important to expose the method or criteria used in the analysis early in the public participation process in order to attain consensus.

The methods used for analysis have certain steps in common:

1. Identification of project actions that may or will have an impact or effect on the environmental categories or factors such as water, land, air, ecology, and human settlements and socioeconomic and related subcategories. Another category grouping might be physical/chemical, ecological, aesthetic, social, with subcategories under each (as shown in Figures 2-6 and 2-7).
2. Selection of parameters, criteria, or standards within each subcategory that will measure the quality of the category.
3. Measurement and interpretation of the significance of the parameters and effect on each of the categories.

These are discussed further below.

The U.S. Department of Housing and Urban Development (HUD) developed guidelines to assist urban areas and cities in assessing the environmental impacts of housing and urban development actions. Its broad point of view recognizes the social as well as the physical components for good environmental quality, in addition to the subcategories under each. See Figure 2-6.

Leopold et al. prepared a circular[11] to help determine "the probable impact of the proposed action on the environment," which can also serve as a guide and basis for preparation of the environmental impact statement called for under Section 102(2)(C) of NEPA. A generalized matrix is included that calls for value judgments* (numerical 1–10) to evaluate the effects on the environment of the proposed action, including their magnitude and importance. The authors recognize that the matrix may not cover all situations but is nevertheless quite extensive. Those effects that are believed to be significant (cause death or serious harm or have a substantial probability of causing death or

* Value judgments: evaluation of scientific knowledge by an expert and the value society places on a factor or action.

Social

Services
- Education facilities
- Employment
- Commercial facilities
- Health care/social services
- Liquid waste disposal
- Solid waste disposal
- Water supply
- Storm-water drainage
- Police
- Fire
- Recreation
- Transportation
- Cultural facilities

Safety
- Structures
- Materials
- Site hazards
- Circulation conflicts
- Road safety and design

Physiological well-being
- Noise
- Vibration
- Odor
- Light
- Temperature
- Disease

Sense of community
- Structural organization
- Homogeneity and diversity
- Physical stock and facilities

Psychological well-being
- Physical threat
- Crowding
- Nuisance

Historic value
- Historic structures
- Historic sites and districts

Visual quality
- Visual content
- Formal coherence
- Apparent access

Physical

Geology
- Unique features
- Resource value
- Slope stability/rockfall
- Foundation stability
- Depth of impermeable layers
- Subsidence
- Weathering/chemical release
- Tectonic activity/vulcanism

Soils
- Slope stability
- Foundation support
- Shrink-swell
- Frost susceptibility
- Liquefaction
- Erodibility
- Permeability

Special features
- Sanitary landfill
- Wetlands
- Coastal zones/shorelines
- Mine dumps/spoil areas

Water
- Hydrologic balance
- Aquifer yield
- Groundwater recharge
- Groundwater flow direction
- Depth to water table
- Drainage/channel form
- Sedimentation
- Impoundment leakage and slope failure
- Flooding
- Water quality

Biota
- Plant and animal special lists
- Vegetative community types
- Diversity
- Productivity
- Nutrient cycling

Climate and air
- Macroclimate hazards
- Forest and range fires
- Heat balance
- Wind alteration
- Humidity and precipitation
- Generation and dispersion of contaminants
- Shadow effects

Energy
- Energy requirements
- Conservation measures
- Environmental significance

Figure 2-6 Principal components of environment. (*Source:* S. J. Bellomo, "Environmental Assessment Guidelines for HUD: Interim Summary," *J. Urban Plan. Dev. Div.*, ASCE, May 1978, pp. 21–36.)

serious harm) or have a large magnitude and importance are then identified for comprehensive discussion in the statement.

The matrix lists 100 proposed actions horizontally that may cause environmental impact and 88 environmental characteristics and conditions or categories vertically for a total of 8800 possible interactions. The matrix would

Physical/Chemical

Water
- Biochemical oxygen demand
- Groundwater flow
- Dissolved oxygen
- Fecal coliforms
- Inorganic carbon
- Inorganic nitrogen
- Inorganic phosphate
- Heavy metals
- Pesticides
- Petrochemicals
- pH
- Stream flow
- Temperature
- Total dissolved solids
- Toxic substances
- Turbidity

Noise
- Intensity
- Duration
- Frequency

Land
- Soil erosion
- Floodplain usage
- Buffer zones
- Soil suitability for use
- Compatibility of land uses
- Solid waste disposal

Air
- Carbon monoxide
- Hydrocarbons
- Nitrogen oxides
- Particulate matter
- Photochemical oxidants
- Sulfur oxides
- Methane
- Hydrogen and organic sulfides
- Other

Ecological

Species and populations
- Game and nongame animals
- Natural vegetation
- Managed vegetation
- Resident and migratory birds
- Sports and commercial fisheries
- Pest species

Habitats and Communities
- Species diversity
- Rare and endangered species
- Food chain index

Ecosystems
- Productivity
- Biogeochemical cycling
- Energy flow

Aesthetic

Land
- Geologic surface material
- Relief and topography

Air
- Odor
- Visual
- Sounds

Water
- Flow
- Clarity
- Interface land and water
- Floating materials

Biota
- Animals—wild and domestic
- Vegetation type
- Vegetation diversity

Man-made objects
- Man-made objects
- Consonance with environment

Composition
- Composite effect
- Unique composition
- Mood atmosphere

Figure 2-7 Assessment parameters. (*Source: Environmental Assessments of Effective Water Quality Management and Planning,* U.S. Environmental Protection Agency, Washington, DC, April 1972, p. 21; as cited in ref. 11, pp. 22–23.)

Social

Individual environmental interests	*Individual well-being*
Educational/scientific	Physiological health
Cultural	Psychological health
Historical	Safety
Leisure/recreation	Hygienic
Social Interactions	*Community well-being*
Political	Community well-being
Socialization	
Religious	
Family	
Economic	

Figure 2-7 (*Continued*)

show the broad concerns considered and reduce discussion primarily to those effects determined to be significant and to those repeatedly affected.

Another example[12] to ensure consideration of potential impacts lists the needed skills and the broad categories that might be affected:

land Geography, geology, soils, geomorphology, land resources economics;
air Meteorology, bioclimatology;
water hydrology, limnology;
plant Botany, forestry, microbiology;
animal zoology, wildlife; and
humanan anthropology, sociology, medicine, economics, geography.

Having selected the broad areas affected, the next step is an in-depth analysis of those areas.

Another procedure for the preparation of an environmental impact assessment categorizes environmental attributes (parameters or variables) under physical/chemical, ecological, aesthetic, and social, as shown in Figure 2-7.[13] The more significant or critical parameters or variables affected by the proposed actions or activities are selected for further study to identify significant activities and then measure the effects (primary and indirect) of the activities of humans on themselves and on the environment (and the environment on humans). The effects of the actions or activities are evaluated as positive or negative (work sheets are useful for this purpose) and summarized as in Figure 2-8; the results are weighed and the total effects noted as none, moderate, or significant. Tables 2-2 and 2-3 can be helpful in this regard. Evaluation and interpretation of the data assembled, including methods to mitigate adverse effects, can then assist in making the environmental impact assessment and in preparing the environmental impact statement, if found necessary.

Since the goal is to measure the impact of the project being studied on the environmental attributes, a great deal of expert professional judgment is

Category		ATTRIBUTE NUMBER	Attribute	*Net Positive Impact +	Net Negative Impacts X
Air		1	Diffusion factor		
		2	Particulates		
		3	Sulphur oxides		
		4	Hydrocarbons		
		5	Nitrogen oxide		
		6	Carbon monoxide		
		7	Photochemical oxidants		
		8	Hazardous toxicants		
		9	Odor		
Water		10	Aquifer safe yield		
		11	Flow variations		
		12	Oil		
		13	Radioactivity		
		14	Suspended solids		
		15	Thermal pollution		
		16	Acid and alkali		
		17	Biochemical oxygen demand		
		18	Dissolved oxygen (DO)		
		19	Dissolved solids		
		20	Nutrients		
		21	Toxic compounds		
		22	Aquatic life		
		23	Fecal coliform		
Land		24	Erosion		
		25	Natural hazard		
		26	Land use patterns		
Ecology		27	Large animals (wild and domestic)		
		28	Predatory birds		
		29	Small game		
		30	Fish, shell fish, and water fowl		
		31	Field crops		
		32	Threatened species		
		33	Natural land vegetation		
		34	Aquatic plants		
Sound		35	Physiological effects		
		36	Psychological effects		
		37	Communication effects		
		38	Performance effects		
		39	Social behavior effects		
Socioeconomic	Human	40	Life styles		
		41	Psychological needs		
		42	Physiological systems		
		43	Community needs		
	Economic	44	Regional economic stability		
		45	Public sector revenue		
		46	Per capita consumption		

☐ No Significant Impact

▨ Moderate Impact

▩ Significant Impact

Project Name ____________________

Project Number ____________________

Alternative ____________________

***Positive impacts are shown above the attribute number and negative impacts below.**

Figure 2-8 Summary of impacts. (*Source: Environmental Quality Handbook for Environmental Impact Analysis,* Department of the Army, Superintendent of Documents, U.S. Government Printing Office, Washington, DC, April 1975, p. 46.)

TABLE 2-2 Air Quality Parameters

Pollutant	High	Moderate	Poor	Federal Air Quality Standards	Notes
Particulates[a] (Mg/m^3)	0 to 80	80 to 230	230 to 500+	75	Visibility affected as low as 25 $\mu g/m^3$; human health effects begin at about 200 $\mu g/m^3$; condensation nuclei less desirable in concentrations of less than 25 $\mu g/m^3$; all based on 24-hr average annual concentration.
Sulfur oxides[b] (ppm)	0 to 0.10	0.10 to 0.17	0.17 to 0.25+	0.03	The minimum SO_2 concentration for vegetation damage is 0.03 ppm; less than 0.03 ppm can denote a safe environment; increased mortality observed at 0.2 ppm SO_2.
Hydrocarbons[c] (ppm)	0 to 0.19	0.19 to 0.27	0.27 to 0.4+	0.24	Conditions for smog development approached at 0.15 to 0.25 ppm.
Nitrogen oxides[d] (ppm)	0 to 0.25	0.025 to 0.075	0.075 to 0.20+	0.05	Nitrogen dioxide is about four times more toxic than nitric oxide. Nitrogen dioxide below 0.05 ppm does not pose a health problem, but above that level begins to act as a toxic agent.

TABLE 2-2 (*Continued*)

Pollutant	High	Moderate	Poor	Federal Air Quality Standards	Notes
Carbon monoxide[e] (ppm)	—	—	—	9	Concentrations of 10 to 15 ppm for 8 hr or more can cause adverse health effects; 30 ppm can cause physiologic stress in patients with heart disease; 8 to 14 ppm correlated with increased fatality in hospitalized heart patients.
Photochemical oxidants[f] (ppm) (Ozone)	—	—	—	0.12	Data on animal and human effects inadequate. Leaf injury in sensitive species after 4-hr exposure to 0.0005 ppm. Polynmers and rubber adversely affected. Smog develops at concentrations of 0.15 to 0.25 ppm.
Asbestos	0.0	None visible	Visible	—	Long-term exposure to high concentrations of asbestos dust can cause asbestosis.
Beryllium (mg/m^3)	0.01	0.10	Greater than 0.10	—	Above 0.01 $\mu g/m^3$ produces disease; at 0.10 or above larger number develop disease; should not exceed 0.01 $\mu g/m^3$ over 30-day period.

Mercury (mg/m^3)	0.0	0.1	Greater than 1.0		Mercury should not exceed 1.0 $\mu g/m^3$ over 30-day averaging period.
Odor	No odor to odor threshold	Odor threshold to slight odor	Slight odor to strong odor	—	Odor threshold can be detected by 5 to 10 percent of panelists. Moderate odor can be detected by about 40 percent; strong odor by 100 percent.

Source: Information abstracted from *Environmental Quality Handbook for Environmental Impact Analysis,* Department of the Army, April 1975, pp. A-1 to A-21. Supt. of Documents, GPO, Washington, D.C.

[a] Based on 24-hr annual geometric mean.

[b] Based on 24-hr annual arithmetic mean.

[c] Based on 3-hr average annual concentration 0600 to 0900.

[d] Based on average annual concentration.

[e] Based on maximum 8-hr concentration not to be exceeded more than once a year.

Note: Lead average over 3-month period not to exceed 1.5 $\mu g/m^3$. See also Federal Air Quality Standards, Chapter 6.

TABLE 2-3 Selected Attributes (Variables) and Environmental Impact Categories—Water Quality

		Environmental Impact Category[a]				
Selected Attributes	Observed Condition	1	2	3	4	5
Physical						
Aquifer safe yield[b]	Changes occurring in physical attributes of aquifer (porosity, permeability, transmissibility, storage coefficient, etc.)	No change	No change	Slight change	Significant change	Extensive change
Flow variation[c]	Flow variation attributed to activities: Q_{max}/Q_{min}	None	None	Slight	Significant	Extensive
Oil[d]	Visible silvery sheen on surface, oily taste and odor to water and/or to fish and edible invertebrates, coating of banks and bottom or tainting of attached associated biota	None	None	Slight	Significant	Extensive
Radioactivity[d]	Measured radiation limit 10^{-7} μci/ml	Equal to or less	Equal to or less	Exceed limit	Exceed limit	Exceed limit
Suspended solids[c]	1. Sample observed in a glass bottle	Clear	Clear	Fairly clear	Slightly turbid	Turbid
	2. Turbidity in Jackson Turbidity Units	3 or less	10	40	60	140
	3. Suspended solids mg/1	4 or less	10	15	20	35
Thermal discharge[c]	Magnitude of departure from natural condition	0	2	4	6	10

Chemical						
Acid and alkali[d]	Departure from natural condition, pH units	0	1	2	3	4
BOD[d]	mg/l	1	2	3	5	10
DO[c]	percent saturation	100	85	75	60	Low
Dissolved solids[d]	mg/l	500 or less	1000	2000	5000	High
Nutrients[c]	Total phosporus, mg/l	0.02 or less	0.05	0.10	0.20	Large
Toxic compounds[d]	Concentration, mg/l	Not detected	Traces	Small	Large	Large
Biological						
Fecal coliforms[d]	Number per 100 ml	50 or below	5000	20,000	250,000	Large
Aquatic life[c]	Green algae	Scarce	Moderate quantities in shallows	Plentiful in shallows	Abundant	Abundant
	Gray algae	Scarce	Scarce	Scarce	Present	Plentiful
	Delicate fish; trout, grayling	May be plentiful	Plentiful	Probably absent	Scarce	Absent
	Coarse fish; chub, dace, carp, roach	May be present	Plentiful	Plentiful	Scarce	Absent
	Mayfly naiad, stonefly nymph	May be plentiful	Plentiful	Scarce	Absent	Absent
	Bloodworm, sludge worm, midge larvae, rat-tailed maggot, sewage fly larvae and pupa	May be absent	Scarce	May be present	Plentiful	Abundant

TABLE 2-3 (*Continued*)

Source: Environmental quality handbook for Environmental Impact Analysis, Headquarters, Department of the Army, April 1975, Supt. of Documents, GPO, Washington, D.C.

[a] *Environmental Impact Category.* Category 1 indicates most desirable condition; Category 5 indicates an extensive adverse condition. Because all attributes are related to environmental quality between 0 and 1, it is possible to compare the different attributes and five categories on a common base. Each category is equivalent to approximately 20 percent of the overall environmental quality. In the physical sense, water quality for five categories will be very clean, clean, fairly clean, doubtful and bad. Environmental impact may be adverse or favorable. Adverse impact will deteriorate the environmental quality while favorable impact will improve the quality. Proper signs and weights must be used to achieve overall effects.

[b] Applies to groundwater systems only.

[c] Applies to surface water systems only.

[d] Applies to both the groundwater and surface water.

EPA stream water quality indicators are: fecal coliform (200 colonies per 100 ml), dissolved oxygen (5 mg/l), total phosphorus (0.1 mg/l), total mercury (2 μg/ml), total lead (50 μg/ml), and total cadmium (4 to 10 μg/ml).

needed to identify, evaluate, and weigh the significance of the information assembled.

In projects such as a new highway, industry, or housing development, the possible effects and their measurement must be considered first in the planning and design phase and then during the construction and operational phases. The same tabulations, checklists, and matrices should be made for the alternatives. In all cases, a combination of appropriate talents is needed to ensure adequate consideration of all factors that might be impacted, including mitigation of adverse effects and promotion of beneficial effects.

The reader will find it useful to refer to pertinent chapters in this text to help identify and determine the significance of a particular parameter, criteria, or standard. For example, see Chapter 1 for health effects, Chapter 3 for drinking water standards and source protection, Chapter 4 for wastewater treatment and surface and groundwater pollution prevention, Chapter 5 for solid waste management, Chapter 6 for air pollution and noise, and the other chapters as appropriate. Geological Survey Circular 65[11] and the *Environmental Quality Handbook for Environmental Impact Analysis*[13] are also useful in interpreting the significance of information gathered in the environmental analysis.

In addition it is very important to understand that environmental criteria and standards that implement laws and regulation vary significantly with time and place. It is therefore essential that the most up-to-date criteria and standards be used in the planning and impact analysis process. Very frequently there are proposed criteria and standards available that have not yet been adopted. Whether or not to use them is a matter of policy and should be considered in the public participation process.

FRINGE AND RURAL AREA HOUSING DEVELOPMENTS

Growth of Suburbs and Rural Areas

The geographic distribution of the U.S. population since World War II has shifted from cities to suburban areas. Suburban areas are growing faster than central cities. Rural areas are losing population. The size of households has also been changing. The average household in 1960 had 3.29 persons. In 2000 there were 2.59 persons per household.

There is a natural urge within many families to have their own home in the suburbs or in rural areas. Land in the suburbs and rural areas is considered inexpensive and the taxes low. But the cost, if needed, of constructing a private well and sewage disposal system; the lack of adequate fire, police, street cleaning, and refuse collection services; and the future need for constructing new schools and other infrastructure are at first overlooked, as are the increased taxes to provide these services and facilities. Also, whereas the construction cost of community sewage has sometimes been subsidized, the cost of individual on-site septic tank system has not. Certain financing arrangements may be possible for housing group or hamlet alternative systems.

Facilities and Services Needed

Every 1000 new people in a community will require the following, for example:[14]*

1. an additional supply of 100,000 to 200,000 gal of water daily, or 35 to 70 million gal/yr, or 300 individual well-water systems, many equipped with water conditioners;
2. the collection and disposal of 3000 to 4000 lb of solid wastes daily, or 548 to 730 tons/yr;
3. recreational facilities to serve more people with more leisure time;
4. sewage treatment works to handle 100,000 to 150,000 gal/day (gpd), or 35 to 53 million gal/yr containing 170 lb of organic matter (biochemical oxygen demand) per day or 62,000 lb/yr, and 70,000 lb of dry sewage solids/yr or 300 additional septic tanks and appurtenant subsurface disposal facilities;
5. expenditure to control the sources of air pollution and offset the physical damage caused by lack of air pollution control;
6. 4.8 new elementary school rooms, 3.6 new high school rooms, transportation facilities, and additional teachers;
7. 10.0 or more acres of land for schools, parks, and play areas;
8. 1.8 policemen and 1.5 firemen as well as new public service employees in public works, welfare, recreation, health, and administration, plus public buildings;
9. more than a mile of new streets;
10. more streets to clean, free of snow and ice, and drain;
11. two to four additional hospital beds, three nursing home beds, and appurtenant facilities;
12. 1000 new library books, plus library expansion;
13. more automobiles, retail stores, services, commercial and industrial areas, county or state parks, and other private enterprises; and
14. 40 more people eligible for Medicaid, plus welfare costs.

To obtain the fiscal impact of new development, it is necessary to determine the total cost of providing the expected or required services, including capital

* Adapted and updated from ref. 14. This is intended to be illustrative and not necessarily typical.

expenditures,* operation and maintenance, replacement costs, and the total revenues from the development.† The types of services are listed above; their costs can be estimated based on local conditions. Sources of revenue include property taxes, school taxes, fire protection taxes, sales taxes, income taxes, property transfer and other legal fees, business taxes, transient occupancy taxes, interest earnings, permit or license fees, and user charges for recreation, health, water, seweage, solid waste, and other property services. Included also are federal and state allocations and grants, which can be quite substantial. The total revenue can therefore also be estimated. An analysis of cost of services versus revenues, if carefully done, before development takes place, will provide important information on the fiscal impact of a new development on the community.[15] However, other factors must be taken into consideration, such as compatibility with the community comprehensive plan and the environmental impact statement, including the favorable and unfavorable aspects and alternatives as discussed earlier in this chapter, and with social, governmental, and other factors of local importance.

Generally, it has been acknowledged that the average home does not yield enough in property taxes to pay for the municipal services provided and demanded by the people unless supplemented by user charges and other revenues. Encouragement of industry to locate in selected areas in a town can relieve the tax burden. Desirable types of industries are those that will not cause air, noise, or water pollution or make special demands and that will have a high assessed valuation.

Industry also contributes to the economic growth of an area through increased personal income, bank deposits, and retail sales by attracting professional, skilled, and semiskilled manpower. This means more households, people including school children, automobiles, retail stores, restaurants, hotels, motels, malls, and hence jobs.

Many communities desire to maintain the character of the community and not overtax the facilities and services. Some have adopted a policy of controlled or limited growth. This is accomplished by the following‡:

1. zoning regulation—urban growth, large-lot zoning, open space preservation, and cluster development;
2. limiting growth to the capacity of the water supply;

*New developments may be assessed by impact fees for needed capital expenditures, such as for water, sewer, and other services, in proportion to the benefits received.

†The American Farmland Trust (1717 Massachusetts Ave., N.W., Washington, DC 20036) may assist in making a cost analysis of a proposed new development for local officials.

‡The California Supreme Court upheld a law that prohibits construction of new homes in the San Francisco Bay area community of Livermore until educational, sewage disposal, and water supply facilities are built. (“California Court Approves Laws Limiting Building,” *New York Times,* December 16, 1976; San Francisco, December 18, Associated Press.)

3. limiting growth to the capacity of sewage facilities;
4. limiting growth to the capacity of the educational system;
5. Extra charges (impact fees) to developers for schools, parks, water supply, sewage, streets;
6. preservation of agricultural land; and
7. encouraging development of vacant land that is served by streets, water, sewer, and other public services and using land immediately adjacent to existing developed areas with services.

Causes and Prevention of Haphazard Development

Fringe and rural area sanitation is an aspect of healthy living that, like the housing problem in cities, requires the combined talents of many private as well as official agencies and individuals to prevent unsanitary conditions and promote good health and a pleasing environment. Those who can contribute to this goal are the developers and builders, consulting engineers and land planners, health department and environmental protection agency, environmental engineers and sanitarians, local officials, private lending institutions, state agencies, planning and zoning boards, legislators and attorneys, the press, an informed home-buying public, and environmental, scientific, and professional organizations.

Where comprehensive planning and land-use controls are lacking, developments and subdivisions are in many cases poorly planned and without utilities, drainage, or streets worthy of the name. Some lots may be under water or over a shallow water table; on rock shelves, steep slopes, or tight clay soil; or poorly drained. Overflowing septic tank systems and polluted wells become commonplace. Many people "get stuck," and when they seek legal redress, they are confronted with a maxim of English and American law—*caveat emptor,* "let the purchaser beware"—that is, they should examine the article they are buying and act on their own judgment and at their own risk. An official agency having specific legal responsibilities operating in the public interest cannot adopt such a principle.

The premature development of subdivisions causes an accumulation of tax arrears on vacant lots, thereby shifting the financial burden for governmental expenditures onto other properties.[16] The owners of other properties are therefore forced to make up the tax money lost by paying higher taxes or lose their home or place of business, even though they had no part in the land speculation and could not have benefited had the venture been successful.

If the cost and liabilities for subdivision are borne by those who engage in subdivision for profit, rather than by the general public, bona fide developers are aided and irresponsible, unscrupulous developers are discouraged. It is therefore proper that reasonable controls be invoked to regulate land subdivision for the general health and welfare of the people.

The generally accepted methods of preventing subdivision problems and obtaining orderly community growth are education, comprehensive land-use planning, and effective regulation. But laws must be understood and enforceable; they must be reasonable and fair to the developer and investor, to the purchasers of homes, and to the local community. It must be recognized that the owner of land for sale is primarily desirous of subdividing for profit. The banks and mortgage insurers are concerned that dwellings in a subdivision and surrounding areas maintain a high value so as to guarantee a continuing satisfactory return on their investments. The homeowner wants to live and bring up his or her children in a pleasant, healthy environment. The community is interested in seeing that a subdivision does not turn out to be a liability.

Many problems can be prevented or made less difficult to solve if the conditions surrounding the problem are more fully understood. Giving publicity to existing laws, including explanation of their purposes and how to comply with them, is one approach. Attorneys, lending institutions, realtors, builders and subdividers, local officials and service clubs, soil conservation and county extension services, land planners and consulting engineers, environmental organizations, the home-buying public, and the local press are some of the important groups that can make a subdivision law more effective. The local health department, conservation department, and planning agency, through consultation, advice, talks, leaflets, and letters and by personal contact, can explain the intent of the law and expedite compliance with it. Some excellent bulletins (see the Bibliography at the end of this chapter) are available to the consulting engineer, land planner, builder, and subdivider for their information and guidance.

When considering the many educational measures that can be applied to control or solve subdivision problems, one must not forget the opportunities available to the administrative and enforcing agencies to prevent the problems in the first place. Immediate notification of the subdivider at the first sign of activity, followed by strict surveillance, can prevent many problems from getting out of hand. Informal conferences with interested parties, explanation of the advantages of filing proper plans for public sewer and water supply and other facilities, and the offer of advice to help solve problems will usually convince the reasonable individual there is little to lose and much to gain by complying with the law. In some instances, a hearing before the proper board or commissioner will yield the desired result; in rare instances, legal action is necessary.

A city, village, or town may also adopt a local sewage and waste ordinance as part of its sanitary code, building code, plumbing code, zoning, or planning ordinance. This is done in cooperation with planning and other agencies having jurisdiction. The individual planning to put in an on-site system is required to make application to the designated department for a permit to build, at which time he or she also makes application to the health department for approval of a private sewage disposal or treatment system based on soil percolation tests, soils maps, and a recommended design. The health department, registered architect, or professional engineer presents design recommendations and then inspects during construction. A certificate of compliance is issued by the health department when the system is properly installed. No dwelling or structure is permitted to be occupied or any facility or appurtenance used until the issuance of the health department certification. Potential subdivisions are then brought to the attention of the health department and control measures instituted before building starts.

An educational and persuasive tool is reference to legal decisions and opinions to help convince the skeptic. Numerous decisions have been handed down affirming the right of local agencies to control subdivision development, require engineering plans of proposed water supply and sewerage, and, in some instances, require installation of sewers rather than septic tank systems.[17]

Health and environmental protection department realty subdivision laws may be enacted on a state level and enforced on both a state and local level or the laws may be enacted and enforced on a local level, where a competent engineering division is provided by the local health department. The former procedure may be preferred when political and administrative problems are anticipated. A county land-use policy reinforced by approved land-use plans and state environmental permit and financial assistance policies can be most helpful. The best solution to this complex problem is a high level of harmony among decisions in all levels of government, as identified in Figure 2-2.

Sample laws, regulations, and guidelines are available from many state and local health, environmental, and planning agencies.

Cooperative Effort Needed

Developers and builders can simplify their sanitation problems by selecting vacant land that is within or contiguous to communities already having water and sewer services. This makes possible the economical extension of these utilities: smaller lots, if desired, than would be required with individual wells and septic tank leaching systems and, hence, more lots and a more desirable development. If the extension of water or sewer lines is not possible, then the developer or builder can in many cases construct a water system and/or sewers and treatment plant with the cooperation of local officials. In such cases maintenance and operation of the systems should be guaranteed. It is also possible to construct these facilities on a planned step-by-step construction basis so as to reduce or spread out the financial burden of the initial plant cost.

Consulting engineers are sometimes reluctant to take a small subdivision job involving the design of roads, drainage, water supply, and sewage systems. The time and effort needed to work out satisfactory plans may appear to be too great for the fee that can be reasonably charged. Actually, this is where the professional engineers can perform a real public service by wise advice and sound design. Here is an opportunity for the application of imagination and initiative by not only engineers but also land planners, builders and contractors, investors, and equipment manufacturers in designing and producing less expensive and more efficient sanitary devices as well as a more desirable living environment for population groups involving 50 to 1000 or more persons.

Local officials can encourage and direct proper development by sympathetic cooperation, by assisting in the formation of water and sewer districts, and through the enforcement of planning and zoning ordinances. Enlightened public officials are no more desirous of encouraging unsanitary and haphazard construction than the health department. The submergence of sectional jealousies, the formation of drainage area sanitary districts crossing town, city, or village boundary lines, and annexation, if necessary, are additional aides. In this connection, county and regional planning offer a great deal of promise. Policy agreements regarding certain services can be made among contiguous cities, villages, and townships through a county planning commission or similar agency. Development of certain lands could be encouraged by mutual understanding to extend more complete fire and police protection, sewers and water mains, snow plowing service, and refuse collection only to areas designated for development. The county real estate division can cooperate by encouraging the purchase of vacant tax-delinquent land in these delineated areas. Developers and builders would be required to do their part by agreeing to certain deed restrictions, improvements, and zoning and also to share in the cost of constructing water and sewer lines. Participating communities could properly require larger lots outside of areas without water and sewer lines and agree to the review and approval of all subdivision plots by the coordinating agency. Prior to making this determination, the local soil conservation service, health department, and planning board should give a joint preliminary opinion on the suitability of the soil and geology for on-lot subsurface sewage disposal and well-water supply. A consultant can also be retained to make this determination.

Involved federal agencies and lending institutions are obligated to comply with state and local sanitary code regulations. They usually withhold payments where sanitary facilities do not meet existing legal requirements. Attorneys, realtors, and mortgage and title investigators can protect their clients' interests and help make sounder investments if the adequacy of existing or proposed drainage, water supply, and sewage disposal facilities at a property are also investigated before investment is recommended.

County, city, and state health or environmental agencies and their staffs have the responsibility to enforce the state and local public health and environmental laws. They can give assistance and guidance to the developer, builder, and engineer and help in interpreting the intent and complying with the laws. Consultation with the health and/or environmental agency having jurisdiction concerning the supply of water and disposal of sewage will expedite the submission and approval of satisfactory subdivision plans. Health department personnel are often called on to talk before service clubs, professional groups, and community associations. This offers opportunities to explain the protection provided by existing laws and the services rendered by the health department to promote a better way of life through a healthier environment.

Subdivision Planning

Haphazard development can be prevented by comprehensive local and regional planning if local zoning and gowth management plans are hamonized with county and state transportation and environmental plans as well as permit and financial assistance. In the absence of such control, public and private acquisition of large potential sites and their preparation for multipurpose uses, including residential development, have merit. Raw land would be planned for residential, recreational, open-space, commercial, industrial, agricultural, or supporting uses. This would then be followed by development and improvement of roads, water supply, drainage, sewers, and other utilities, including wastewater and solid waste disposal facilities. The land would then be sold to private enterprise for development as planned. Such planning should also anticipate, where appropriate, densities that will support local transit and light-rail commuter systems.

In the planning of a housing development, careful consideration should be given to the site selection and planning factors discussed earlier in this chapter. Any deleterious or hazardous site conditions must be identified and ameliorated prior to development. An environmental impact analysis is usually needed. The subdivision is dependent on the region and its central community for employment and cultural needs, and the central community is dependent on the surrounding development for human resources and economic survival. Controlled environmental conditions in a newly developed subdivision can only be ensured if the neighboring inhabitants live under equally desirable conditions. No matter how remote a new subdivision may be from the urban centers, it is still an extension of the existing environment and is affected by it. The subdivision, in turn, influences the surrounding area environment by the character of its growth and the standards of its facilities and services. This interdependence must always be kept in mind.

Planning, subdivision, growth management, and zoning regulations are based on the rights of government to exercise its police power to control the private uses of land for the protection of the general health, safety, and welfare. A planning board can be empowered to prepare a comprehensive plan to guide the physical development of land and public services within a delineated area. In carrying out this function, the planning board may prepare an official map; make investigations, sketches, and reports relating to planning and community development; review and make recommendations for approval of plans of proposed subdivisions and other development; advise concerning capital budget and long-term capital improvement programs; define problems; and conduct research and analyses.

Enforcement tools available to the planning board are subdivision regulation, the zoning code, and support by state agencies in connection with improvement programs, permits, and financial assistance relating to parks, major highways, sewers and water supply, including treatment plants, and desirable type of land development and redevelopment.

Land planning and growth management are specialized activities. Frequently, the importance of comprehensive design is ignored by the developer or its significance is not realized, yet nothing could be more fundamental in the subdivision of land. A future community being created can be a good place in which to live and work and in which to invest in a home or it can be an undesirable subdivision right from the start. The planning board should determine if the land is suitable for housing, business, or industry or should be retained as farm land or open space. It would be misleading, for example, to classify land as ‘‘residential’’ on a land-use plan where no sewers exist or are proposed and where the soil is impermeable clay or existing traffic congestion would be made worse by additional traffic flow. The demand and need for the intended use should govern whether immediate or future development is indicated. Then the subdivision designer should fit the proposed project in with the community zoning, major streets and parkways, recreational areas, churches, schools, shopping centers, and so forth, and design the interior elements of the subdivision accordingly. Due regard must be given to topography, roads, lot sizes and shapes, water supply, sewage disposal, gas and electricity, drainage, recreational areas, schools, easements for utilities, trees, and landscaping as well as the environmental impact of the proposed land use.

Figure 2-9 illustrates the different ways in which a plot of land may be subdivided. An increased number of lots and a reduced cost of public improvements per lot are common results of good design. This of course is advantageous to the developer, the homeowner, and the community.

The legal steps and authority for the formation of a planning board are usually given in state laws. Ordinances creating local planning boards are obtainable from state planning agencies where established. Subdivision regulations suggested by the planning board should also be available from this source. Any regulations considered for adoption should be adapted to the local conditions.

Design of Water and Sewage Service for Subdivisions

Water and sewage service for a subdivision can be provided in many different ways. The preferred method is the extension of existing water lines and sewers. If the property is not located within the boundaries of an existing service district, the facilities may become available by annexation to the central municipality, through the formation of an improvement district, or through a utility corporation if permitted by the existing laws. Where a county or regional service district or authority exists, it would be the controlling agency. If a public water supply or sewage system is not available, developers can

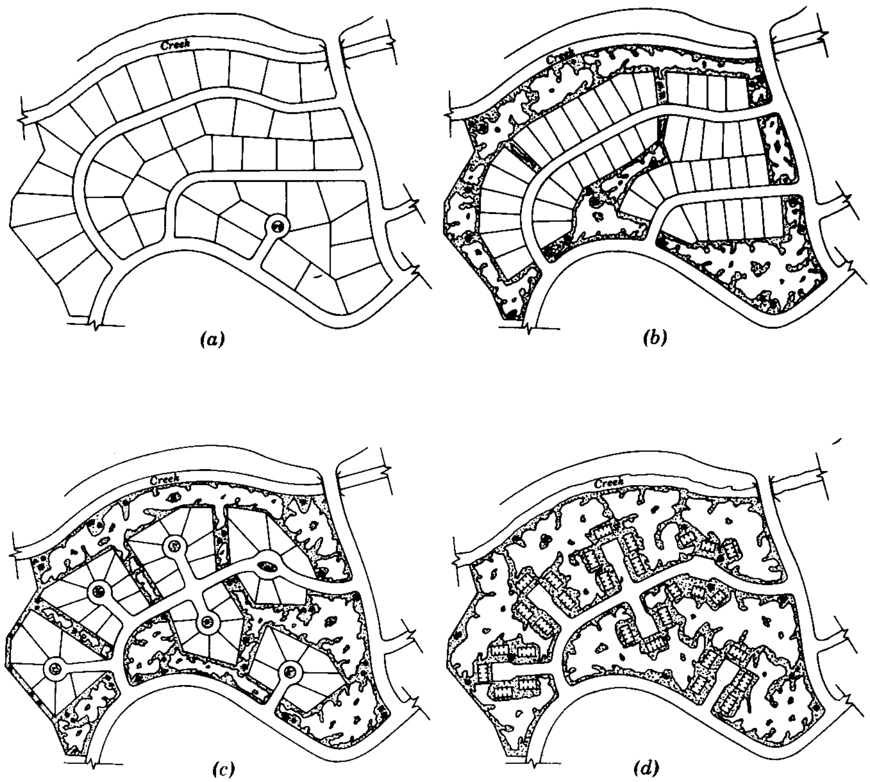

Figure 2-9 Types of subdivision development. (*a*) *Standard subdivision*. The area is completely subdivided into 46 lots. No open space and only a few lots have access to the creek. (*b*) *Density zoning*. Same number of conventional lots but with half the area in open space. (*c*) *True cluster development*. Again 46 lots on 23 acres, but lots are grouped. (*d*) 110 townhouses on same parcel. Over half the land is untouched, and at 4.7 units per acre, this would be rather crowded if these were single-family units. On clear, flat land, quality townhouse developments can run 10 to 14 units per acre with low-cost projects even higher. Various possibilities exist for subdividing this net area of 23 acres. The one chosen will affect the amount of open space regardless of the number of units. (*Source:* G. C. Bestor, "Trends in Residential Development," *Civil Eng.*, ASCE, September 1969. Reproduced by permission of the publisher, ASCE.)

ask the town to establish a district and construct their own facilities, including treatment plants. See Chapters 3 and 4.

Rising federal and state environmental standards for drinking, sewage and stormwater systems together with aging of systems that require preventive maintenance have increased the cost of these systems and consequently the service charges or taxes that support them.

At the same time, the flight to the suburbs has greatly increased the per-capita cost of infrastructure both in the city and in the suburbs. We are now reaching a point where these charges can be expected to consume an increasing share of the household budget. At the same time, the number of connections required to sustain a financially viable system has risen in the past several decades from about 100 to about 1000. This means that a growing number of small systems are no longer financially viable. In view of this, questions of future financial viability, size, ownership, and quality of management of such systems need to be addressed as part of the planning and design of future subdivisions.

The design of small water systems is given in Chapter 3. Experiences in new subdivisions show that peak water demands of 6 to 10 times the average daily consumption rate are not unusual. Lawn-sprinkling demand has made necessary sprinkling controls, metering, or the installation of larger distribution and storage facilities and, in some instances, ground storage and booster stations. As previously stated, every effort should be made to serve a subdivision from an existing public water supply. Such supplies can afford to employ competent personnel and are in the business of supplying water, whereas a subdivider is basically in the business of developing land and does not wish to become involved in operating a public utility.

In general, when it is necessary to develop a central water system to serve the average subdivision, consideration should first be given to a drilled well-water supply. Infiltration galleries or special shallow wells may also be practical sources of water. Such water systems usually require a minimum of supervision and can be developed to produce a known quantity of water of a satisfactory sanitary quality. Simple chlorination treatment will normally provide the desired factor of safety. Test wells and sampling will indicate the most probable dependable yield and the physical, chemical, and bacterial quality of the water. Well logs should be kept.

Where a clean, clear lake supply or stream is available, chlorination and slow sand filtration can provide reliable treatment with daily supervision for the small development. The turbidity of the water to be treated should not exceed 30 nephelometric turbidity units (NTU). Preliminary settling may be indicated in some cases.

Other more elaborate types of treatment plants, such as rapid sand filters, are not recommended for small water systems unless specially trained operating personnel can be assured. Pressure filters have limitations, as explained in Chapter 3. Regulatory approval of plans and specifications is required.

The design of small rapid and slow sand filter and well-water systems is explained and illustrated in Chapter 3.

Many rural areas are remote from population centers and public water supplies and sewers. In such cases, individual well-water and septic tank sewage disposal systems offer the only practical answer for the immediate future. However, to be acceptable, individual sanitary facilities must be carefully designed, constructed, and maintained in accordance with good standards. Where the soil is unsuitable for the disposal of sewage by conventional subsurface means, every effort must be made to prevent the subdivision of land until public sewers, including treatment and drainage if needed, can be provided unless a satisfactory alternate can be agreed upon.

In some situations, public water supply is available, leaving only the problem of sewage disposal. In rarer situations, public sewers are available, making construction of individual wells necessary. Although the sanitary problems are simplified in such cases, there is still need for careful design, construction, and maintenance of the individual facility that needs to be provided.

Where individual on-site wells are proposed for a subdivision, a hydrogeological study, including test wells, may be indicated to ensure the aquifer can supply adequate water for each proposed dwelling well. It may also be desirable to require that a well be drilled on a lot and tested (for yield and microbiological, chemical, and physical quality) before a permit to build is given to demonstrate that the water supply is of satisfactory sanitary quality and is adequate. An adequate supply for a single home is a well having a sustained yield of at least 5 gal/min. In limited situations, a lesser yield may be acceptable, but a special engineered design, including double pumping and storage, is usually required.

When either individual well or septic tank systems are required or when both are required the preparation of a proper subdivision plan makes possible the proper and orderly installation of these facilities on individual lots. When homes are built in accordance with the approved plan, the intent of a subdivision control law is accomplished in the interest of the future homeowners and community. Some health departments have issued practical instructions to design engineers regarding the preparation and submission of plans for realty subdivisions. Such information simplifies the submission of satisfactory plans and also has a salutary educational effect on the design engineer who has not had extensive experience in subdivision planning and design.

Details included on a subdivision plan are a location map, topography, typical soil-boring profile, lot sizes, roads, drainage, and location of soil tests and results; typical lot layouts showing the location of the house, well, sewage disposal system, and critical materials and dimensions; sketches showing drilled well development and protection, pump connection and sanitary seal, depth to water and yield, or a community water system; and sewage disposal units, design, and sizes, including septic tank, distribution box, absorption field, and leaching pit. Construction details of drilled wells, including pump connections and sanitary seals, are given and illustrated in Chapter 3. Septic tank, distribution box, absorption field, and leaching pit details are given and illustrated in Chapter 4.

There is a danger in the preparation of subdivision plans, as in other engineering and architectural plans, to copy details blindly, particularly with computerized design. Such carelessness defeats the purpose of employing a consultant or design engineer and is contrary to professional practice. Subdivision plans involving individual wells, sewage disposal systems, and storm drainage must be adapted to the topography and geological formations existing at the particular property. It is well known that no two properties are exactly alike; each requires careful study and adaptation of general principles and typical details so that a proper engineering plan results. For example, the soil percolation tests and soils information determine the type and size of the required sewage disposal system. The slope of the ground determines the relative locations of the wells and sewage disposal systems on each lot; in most cases, these must be established on the plot plan to prevent further interference. The type of well, required minimum depth of casing, need for cement grouting of the annular space around the outside of the casing, and sealing of the bottom of the casing in solid rock vary with each property. These are just a few considerations to elicit the need for the application of engineering training and experience to perform a proper professional service.

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3 Water Supply

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INTRODUCTION

A primary requisite for good health is an adequate supply of water that is of satisfactory sanitary quality. It is also important that the water be attractive and palatable to induce its use; otherwise, consumers may decide to use water of doubtful quality from a nearby unprotected stream, well, or spring. Where a municipal water supply passes near a property, the owner of the property should be urged to connect to it because such supplies are usually under competent supervision.

When a municipal water supply is not available, the burden of developing a safe water supply rests with the owner of the property. Frequently, private supplies are so developed and operated that full protection against dangerous or objectionable pollution is not afforded. Failure to provide satisfactory water supplies in most instances must be charged either to negligence or ignorance because it generally costs no more to provide a satisfactory installation that will meet good health department standards.

The following definitions are given in the National Drinking Water Regulations as amended through January 14, 2002 (2000 *Code of Federal Regulations,* Title 40, Vol. 19, Part 141):

> *Public water system* means either a community or noncommunity system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least 15 service connections, or regularly serves an average of 25 individuals daily at least 60 days out of the year. Such term includes (1) any collection, treatment, storage, and distribution facilities under the control of the operator of such system and used primarily in connection with such system, and (2) any collection or pretreatment storage

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0-471-41813-7

facilities not under such control which are used primarily in connection with such system.

A *community water system* has at least 15 service connections used by year-round residents, or regularly serves at least 25 year-round residents. These water systems generally serve cities and towns. They may also serve special residential communities, such as mobile home parks and universities, which have their own drinking water supply.

A *noncommunity water system* is a public water system that is not a community water system, and can be either a "transient noncommunity water system" (TWS) or a "non-transient noncommunity water system" (NTNCWS). TWSs typically serve travelers and other transients at locations such as highway rest stops, restaurants, and public parks. The system serves at least 25 people a day for at least 60 days a year, but not the same 25 people. On the other hand, NTNCWSs serve the same 25 persons for at least 6 months per year, but not year round. Some common examples of NTNCWSs are schools and factories (or other workplaces) that have their own supply of drinking water and serve 25 of the same people each day.

In 2000 there were approximately 167,000 public water systems in the United States serving water to a population of nearly 284 million Americans. There were 54,064 community water systems, of which 11,403 were surface water supplies and 42,661 were groundwater supplies. There were 113,769 noncommunity water systems, of which 2733 were surface water supplies and 111,036 were groundwater supplies. Of the community water systems, 45,837 are small systems that serve populations less than 3300; 4458 are medium systems and serve populations between 3300 and 10,000; and 3769 are large systems serving populations over 10,000. In terms of numbers, the small and very small community and noncommunity water systems represent the greatest challenge to regulators and consultants—both contributing to over 91 percent of the regulatory violations in 2000.[1]

In addition to public water systems, the U.S. Geological Survey estimated that 42.4 million people were served by their own individual water supply systems in 1995. These domestic systems are—for the most part—unregulated by either state or county health departments.[2]

A survey made between 1975 and 1977 showed that 13 to 18 million people in communities of 10,000 and under used individual wells with high contamination rates.[3] The effectiveness of state and local well construction standards and health department programs has a direct bearing on the extent and number of contaminated home well-water supplies in specific areas.

A safe and adequate water supply for 1.8 billion people,[4] about one-third of the world's population, is still a dream. The availability of any reasonably clean water in the less developed areas of the world just to wash and bathe would go a long way toward the reduction of such scourges as scabies and other skin diseases, yaws and trachoma, and high infant mortality. The lack of safe water makes high incidences of shigellosis, amebiasis, schistosomiasis,* leptospirosis, infectious hepatitis, giardiasis, typhoid, and paratyphoid fever commonplace.[5] Ten million persons suffer from dracunculiasis or guinea worm disease in Africa and parts of Asia.[6] It has been estimated that there are 250 million new cases of waterborne diseases per year and 25,000 people (mostly children) die daily from them throughout the world.[7] Three-fourths of all illnesses in the developing world are associated with inadequate water and sanitation.[8] It is believed that the provision of safe water supplies, accompanied by a program of proper excreta disposal and birth control, could vastly improve the living conditions of millions of people in developing countries of the world.[9] In 1982, an estimated 46 percent of the population of Latin America and the Caribbean had access to piped water supply and 22 percent had access to acceptable types of sewage disposal.[10]

The diseases associated with the consumption of contaminated water are discussed in Chapter 1 and summarized in Figure 1-2.

Groundwater Pollution Hazard

Table 3-1 shows a classification of sources and causes of groundwater pollution. The 20 million [1992 Environmental Protection Agency (EPA) Needs Survey Report to Congress] residential cesspool and septic tank soil absorption systems alone discharge about 400 billion gal of sewage per day into the ground, which in some instances may contribute to groundwater pollution. This is in addition to sewage from restaurants, hotels, motels, resorts, office buildings, factories, and other establishments not on public sewers. The contribution from industrial and other sources shown in Table 3-1 is unknown. It is being inventoried by the EPA and is estimated at 900 billion gal.year,[11] the EPA, with state participation, is also developing a groundwater protection strategy. Included in the strategy is the classification of all groundwater and protection of existing and potential drinking water sources and ''ecologically vital'' waters.

Groundwater pollution problems have been found in many states. Primarily, the main cause is organic chemicals, such as trichloroethylene, 1,1,1-trichloroethane, benzene, perchlorate, gasoline (and gasoline additives such as MTBE), pesticides and soil fumigants, disease-causing organisms, and nitrates. Other sources are industrial and municipal landfills; ponds, pits, and lagoons; waste oils and highway deicing compounds; leaking underground storage tanks and pipelines; accidental spills; illegal dumping; and abandoned oil and gas wells. With 146 million people in the United States dependent on

* Three hundred million cases of schistosomiasis worldwide were estimated in 1986, spread mostly through water contact.

TABLE 3-1 Classification of Sources and Causes of Groundwater Pollution Used in Determining Level and Kind of Regulatory Control

Wastes		Nonwastes	
Category I[a]	Category II[b]	Category III[c]	Category IV[d]
Land application of wastewater: spray irrigation, infiltration–percolation basins, overland flow	Surface impoundments: waste-holding ponds, lagoons, and pits	Buried product storage tanks and pipelines	Saltwater intrusion: seawater encroachment, upward coning of saline groundwater
Subsurface soil absorption systems: septic systems	Landfills and other excavations: landfills for industrial wastes, sanitary landfills for municipal solid wastes, municipal landfills	Stockpiles: highway deicing stockpiles, ore stockpiles	River infiltration
Waste disposal wells and brine injection wells	Water and wastewater treatment plant sludges, other excavations (e.g., mass burial of livestock)	Application of highway deicing salts	Improperly constructed or abandoned wells
Drainage wells and sumps	—	Product storage ponds	Farming practices (e.g., dry-land farming)
Recharge wells	Animal feedlots	Agricultural activities: fertilizers and pesticides, irrigation return flows	
	Leaky sanitary sewer lines	Accidental spills	
	Acid mine drainage		
	Mine spoil pipes and tailings		

Source: The Report to Congress, Waste Disposal Practices and Their Effects on Ground Water, Executive Summary, U.S. Environmental Protection Agency, Washington, DC, January 1977, p. 39.

[a] Systems, facilities, or activities designed to discharge waste or wastewaters (residuals) to the land and groundwaters.

[b] Systems, facilities, or activities that may discharge wastes or wastewaters to the land and groundwaters.

[c] Systems, facilities, or activities that may discharge or cause a discharge of contaminants that are not wastes to the land and groundwaters.

[d] Causes of groundwater pollution that are not discharges.

groundwater sources for drinking water,* these resources must be protected from physical, chemical, radiological, and microbiological contamination.

Whereas surface water travels at velocities of feet per second, groundwater moves at velocities that range from less than a fraction of a foot per day to several feet per day. Groundwater organic and inorganic chemical contamination may persist for decades or longer and, because of the generally slow rate of movement of groundwater, may go undetected for many years. Factors that influence the movement of groundwater include the type of geological formation and its permeability, the rainfall and the infiltration, and the hydraulic gradient. The slow uniform rate of flow, usually in an elongated plume, provides little opportunity for mixing and dilution, and the usual absence of air in groundwater to decompose or break down the contaminants add to the long-lasting problem usually created. On the other hand, dilution, microbial activity, surface tension and attraction to soil particles, and soil adsorptive characteristics might exist that could modify, immobilize, or attenuate the pollutant travel. More attention *must* be given to the *prevention* of groundwater pollution and to wellhead protection.

TRAVEL OF POLLUTION THROUGH THE GROUND

Identification of the source of well pollution and tracing the migration of the incriminating contaminant are usually not simple operations. The identification of a contaminant plume and its extent can be truly complex. Comprehensive hydrogeological studies and proper placement and construction of an adequate number of monitoring wells are necessary.

Geophysical methods to identify and investigate the extent and characteristics of groundwater pollution include geomagnetics, electromagnetics, electrical resistivity, ground-probing radar, and photoionization meters.[12] *Geomagnetics* uses an instrument producing a magnetic field to identify and locate buried metals and subsurface materials that are not in their natural or undisturbed state. *Electromagnetics* equipment measures the difference in conductivity between buried materials such as the boundaries of contaminated plumes or landfills saturated with leachate and uncontaminated materials. *Electrical resistivity* measures the resistance a material offers to the passage of an electric current between electric probes, which can be interpreted to identify or determine rock, clay and other materials, porosity, and groundwater limits. *Ground-probing radar* uses radar energy to penetrate and measure reflection from the water table and subsurface materials. The reflection from the materials varies with depth and the nature of the material such as sandy soils versus saturated clays. *Photoionization meters* are used to detect

*Ninety-nine percent of the rural population and 33 percent of the municipal water supplies use groundwater.

the presence of specific volatile organic compounds such as gasoline, and methane in a landfill, through the use of shallow boreholes. Other detection methods are remote imagery and aerial photography, including infrared.

Sampling for contaminants must be carefully designed and performed. Errors can be introduced: Sampling from an unrepresentative water level in a well, contamination of sampling equipment, and incorrect analysis procedure are some potential sources of error. The characteristics of a pollutant, the subsurface formation, the hydraulic conductivity of the aquifer affected, groundwater slope, rainfall variations, and the presence of geological fractures, faults, and channels, make determination of pollution travel and its sampling difficult. Geophysical techniques can help, and great care must be used in determining the number, spacing, location, and depths of sampling wells and screen entry levels. As a rule, monitoring wells and borings will be required to confirm and sample subsurface contamination.

Since the character of soil and rock, quantity of rain, depth of groundwater, rate of groundwater flow, amount and type of pollution, absorption, adsorption, biological degradation, chemical changes, and other factors usually beyond control are variable, one cannot say with certainty through what thickness or distance sewage or other pollutants must pass to be purified. Microbiological pollution travels a short distance through sandy loam or clay, but it will travel indefinite distances through coarse sand and gravel, fissured rock, dried-out cracked clay, or solution channels in limestone. Acidic conditions and lack of organics and certain elements such as iron, manganese, aluminum, and calcium in soil increase the potential of pollution travel. Chemical pollution can travel great distances.

The Public Health Service (PHS) conducted experiments at Fort Caswell, North Carolina, in a sandy soil with groundwater moving slowly through it. The sewage organisms (coliform bacteria) traveled 232 ft, and chemical pollution as indicated by uranin dye traveled 450 ft.[13] The chemical pollution moved in the direction of the groundwater flow largely in the upper portion of the groundwater and persisted for $2\frac{1}{2}$ years. The pollution band did not fan out but became narrower as it moved away from the pollution source. It should be noted that in these tests there was a small draft on the experimental wells and that the soil was a sand of 0.14 mm effective size and 1.8 uniformity coefficient. It should also be noted that, whereas petroleum products tend to float on the surface, halogenated solvents gradually migrate downward.

Studies of pollution travel were made by the University of California using twenty-three 6-in. observation wells and a 12-in. gravel-packed recharge well. Diluted primary sewage was pumped through the 12-in. recharge well into a confined aquifer having an average thickness of 4.4 ft approximately 95 ft below ground surface. The aquifer was described as pea gravel and sand having a permeability of 1900 gal/ft^2/day. Its average effective size was 0.56 mm and uniformity coefficient was 6.9. The medium effective size of the aquifer material from 18 wells was 0.36 mm. The maximum distance of pollution travel was 100 ft in the direction of groundwater flow and 63 ft in other directions. It was found that the travel of pollution was affected not by the groundwater velocity but by the organic mat that built up and filtered out organisms, thereby preventing them from entering the aquifer. The extent of the pollution then regressed as the organisms died away and as pollution was filtered out.[14]

Butler, Orlob, and McGauhey[15] made a study of the literature and reported the results of field studies to obtain more information about the underground travel of harmful bacteria and toxic chemicals. The work of other investigators indicated that pollution from dry-pit privies did not extend more than 1 to 5 ft in dry or slightly moist fine soils. However, when pollution was introduced into the underground water, test organisms (*Balantidium coli*) traveled to wells up to 232 ft away.[13] Chemical pollution was observed to travel 300 to 450 ft, although chromate was reported to have traveled 1000 ft in 3 years, and other chemical pollution 3 to 5 miles. Leachings from a garbage dump in groundwater reached wells 1476 ft away, and a 15-year-old dump continued to pollute wells 2000 ft away. Studies in the Dutch East Indies (Indonesia) report the survival of coliform organisms in soil 2 years after contamination and their extension to a depth of 9 to 13 ft, in decreasing numbers, but increasing again as groundwater was approached. The studies of Butler et al. tend to confirm previous reports and have led the authors to conclude ‘‘that the removal of bacteria from liquid percolating through a given depth of soil is inversely proportional to the particle size of the soil’’ (ref. 15, p. 97).

Knowledge concerning viruses in groundwater is limited, but better methodology for the detection of viruses is improving this situation. Keswick and Gerba[16] reviewed the literature and found 9 instances in which viruses were isolated from drinking water wells and 15 instances in which viruses were isolated from beneath land treatment sites. Sand and gravel did not prevent the travel of viruses long distances in groundwater. However, fine loamy sand over coarse sand and gravel effectively removed viruses. Soil composition, including the presence of clay, is very important in virus removal as it is in bacteria removal. The movement of viruses through soil and in groundwater requires further study. Helminth eggs and protozoa cysts do not travel great distances through most soils because of their greater size but can travel considerable distances through macropores and crevices. However, nitrate travel in groundwater may be a major inorganic chemical hazard. In addition, organic chemicals are increasingly being found in groundwater. See (a) Removal of Gasoline, Fuel Oil, and Other Organics in an Aquifer; (b) Prevention and Removal of Organic Chemicals; and (c) Synthetic Organic Chemicals Removal in this chapter.

When pumping from a deep well, the direction of groundwater flow around the well within the radius of influence, not necessarily circular, will be toward the well. Since the level of the water in the well will probably be 25 to 150 ft, more or less, below the ground surface, the drawdown cone created by pumping may exert an attractive influence on groundwater, perhaps as far as

100 to 2000 ft or more away from the well, because of the hydraulic gradient, regardless of the elevation of the top of the well. The radius of the drawdown cone or circle of influence may be 100 to 300 ft or more for fine sand, 600 to 1000 ft for coarse sand, and 1000 to 2000 ft for gravel. See Figure 3-1. In other words, distances and elevations of sewage disposal systems and other sources of pollution must be considered relative to the hydraulic gradient and elevation of the water level in the well while it is being pumped. It must also be recognized that pollution can travel in three dimensions in all or part of the aquifer's vertical thickness, dependent on the contaminant viscosity and density, the formation transmissivity, and the groundwater flow. Liquids lighter than water, such as gasoline, tend to collect above the groundwater table. Liquids heavier or more dense tend to pass through the groundwater and accumulate above an impermeable layer.

A World Health Organization (WHO) report reminds us that, in nature, atmospheric oxygen breaks down accessible organic matter and that topsoil (loam) contains organisms that can effectively oxidize organic matter.[17] However, these benefits are lost if wastes are discharged directly into the groundwater by way of sink holes, pits, or wells or if a subsurface absorption system is water logged.

From the investigations made, it is apparent that the safe distance between a well and a sewage or industrial waste disposal system is dependent on many

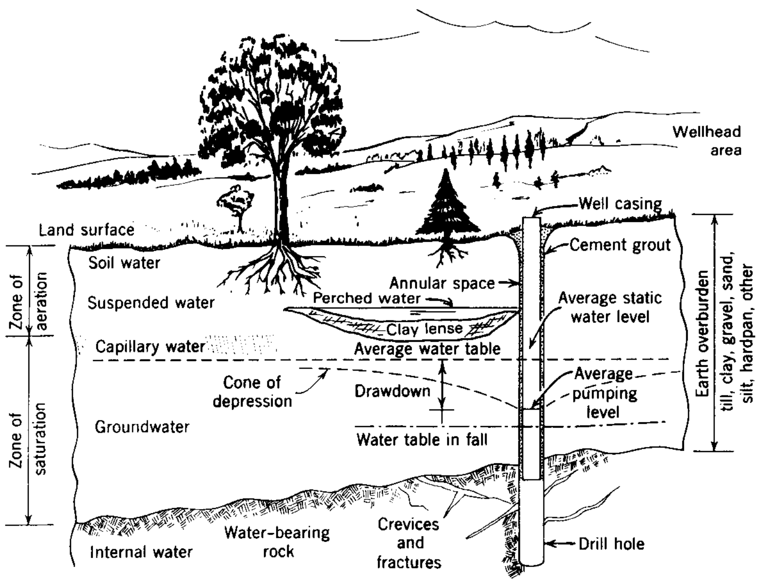


Figure 3-1 A geologic section showing groundwater terms. (*Source: Rural Water Supply,* New York State Department of Health, Albany, NY, 1966.)

variables, including chemical, physical, and biological processes.* Factors to be considered in arriving at a satisfactory answer include the following:

1. The amount of sand, clay, organic (humus) matter, and loam in the soil, the soil structure and texture, the effective size and uniformity coefficient, groundwater level, and unsaturated soil depth largely determine the ability of the soil to remove microbiological pollution deposited in the soil.
2. The volume, strength, type, and dispersion of the polluting material, rainfall intensity and infiltration, and distance, elevation, and time for pollution to travel with relation to the groundwater level and flow and soil penetrated are important. Also important is the volume of water pumped and well drawdown.
3. The well construction, tightness of the pump line casing connection, depth of well and well casing, geological formations penetrated, and sealing of the annular space have a very major bearing on whether a well might be polluted by sewage, chemical spills or wastes, and surface water.
4. The well recharge (wellhead) area, geology, and land use possibly permit groundwater pollution. Local land-use and watershed control is essential to protect and prevent pollution of well-water supplies.

Considerable professional judgment is needed to select a proper location for a well. The limiting distances given in Table 3-2 for private dwellings should be used as a guide. Experience has shown them to be reasonable and effective in most instances *when coupled with a sanitary survey of the drainage area and proper interpretation of available hydrologic and geologic data and good well construction, location, and protection.*[19] See Figure 3-1 for groundwater terms. Well location and construction for public and private water systems should follow regulatory standards. See Source and Protection of Water Supply in this chapter.

Disease Transmission

Water, to act as a vehicle for the spread of a specific disease, must be contaminated with the associated disease organism or hazardous chemical. Disease organisms can survive for periods of days to years depending on their form (cyst, ova) and environment (moisture, competitors, temperature, soil, and acidity) and the treatment given the wastewater. All sewage-contaminated waters must be presumed to be potentially dangerous. Other impurities such

*A summary of the distances of travel of underground pollution is also given in ref. 18.

TABLE 3-2 Minimum Separation Distances (ft) from On-Site Wastewater Sources

Sources	To Well or Suction Line[a]	To Stream, Lake, or Water Course	To Property Line or Dwelling
House sewer (water-tight joints)	25 if cast iron pipe or equal, 50 otherwise	25	—
Septic tank	50	50	10
Effluent line to distribution box	50	50	10
Distribution box	100	100	20
Absorption field	100[b]	100	20
Seepage pit or cesspool	150[b] (more in coarse gravel)	100	20
Dry well (roof and footing)	50	25	20
Fill or built-up system	100	100	20
Evapotranspiration–absorption system	100	50	20
Sanitary privy pit	100	50	20
Privy, water-tight vault	50	50	10
Septic privy or aqua privy	50	50	10

[a] Water service and sewer lines may be in the same trench if cast-iron sewer with water-tight joints is laid at all ponits 12 in. below water service pipe; or sewer may be on dropped shelf at one side at least 12 in. below water service pipe, provided that sewer pipe is laid below frost with tight and root-proof joints and is not subject to settling, superimposed loads, or vibration. Water service lines under pressure shall not pass closer than 10 ft of a septic tank, absorption tile field, leaching pit, privy, or any other part of a sewage disposal system.
[b] Sewage disposal systems located of necessity upgrade or in the general path of drainage to a well should be spaced 200 ft or more away and not in the direct line of drainage. Wells require a minimum 20 ft of casing extended and sealed into an impervious stratum. If subsoil is coarse sand or gravel, do not use seepage pit; use absorption field with 12 in. medium sand on bottom of trench. Also require oversize drill hole and grouted well to a safe depth. See Table 3-15.

as inorganic and organic chemicals and heavy concentrations of decaying organic matter may also find their way into a water supply, making the water hazardous, unattractive, or otherwise unsuitable for domestic use unless adequately treated. The inorganic and organic chemicals causing illness include mercury, lead, chromium, nitrates, asbestos, polychlorinated biphenyl (PCB), polybrominated biphenyl (PBB), mirex, Kepone, vinyl chloride, trichloroethylene, benzene, and others.

Communicable and noninfectious diseases that may be spread by water are discussed in Chapter 1 and listed in Figure 1-2.

WATER QUANTITY AND QUALITY

Water Cycle and Geology

The movement of water can be best illustrated by the hydrologic, or water, cycle shown in Figure 3-2. Using the clouds and atmospheric vapors as a starting point, moisture condenses out under the proper conditions to form rain, snow, sleet, hail, frost, fog, or dew. Part of the precipitation is evaporated while falling; some of it reaches vegetation foliage, the ground, and other surfaces. Moisture intercepted by surfaces is evaporated back into the atmosphere. Part of the water reaching the ground surface runs off to streams, lakes, swamps, or oceans whence it evaporates; part infiltrates the ground and percolates down to replenish the groundwater storage, which also supplies lakes, streams, and oceans by underground flow. Groundwater in the soil helps to nourish vegetation through the root system. It travels up the plant and comes out as transpiration from the leaf structure and then evaporates into the atmosphere. In its cyclical movement, part of the water is temporarily retained by the earth, plants, and animals to sustain life. The average annual precipitation in the United States is about 30 in., of which 72 percent evaporates from water and land surfaces and transpires from plants and 28 percent contributes to the groundwater recharge and stream flow.[20] See also Septic Tank Evapotranspiration System, Chapter 4.

The volume of fresh water in the hydrosphere has been estimated to be 6,820,700 mi^3 with 5,800,000 mi^3 in ice sheets and glaciers, 960,000 mi^3 in groundwater, 37,000 mi^3 in lakes and reservoirs, 3400 mi^3 in vapors in the atmosphere, and 300 mi^3 in river water.[21]

When speaking of water, we are concerned primarily with surface water and groundwater, although rainwater and saline water are also considered. In falling through the atmosphere, rain picks up dust particles, plant seeds, bacteria, dissolved gases, ionizing radiation, and chemical substances such as sulfur, nitrogen, oxygen, carbon dioxide, and ammonia. Hence, rain water is not pure water as one might think; it is, however, very soft. Water in streams, lakes, reservoirs, and swamps is known as surface water. Water reaching the ground and flowing over the surface carries anything it can move or dissolve. This may include waste matter, bacteria, silt, soil, vegetation, and microscopic plants and animals and other naturally occurring organic matter. The water accumulates in streams or lakes. Sewage, industrial wastes, and surface and groundwater will cumulate, contribute to the flow, and be acted upon by natural agencies. Water reaching lakes or reservoirs permit bacteria, suspended matter, and other impurities to settle out. On the other hand, microscopic as well as macroscopic plant and animal life grow and die, thereby removing and contributing impurities in the cycle of life.

Part of the water reaching and flowing over the ground infiltrates and percolates down to form and recharge the groundwater, also called underground

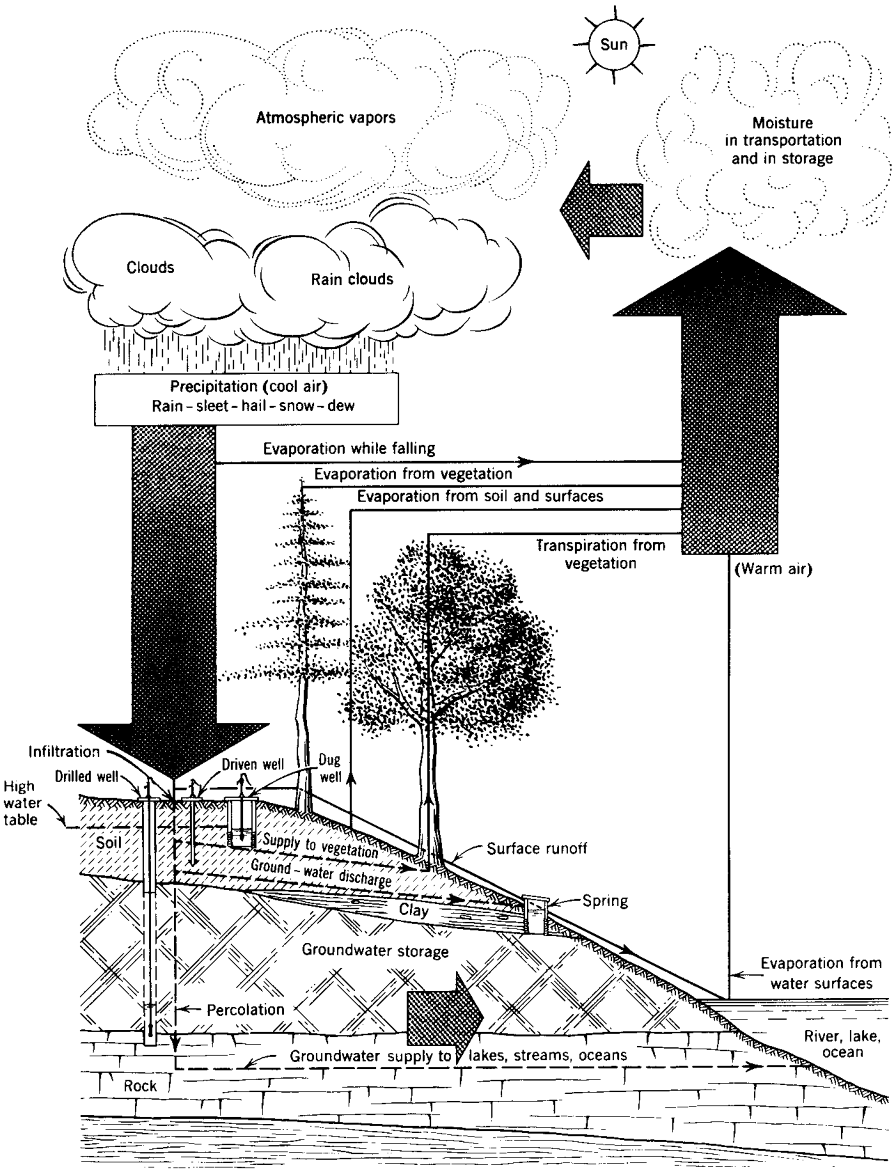


Figure 3-2 Hydrologic or (water) cycle. The oceans hold 317,000,000 mi^3 of water. Ninety-seven percent of the earth's water is salt water; 3 percent of the earth's fresh water is groundwater, snow and ice, fresh water on land, and atmospheric water vapor; 85 percent of the fresh water is in polar ice caps and glaciers. Total precipitation equals total evaporation plus transpiration. Precipitation on land equals 24,000 mi^3/year. Evaporation from the oceans equals 80,000 mi^3/year. Evaporation from lakes, streams, and soil and transpiration from vegetation equal 15,000 mi^3.

water. In percolating through the ground, water will dissolve materials to an extent dependent on the type and composition of the strata through which the water has passed and the quality (acidity) and quantity of water. Groundwater will therefore usually contain more dissolved minerals than surface water. The strata penetrated may be unconsolidated, such as sand, clay, and gravel, or consolidated, such as sandstone, granite, and limestone. A brief explanation of the classification and characteristics of formations is given below.

Igneous rocks are those formed by the cooling and hardening of molten rock masses. The rocks are crystalline and contain quartz, feldspar, mica, hornblende, pyroxene, and olivene. Igneous rocks are not usually good sources of water, although basalts are exceptions. Small quantities of water are available in fractures and faults. Examples are granite, dioxite, gabbro, basalt, and syenite.

Sedimentary formations are those resulting from the deposition, accumulation, and subsequent consolidation of materials weathered and eroded from older rocks by water, ice, or wind and the remains of plants, animals, or material precipitated out of solution. Sand and gravel, clay, silt, chalk, limestone, fossils, gypsum, salt, peat, shale, conglomerates, loess, and sandstone are examples of sedimentary formations. Deposits of sand and gravel generally yield large quantities of water. Sandstones, shales, and certain limestones may yield abundant groundwater, although results may be erratic depending on bedding planes and joints, density, porosity, and permeability of the rock.

Metamorphic rocks are produced by the alteration of igneous and sedimentary rocks, generally by means of heat and pressure. Gneisses and schists, quartzites, slates, marble, serpentines, and soapstones are metamorphic rocks. A small quantity of water is available in joints, crevices, and cleavage planes.

Karst areas are formed by the movement of underground water through carbonate rock fractures and channels, such as in limestone and gypsum, forming caves, underground channels, and sink holes. Because karst geology can be so porous, groundwater movement can be quite rapid (several feet per day). Therefore, well water from such sources is easily contaminated from nearby and distant pollution sources.

Glacial drift is unconsolidated sediment that has been moved by glacier ice and deposited on land or in the ocean.

Porosity is a measure of the amount of water that can be held by a rock or soil in its pores or voids, expressed as a percentage of the total volume. The volume of water that will *drain* freely out of a saturated rock or soil by gravity, expressed as a percentage of the total volume of the mass, is the *effective porosity* or *specific yield*. The volume of water retained is the *specific retention*. This is due to water held in the interstices or pores of the rock or soil by molecular attraction (cohesion) and by surface tension (adhesion). For example, plastic clay has a porosity of 45 to 55 percent but a specific yield of practically zero. In contrast, a uniform coarse sand and gravel mixture has a porosity of 30 to 40 percent with nearly all of the water capable of being drained out.

The *permeability* of a rock or soil, expressed as the standard coefficient of permeability or *hydraulic conductivity,* is the rate of flow of water at 60°F (16°C), in gallons per day, through a vertical cross section of 1 ft^2, under a head of 1 ft, per foot of water travel. There is no direct relationship between permeability, porosity, and specific yield.

Transmissivity is the hydraulic conductivity times the saturated thickness of the aquifer.

Groundwater Flow[22]

The flow through an underground formation can be approximated using Darcy's law, expressed as $Q = KIA$, where

Q = quantity of flow per unit of time, gpd
K = hydraulic conductivity (water-conducting capacity) of the formation, gpd/ft^2 (see Table 3-3)
I = hydraulic gradient, ft/ft (may equal slope of groundwater surface)
A = cross-sectional area through which flow occurs, ft^2, at right angle to flow direction

For example, a sand aquifer within the floodplain of a river is about 30 ft thick and about a mile wide. The aquifer is covered by a confining unit of glacial till, the bottom of which is about 45 ft below the land surface. The difference in water level between two wells a mile apart is 10 ft. The hydraulic conductivity of the sand is 500 gpd/ft^2. Find Q:

$$\begin{aligned} Q &= KIA \\ &= 500 \text{ gpd/ft}^2 \times (10 \text{ ft}/5280 \text{ ft}) \times 5280 \text{ ft} \times 30 \text{ ft} \\ &= 150{,}000 \text{ gpd} \end{aligned}$$

Also,

$$v = \frac{KI}{7.48n}$$

where v = groundwater velocity, ft/day
n = effective porosity as a decimal

Find v:

$$\begin{aligned} v &= \frac{500\text{gpd} \times 10 \text{ ft}/5280 \text{ ft}}{7.48\text{g/ft}^3 \times 0.2} \\ &= 0.63 \text{ ft/day} \end{aligned}$$

Another example[23] is given below using Figure 3-3 and Darcy's law expressed as

TABLE 3-3 Porosity, Specific Yield, and Hydraulic Conductivity of Some Materials

Material	Porosity (vol %)	Specific Yield (%)	Hydraulic Conductivity or Permeability Coefficient,[a] K (gpd/ft^2)
Soils	55[b]	40[b]	10^{-5}–10 (glacial till)
	50–60[e]		
Clay	50[b]	2[b]	10^{-2}–10^{2} (silt, loess)
	45[d]	3[d]	10^{-6}–10^{-2} (clay)
	45–55[c]	1–10[e]	
Sand	25[b]	22[b]	1–10^{2} (silty sand)
	35[d]	25[d]	10–10^{4}
	30–40[c]	10–30[c]	
Gravel	20[b]	19[b]	10^{3}–10^{5}
	25[d]	22[d]	
	30–40[c]	15–30[c]	
Limestone	20[b]	18[b]	10^{-3}–10^{5} (fractured to cavernous, carbonate rocks)
	5[d]	2[d]	
	1–10[c]	0.5–5[e]	
Sandstone	11[b]	6[b]	10^{-4}–10 (fractured to semiconsolidated)
	15[d]	8[d]	
	10–20[c]	5–15[e]	
Shale	5[d]	2[d]	10^{-7}–10^{-3} (unfractured to fractured)
	1–10[c]	0.5–5[c]	
Granite	0.1[b]	0.09[b]	10^{-7}–10^{2} (unfractured to fractured, igneous and metamorphic)
	0.1[d]	0.5[d]	
	1[c]		
Basalt	11[b]	8[d]	10^{-7}–10^{5} (unfractured, fractured, to lava)

Source: D. K. Todd, *Ground Water Hydrology,* 2nd ed., Wiley, New York, 1980.

[a] *Protection of Public Water Supplies from Ground-Water Contamination,* Seminar Publication, EPA/625/4-85/016, Center for Environmental Research Information, Cincinnati, OH, September 1985, p. 11.

[b] R. C. Heath, *Basic Ground-Water Hydrology,* U.S. Geological Survey Paper 2220, U.S. Government Printing Office, Washington, DC, 1983.

[c] H. Ries and T. L. Watson, *Engineering Geology,* Wiley, New York, 1931.

[d] R. K. Linsley and J. B. Franzini, *Water Resources Engineering,* McGraw-Hill, New York, 1964.

[e] F. G. Driscoll, *Groundwater and Wells,* 2nd ed., Johnson Division, St. Paul, MN, 1986, p. 67.

$$v = Ks$$

where v = velocity of flow through an aquifer
K = coefficient of permeability (hydraulic conductivity)
s = hydraulic gradient

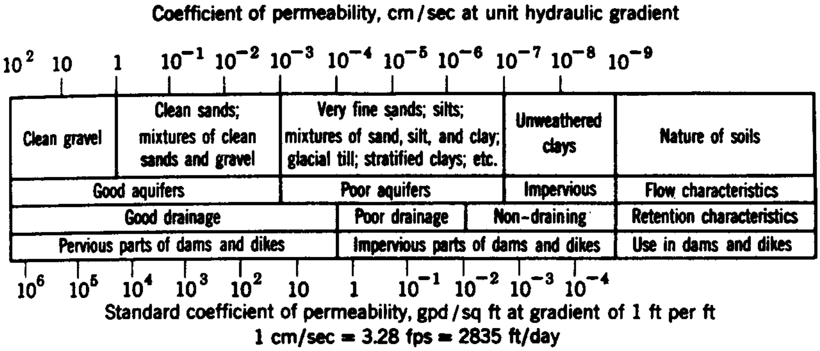


Figure 3-3 Magnitude of coefficient of permeability for different classes of soils. (*Source:* G. M. Fair, J. C. Geyer, and D. A. Okun, *Water and Wastewater Engineering,* Wiley, New York, 1966, pp. 9–13.)

Also,

$$Q = va$$

where Q = discharge
a = cross-sectional area of aquifer

Example (1) Estimate the velocity of flow (ft/day) and the discharge (gpd) through an aquifer of very coarse sand 1000 ft wide and 50 ft thick when the slope of the groundwater table is 20 ft/m. (2) Find the standard coefficient of permeability and the coefficient of transmissibility on the assumption that the water temperature is 60°F (16°C).

1. From Figure 3-3 choose a coefficient of permeability $K = 1.0$ cm/sec = 2835 ft/day. Because $s = 20/5280$, $v = 2835 \times 20/5280 = 11$ ft/day and $Q = 11 \times 1000 \times 50 \times 7.5 \times 10^{-6} = 4.1$ mgd.
2. The standard coefficient of permeability is $2835 \times 7.5 = 2.13 \times 10^4$, and the coefficient of transmissibility becomes $2.13 \times 10^4 \times 50 = 1.06 \times 10^6$.

The characteristics of some materials are given in Table 3-3.

Groundwater Classification

The EPA has proposed the following groundwater classification system (ref. 24, pp. 335):

Class I: *Special Ground Water* are those which are highly vulnerable to contamination because of the hydrological characteristics of the areas in which they occur *and* which are also characterized by either of the following two factors:

a) Irreplaceable, in that no reasonable alternative source of drinking water is available to substantial populations; or
b) Ecologically vital, in that the aquifer provides the base flow for a particularly sensitive ecological system that, if polluted, would destroy a unique habitat.

Class II: *Current and Potential Sources of Drinking Water and Waters Having Other Beneficial Uses* are all other groundwaters which are currently used or are potentially available for drinking water or other beneficial use.

Class III: *Ground Waters Not Considered Potential Sources of Drinking Water and of Limited Beneficial Use* are ground waters which are heavily saline, with Total Dissolved Solids (TDS) levels over 10,000 mg/l, or are otherwise contaminated beyond levels that allow cleanup using methods employed in public water system treatment. These ground waters also must not migrate to Class I or Class II ground waters or have a discharge to surface water that could cause degradation.

This classification system has been debated at great length. Some states have adopted stricter standards and eliminated class III, whereas others have added classifications.

Water Quality

The cleanest available sources of groundwater and surface water should be protected, used, and maintained for potable water supply purposes. Numerous parameters are used to determine the suitability of water and the health significance of contaminants that may be found in untreated and treated water. Watershed and wellhead protection regulations should be a primary consideration.

Microbiological, physical, chemical, and microscopic examinations are discussed and interpreted in this chapter under those respective headings. Water quality can be best assured by maintaining water clarity, chlorine residual in the distribution system, confirmatory absence of indicator organisms, and low bacterial population in the distributed water.[25]

Table 3-4 shows the standards for drinking water coming out of a tap served by a public water system. These are based on the National Primary Drinking Water Standards developed under the Safe Drinking Water Act of 1974 as amended in 1986 and 1996. The maximum contaminant level goals (MCLGs) in Table 3-4 are nonenforceable health goals that are to be set at levels at which no known or anticipated adverse health effects occur and that allow an adequate margin of safety. Maximum contaminant levels (MCLs) are enforceable and must be set as close to MCLGs as is feasible, based on

TABLE 3-4 Summary of National Primary Drinking Water Regulations, January 2002

Name of Contaminant	Maximum Contaminant Level (MCL) (mg/l unless noted)	Health Effects of Contaminant
	Inorganic Chemicals	
Antimony	0.006	Decreased longevity, blood effects
Asbestos (fiber length >10 μm)	7 million fibers per liter (MFL)	Lung tumors/cancer risk
Barium	2	Circulatory/gastrointestinal effects
Beryllium	0.004	Bone/lung effects/cancer risk
Cadmium	0.005	Liver/kidney/bone/circulatory effects
Chromium (total)	0.1	Liver/kidney/circulatory effects
Copper	Treatment technique (action limit 1.3)	Gastrointestinal/liver/kidney effects
Cyanide	0.2	Thyroid/neurologic effects
Fluoride	4	Skeletal effects
Lead	Tretament technique (action limit 0.015)	Cancer risk/kidney/nervous system effects Highly toxic to infants
Mercury (inorganic)	0.002	Kidney damage
Nickel	0.1	Nervous system/liver/heart effects/dermatitis
Nitrate (as N)	10	Methemoglobinemia (blue baby syndrome)/diuresis
Nitrite (as N)	1	Methemoglobinemia (blue baby syndrome)
Selenium	0.05	Nervous system/kidney/liver/circulatory effects
Thallium	0.002	Kidney/liver/brain/intestine effects
Arsenic Rule		
Arsenic	0.010	Cancer risk/cardiovascular and dermal effects

Radionuclides		
Combined radium-226 and radium-228	5 pCi/l	Cancer risk
Gross alpha (excluding radon and uranium)	15 pCi/l	Cancer risk
Beta particle and photon	4 mrem/year	Cancer risk
Radioactivity, uranium	0.030	Kidney effects/cancer risk
	Organic Chemicals	
SYNTHETIC ORGANIC COMPOUNDS		
2,3,7,8-TCDD (Dioxin)	0.00000003	Cancer risk/reproductive effects
2,4,5-TP (Silvex)	0.05	Liver/kidney effects
2,4-D	0.07	Nervous system/liver/kidney effects
Acrylamide	Treatment technique	Cancer risk/nervous system effects
Alachlor	0.002	Cancer risk/liver/kidney/spleen effects
Aldicarb[a]	0.003	Nervous system effects
Aldicarb sulfone[a]	0.003	Nervous system effects
Aldicarb sulfoxide[a]	0.004	Nervous system effects
Atrazine	0.003	Cardiologic effects/cancer risk/muscular degeneration
Carbofuran	0.04	Nervous/reproductive system effects
Chlordane	0.002	Cancer risk/liver/kidney/spleen effects
Dalapon	0.2	Kidney effects
Di(2-ethylhexyl)adipate	0.4	Liver/bone effects/cancer risk
1,2-Dibromo-3-chlorpropane (DBCP)	0.0002	Cancer risk/kidney/reproductive effects
Di(2-ethylhexyl)phthalate (DEHP)	0.006	Cancer risk/liver/reproductive effects
Dinoseb	0.007	Thyroid/reproductive organ effects

TABLE 3-4 (*Continued*)

Name of Contaminant	Maximum Contaminant Level (MCL) (mg/l unless noted)	Health Effects of Contaminant
Diquat	0.02	Ocular effects
Endothall	0.1	Kidney/liver/gastrointestinal effects
Endrin	0.002	Liver effects
Epichlorohydrin	Treatment technique	Cancer risk/circulatory/stomach effects
Ethylene dibromide (EDB)	0.00005	Cancer risk/liver/heart/kidney/nervous system effects
Glyphosate	0.7	Kidney/reproductive effects
Heptachlor	0.0004	Cancer risk/liver effects
Heptachlor epoxide	0.0002	Cancer risk
Hexachlorobenzene	0.001	Cancer risk/liver/reproductive effects
Hexachlorocyclopentadiene (HEX)	0.05	Kidney/stomach effects
Lindane	0.0002	Kidney/liver/nervous/circulatory effects
Methoxychlor	0.04	Kidney/liver/nervous/developmental effects
Oxamyl (Vydate)	0.2	Nervous system effects
PAHs (benzo[*a*]pyrene)	0.0002	Cancer risk/developmental/reproductive effects
PCBs polychlorinated biphenyls)	0.0005	Cancer risk/liver/gastrointestinal effects
Pentachlorophenol	0.001	Cancer risk/reproductive/liver/kidney effects
Picloram	0.5	Nervous system/liver effects
Simazine	0.004	Cancer risk/liver/kidney/thyroid effects
Toxaphene	0.003	Cancer risk/liver/kidney/nervous system effects

VOLATILE ORGANIC COMPOUNDS		
1,1-Dichloroethylene	0.007	Kidney/liver effects/cancer risk
1,1,1-Trichloroethane	0.2	Liver/circulatory/nervous system effects
1,1,2-Trichloroethane	0.005	Kidney/liver effects/cancer risk
1,2-Dichloroethane	0.005	Cancer risk
1,2-Dichloroprapane	0.005	Cancer risk/liver/kidney/gastrointestinal effects
1,2,4-Trichloroethane	0.07	Kidney/liver/adrenal gland effects
Benzene	0.005	Cancer risk/nervous system effects
Carbon tetrachloride	0.005	Cancer risk/liver effects
Chlorobenzene	0.1	Nervous system/liver effects
Cis-1,2-dichloroethylene	0.07	Liver/nervous/circulatory effects
Dichloromethane	0.005	Cancer risk/liver effects
Ethylbenzene	0.7	Kidney/liver/nervous system effects
Ortho-dichlorobenzene	0.6	Kidney/liver/blood cell/nervous system effects
Para-dichlorobenzene	0.075	Cancer risk/liver/circulatory effects
Styrene	0.1	Liver/nervous system effects/cancer risk
Tetrachloroethylene (PCE)	0.005	Cancer risk/liver/kidney/nervous system effects
Toluene	1	Kidney/liver effects
Trans-1,2-dichloroethylene	0.1	Nervous system/liver/circulatory effects
Trichloroethylene (TCE)	0.005	Cancer risk/liver effects
Vinyl chloride	0.002	Cancer risk/neurologic/liver effects
Xylenes (total)	10	kidney/liver/nervous system effects

TABLE 3-4 (*Continued*)

Name of Contaminant	Maximum Contaminant Level (MCL) (mg/l unless noted)	Health Effects of Contaminant
	Microbiologic Contaminants	
TOTAL COLIFORM RULE (TCR)		
Total coliforms; fecal coliforms; *Escherichia coli*	Less than 40 samples/month; no more than one positive for total coliforms. If 40 samples or more per month, or more than 5% positive. Maximum contaminate level goal (MCLG) = 0 for total coliform, fecal coliform, and *E. coli*. Every sample containing total coliforms must be analyzed for fecal coliforms.	Presence of fecal coliform or *E. coli* may indicate potential contamination that can cause diarrhea, cramps, nausea, headaches, or other symptoms.
SURFACE WATER TREATMENT RULE		
Turbidity	Treatment technique	None; interferes with disinfection
Giardia	Treatment technique (MCLG = 0)	Giardiasis
Enteric Viruses	Treatment technique (MCLG = 0)	Gastrointestinal and other viral infections
Legionella	Treatment technique (MCLG = 0)	Legionnaire's disease
Heterotrophic plate count (HPC)	Treatment technique (MCLG = none)	Gastrointestinal infections
INTERIM ENHANCED SURFACE WATER TREATMENT RULE (IESWTR)		
Turbidity	Treatment technique	None; interferes with disinfection
Cryptosporidium	Treatment technique (MCLG = 0)	Cryptosporidiosis
FILTER BACKWASH RULE		
Cryptosporidium	Tretment technique (MCLG = 0)	Cryptosporidiosis

LONG TERM 1 ENHANCED SURFACE WATER TREATMENT RULE (LT1ESWTR)		
Cryptosporidium	Treatment technique (MCLG = 0)	Cryptosporidiosis
Giardia	Treatment technique (MCLG = 0)	Giardiasis
Viruses	Treatment technique (MCLG = 0)	Gastrointestinal and other viral infections
	Disinfectants and Disinfection By-Products: Stage 1 D/DBPR	
DISINFECTANTS		
Chlorine	Maximum disinfectant residual level (MRDL)-4.0 (as Cl_2)	
Chloramines	MRDL-4.0 (as Cl_2)	Hemolytic anemia in dialysis
Chlorine dioxide	MRDL-0.8 (as ClO_2)	
DISINFECTION BY-PRODUCTS		
Total trihalomethanes (TTHMs)	0.080	Cancer risk/reproductive effects
Haloacetic acids (HAA5)	0.060	Cancer risk
Chlorite	1.0	Cancer risk
Bromate	0.010	Cancer risk/nervous system/liver effects
Total organic carbon (TOC)	Treatment technique	

[a] Aldicarb and metabolites are presently stayed, pending reproposal.

the use of best technology, treatment techniques, analytical capabilities, costs, and other means. The EPA has based the MCLs on the potential health effects from the ingestion of a contaminant on the assumption that the effects observed (of a high dose) in animals may occur (at a low dose) in humans. This assumption has engendered considerable debate.

Secondary regulations, shown in Table 3-5, have also been adopted, but these are designed to deal with taste, odor, and appearance of drinking water and are not mandatory unless adopted by a state. Although not mandatory, these parameters have a very important indirect health significance. Water that is not palatable is not likely to be used for drinking, even though reported to be safe, in both developed and underdeveloped areas of the world. A questionable or contaminated water source may then be inappropriately used.

TABLE 3-5 Secondary Drinking Water Regulations

Contaminant	Effect	Level
pH	Water should not be too acidic or too basic.	6.5–8.5
Chloride	Taste and corrosion of pipes	250 mg/l
Copper	Taste and staining of porcelain	1 mg/l
Foaming agents	Aesthetic	0.5 mg/l
Sulfate	Taste and laxative effects	250 mg/l
Total dissolved solids (hardness)	Taste and possible relation between low hardness and cardiovascular disease, also an indicator of corrosivity (related to lead levels in water); can damage plumbing and limit effectiveness of soaps and detergents	500 mg/l
Zinc	Taste	5 mg/l
Fluoride	Dental fluorosis (a brownish discoloration of the teeth)	2 mg/l
Color	Aesthetic	15 color units
Corrosivity	Aesthetic and health related (corrosive water can leach pipe materials, such as lead, into the drinking water)	Noncorrosive
Iron	Taste	0.3 mg/l
Manganese	Taste	0.05 mg/l
Odor	Aesthetic	3 threshold odor number

Source: U.S. Environmental Protection Agency, Fact Sheet, Office of Water, Washington, DC, September 1998.

Tables 3-6 to 3-10 give World Health Organization (WHO) water quality guidelines. It is not intended that the individual values in Tables 3-6 to 3-10 be used directly. Guideline values in the tables must be used and interpreted in conjunction with the information contained in the appropriate sections of Chapters 2 to 5 of *Guidelines for Drinking-Water Quality,* second Edition, volume 2, WHO, Geneva, 1996, 1998.

National secondary drinking water regulations shown in Table 3-5 are federally nonenforceable regulations that control contaminants in drinking water affecting the aesthetic qualities related to public acceptance of drinking water. These levels represent reasonable goals for drinking water quality. States may establish higher or lower levels, which may be appropriate dependent upon local conditions such as unavailability of alternate source waters or other compelling factors, provided that public health and welfare are not adversely affected.

It is recommended that the parameters in these regulations be monitored at intervals no less frequent than the monitoring performed for inorganic chemical contaminants listed in the National Primary Drinking Water Regulations as applicable to community water systems. More frequent monitoring would be appropriate for specific parameters such as pH, color, and odor under certain circumstances as directed by the state.

Sampling and Quality of Laboratory Data

Raw and finished water should be continually monitored. Prior arrangements should also be made for the treatment plant to be immediately notified by upstream dischargers in case of wastewater treatment plant operational failures or accidental releases of toxic or other hazardous substances. A water treatment plant should have a well-equipped laboratory, certified operator, and qualified chemist. Disinfectant residual, turbidity, and pH should be monitored continuously where possible. In addition to routine testing equipment, equipment at large plants usually include a zeta meter for coagulant dosing measurements, a nephelometer for turbidity readings, a flame spectrophotometer for measuring inorganic chemicals, and a gas chromatograph with spectrophotometer instrument to measure organic chemicals in low concentrations (micrograms per liter or less). The analytical methods for MCL determination approved by the EPA for volatile chemicals include gas chromatography and gas chromatography–spectrometry techniques. The MCLG for a probable human carcinogen is proposed to be ‘‘zero,’’ the limit of detection for regulatory purposes. The MCLGs are unenforceable health goals for public water systems that cause no known or adverse health effects and incorporate an adequate margin of safety. The MCL is an enforceable standard established in the primary drinking water regulations that takes economic factors into consideration, in addition to no unreasonable risk to health. It should be understood that failure to report the presence of certain chemicals or microorganisms does not mean they are not present if the laboratory does not

TABLE 3-6 Microbiological and Biological Quality

	Unit	Guideline Value	Remarks
		I. Microbiological Quality	
A. PIPED WATER SUPPLIES			
A.1 Treated Water Entering Distribution System			
Fecal coliforms	Number/100 ml	0	Turbidity <1 NTU; for disinfection with chlorine, pH preferably <8.0; free chlorine residual 0.2–0.5 mg/l following 30 min (minimum) contact
Coliform organisms	Number/100 ml	0	
A.2 Untreated Water Entering Distribution System			
Fecal coliforms	Number/100 ml	0	
Coliform organisms	Number/100 ml	0	In 98% of samples examined throughout the year, in the case of large supplies when sufficient samples are examined
		3	In an occasional sample, but not in consecutive samples
A.3 Water in Distribution System			
Fecal coliforms	Number/100 ml	0	—
Coliform organisms	Number/100 ml	0	In 95% of samples examined throughout year, in the case of large supplies when sufficient samples are examined
		3	In an occasional sample, but not in consecutive samples
B. UNPIPED WATER SUPPLIES			
Fecal coliforms	Number/100 ml	0	
Coliform organisms	Number/100 ml	10	Should not occur repeatedly; if occurrence is frequent and if sanitary protection cannot be improved, an alternative source must be found if possible

C. BOTTLED DRINKING WATER			
Fecal coliforms	Number/100 ml	0	Source should be free from fecal contamination.
Coliform organisms	Number/100 ml	0	—
D. EMERGENCY WATER SUPPLIES			
Fecal coliforms	Number/100 ml	0	Advise public to boil water in case of failure to meet guideline values.
Coliform organisms	Number/100 ml	0	—
Enteroviruses	—	No guideline value set	—
		II. Biological Quality	
Protozoa (pathogenic)	—	No guideline value set	—
Helminths (pathogenic)	—	No guideline value set	—
Free-living organisms (algae, others)	—	No guideline value set	—

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations,* World Health Organization, Geneva, 1984, Table 1. Reproduced with permission.

TABLE 3-7 Inorganic Constituents of Health Significance

Constituent	Unit	Guideline Value
Arsenic	mg/l	0.05
Asbestos	—	No guideline value
Barium	—	No guideline value
Beryllium	—	No guideline value
Cadmium	mg/l	0.005
Chromium	mg/l	0.05
Cyanide	mg/l	0.1
Fluoride	mg/l	1.5
Hardness	—	No health-related guideline value
Lead	mg/l	0.05
Mercury	mg/l	0.001
Nickel	—	No guideline value
Nitrate	mg/l (N)	10
Nitrite	—	No guideline value
Selenium	mg/l	0.01
Silver	—	No guideline value
Sodium	—	No guideline value

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations,* World Health Organization, Geneva, 1984, Table 2. Reproduced with permission.

[a]Natural or deliberately added; local or climatic conditions may necessitate adaptation.

examine for them. All examinations should be made in accordance with the procedures given in *Standard Methods for the Examination of Water and Wastewater,* latest edition or one approved by the EPA (see the Bibliography).

Water samples may be continuous (such as for turbidity or particle counting), grab (instantaneous), composite (an accumulation of grab samples of equal volume), or flow-weighted composite (proportional to volume of flow). Most drinking water samples are grab, although this can be misleading when sampling for organic chemicals or heavy metals. Wastewater samples are composite or flow-weighted composite. When sampling, laboratory collection procedures should be followed.

Drinking water samples should be collected at times of maximum water usage from representative locations including residences. The sampling tap should be clean, not leaking (except in the case of lead and copper monitoring), and flushed for 2 to 3 min before sample collection. A 1-in. air space should be left on top of the bottle for a bacteriological sample. The bottle should be completely filled for a chemical sample; there must be no air bubble at the top. A laboratory-prepared bottle should be used.

Examination of a nonrepresentative sample is a waste of the sample collector's and the laboratory's time. It will give misleading information that can lead to incorrect and costly actions, discredit the agency or organization involved, and destroy a legal action or research conclusion.

TABLE 3-8 Organic Constituents of Health Significance

	Unit	Guideline Value	Remarks
Aldrin and dieldrin	μg/l	0.03	
Benzene	μg/l	10[a]	
Benzol[*a*]pyrene	μg/l	0.01[a]	
Carbon tetrachloride	μg/l	3[a]	Tentative guideline value[b]
Chlordane	μg/l	0.3	—
Chlorobenzenes	μg/l	No health-related guideline value	Odor threshold concentration between 0.1 and 3 μg/l
Chloroform	μg/l	30[a]	Disinfection efficiency must not be compromised when controlling chloroform content
Chlorophenols	μg/l	No health-related guideline value	Odor threshold concentration 0.1 μg/l
2,4-D	μg/l	100[c]	
DDT	μg/l	1	
1,2-Dichloroethane	μg/l	10[a]	
1,1-Dichloroethene[d]	μg/l	0.3[a]	
Heptachlor and heptachlor epoxide	μg/l	0.1	
Hexachlorobenzene	μg/l	0.01[a]	
Gamma-HCH (lindane)	μg/l	3	
Methoxychlor	μg/l	30	
Pentachlorophenol	μg/l	10	
Tetrachloroethene[e]	μg/l	10[a]	Tentative guideline value[b]
Trichloroethene[f]	μg/l	30[a]	Tentative guideline value[b]
2,4,6-Trichlorophenol	μg/l	10[a,c]	Odor threshold concentration, 0.1 μg/l
Trihalomethanes		No guideline value	See chloroform

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations,* World Health Organization, Geneva, 1984, Table 3. Reproduced with permission.

[a] These guideline values were computed from a conservative hypothetical mathematical model that cannot be experimentally verified and values should therefore be interpreted differently. Uncertainties involved may amount to two orders of magnitude (i.e., from 0.1 to 10 times the number).

[b] When the available carcinogenicity data did not support a guideline value but the compounds were judged to be of importance in drinking water and guidance was considered essential, a tentative guideline value was set on the basis of the available health-related data.

[c] May be detectable by taste and odor at lower concentrations.

[d] Previously known as 1,1-dichloroethylene.

[e] Previously known as tetrachloroethylene.

[f] Previously known as trichloroethylene.

There is a tendency to collect more samples and laboratory data than are needed. The tremendous resources in money, manpower, and equipment committed to the proper preparation, collection, and shipment of the samples and

TABLE 3-9 Aesthetic Quality

Characteristic	Unit	Guideline Value	Remarks
Aluminum	mg/l	0.2	
Chloride	mg/l	250	
Chlorobenzenes and chlorophenols	—	No guideline value	These compounds may affect taste and odor.
Color	True color units (TCU)	15	
Copper	mg/l	1.0	
Detergents	—	No guideline value	There should not be any foaming or taste and odor problems.
Hardness	mg/l (as $CaCO_3$)	500	
Hydrogen sulfide	—	Not detectable by consumers	
Iron	mg/l	0.3	
Manganese	mg/l	0.1	
Oxygen, dissolved	—	No guideline value	
pH	—	6.5–8.5	
Sodium	mg/l	200	
Solids, total dissolved	mg/l	1000	
Sulfate	mg/l	400	
Taste and odor	—	Inoffensive to most consumers	
Temperature	—	No guideline value	
Turbidity	Nephelometric turbidity units (NTU)	5	Preferably <1 for disinfection efficiency
Zinc	mg/l	5.0	

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations,* World Health Organization, Geneva, 1984, Table 4. Reproduced with permission.

to the analytical procedures involved are lost sight of or misunderstood. Actually, a few carefully selected samples of good quality can usually serve the intended purpose.

The purpose or use of the laboratory data should determine the number of samples and quality of the laboratory work. Data of high quality are needed for official reporting and to support enforcement action or support a health effects study, while data of lesser quality may be acceptable for trend, screen-

TABLE 3-10 Radioactive Constituents

	Unit[a]	Guideline Value
Gross alpha activity	Bq/l	0.1
Gross beta activity	Bq/l	1

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations,* World Health Organization, Geneva, 1984, Table 5. Reproduced with permission.

Notes: (a) If the levels are exceeded, more detailed radionuclide analysis may be necessary.
(b) Higher levels do not necessarily imply that the water is unsuitable for human consumption

[a] One bequerel (Bq) = 2.7×10^{-11} curie.

ing, or monitoring purposes. High-quality legal data must follow official sample collection, identification, shipment, and analytical procedures exactly and without deviation.

The goal of a quality assurance program is to obtain scientifically valid, defensible data of known precision and accuracy to fulfill the water and/or wastewater utility's responsibility to protect and enhance the nation's environment.[26]

The laboratory is an essential ingredient of the effectiveness of the environmental program. However, the laboratory must resist the temptation to become involved in program operation and regulation activities since its function does not involve sanitary surveys, routine inspection, performance evaluation, program enforcement, responsibility, regulation continuity, and effectiveness. In addition, its limited resources would be misdirected and diluted to the detriment of its primary function. This does not mean that the laboratory should not be involved in training, treatment plant laboratory certification, and solving difficult water plant operational problems.

Sanitary Survey and Water Sampling[27,28]

A sanitary survey is necessary to determine the reliability of a water system to continuously supply safe and adequate water to the consumer. It is also necessary to properly interpret the results of water analyses and evaluate the effects of actual and potential sources of pollution on water quality. The value of the survey is dependent on the training and experience of the investigator. When available, one should seek the advice of the regulatory agency sanitary engineer or sanitarian. Watershed protection includes enactment of watershed rules and regulations and regular periodic surveillance and inspections. It, in effect, becomes epidemiological surveillance and is a study of environmental factors that may affect human health. Watershed rules and regulations are legal means to control land use that might cause pollution of the water draining off and into the watershed of the water supply source.

If the source of water is a natural or man-made lake, attention would be directed to the following, for each contributes distinctive characteristics to the water: entire drainage basin and location of sewage and other solid and liquid waste disposal or treatment systems; bathing areas; stormwater drains; sewer outfalls; swamps; cultivated areas; feed lots; sources of erosion, sediment and pesticides; and wooded areas, in reference to the pump intake. When water is obtained from a stream or creek, all land and habitation above the water supply intake should be investigated. This means inspection of the entire watershed drainage area so that actual and potential sources of pollution can be determined and properly evaluated and corrective measures instituted. All surface-water supplies must be considered of doubtful sanitary quality unless given adequate treatment, depending on the type and degree of pollution received.

Sanitary surveys have usually emphasized protection of surface-water supplies and their drainage areas. Groundwater supplies such as wells, infiltration galleries, and springs have traditionally been protected by proper construction and location (at an arbitrary ''safe'' distance from potential sources of pollution and not directly downgrade). The rule-of-thumb distance of 75, 100, or 200 ft, coupled with well construction precautions, has usually served this purpose in most instances, such as for on-site residential wells, in the absence of hydrogeological and engineering investigation and design. However, greater attention is being given to potential distant sources of pollution, especially chemical sources.

The 1996 amendments to the Safe Drinking Water Act require a more sophisticated approach referred to as wellhead protection of groundwater sources. The wellhead is defined as ''the surface and subsurface area surrounding a water well or wellfield supplying a public water system through which contaminants are reasonably likely to move toward and reach such well or wellfield.''* Determination of the aquifer limits and the drainage area tributary to a well or wellfield, an infiltration gallery, or spring, and the reasonable time of potential contaminants' travel, requires knowledge of the geological formations in the area and the groundwater movement in adjacent and distant tributary areas. In confined or artesian aquifers, this is not readily apparent. The water may originate nearby or at a considerable distance, depending on the extent to which the aquifer formation is confined, channeled, or fractured and on its depth. The U.S. Geological Survey and state geological and water resources agencies may be able to provide information on the local geology and the aquifers. Protection of the tributary wellhead area, would require governmental land-use controls, watershed rules and regulations, water purveyor ownership, and public cooperation. To accomplish this, it is first necessary to geographically identify the wellhead area, including groundwater flow, and all existing and potential sources of contamination in that area. This

*Also defined as the area between a well and the 99 percent theoretical maximum extent of the stabilized cone of depression. CFR Title 40, Subchapter D, Part 141, U.S. Government Printing Office, July 1999.

must be supplemented by the controls mentioned, including enactment of watershed (wellhead) protection rules and regulations, and their enforcement. See Source and Protection of Water Supply, this chapter.

The sanitary survey would include, in addition to the source as noted above, the potential for and effects of accidental chemical spills and domestic sewage or industrial waste discharges and leachate from abandoned and existing hazardous waste and landfill sites. Included in the survey would be inspection and investigation of the reservoir, intake, pumping station, treatment plant, and adequacy of each unit process; operation records; distribution system carrying capacity, head losses, and pressures; storage facilities; emergency source of water and plans to supply water in emergency; integrity of laboratory services; connections with other water supplies; and actual or possible cross-connections with plumbing fixtures, tanks, structures, or devices that might permit backsiphonage or backflow. Certification of operators, the integrity and competence of the person in charge of the plant, and adequacy of budgetary support are important factors. Consideration should also be given to land-use plans and the purchase of hydrogeologically sensitive areas and zoning controls.

Water samples are collected as an adjunct to the sanitary survey as an aid in measuring the quality of the raw water and effectiveness of treatment given. Microbiological examinations; chemical, radiochemical, and physical analyses; and microscopic examinations may be made depending on the sources of water, climate, geology, hydrology, waste disposal practices on the watershed, problems likely to be encountered, and purpose to be served. In any case, all samples should be properly collected, transported, and preserved as required, and tests should be made by an approved laboratory in accordance with the procedures provided in the latest edition of *Standard Methods for the Examination of Water and Wastewater*[29] or as approved by the EPA.

A sanitary technique and a glass or plastic sterile bottle supplied and prepared by the laboratory for the purpose should be used when collecting a water sample for bacteriological examination. Hands or faucet must not touch the edge of the lip of the bottle or the plug part of the stopper. The sample should be taken from a clean faucet that does not have an aerator or screen and that is not leaking or causing condensation on the outside. Flaming of the tap is optional. The water should be allowed to run for about 2 to 3 min to get a representative sample. To check for metals and bacteria in household plumbing, the sample must be taken as a "standing" sample without preliminary running of water. A household water softener or other treatment unit may introduce contamination. If a sample from a lake or stream is to be collected, the bottle should be dipped below the surface with a forward sweeping motion so that water coming in contact with the hands will not enter the bottle. When collecting a sample for bacteriological examination, there should be an air space in the bottle. When collecting samples of chlorinated water, the sample bottle should contain sodium thiosulfate to dechlorinate the water. It is recommended that all samples be examined promptly after collection and within 6 to 12 hr if possible. After 24 to 48 hr, examinations may not be reliable.

The chemical and physical analyses may be for industrial or sanitary purposes, and the determinations made will be either partial or complete, depending on the information desired. Water samples for inorganic chemical analyses are usually collected in 1-liter polyethylene containers, new or acid washed if previously used. Samples for lead in drinking water at a tap or from a drinking fountain should be collected in the morning before the system has been used and flushed out and also during the day when the water is being used. Samples for organic chemical analyses are usually collected in 40-ml glass vials or 1-liter glass bottles with Teflon-lined closure.[30] Special precautions are necessary to ensure collection of representative samples free of incidental contamination and without loss of volatile fractions.[31] Containers must be completely filled. A special preservative is added for certain tests, and delivery time to the laboratory is sometimes specified. Samples are also collected for selected tests to control routine operation of a water plant and to determine the treatment required and its effectiveness.

Samples for microscopic examination should be collected in clean widemouth bottles having a volume of 1 or 2 liters from depths that will yield representative organisms. Some organisms are found relatively close to the surface, whereas others are found at middepth or near the bottom, depending on the food, type of organism, and clarity and temperature of the water. Microscopic examinations can determine the changing types, concentrations and locations of microscopic organisms, control measures or treatment indicated, and time to start treatment. A proper program can prevent tastes and odors by eliminating the responsible organisms that secrete certain oils before they can cause the problem. In addition, objectionable appearances in a reservoir or lake are prevented and sedimentation and filter runs are improved. Attention should also be given to elimination of the conditions favoring the growth of the organisms. See also (a) Microscopic Examination and (b) Control of Microorganisms, this chapter.

Sampling Frequency

The frequency with which source and distribution system water samples are collected and used for bacteriologic, chemical, radiologic, microscopic, and physical analyses is usually determined by the regulatory agency, the water quality historical record, plant operational control requirements, and special problems. Operators of public water systems and industrial and commercial water systems will want to collect more frequent but carefully selected samples and make more analyses to detect changes in raw water quality to better control treatment, plant operation, and product quality.

The number of distribution system samples is usually determined by the population served, quality of the water source, treatment, past history, and special problems. Table 3-11 shows the minimum required sampling fre-

TABLE 3-11 Total Coliform Sampling Requirements According to Population Served

Population Served	Minimum Number of Routine Samples per Month[a]	Population Served	Minimum Number of Routine Samples per Month[a]
25–1000[b]	1[c]	59,001–70,000	70
1001–2500	2	70,001–83,000	80
2501–3300	3	83,001–96,000	90
3301–4100	4	96,001–130,000	100
4101–4900	5	130,001–220,000	120
4901–5800	6	220,001–320,000	150
5801–6700	7	320,001–450,000	180
6701–7600	8	450,001–600,000	210
7601–8500	9	600,001–780,000	240
8501–12900	10	780,001–970,000	270
12,901–17,200	15	970,001–1,230,000	300
17,201–21,500	20	1,230,001–1,520,000	330
21,501–25,000	25	1,520,001–1,850,000	360
25,001–33,000	30	1,850,001–2,270,000	390
33,001–41,000	40	2,270,001–3,020,000	420
41,001–50,000	50	3,020,001–3,960,000	450
50,001–59,000	60	3,960,001 or more	480

Source: Fact Sheet, Drinking Water Regulations under the Safe Drinking Water Act, Office of Drinking Water, U.S. Environmental Protection Agency, Washington, DC, May 1990, p. 22.

[a]In lieu of the frequency specified, a noncommunity water system (NCWS) using groundwater and serving 1000 persons or fewer may monitor at a lesser frequency specified by the state until a sanitary survey is conducted and reviewed by the state. Thereafter, NCWSs using groundwater and serving 1000 persons or fewer must monitor in each calendar quarter during which the system provides water to the public, unless the state determines that some other frequency is more appropriate and notifies the system (in writing). Five years after promulgation, NCWSs using groundwater and serving 1000 persons or fewer must monitor at least once a year. A NCWS using surface water or groundwater under the direct influence of surface water, regardless of the number of persons served, must monitor at the same frequency as a like-sized community water system (CWS). A NCWS using groundwater and serving more than 1000 persons during any month must monitor at the same frequency as a like-sized CWS, except that the state may reduce the monitoring frequency for any month the system serves 1000 persons or fewer.

[b]Include public water systems that have at least 15 service connections but serve fewer than 25 persons.

[c]For a CWS serving 25–1000 persons, the state may reduce this sampling frequency if a sanitary survey conducted in the last 5 years indicates that the water system is supplied solely by a protected groundwater source and is free of sanitary defects. However, in no case may the state reduce the frequency to less than once a quarter.

quency for coliform density at community water systems in the United States. If routine sampling results in a ‘‘positive’’ indication of coliform bacteria, repeat sampling must be performed to verify the presence of actual bacteria. Table 3-11a presents the number of repeat samples nececcary to verify

TABLE 3-11a Monitoring and Repeat Sample Frequency After Total Coliform-Positive Routine Sample

Samples per Month	Number of Repeat Samples[a]	Number of Routine Samples Next Month[b]
1	4	5
2	3	5
3	3	5
4	3	5
5 or greater	3	See Table 3-11

Source: Fact Sheet, Drinking Water Regulations under the Safe Drinking Water Act, Office of Drinking Water, U.S. Environmental Protection Agency, Washington, DC, December 1990, pp. 23–25.

[a]Number of repeat samples in the same month for each total coliform-positive routine sample.

[b]Except where state has invalidated the original routine sample, substitutes an on-site evaluation of the problem or waives the requirement on a case-by-case basis.

whether or not the system is contaminated. At noncommunity water supplies a sample is collected in each quarter during which the system provides water to the (traveling) public. The minimum sampling frequency recommended by the WHO is shown in Table 3-12. Sampling points should reflect the quality of the water in the distribution system and be at locations of greatest use.

Fecal coliforms/*E. coli;* Heterotrophic Bacteria (HPC)

- If any routine or repeat sample is total coliform positive, the system must also analyze that total coliform positive culture to determine if fecal coliforms or *E. coli* are present. If fecal coliforms or *E. coli* are detected, the system must notify the state before the end of the same business day, or, if detected after the close of business for the state, by the end of the next business day.
- If any repeat sample is fecal coliform or *E. coli* positive or if a fecal coliform- or *E. coli*-positive original sample is followed by a total coliform-positive repeat sample and the original total coliform-positive

TABLE 3-12 Distribution System Sampling

Population Served	Minimum Number of Samples
<5000	1 per month
5000–100,000	1 per 5000 population per month
>100,000	1 per 10,000 population per month

Source: Guidelines for Drinking-Water Quality, Vol. 1: *Recommendations,* World Health Organization, Geneva, 1984, p. 24.

sample is not invalidated, it is an acute violation of the MCL for total coliforms.

- The state has the discretion to allow a water system, on a case-by-case basis, to forego fecal coliform or *E. coli* testing on total coliform-positive samples if the system complies with all sections of the rules that apply when a sample is fecal coliform positive.
- State invalidation of the routine total coliform-positive sample invalidates subsequent fecal coliform- or *E. coli*-positive results on the same sample.
- Heterotrophic bacteria can interfere with total coliform analysis. Therefore, if the total coliform sample produces (1) a turbid culture in the absence of gas production using the multiple-tube fermentation (MTF) technique; (2) a turbid culture in the absence of an acid reaction using the presence–absence (PA) coliform test; or (3) confluent growth or a colony number that is "too numerous to count" using the membrane filter (MF) technique, the sample is invalid (unless total coliforms are detected, in which case the sample is valid). The system must collect another sample within 24 hr of being notified of the result from the same location as the original sample and have it analyzed for total coliforms.

Analytical Methodology

- Total coliform analyses are to be conducted using the 10-tube MTF technique, the MF Technique, the PA coliform test, or the minimal media ONPG-MUG test (Autoanalysis Colilert System). The system may also use the five-tube MTF technique (20-ml sample portions) or a single culture bottle containing the MTF medium as long as a 100-ml water sample is used in the analysis.
- A 100-ml standard sample volume must be used in analyzing for total coliforms, regardless of the analytical method used.

Invalidation of Total Coliform-Positive Samples

- All total coliform-positive samples count in compliance calculations, except for those samples invalidated by the state. Invalidated samples do not count toward the minimum monitoring frequency.
- A state may invalidate a sample only if (1) the analytical laboratory acknowledges that improper sample analysis caused the positive result; (2) the system determines that the contamination is a domestic or other nondistribution system plumbing problem; or (3) the state has substantial grounds to believe that a total coliform-positive result is due to some circumstance or condition not related to the quality of drinking water in the distribution system if (a) this judgment is explained in writing, (b) the document is signed by the supervisor of the state official who draws

this conclusion, and (c) the documentation is made available to the EPA and the public.

Variances and Exemptions: None Allowed Sanitary Surveys

- Periodic sanitary surveys are required for all systems collecting fewer than five samples a month every 5 years at community water systems and every 10 years at noncommunity water systems using protected and disinfected groundwater.

Water Analyses

All analyses should be made in accordance with *Standard Methods*[29] in order to provide confidence in the analytical results. As indicated previously, the interpretation of water analyses is based primarily on the sanitary survey of the water system and an understanding of the criteria used in the development of the standards used to establish drinking water quality. A water supply that is coagulated and filtered would be expected to be practically clear, colorless, and free of iron, whereas the presence of some turbidity, color, and iron in an untreated surface water supply may be accepted as normal. A summary is given below of the constituents and concentrations considered significant in water examinations. Other compounds and elements not mentioned are also found in water. The effectiveness of unit treatment processes can be measured using the tests for total coliforms, fecal coliforms, fecal streptococci, and the standard plate count 6 months prior to and 12 months after the process is put into use.

A properly developed, protected, and chlorinated well-water supply showing an absence of coliform organisms can usually be assumed to be free of viruses, protozoa, and helminths if supported by a satisfactory sanitary survey. This is not necessarily so with a surface-water supply. Chemical examinations are needed to ensure the absence of toxic organic and inorganic chemicals.

A final point: The results of a microbiological or chemical examination reflect the quality of the water only at the time of sampling and must be interpreted in the light of the sanitary survey. However, inorganic chemical examination results from well water supplies are not likely to change significantly from day to day or week to week when collected under the same conditions. Nevertheless, any change is an indication of probable contamination and reason for investigation to determine the cause. The chemical characteristics of well water are a reflection of the geological formations penetrated. Some bacterial and chemical analyses are shown in Table 3-13.

Heterotrophic Plate Count—The Standard Plate Count

The standard plate count is the total colonies of bacteria developing from measured portions (two 1 ml and two 0.1 ml) of the water being tested, which

TABLE 3-13 Some Bacterial and Chemical Analyses

Source of Sample	Dug Well	Lake	Reservoir	Deep Well	Deep Well
Time of year	—	April	October	—	—
Treatment	None	Chlorine	None	None	None
Bacteria per milliliters agar, 35°C, 24 hr	—	3	—	1	>5000
Coliform MPN per 100 ml	—	<2.2	—	<2.2	≥2400
Color, units	0	15	30	0	0
Turbidity, units	Trace	Trace	Trace	Trace	5.0
Odor					
Cold	2 vegetative	2 aromatic	1 vegetative	1 aromatic	3 disagreeable
Hot	2 vegetative	2 aromatic	1 vegetative	1 aromatic	3 disagreeable
Iron, mg/l	0.15	0.40	0.40	0.08	0.2
Fluorides, mg/l	<0.05	0.005	—	—	—
Nitrogen as ammonia, free, mg/l	0.002	0.006	0.002	0.022	0.042
Nitrogen as ammonia, albuminoid, mg/l	0.026	0.128	0.138	0.001	0.224
Nitrogen as nitrites, mg/l	0.001	0.001	0.001	0.012	0.030
Nitrogen as nitrates, mg/l	0.44	0.08	0.02	0.02	0.16
Oxygen consumed, mg/l	1.1	2.4	7.6	0.5	16.0
Chlorides, mg/l	17.0	5.4	2.2	9.8	6.6
Hardness (as $CaCO_3$), total, mg/l	132.0	34.0	84.0	168.0	148.0
Alkalinity (as $CaCO_3$), mg/l	94.0	29.0	78.0	150.0	114.0
pH value	7.3	7.6	7.3	7.3	7.5

have been planted in petri dishes with a suitable culture medium (agar) and incubated for 48 hr at 95°F (35°C). Bottled water is incubated at 35°C for 72 hr.[29] Only organisms that grow on the media are measured. Drinking water will normally contain some nonpathogenic bacteria; it is almost never sterile.

The test is of significance when used for comparative purposes under known or controlled conditions to show changes from the norm and determine if follow-up investigation and action are indicated. It can monitor changes in the quality (organic nutrients) of the water in the distribution system and storage reservoirs; it can be used to detect the presence of *Pseudomonas, Flavobacterium,* and other secondary invaders that could pose a health risk in the hospital environment; it can call attention to limitations of the coliform test when the average of heterotrophic plate counts in a month exceeds 100 to 500 per ml; it can show the effectiveness of distribution system residual chlorine and possible filter breakthrough; it can show distribution system deterioration, main growth, and sediment accumulation; and it can be used to assess the quality of bottled water. Large total bacterial populations (greater than 1000 per ml) may also support or suppress growth of coliform organisms. Taste, odor, or color complaints may also be associated with bacterial or other growths in mains or surface-water sources.[32] Bacterial counts may increase in water that has been standing if nutrients are present, such as in reservoirs after copper sulfate treatment and algae destruction or in dead-end mains. These are of no sanitary significance. Mesophilic fungi and actinomycetes, sometimes associated with tastes and odors, may be found in treated water.

Bacterial Examinations

The bacterial examinations for drinking water quality should always include, as a minimum, tests for total organisms of the coliform group, which are *indicative* of fecal contamination or sewage pollution. They are a normal inhabitant of the intestinal tract of humans and other animals. The goal is no coliform organisms in drinking water. In the past, the coliform group was referred to as the *B. coli* group and the *coli–aerogenes* group. The count for the total coliform group of organisms may include *Escherichia coli,* which is most common in the feces of humans and other warm-blooded animals; *Klebsiella pneumoniae,** which is found in feces and sputum, on fresh vegetables, and in organically rich surface water; *Enterobacter cloacae,* which is found in feces of warm-blooded animals in smaller number than *E. coli,* also in pipe joints, soil, and vegetation; *Citrobacter freundii,* which is normally found in soil and water, also in feces of humans and other warm-blooded animals; and *Enterobacter aerogenes,* which is found in human and other warm-blooded

*May have been identified in the past as *Aerobacter aerogenes*.

animal feces, soil, pipe joints, and vegetation.* Coliforms are also found in slimes, pump leathers, swimming pool ropes, stormwater drainage, surface waters, and elsewhere.

The tests for fecal coliforms, *E. coli,* fecal streptococci, and *Clostridium perfringens* may be helpful in interpreting the significance of surface-water tests for total coliforms and their possible hazard to the public health. Tests for *Pseudomonas* spp. may indicate the condition in water mains.

Coliform bacteria are not normally considered disease organisms. However, pathogenic (enterotoxigenic) strains of *E. coli* have caused outbreaks of ''traveler's diarrhea'' and gastroenteritis in institutions and in communities associated with food, raw milk, water, or fomites. The enteropathogenic strains have been associated with outbreaks in newborn nurseries. The test for *E. coli* at 95°F (35°C) is recommended as being a more specific indicator of fecal contamination in Denmark, Belgium, England, France,[33] and the United States. More extensive laboratory procedures are needed to identify *E. coli* and the enteropathogenic *E. coli. Escherichia coli* makes up about 95 percent of the fecal coliforms.

The coliform group of organisms includes all of the aerobic and facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that ferment lactose with acid and gas formation within 24 to 48 hr at 95 to 99°F (35–37°C). This is the presumptive test that can be confirmed and completed by carrying the test further as outlined in *Standard Methods*.[29] Coliform species identification is useful in interpreting the significance of the total coliform test where the cause is unclear. Differentiation can confirm the presence of *E. coli,* and hence fecal contamination, or other types of coliforms as previously explained. Prior to December 31, 1990, the results in the MTF were reported as the most probable number (MPN) of coliform bacteria, a statistical number most likely to produce the test results observed, per 100 ml of sample.

A review of the coliform rule by the EPA, as required by the 1986 amendment to the Safe Drinking Water Act, led to the development of a new regulatory standard effective December 31, 1990. This new standard is based on the presence or absence of total coliform bacteria rather than bacterial density. The new standard sets the MCL for total coliforms as follows:

Monthly Number of Samples	MCL
Fewer than 40	No more than 1 positive sample
40 or more	No more than 5.0% positive

In addition, an acute violation necessitating immediate public notification

* *Enterobacter* and *Klebsiella* are not considered pathogenic to humans, but may be associated with disease-causing organisms found in feces.

via broadcast media is required if a routine sample tests positive for total coliforms and for fecal coliforms or *E. coli* and any repeat sample tests positive for total coliforms or a routine sample tests positive for total coliforms and negative for fecal coliforms or *E. coli* and any repeat sample is positive for fecal coliforms or *E. coli*.

If the MTF method is used, the sample size is 100 ml. Either five 20-ml portions or ten 10-ml portions can be used. If any tube has gas formation, the sample is total coliform positive.

If the membrane filter technique is used, the coliform bacteria trapped on the filter produce dark colonies with a metallic sheen within 24 hr (18–22 hr) on an Endo-type medium containing lactose when placed in a 35°C incubator. The dark colonies are presumed to be of the coliform group and the sample is reported as coliform positive. The test can be carried further for coliform differentiation by following the procedure in *Standard Methods*.[29] Suspended matter, algae, and bacteria in large amounts interfere with the membrane filter (0.45 μm) procedure. Bacterial overgrowth on the filter would indicate an excessive bacterial population that should be investigated as to cause and significance.

For many years the MTF test and the membrane filtration (MF) test have been the approved methods for detecting the presence of coliform organisms. Another test, known as the Colilert test, was approved by the EPA in 1989 for the presence or absence of total coliform. A 100-ml sample and one 100-ml tube with a specially prepared media or a set of five 10-ml tubes* are used to which the test water is added and incubated at 95 to 99°F (35–37°C). A sterile technique must of course be used. The results are available within 24 hr or may be extended to 48 hr. The presence of coliform is shown by a color change to yellow, the absence by no color change. The presence of *E. coli* is also shown by fluorescence of the tube when viewed under ultraviolet (UV) light. Heterotrophic bacteria levels of 5000 to 700,000 per ml did not interfere with the Colilert test.

The *fecal coliform test* involves incubation at 112°F (44.5°C) for 24 hr and measures mostly *E. coli* in a freshly passed stool of humans or other warm-blooded animals. A loop of broth from each positive presumptive tube incubated at 95°F (35°C) in the total coliform test is transferred to EC (*E. coli*) broth and incubated at 112°F (44.5°C) in a waterbath; formation of gas within 24 hr indicates the presence of fecal coliform and hence also possibly dangerous contamination. Maintenance of 112°F (44.5 ± 0.2°C) is critical. Nonfecal organisms generally do not produce gas at 112°F (44.5°C). The test has greatest application in the study of stream pollution, raw water sources, sea waters, wastewaters, and the quality of bathing waters. An average individual contributes about 2 billion coliform per day through excrement.

*Standard tables are used to determine the MPN when more than one tube is used.

The *fecal streptococci* test (enterococci) uses special agar media incubated at 95°F (35°C) for 48 hr. Dark red to pink colonies are counted as fecal streptococci. They are also normally found in the intestinal tract of warm-blooded animals, including humans. Most (about 80%) of the human fecal streptococci are *Streptococcus faecalis; Streptococcus bovis* is associated with cows, and *Streptococcus equinus* with horses. These organisms may be more resistant to chlorine than coliform and survive longer in some waters but usually die off quickly outside the host. If found, it would indicate recent pollution. An average individual contributes approximately 450 million *fecal streptococci* per day.

The test for *C. perfringens* (*Clostridium welchii*), which is found in the intestines of humans and animals, may be of value in the examination of polluted waters and waters containing certain industrial wastes. Clostridia sporulate under unfavorable conditions and can survive indefinitely in the environment; they are more resistant than escherichia and streptococci. Therefore, their presence indicates past or possibly intermittent pollution.

In domestic sewage, the fecal coliform concentration is usually at least four times that of the fecal streptococci and may constitute 30 to 40 percent of the total coliforms. In stormwater and wastes from livestock, poultry, animal pets, and rodents, the fecal coliform concentration is usually less than 0.4 of the fecal streptococci. In streams receiving sewage, fecal coliforms may average 15 to 20 percent of the total coliforms in the stream. The presence of fecal coliform generally indicates fresh and possibly dangerous pollution. The presence of intermediate *aerogenes–cloacae* (IAC) subgroups of coliform organisms suggests past pollution or, in a municipal water supply, defects in treatment or in the distribution system.[34] A ratio of fecal coliforms to *C. perfringens* greater than 100 indicates sewage discharge.

The presence of any coliform organism in drinking water is a danger sign: It must be carefully interpreted in the light of water turbidity, chlorine residual, bacterial count, and sanitary survey, and it must be promptly eliminated. There may be some justification for permitting a low coliform density in developing areas of the world where the probability of other causes of intestinal diseases greatly exceeds those caused by water, as determined by epidemiological information. The lack of any water for washing promotes disease spread.

It must be understood and emphasized that the absence of coliform organisms or other indicators of contamination does not in and of itself ensure that the water is always safe to drink unless it is supported by a satisfactory, comprehensive sanitary survey of the drainage area, treatment unit processes, storage, and distribution system (including backflow prevention). Nor does the absence of coliforms ensure the absence of viruses, protozoa, or helminths unless the water is coagulated, flocculated, settled, gravity filtered, and chlorinated to yield a free residual chlorine of at least 0.5 mg/l, preferably for 1 hr before it is available for consumption. The WHO recommends a free residual chlorine of at least 0.5 mg/l with a contact period of at least 30 min at a pH below 8.0 and a nephelometric turbidity unit (NTU) of 1 or less. A free ozone of 0.2 to 0.4 mg/l for 4 min has been found to be effective to inactivate viruses in clean water (ref. 27, Vol. 2, p. 28). Chlorine dioxide and chloramine treatment may also be used. See Disinfection, this chapter.

Biological Monitoring

A seven-day biological toxicity test of raw water may be useful to measure chronic effects. Indicators may include the fathead minnow and *Ceriodaphnia,* their survival, growth rate, and reproduction. In some instances, biological monitoring will be more meaningful than environmental monitoring: It can measure the combined effect of air, water, and food pollutants on an organism or animal; this information can be more closely related to potential human health effects. See also Biomonitoring, Chapter 4.

Virus Examination

The examination of water for enteroviruses has not yet been simplified to the point where the test can be made routinely for compliance monitoring as for coliform. Viruses range in size from 0.02 to 0.1 μm. There are more than 100 different types of enteric viruses known to be infective. Fecal wastes may contain enteroviruses (echoviruses, polioviruses, and coxsackieviruses—groups A and B) as well as adenoviruses, reoviruses, rotaviruses, Norwalk viruses, and infectious hepatitis viruses (viral hepatitis A).

Enteroviruses may be more resistant to treatment and environmental factors than fecal bacteria, persist longer in the water environment, and remain viable for many months dependent on temperature and other factors. Enteric viruses, such as protozoa (*Giardia lamblia, Entamoeba histolytica,* and *Cryptosporidium* spp.), may be present even if coliform are absent.

Normally a large volume of water (100–500 gal) must be sampled and an effective system used to capture, concentrate, and identify viruses. Results may not be available until one or two weeks later (ref. 27, Vol. 2, p. 34). Special analytical laboratory facilities and procedures are required. See *Standard Methods*.[29] A virus standard for drinking water has not been established. A goal of zero to not more than 1 plaque-forming unit (pfu) per 1000 gal of drinking water has been suggested.

Since monitoring for enteric viruses is not feasible for routine control of water treatment plant operation, the EPA is requiring specific treatment, or the equivalent, of all surface waters and mandatory chlorination, or equivalent protection, of all groundwaters. Coagulation, flocculation, settling, and rapid sand filtration; slow sand filtration; and lime-soda softening process remove 99 percent or more of the viruses. A pH above 11 inactivates viruses.

Free chlorine is more effective than combined chlorine in inactivating viruses and is more effective at low pH. Turbidity can shield viruses and make chlorination only partially effective. Based on available information, the WHO considers treatment adequate if a turbidity of 1 NTU or less is achieved and the free residual chlorine is at least 0.5 mg/l after a contact period of at least 30 min at a pH below 8.0. Prudence would dictate that water obtained from a source known to receive sewage wastes should be coagulated, flocculated, settled, filtered, and disinfected to produce at least 0.4 mg/l free residual chlorine for 2 hr before delivery. Ozone is also an effective disinfectant for clean water if residuals of 0.2 to 0.4 mg/l are maintained for 4 min, but the residual does not remain in the distribution system (ref. 27, Vol. 1, p. 28). The EPA requires 99.99 percent removal and/or inactivation of enteric viruses.

Protozoa and Helminths Examination

The complex procedure to sample, collect, prepare, and positively identify the protozoan cysts of *Giardia lamblia* is impractical for the routine control of water treatment. Because of this, the EPA requires complete treatment of surface waters unless the absence of giardia cysts can be demonstrated and assured by other acceptable means. Sampling for giardia cysts usually involves the filtration of about 500 gal of the water through a 1-μm-pore-size cartridge filter at a rate of about 1 gal/min. The filter extract and sediment collected are concentrated, slides are prepared, and the giardia cyst identified microscopically. Giardia cysts cannot be cultured. Ongerth[35] developed a procedure using a 5-μm-pore-size filter and a 10-gal sample that was reported to be efficient in recovering giardia cysts. Reservoir retention of 30 to 200 days did not reduce cyst concentration. It should be noted that whereas the giardia cyst is about 10 to 15 μm in size, the cryptosporidium oocyst is about 3 to 6 μm in size. The absence of coliform organisms does not indicate the absence of protozoa. Waterborne diseases caused by protozoa include amebic dysentery (amebiasis, *E. histolytica*), giardiasis (*G. lamblia*), cryptosporidiosis (*Cryptosporidium* spp.), meningoencephalitis (*Naegleria fowleri* and *Acanthamoeba culbertsoni*), and balantidiasis (*B. coli*). Person-to-person contact, poor personal hygiene, and food are also common means of transmission of the diseases. Meningoencephalitis, also known as primary amebic meningoencephalitis, a rare but almost always fatal disease, is associated with swimming or bathing in warm, fresh, and brackish water. Immersion of the head (nasal passages) in the contaminated water is usually involved. The organism is commonly found in soil, fresh water, and decaying vegetation.

The helminths include roundworms, tapeworms, and flukes. The most common disease, spread by *Dracunculus medinensis* in drinking water, is dracontiasis, also known as Guinea-worm infection. Other helminths, such as *Fasciola, Schistosoma, Fasciolopsis, Echinococcus,* and *Ascaris* are more likely to be transmitted by contaminated food and hand to mouth, particularly in areas where sanitation and personal hygiene are poor. Helminths are 50 to 60 μm in size.

Because of the resistance of the protozoa and helminths to normal chlorination and the lack of routine analytical procedures for water treatment plant operation control, complete water treatment is required for drinking water.

Specific Pathogenic Organisms

It is not practical to routinely test for and identify specific disease organisms causing typhoid, paratyphoid, infectious hepatitis A, shigellosis, cholera, and others. (See Figure 1-2 for water treatment plant operation control.) The procedures would be too complex and time consuming for routine monitoring. However, laboratory techniques, media, and equipment are available for special studies and investigations where specific organism identification is indicated.

Physical Examinations

Odor Odor should be absent or very faint for water to be acceptable, less than 3 threshold odor number (TON). Water for food processing, beverages, and pharmaceutical manufacture should be essentially free of taste and odor. The test is very subjective, being dependent on the individual senses of smell and taste. The cause may be decaying organic matter, wastewaters including industrial wastes, dissolved gases, and chlorine in combination with certain organic compounds such as phenols. Odors are sometimes confused with tastes. The sense of smell is more sensitive than taste. Activated carbon adsorption, aeration, chemical oxidation (chlorine, chlorine dioxide, ozone, potassium permanganate), and coagulation and filtration will usually remove odors and tastes. Priority should first be given to a sanitary survey of the watershed drainage area and the removal of potential sources or causes of odors and tastes.

A technique for determining the concentration of odor compounds from a water sample to anticipate consumer complaints involves the "stripping" of odor compounds from a water sample that is adsorbed onto a carbon filter. The compounds are extracted from the filter and injected into a gas chromatograph–mass spectrometer for identification and quantification.[36]

Taste The taste of water should not be objectionable; otherwise, the consumer will resort to other sources of water that might not be of satisfactory sanitary quality. Algae, decomposing organic matter, dissolved gases, high concentrations of sulfates, chlorides, and iron, or industrial wastes may cause tastes and odors. Bone and fish oil and petroleum products such as kerosene and gasoline are particularly objectionable. Phenols in concentrations of 0.2 ppb in combination with chlorine will impart a phenolic or medicinal taste to drinking water. The taste test, like the odor test, is very subjective and may be dangerous to laboratory personnel. As in odor control, emphasis should be placed on the removal of potential causes of taste problems. See discussions of causes and methods to remove or reduce tastes and odors, this chapter.

Turbidity Turbidity is due to suspended material such as clay, silt, or organic and inorganic materials. Enhanced surface-water regulations in the United States require that the maximum contaminant level for turbidity not exceed 0.5 NTU in 95% of the samples taken every month and must never exceed 1 NTU. Additionally, the utility must maintain a minimum of 0.2 mg/l free chlorine residual at representative points within the distribution system. Turbidity measurements are made in terms of nephelometric turbidity units (NTU), Formazin turbidity units (FTU), and Jackson turbidity units (JTU). The lowest turbidity value that can be measured directly on the Jackson candle turbidimeter is 25 units. There is no direct relationship between NTU or FTU readings and JTU readings.[29] The NTU is the standard measure, requiring use of a nephelometer, which measures the amount of light scattered, usually at 90° from the light direction, by suspended particles in the water test sample. It can measure turbidities of less than 1 unit and differences of 0.02 unit. Secondary turbidity measurement standards calibrated against the Formazin standard may also be accepted by the EPA.

The public demands sparkling clear water. This implies a turbidity of less than 1 unit; a level of less than 0.1 unit, which is obtainable when water is coagulated, flocculated, settled, and filtered, is practical. Turbidity is a good measure of sedimentation, filtration, and storage efficiency, particularly if supplemented by the total microscopic and particle count. Increased chlorine residual, bacteriological sampling, and main flushing is indicated when the maximum contaminant level for turbidity is exceeded in the distribution system until the cause is determined and eliminated. Turbidity will interfere with proper disinfection of water, harbor microorganisms, and cause tastes and odors. As turbidity increases, coliform masking in the membrane filter technique is increased.

The American Water Works Association recommends an operating level of no more than 0.3 NTU in filter plant effluent and a goal of no more than 0.2 NTU.

An increase in the turbidity of well water after heavy rains may indicate the entrance of inadequately purified groundwater.

Color Color should be less than 15 true color units* (sample is first filtered), although persons accustomed to clear water may notice a color of only 5 units. The goal is less than 3 units. Water for industrial uses should generally have a color of 5 to 10 or less. Color is caused by substances in solution,

*Cobalt platinum units.

known as true color, and by substances in suspension, mostly organics causing apparent or organic color. Iron, copper, manganese, and industrial wastes may also cause color.

Water that has drained through peat bogs, swamps, forests, or decomposing organic matter may contain a brownish or reddish stain due to tannates and organic acids dissolved from leaves, bark, and plants. Excessive growths of algae or microorganisms may also cause color.

Color resulting from the presence of organics in water may also cause taste, interfere with chlorination, induce bacterial growth, make water unusable by certain industries without further treatment, foul anion exchange resins, interfere with colorimetric measurements, limit aquatic productivity by absorbing photosynthetic light, render lead in pipes soluble, hold iron and manganese in solution causing color and staining of laundry and plumbing fixtures, and interfere with chemical coagulation. Chlorination of natural waters containing organic water color (and humic acid) results in the formation of trihalomethanes including chloroform. This is discussed later.

Color can be controlled at the source by watershed management. Involved is identifying waters from sources contributing natural organic and inorganic color and excluding them, controlling beaver populations, increasing water flow gradients, using settling basins at inlets to reservoirs, and blending water.[37] Coagulation, flocculation, settling, and rapid sand filtration should reduce color-causing substances in solution to less than 5 units, with coagulation as the major factor. Slow sand filters should remove about 40 percent of the total color. True color is costly to remove. Oxidation (chlorine, ozone) or carbon adsorption also reduces color.

Temperature The water temperature should preferably be less than 60°F (16°C). Groundwaters and surface waters from mountainous areas are generally in the temperature range of 50 to 60°F (10–16°C). Design and construction of water systems should provide for burying or covering of transmission mains to keep drinking water cool and prevent freezing in cold climates or leaks due to vehicular traffic. High water temperatures accelerate the growth of nuisance organisms, and taste and odor problems are intensified. Low temperatures somewhat decrease the disinfection efficiency.

Microscopic Examination

Microscopic and macroscopic organisms that may be found in drinking water sources include bacteria, algae, actinomycetes, protozoa, rotifers, yeasts, molds, and small crustacea, worms, and mites. Most algae contain chlorophyll and require sunlight for their growth. The small worms are usually insect larvae. Larvae, crustacea, worms, molds or fungi, large numbers of algae, or filamentous growths in the drinking water would make the water aesthetically unacceptable and affect taste and odor. Immediate investigation to eliminate the cause would be indicated.

The term "plankton" includes algae and small animals such as cyclops and daphnia. Plankton are microscopic plants and animals suspended and floating in fresh and salt water and are a major source of food for fish. Algae include diatoms, cyanophyceae or blue-green algae (bacteria), and chlorophyceae or green algae; they are also referred to as phytoplankton. Protozoan and other small animals are referred to as zooplankton. They feed on algae and bacteria. The microbial flora in bottom sediments are called the benthos.[38] Phototrophic microorganisms are plankton primarily responsible for the production of organic matter via photosynthesis.

Algal growths increase the organic load in water, excrete oils that produce tastes and odors, clog sand filters, clog intake screens, produce slimes, interfere with recreational use of water, may cause fish kills when in "bloom" and in large surface "mats" by preventing replenishment of oxygen in the water, become attached to reservoir walls, form slimes in open reservoirs and recirculating systems, and contribute to corrosion in open steel tanks[39] and disintegration of concrete. Algae increase oxygen and heavy concentrations reduce hardness and salts. In the absence of carbon dioxide, algae break down bicarbonates to carbonates, thereby raising the water pH to 9 or higher. Algae also contribute organics, which on chlorination add to trihalomethane formation.

Microscopic examination involves collection of water samples from specified locations and depths. The sample is preserved by the addition of formaldehyde if not taken immediately to the laboratory. At the laboratory the plankton in the sample is concentrated by means of a centrifuge or a Sedgwick–Rafter sand filter. A 1-ml sample of the concentrate is then placed in a Sedgwick–Rafter counting cell for enumeration using a compound microscope fitted with a Whipple ocular micrometer. The Lackey Drop Microtransect Counting Method is also used, particularly with samples containing dense plankton populations.[29] Enumeration methods include total cell count, clump count, and areal standard unit count.

Examinations of surface-water sources, water mains, and well-water supplies, which are sources of difficulty, should be made weekly to observe trends and determine the need for treatment or other controls and their effectiveness before the organisms reach nuisance proportions. The "areal standard unit" represents an area 20 microns (μm) square or 400 μm^2. One micrometer equals 0.001 mm. Microorganisms are reported as the number of areal standard units per milliliter. Protozoa, rotifers, and other animal life are individually counted. Material that cannot be identified is reported as areal standard units of amorphous matter (detritus). The apparatus, procedure, and calculation of results and conversion to "Cubic Standard Units" is explained in *Standard Methods*.[29]

When more than 300 areal standard units, or organisms, per milliliter is reported, treatment with $CuSO_4$ is indicated to prevent possible trouble with tastes and odors or short filter runs. When more than 500 areal standard units or cells per milliliter is reported, complaints can be expected and the need for immediate action is indicated. A thousand units or more of amorphous matter indicates probable heavy growth of organisms that have died and disintegrated or organic debris from decaying algae, leaves, and similar materials.

The presence of asterionella, tabellaria, synedra, beggiatoa, crenothrix, *Sphaerotilis natans,* mallomonas, anabaena, aphanizomenon, volvox, ceratium, dinobryon, synura, uroglenopsis, and other, some even in small concentrations, may cause tastes and odors that are aggravated where marginal chlorine treatment is used. Free residual chlorination will usually reduce the tastes and odors. More than 25 areal standard units per milliliter of synura, dinobryon, or uroglena, or 300 to 700 units of asterionella, dictyosphaerium, aphanizomenon, volvox, or ceratium in chlorinated water will usually cause taste and odor complaints. The appearance of even 1 areal standard unit of a microorganism may be an indication to start immediate copper sulfate treatment if past experience indicates that trouble can be expected.

The blue-green algae, anabaena, microcystis (polycystis), nodularia, gloeotrichia, coelosphaerium, *Nostoc rivulare,* and aphanizomenon in large concentrations have been responsible for killing fish and causing illness in horses, sheep, dogs, ducks, chickens, mice, and cattle.[40] Illness in humans from these causes has been suspected but confirmatory evidence is limited (ref. 27, Vol. 2, p. 54). Gorham[41] estimated that the oral minimum lethal dose of decomposing toxic microcystis bloom for a 150-lb man is 1 to 2 qt of thick, paintlike suspension and concluded that toxic waterblooms of blue-green algae in public water supplies are not a significant health hazard. Red tides caused by the dinoflagellates *Gonyaulax monilata* and *Gymnodinium brevis* have been correlated with mass mortality of fish.[41] Coagulation, flocculation, sedimentation, and filtration do not remove algal toxins nor does the usual activated carbon treatment.

Investigation of conditions contributing to or favoring the growth of plankton in a reservoir and their control should reduce dependence on copper sulfate treatment. See Control of Microorganisms, this chapter.

Chemical Examinations*

The significance of selected chemical elements and compounds in drinking water is discussed below. An intake of 2 liters of water per day per person is assumed in determining health effects. The MCL is the National Drinking Water Regulation maximum contaminant level. The maximum contaminant level goal (MCLG) is a desirable one and is nonmandatory unless specifically made so by a state. The WHO level represents a guideline value "of a con-

*Results are reported as milligrams per liter (mg/l), which for all practical purposes can be taken to be the same as parts per million (ppm), except when the concentrations of substances in solution approach or exceed 7000 mg/l, when a density correction should be made.

stituent that ensures an aesthetically pleasing water and does not result in any significant risk to the health of the consumer'' (ref. 27, Vol. 1, pp. 1, 107). A value in excess of the guideline value does not in itself imply that the water is unsuitable for consumption. A comprehensive discussion of health-related inorganic and organic constituents can be found in *Guidelines for Drinking-Water Quality,* Vol. 2, WHO, Geneva, 1984. Gas chromatographic mass spectrometry is considered the best method for identifying and quantifying specific organic compounds in an unknown sample. The removal of organic and inorganic chemicals from drinking water is reviewed later in this chapter.

Albuminoid Ammonia Albuminoid ammonia represents ''complex'' organic matter and thus would be present in relatively high concentrations in water supporting algae growth, receiving forest drainage, or containing other organic matter. Concentrations of albuminoid ammonia higher than about 0.15 mg/l, therefore, should be appraised in the light of origin of the water and the results of microscopic examination. In general, the following concentrations serve as a guide: low—less than 0.06 mg/l; moderate—0.06 to 0.15 mg/l; high—0.15 mg/l or greater. When organic nitrogen and ammonia nitrogen forms are found together, they are measured as Kjeldahl nitrogen.

Alkalinity The alkalinity of water passing through distribution systems with iron pipe should be in the range of 30 to 100 mg/l, as $CaCO_3$, to prevent serious corrosion; up to 500 mg/l is acceptable, although this factor must be appraised from the standpoint of pH, hardness, carbon dioxide, and dissolved-oxygen content. Corrosion of iron pipe is prevented by the maintenance of calcium carbonate stability. Undersaturation will result in corrosive action in iron water mains and cause red water. Oversaturation will result in carbonate deposition in piping and water heaters and on utensils. See Corrosion Cause and Control, this chapter. Potassium carbonate, potassium bicarbonate, sodium carbonate, sodium bicarbonate, phosphates, and hydroxides cause alkalinity in natural water. Calcium carbonate, calcium bicarbonate, magnesium carbonate, and magnesium bicarbonate cause hardness as well as alkalinity. Sufficient alkalinity is needed in water to react with added alum to form a floc in water coagulation. Insufficient alkalinity will cause alum to remain in solution. Bathing or washing in water of excessive alkalinity can change the pH of the lacrimal fluid around the eye, causing eye irritation.

Aluminum The EPA-recommended goal is less than 0.05 mg/l; the WHO guideline is 0.2 mg/l (ref. 27, Vol. 1, pp. 6–7; Vol 2, p. 88). Aluminum is not found naturally in the elemental form, although it is one of the most abundant metals on the earth's surface. It is found in all soils, plants, and animal tissues. Aluminum-containing wastes concentrate in and can harm shellfish and bottom life.[42] Alum as aluminum sulfate is commonly used as a coagulant in water treatment; excessive aluminum may pass through the filter with improper pH control. Precipitation may take place in the distribution system or on standing when the water contains more than 0.5 mg/l. Its presence in filter plant effluent is used as a measure of filtration efficiency. Although ingested aluminum does not appear to be harmful, aluminum compounds have been associated with neurological disorders in persons on kidney dialysis machines. Aluminum in the presence of iron may cause water discoloration. There may be an association between aluminum and Alzheimer's disease, but this has not been confirmed.[43]

Arsenic The MCL for arsenic in drinking water was lowered from 0.05 mg/l to 0.01 mg/l by the EPA in January 2001. The WHO guideline is also 0.01 mg/l. [The Occupational Safety and Health Administration (OSHA) standard is 10 $\mu g/m^3$ for occupational exposure to inorganic arsenic in air over an 8-hr day; 2 $\mu g/m^3$ for 24 hr exposure to ambient air.[44]] A probable lethal oral dose is 5 to 20 mg/kg depending on the compound and individual sensitivity. Sources of arsenic are natural rock formations (phosphate rock), industrial wastes, arsenic pesticides, fertilizers, detergent "presoaks," and possibly other detergents. It is also found in foods, including shellfish and tobacco, and in air in some locations.

There is ample evidence that defines a relationship between certain cancers (e.g., skin, bladder, kidney, lung, liver) and high levels of arsenic in drinking water (i.e., above 0.2 mg/l). There is significant debate, however, if these cancers are seen at lower levels of arsenic. Arsenic occurs naturally as arsenic, +3 (arsenite) and arsenic, +5 (arsenate). Arsenites are more toxic than arsenates. Arsenic may be converted to dimethylarsine by anaerobic organisms and accumulate in fish, similar to methylmercury.[46] A concentration of 10 $\mu g/l$ (0.01 mg/l) is believed to be protective of public health with over 3,000 public water systems needing to install removal systems by February 2006. For treatment, see Removal of Inorganic Chemicals, this chapter.

Asbestos Most asbestos-related diseases (mesotheliomas) are associated with the breathing of air containing asbestos fibers as long as 20 years earlier. Sources of exposure include working or living in the immediate vicinity of crocidolite mines, asbestos insulation and textile factories, and shipyards. (See Chapter 1.) Asbestos in drinking water may come from certain naturally occurring silicate materials in contact with water or from eroded asbestos cement pipe. A study (1935–1973) on the incidence of gastrointestinal cancer and use of drinking water distributed through asbestos cement (A/C) pipe reached the preliminary conclusion that "no association was noted between these asbestos risk sources and gastrointestinal tumor incidence."[47] A subsequent study concluded "the lack of coherent evidence for cancer risk from the use of A/C pipe is reassuring."[48] An EPA study shows no statistical association between deaths due to certain types of cancer and the use of A/C pipe. British researchers reported that the cancer risk was "sensibly zero" or exceedingly low[49]: "Available studies on humans and animals do not provide evidence to support the view that ingestion of drinking water containing asbestos causes organ-specific cancers." Nevertheless, exposure to the asbestos fibers in drinking water should be reduced. Conventional water treatment, including coagulation and filtration, will remove more than 90 percent of the asbestos fibers in the raw water.[50]

Asbestos cement pipe was found to behave much like other piping materials, except polyvinyl chloride (PVC), that are commonly used for the distribution of drinking water. It has been concluded that, where "aggressive water conditions exist, the pipe will corrode and deteriorate; if aggressive water conditions do not exist, the pipe will not corrode and deteriorate."[51] Aggressive water can leach calcium hydroxide from the cement in A/C pipe. The American Water Works Association (AWWA) Standard C400-77 establishes criteria for the type of pipe to use for nonaggressive water ($\geq$12.0), moderately aggressive water (10.9–11.9), and highly aggressive water ($\leq$10.0) based on the sum of the pH plus the log of the alkalinity times the calcium hardness, as calcium carbonate. Remedial measures, in addition to pH adjustment and control of corrosion, include chemical addition to build up a protective film, elimination of hydrogen sulfide, rehabilitation and lining of existing pipe, pipe replacement, and a flushing program. Asbestos cement pipe should not be used to carry aggressive water.

If the water is heavily contaminated, its use for humidifiers, showers, food preparation, clothes laundering, and drinking is not advised since the asbestos fibers can become airborne and be inhaled. The EPA has recommended a maximum contaminant level of 7.1×10^6 asbestos fibers longer than 10 μm/l from all sources, including naturally occurring asbestos. On July 6, 1989, the EPA ruled to prohibit manufacture, importation, and processing of asbestos in certain products and to phase out the use of asbestos in all other products. This action was meant to reduce airborne asbestos in the workplace and ambient air and thereby the carcinogenic health risk associated with the inhalation of asbestos fibers. See also Asbestos Diseases, Chapter 1.

Barium Barium may be found naturally in groundwater (usually in concentrations less than 0.1 mg/l) and in surface water receiving industrial wastes; it is also found in air. It is a muscle stimulant and in large quantities may be harmful to the nervous system and heart. The fatal dose is 550 to 600 mg. The MCL is 2 mg/l in drinking water. A WHO guideline has not been established; concentrations of 10 mg/l are not considered significant. Barium can be removed by weak-acid ion exchange.

Benzene[52] This chemical is used as a solvent and degreaser of metals. It is also a major component of gasoline. Drinking water contamination generally results from leaking underground gasoline and petroleum tanks or improper waste disposal. Benzene has been associated with significantly increased risks of leukemia among certain industrial workers exposed to relatively large amounts of this chemical during their working careers. This chemical has also been shown to cause cancer in laboratory animals when the animals are exposed to high levels over their lifetimes. Chemicals that cause increased risk of cancer among exposed industrial workers and in laboratory animals also may increase the risk of cancer in humans who are exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for benzene at 0.005 mg/l to reduce the risk of cancer or other adverse health effects observed in humans and laboratory animals. The OSHA standard is 1 mg/l with 5 mg/l for short-term (15-min) exposure.[53]

Cadmium The federal drinking water MCL for cadmium is 0.005 mg/l. The WHO guideline is 0.005 mg/l.[27] Common sources of cadmium are water mains and galvanized iron pipes, tanks, metal roofs where cistern water is collected, industrial wastes (electroplating), tailings, pesticides, nickel plating, solder, incandescent light filaments, photography wastes, paints, plastics, inks, nickel–cadmium batteries, and cadmium-plated utensils. It is also found in zinc and lead ores. Cadmium vaporizes when burned; salts of cadmium readily dissolve in water and can, therefore, be found in air pollutants, wastewater, wastewater sludge, fertilizer, land runoff, some food crops, tobacco, and drinking water. Beef liver and shellfish are very high in cadmium. Large concentrations may be related to kidney damage, hypertension (high blood pressure), chronic bronchitis, and emphysema. Cadmium builds up in the human body, plants, and food animals. It has a biological half-life of about 20 years (18–38) (ref. 27, Vol. 1, pp. 6–7; Vol. 2, p. 88). The direct relationship between cardiovascular death rates in the United States, Great Britain, Sweden, Canada, and Japan and the degree of softness or acidity of water point to cadmium as the suspect.[54] In 1972, the Joint WHO Food and Agriculture Organization Expert Committee on Food Additives established a provisional tolerable weekly cadmium intake of 400 to 500 μg. Cadmium removal from water is discussed later in this chapter.

Carbon–Chloroform Extract (CCE) and Carbon–Alcohol Extract (CAE) (Tests No Longer Routinely Used) Carbon–chloroform extract may include chlorinated hydrocarbon pesticides, nitrates, nitrobenzenes, aromatic ethers, and many others adsorbed on an activated carbon cartridge. Water from uninhabited and nonindustrial watersheds usually show CCE concentrations of less than 0.04 mg/l. The taste and odor of drinking water can be expected to be poor when the concentration of CCE reaches 0.2 mg/l. Carbon–alcohol extract measures gross organic chemicals including synthetics. A goal of less than 0.04 mg/l CCE and 0.10 mg/l CAE has been proposed.

Carbon Dioxide The only limitation on carbon dioxide is that pertaining to corrosion. It should be less than 10 mg/l, but when the alkalinity is less than 100 mg/l, the CO_2 concentration should not exceed 5.0 mg/l.

Carbon Tetrachloride[52] This chemical was once a popular household cleaning fluid. It generally gets into drinking water by improper disposal. This chemical has been shown to cause cancer in laboratory animals such as rats and mice when exposed at high levels over their lifetimes. Chemicals that cause cancer in laboratory animals may also increase the risk of cancer in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for carbon tetrachloride at 0.005 mg/l to reduce the risk of cancer or other adverse health effects observed in laboratory animals. The WHO *tentative* guideline value is 3 μg/l.

Chlorides of Intestinal Origin Natural waters remote from the influence of ocean or salt deposits and not influenced by local sources of pollution have a low chloride content, usually less than 4.0 mg/l. Due to the extensive salt deposits in certain parts of the country, it is impractical to assign chloride concentrations that, when exceeded, indicate the presence of sewage, agricultural, or industrial pollution, unless a chloride record over an extended period of time is kept on each water supply. In view of the fact that chlorides are soluble, they will pass through pervious soil and rock for great distances without diminution in concentration, and thus the chloride content must be interpreted with considerable discretion in connection with other constituents in the water. The concentration of chlorides in urine is about 5000 mg/l, in septic tank effluent about 80 mg/l, and in sewage from a residential community 50 mg/l depending on the water source.

Chlorides of Mineral Origin The WHO guideline for chloride ion is 250 mg/l (ref. 27, Vol. 1, pp. 80, 81, 85). A goal of less than 100 mg/l is recommended. The permissible chloride content of water depends on the sensitivity of the consumer. Many people notice a brackish taste imparted by 125 mg/l of chlorides in combination with sodium, potassium, or calcium, whereas others are satisfied with concentrations as high as 250 mg/l. Irrigation waters should contain less than 200 mg/l. When the chloride is in the form of sodium chloride, use of the water for drinking may be inadvisable for persons who are under medical care for certain forms of heart disease. The main intake of chlorides is with foods. (See Chapter 1.) Hard water softened by the ion exchange or lime-soda process (with Na_2CO_3) will increase sodium concentrations in the water. Salt used for highway deicing may contaminate groundwater and surface-water supplies. Its use should be curtailed and storage depots covered. Chlorides can be removed from water by distillation, reverse osmosis, or electrodialysis and minimized by proper aquifer selection and well construction. Water sources near oceans or in the vicinity of underground salt deposits may contain high salt concentrations. Well waters from sedimentary rock are likely to contain chlorides. The corrosivity of water is increased by high concentrations of chlorides, particularly if the water has a low alkalinity.

Chromium The total chromium MCL and WHO guideline[27] is 0.1 mg/l in drinking water. Chromium is found in cigarettes, some foods, the air, and industrial plating, paint, and leather tanning wastes. Chromium deficiency is associated with atherosclerosis. Hexavalent chromium dust can cause cancer of the lungs[55] and kidney damage.

Copper The EPA action level for copper is 1.3 mg/l; the WHO guideline is 1.0 mg/l.[27] The goal is less than 0.2 mg/l. Concentrations of this magnitude are not present in natural waters but may be due to the corrosion of copper or brass piping; 0.5 to 1.0 mg/l in soft water stains laundry and plumbing fixtures blue-green. A concentration in excess of 0.2 to 0.3 mg/l will cause an "off" flavor in coffee and tea; 5 mg/l or less results in a bitter metallic taste; 1 mg/l may affect film and reacts with soap to produce a green color in water; 0.25 to 1.0 mg/l is toxic to fish. Corrosion of galvanized iron and steel fittings is reported to be enhanced by copper in public water supplies. Copper appears to be essential for all forms of life, but excessive amounts are toxic to fish. The estimated adult daily requirement is 2.0 mg, coming mostly from food. Copper deficiency is associated with anemia. Copper salts are commonly used to control algal growths in reservoirs and slime growths in water systems. Copper can be removed by ion exchange, conventional coagulation, sedimentation, filtration, softening, or reverse osmosis; when caused by corrosion of copper pipes, it can be controlled by proper water treatment and pH control. Copper sulfate treatment of the water source for algae control may contribute copper to the finished water. Electrical grounding to copper water pipe can add to the copper dissolution.

Corrosivity Water should be noncorrosive. Corrosivity of water is related to its pH, alkalinity, hardness, temperature, dissolved oxygen, carbon dioxide, total dissolved solids, and other factors. Waters high in chlorides and low in alkalinity are particularly corrosive. Since a simple, rapid test for corrosivity is not available, test pipe sections or metal coupons (90-day test) are used, supplemented, where possible, by water analyses such as calcium carbonate saturation, alkalinity, pH, and dissolved solids and gases. Incrustation on stainless steel test pipe or metal coupon should not exceed 0.05 mg/cm^2; loss by corrosion of galvanized iron should not exceed 5.00 mg/cm^2 (AWWA). The corrosion of copper tubing increases particularly when carrying water above 140°F (60°C). Schroeder[55] reports that pewter, britannia metal, water pipes, and cisterns may contain antimony, lead, cadmium, and tin, which leach out in the presence of soft water or acidic fluids. Soft water flowing over galvanized iron roofs or through galvanized iron pipes or stored in galvanized tanks contains cadmium and zinc. Ceramic vessels contain antimony, beryllium, barium, nickel, and zirconium; pottery glazes contain lead, all of which may be leached out if improper firing and glazing are used. Corrosivity is controlled by pH, alkalinity, and calcium carbonate adjustment, including use of lime, sodium carbonate, and/or sodium hydroxide. Other means include the addition of polyphosphate, orthophosphate, and silicates and pH control. In any case, corrosion-resistant pipe should be used where possible.

Cyanide Cyanide is found naturally and in industrial wastes. Cyanide concentrations as low as 10 μg/l have been reported to cause adverse effects in fish. Long-term consumption of up to 4.7 mg/day has shown no injurious effects (ref. 45, pp. 128–136). The cyanide concentration in drinking water should not exceed 0.2 mg/l. The probable oral lethal dose is 1.0 mg/kg. The WHO guideline is 0.1 mg/l. An MCL and MCLG of 0.2 mg/l has been established by the EPA. Cyanates can ultimately decompose to carbon dioxide and nitrogen gas (ref. 27, Vol. 2, p. 97). Cyanide is readily destroyed by conventional treatment processes.

1,1-Dichloroethylene[52] This chemical is used in industry and is found in drinking water as a result of the breakdown of related solvents. The solvents are used as cleaners and degreasers of metals and generally get into drinking water by improper waste disposal. This chemical has been shown to cause liver and kidney damage in laboratory animals such as rats and mice when exposed at high levels over their lifetimes. Chemicals that cause adverse effects in laboratory animals may also cause adverse health effects in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for 1,1-dichloroethylene at 0.007 mg/l to reduce the risk of the adverse health effects observed in laboratory animals.

1,2-Dichloroethane[52] This chemical is used as a cleaning fluid for fats, oils, waxes, and resins. It generally gets into drinking water from improper waste disposal. This chemical has been shown to cause cancer in laboratory animals such as rats and mice when exposed at high levels over their lifetimes. Chemicals that cause cancer in laboratory animals may also increase the risk of cancer in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for 1,2-dichloroethane at 0.005 mg/l to reduce the risk of cancer or other adverse health effects observed in laboratory animals. The WHO guideline is 10 μg/l.

Dissolved Oxygen Water devoid of dissolved oxygen frequently has a ‘‘flat’’ taste, although many attractive well waters are devoid of oxygen. In general, it is preferable for the dissolved-oxygen content to exceed 2.5 to 3.0 mg/l to prevent secondary tastes and odors from developing and to support fish life. Game fish require a dissolved oxygen of at least 5.0 mg/l to reproduce and either die off or migrate when the dissolved oxygen falls below 3.0 mg/l. The concentration of dissolved oxygen in potable water may be related to problems associated with iron, manganese, copper, and nitrogen and sulfur compounds.

Fluorides Fluorides are found in many groundwaters as a natural constituent, ranging from a trace to 5 mg/l or more, and in some foods. Fluorides in concentrations greater than 4 mg/l can cause the teeth of children to become mottled and discolored, depending on the concentration and amount of water consumed. Mottling of teeth has been reported very occasionally above 1.5 mg/l according to WHO guidelines. Drinking water containing 0.7 to 1.2 mg/l natural or added fluoride is beneficial to children during the time they are developing permanent teeth. An optimum level is 1.0 mg/l in temperate climates. In 1983, an estimated 123 million people in the United States had access to fluoridated water (0.7 mg/l or greater) and an additional 10.7 million were served by naturally fluoridated water. The incidence of dental cavities or tooth decay has been reduced by about 60 percent. More than 65 percent of the nation's nine-year-old children are free of tooth decay according to the federal Centers for Disease Control and Prevention (CDC).[56] (See also Dental Caries, Chapter 1.) The maximum contaminant level in drinking water has been established in the National Drinking Water Regulations at 4 mg/l. The probable oral lethal dose for sodium fluoride is 70 to 140 mg/kg. Fluoride removal methods include reverse osmosis, lime softening, ion exchange using bone char or activated alumina, and tricalcium phosphate adsorption. It is not possible to reduce the fluoride level to 1 mg/l using only lime.[57] The WHO and CDC reports show no evidence to support any association between fluoridation of drinking water and the occurrence of cancer (1982).

Free Ammonia Free ammonia represents the first product of the decomposition of organic matter; thus, appreciable concentrations of free ammonia usually indicate "fresh pollution" of sanitary significance. The exception is when ammonium sulfate of mineral origin is involved. The following values may be of general significance in appraising free ammonia content in groundwater: low—0.015 to 0.03 mg/l; moderate—0.03 to 0.10 mg/l; high—0.10 mg/l or greater. In treated drinking water, the goal is less than 0.1 mg/l, but less than 0.5 mg/l is acceptable. Special care must be exercised to allow for ammonia added if the "chlorine–ammonia" treatment of water is used or if crenothrix organisms are present. If ammonia is present or added, chloramines are formed when chlorine is added to the water. Ammonia in the range of 0.2 to 2.0 mg/l is toxic to many fish. A recommended maximum is 0.5 mg/l—0.2 mg/l for rainbow trout. Chloramines are also toxic to other aquatic life. Ammonia serves as a plant nutrient, accelerating eutrophication in receiving waters. It is converted to nitrite and then to nitrate, first by *Nitrosomonas* and then by *Nitrobacter* organisms. Ammonia can be removed by breakpoint or superchlorination.

Hardness Hardness is due primarily to calcium and secondarily to magnesium carbonates and bicarbonates (carbonate or temporary hardness that can be removed by heating) and calcium sulfate, calcium chloride, magnesium sulfate, and magnesium chloride (noncarbonate or permanent hardness, which cannot be removed by heating); the sum is the total hardness expressed as calcium carbonate. In general, water softer than 50 mg/l, as $CaCO_3$, is corrosive, whereas waters harder than about 80 mg/l lead to the use of more soap and above 200 mg/l may cause incrustation in pipes. Lead, cadmium, zinc, and copper in solution are usually caused by pipe corrosion associated with soft water. Desirable hardness values, therefore, should be 50 to 80 mg/l, with 80 to 150 mg/l as passable, over 150 mg/l as undesirable, and greater than 500 as unacceptable. The U.S. Geological Survey (USGS) and WHO (ref. 27, Vol. 2, p. 264) classify hardness, in milligrams per liter as $CaCO_3$, as 0 to 60 soft, 61 to 120 moderately hard, 121 to 180 hard, and more than 180 very hard. Waters high in sulfates (above 600 to 800 mg/l calcium sulfate, 300 mg/l sodium sulfate, or 390 mg/l magnesium sulfate) are laxative to those not accustomed to the water. Depending on alkalinity, pH, and other factors, hardness above 200 mg/l may cause the buildup of scale and flow reduction in pipes. In addition to being objectionable for laundry and other washing purposes due to soap curdling, excessive hardness contributes to the deterioration of fabrics. Hard water is not suitable for the production of ice, soft drinks, felts, or textiles. Satisfactory cleansing of laundry, dishes, and utensils is made difficult or impractical. When heated, bicarbonates precipitate as carbonates and adhere to the pipe or vessel. In boiler and hot-water tanks, the scale resulting from hardness reduces the thermal efficiency and eventually causes restriction of the flow or plugging in the pipes. Calcium chloride, when heated, becomes acidic and pits boiler tubes. Hardness can be reduced by lime-soda ash chemical treatment or the ion exchange process, but the sodium concentration will be increased. See Water Softening, this chapter. Desalination will also remove water hardness.

There seem to be higher mortality rates from cardiovascular diseases in people provided with soft water than in those provided with hard water. Water softened by the ion exchange process increases the sodium content of the finished water. The high concentration of sodium and the low concentration of magnesium have been implicated, but low concentrations of chromium and high concentrations of copper have also been suggested as being responsible. High concentrations of cadmium are believed to be associated with hypertension. Cause and effect for any of these is not firm. (See Cardiovascular Diseases, Chapter 1.)

Hydrogen Sulfide Hydrogen sulfide is most frequently found in groundwaters as a natural constituent and is easily identified by a rotten-egg odor. It is caused by microbial action on organic matter or the reduction of sulfate ions to sulfide. A concentration of 70 mg/l is an irritant, but 700 mg/l is highly poisonous. In high concentration, it paralyzes the sense of smell, thereby making it more dangerous. Black stains on laundered clothes and black deposits in piping and on plumbing fixtures are caused by hydrogen sulfide in the presence of soluble iron. Hydrogen sulfide in drinking water should not be detectable by smell or exceed 0.05 mg/l. Hydrogen sulfide predominates at pH of 7.0 or less. It is removed by aeration or chemical oxidation followed by filtration.

Iron Iron is found naturally in groundwaters and in some surface waters and as the result of corrosion of iron pipe. Iron deposits and mining operations and distribution systems may be a source of iron and manganese. Water should have a soluble iron content of less than 0.1 mg/l to prevent reddish-brown staining of laundry, fountains, and plumbing fixtures and to prevent pipe deposits. The secondary MCL and WHO guideline level is 0.3 mg/l; the goal should be less than 0.05 mg/l. Some staining of plumbing fixtures may occur at 0.05 mg/l. Precipitated ferric hydroxide may cause a slight turbidity in water that can be objectionable and cause clogging of filters and softener resin beds. In combination with manganese, concentrations in excess of 0.3 mg/l cause complaints. Precipitated iron may cause some turbidity. Iron in excess of 1.0 mg/l will cause an unpleasant taste. A concentration of about 1 mg/l is noticeable in the taste of coffee or tea. Conventional water treatment or ion exchange will remove iron. Chlorine or oxygen will precipitate soluble iron. Iron is an essential element for human health. See Iron and Manganese Occurrence and Removal, this chapter.

Lead The EPA requires that when more than 10 percent of tap water samples exceed 15 μg/l, the utility must institute corrosion control treatment. Concentrations exceeding this value occur when corrosive waters of low mineral content and softened waters are piped through lead pipe and old lead house services. Zinc-galvanized iron pipe, copper pipe with lead-based solder joints, and brass pipe, faucets, and fittings may also contribute lead. The lead should not exceed 5 μg/l in the distribution system.

Lead, as well as cadmium, zinc, and copper, is dissolved by carbonated beverages, which are highly charged with carbon dioxide. Limestone, galena, water, and food are natural sources of lead. Other sources are motor vehicle exhaust, certain industrial wastes, mines and smelters, lead paints, glazes, car battery salvage operations, soil, dust, tobacco, cosmetics, and agricultural sprays. Fallout from airborne pollutants also contributes significant concentrations of lead to water supply reservoirs and drainage basins. About one-fifth of the lead ingested in water is absorbed. The EPA estimates that in young children about 20 percent of lead exposure comes from drinking water; dust contributes at least 30 percent, air 5 to 20 percent, and food 30 to 45 percent.[58]

The Safe Drinking Water Amendments of 1986 require that any pipe, solder, or flux used in the installation or repair of any public water system or any plumbing connected to a public water system shall be lead free. Acceptable substitutes for lead solder are tin–silver, tin–antimony, and tin–copper. Solder and flux containing not more than 0.2 percent lead and pipes and pipe fittings containing not more than 8.0 percent lead are considered to be lead free. Lead-free solder may contain trace amounts of lead, tin, silver, and copper. (Leaded joints necessary for the repair of cast-iron water mains are excluded from the prohibition.) Exposure to lead in tap water is more likely in new homes, less than 5 years old, where plumbing contains lead solder or flux. A survey by the AWWA showed an average lead concentration of 193.3 μg/l in first-draw samples from homes less than 2 years old, 45.7 μg/l from homes 2 to 5 years old, 16 μg/l from homes 5 to 10 years old, and 8.2 μg/l from homes older than 10 years.[59] Hot water would normally contain higher concentrations of lead. Lead flux is reported to dissolve at about 140 to 150°F (60–66°C). Hot-water flushing is an economical method for removing residual flux from piping in newer buildings.[60] Galvanic corrosion due to dissimilar metals—copper and lead–tin solder—will also contribute lead. Electric water cooler piping, water contact surfaces, and fittings have also been implicated as sources of lead in drinking water. Defective coolers are being replaced.

Water containing lead in excess of the standard should not be used for baby formula or for cooking or drinking. Flushing the standing water out of a faucet for about 1 min will minimize the lead concentration, but it does not solve the problem. The Secretary of Housing and Urban Development and the Administrator of the Veterans' Administration may not ensure or guarantee a mortgage or furnish assistance with respect to newly constructed residential property, which contains a potable water system, unless such system uses only lead-free pipe, solder, and flux.

The EPA proposed (1988) the following measures and standards to control lead in community and noncommunity nontransient water systems:

1. corrosion control when tap water sample average exceeds 0.01 mg/l, when the pH level is less than 8.0 in more than 5 percent of samples, and when the copper level exceeds 1.3 mg/l (pH not greater than 9.0, alkalinity of 25–100 mg/l as calcium carbonate);
2. an MCL for lead of 0.005 mg/l and a MCLG of zero leaving the treatment plant;
3. an MCL and an MCLG for copper of 1.3 mg/l; and
4. tap water lead of 0.01 mg/l or less on average or 0.01 mg/l in not more than 5 percent of samples.*

Water treatment or use of a corrosion inhibitor is advised where indicated. Conventional water treatment, including coagulation, will partially remove natural or man-made lead in raw water. Measures to prevent or minimize lead dissolution include maintenance of $pH \geq 8.0$ and use of zinc orthophosphate or polyphosphates. Silicates may have a long-term beneficial effect. No apparent relationship was found between lead solubility and free chlorine residual, hardness, or calcium level. Electrical grounding to plumbing increased lead levels. Alkalinity level control was not of value at pH 7.0 to <8.0.[61] However, since only 3 to 5 percent of the free chlorine is in the active hy-

*The EPA subsequently established an action level of 0.015 mg/l in not more than 10 percent of samples of tap water that has been allowed to stand at least 6 hr (usually the first draw in the morning) from dwelling units that contain copper pipes with lead solder installed after 1982.

pochlorous acid form at pH 9.0 whereas 23 to 32 percent is in the hypochlorous acid form at pH 8.0, pH level control is critical for corrosion control and the maintenance of disinfection efficiency.

Removal of lead service lines is required if treatment is not adequate to reduce lead level.

Manganese Manganese is found in gneisses, quartzites, marbles, and other metamorphic rocks and hence in well waters from these formations. It is also found in many soils and sediments, such as in deep lakes and reservoirs, and in surface water. Manganese concentrations (MCL) should be not greater than 0.05 mg/l, and preferably less than 0.01, to avoid the black-brown staining of plumbing fixtures and laundry when chlorine bleach is added. The WHO guideline value for manganese is 0.1 mg/l.

Concentrations greater than 0.5 to 1.0 mg/l may give a metallic taste to water. Concentrations above 0.05 mg/l or less can sometimes build up coatings on sand filter media, glass parts of chlorinators, and concrete structures and in piping, which may reduce pipe capacity. When manganous manganese in solution comes in contact with air or chlorine, it is converted to the insoluble manganic state, which is very difficult to remove from materials on which it precipitates. Excess polyphosphate for sequestering manganese may prevent absorption of essential trace elements from the diet[62]; it is also a source of sodium. See Iron and Manganese Occurrence and Removal, this chapter.

Mercury Episodes associated with the consumption of methylmercury-contaminated fish, bread, pork, and seed have called attention to the possible contamination of drinking water. Mercury is found in nature in the elemental and organic forms. Concentrations in unpolluted waters are normally less than 1.0 μg/l. The organic methylmercury and other alkylmercury compounds are highly toxic, affecting the central nervous system and kidneys. It is taken up by the aquatic food chain. The maximum permissible contaminant level in drinking water is 0.002 mg/l as total mercury. The WHO guideline is 0.001 mg/l. See also Mercury Poisoning, Chapter 1.

Methylene Blue Active Substances (MBASs) The test for MBASs also shows the presence of alkyl benzene sulfonate (ABS), linear alkylate sulfonate (LAS), and related materials that react with methylene blue. It is a measure of the apparent detergent or foaming agent and hence sewage presence. The composition of detergents varies. Household wash water in which ABS is the active agent in the detergent may contain 200 to 1000 mg/l. Alkyl benzene sulfonate has been largely replaced by LAS, which can be degraded under aerobic conditions; if not degraded, it too will foam at greater than 1 mg/l concentration. Both ABS and LAS detergents contain phosphates that may, if allowed to enter, fertilize plant life in lakes and streams. The decay of plants will use oxygen, leaving less for fish life and wastewater oxidation.

Because of these effects, the use of detergents containing phosphates have been banned in some areas. In any case, the presence of MBAS in well-water supply is objectionable and an indication of sewage pollution, the source of which should be identified and removed, even though it has not been found to be of health significance in the concentrations found in drinking water. The level of MBAS in a surface water is also an indicator of sewage pollution. Carbon adsorption can be used to remove MBAS from drinking water. Foaming agents should be less than 0.5 mg/l; 1.0 mg/l is detectable by taste. Anionic (nondegradable) detergents should not exceed 0.2 mg/l.

Nitrates Nitrates represent the final product of the biochemical oxidation of ammonia. Its presence is probably due to the presence of nitrogenous organic matter of animal and, to some extent, vegetable origin, for only small quantities are naturally present in water. Septic tank systems may contribute nitrates to the groundwater if free oxygen is present. Manure and fertilizer contain large concentrations of nitrates. However, careful management practices of efficient utilization of applied manure and fertilizer by crops will reduce nitrates leaching below the root zone. Shallow (18–24-in.) septic tank absorption trenches will also permit nitrate utilization by vegetation. The existence of fertilized fields, barnyards, or cattle feedlots near supply sources must be carefully considered in appraising the significance of nitrate content. Furthermore, a cesspool may be relatively close to a well and contributing pollution without a resulting high nitrate content because the anaerobic conditions in the cesspool would prevent biochemical oxidation of ammonia to nitrites and then nitrates. In fact, nitrates may be reduced to nitrites under such conditions. In general, however, nitrates disclose the evidence of "previous" pollution of water that has been modified by self-purification processes to a final mineral form. Allowing for these important controlling factors, the following ranges in concentration may be used as a guide: low, less than 0.1 mg/l; moderate, 0.1 to 1.0 mg/l; high, greater than 1.0 mg/l. Concentrations greater than 3.0 mg/l indicate significant man-made contribution.

The presence of more than 10 mg/l of nitrate expressed as nitrogen, the maximum contaminant level in drinking water, appears to be the cause of methemoglobinemia, or "blue babies." The standard has also been expressed as 45 mg/l as nitrate ion (10 mg/l as nitrogen). Methemoglobinemia is largely a disease confined to infants less than three months old but may affect children up to age six. Boiling water containing nitrates increases the concentration of nitrates in the water. The recommended maximum for livestock is 100 mg/l. (See also Methemoglobinemia, Chapter 1.)

Nitrate is corrosive to tin and should be kept at less than 2 mg/l in water used in food canning. There is a possibility that some forms of cancer might be associated with very high nitrate levels.

Nitrates may stimulate the growth of water plants, particularly algae if other nutrients such as phosphorus and carbon are present. Nitrates seem to serve no useful purpose, other than as a fertilizer. Gould (ref. 63) points out that

> a more objective review of literature would perhaps indicate that without any sewage additions most of our waterways would contain enough nitrogen and phosphorous (due to nonpoint pollution source) to support massive algal blooms and that the removal of these particular elements would have little effect on existing conditions.

The feasible methods for the removal of nitrates are anion exchange, reverse osmosis, distillation, and electrodialysis. See Nitrate Removal, this chapter.

Nitrites Nitrites represent the first product of the oxidation of free ammonia by biochemical activity. Free oxygen must be present. Unpolluted natural waters contain practically no nitrites, so concentrations exceeding the very low value of 0.001 mg/l are of sanitary significance, indicating water subject to pollution that is in the process of change associated with natural purification. The nitrite concentration present is due to sewage and the organic matter in the soil through which the water passes. Nitrites in concentrations greater than 1 mg/l in drinking water are hazardous to infants and should not be used for infant feeding.

Oxidation–Reduction Potential (ORP, Also Redox) Oxidation–reduction potential is the potential required to transfer electrons from the oxidant to the reductant and is used as a qualitative measure of the state of oxidation in water treatment systems.[64] An ORP meter is used to measure in millivolts the oxidation–loss of electrons or reduction–gain of electrons.

Oxygen-Consumed Value This represents organic matter that is oxidized by potassium permanganate under the test conditions. Pollution significant from a bacteriological examination standpoint is accompanied by so little organic matter as not to significantly raise the oxygen-consumed value. For example, natural waters containing swamp drainage have much higher oxygen-consumed values than water of low original organic content that are subject to bacterial pollution. This test is of limited significance.

Para-*Dichlorobenzene*[52] This chemical is a component of deodorizers, moth balls, and pesticides. It generally gets into drinking water by improper waste disposal. This chemical has been shown to cause liver and kidney damage in laboratory animals such as rats and mice exposed to high levels over their lifetimes. Chemicals that cause adverse effects in laboratory animals also may cause adverse health effects in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for *para*-dichlorobenzene at 0.075 mg/l to reduce the risk of the adverse health effects observed in laboratory animals.

Pesticides Pesticides include insecticides, herbicides, fungicides, rodenticides, regulators of plant growth, defoliants, or desiccants. Sources of pesticides in drinking water are industrial wastes, spills and dumping of pesticides, and runoff from fields, inhabited areas, farms, or orchards treated with pesticides. Surface and groundwater may be contaminated. Conventional water treatment does not adequately remove pesticides. Powdered or granular activated carbon treatment may also be necessary. Maximum permissible contaminant levels of certain pesticides in drinking water and their uses and health effects are given in Table 3-4.

pH* The pH values of natural water range from about 5.0 to 8.5 and are acceptable except when viewed from the standpoint of corrosion. A guideline value of 6.5 to 8.5 is suggested. The pH is a measure of acidity or alkalinity using a scale of 0.0 to 14.0, with 7.0 being the neutral point, a higher value being alkaline and lower value acidic. The bactericidal, virucidal, and cysticidal efficiency of chlorine as a disinfectant increases with a decrease in pH. The pH determination in water having an alkalinity of less than 20 mg/l by using color indicators is inaccurate. The electrometric method is preferred in any case. The ranges of pH color indicator solutions, if used, are as follows: bromphenol blue, 3.0 to 4.6; bromcresol green, 4.0 to 5.6; methyl red, 4.4 to 6.0; bromcresol purple, 5.0 to 6.6; bromthymol blue, 6.0 to 7.6; phenol red, 6.8 to 8.4; cresol red, 7.2 to 8.8; thymol blue, 8.0 to 9.6; and phenol phthalein, 8.6 to 10.2. Waters containing more than 1.0 mg/l chlorine in any form must be dechlorinated with one or two drops of $\frac{1}{4}$ percent sodium thiosulfate before adding the pH indicator solution. This is necessary to prevent the indicator solution from being bleached or decolorized by the chlorine and giving an erroneous reading. The germicidal activity is greatly reduced at a pH level above 8.0. Corrosion is associated with pH levels below 6.5 to 7.0 and with carbon dioxide, alkalinity, hardness, and temperature.

Phenols The WHO guideline for individual phenols, chlorophenols, and 2,4,6-trichlorophenol is not greater than 0.1 μg/l (0.1 ppb), as the taste and odor can be detected at or above that level after chlorination. The odor of some chlorophenols is detected at 1 μg/l. In addition, 2,4,6-trichlorophenol, found in biocides and chlorinated water containing phenol, is considered a chemical carcinogen based on animal studies (ref. 27, Vol. 1, pp. 74–76, 85). The guideline for pentachlorophenol in drinking water, a wood preservative, is 0.001 mg/l based on its toxicity. It also causes objectionable taste and odor. If the water is not chlorinated, phenols up to 100 μg/l are acceptable.(ref. 27, Vol. 1, pp. 74–76, 85). Phenols are a group of organic compounds that

*pH is defined as the logarithm of the reciprocal of the hydrogen ion concentration. The concentration increases and the solution becomes more acidic as the pH value decreases below 7.0; the solution becomes more alkaline as the concentration decreases and the pH value increases above 7.0.

are byproducts of steel, coke distillation, petroleum refining, and chemical operations. They should be removed prior to discharge to drinking water sources. Phenols are also associated with the natural decay of wood products, biocides, and municipal wastewater discharges. The presence of phenols in process water can cause serious problems in the food and beverage industries and can taint fish. Chlorophenols can be removed by chlorine dioxide and ozone treatment and by activated carbon. The AWWA advises that phenol concentrations be less than 2.0 μg/l at the point of chlorination. Chlorine dioxide, ozone, or potassium permanganate pretreatment is preferred, where possible, to remove phenolic compounds.

Phosphorus High phosphorus concentrations, as phosphates, together with nitrates and organic carbon are often associated with heavy aquatic plant growth, although other substances in water also have an effect. Fertilizers and some detergents are major sources of phosphates. Uncontaminated waters contain 10 to 30 μg/l total phosphorus, although higher concentrations of phosphorus are also found in ''clean'' waters. Concentrations associated with nuisances in lakes would not normally cause problems in flowing streams. About 100 μg/l complex phosphate interferes with coagulation. Phosphorus from septic tank subsurface absorption system effluents is not readily transmitted through sandy soil and groundwater.[66] Most waterways naturally contain sufficient nitrogen and phosphorus to support massive algal blooms. See Nitrates, this section, and Eutrophication, Chapter 4.

Polychlorinated Biphenyls (PCBs) Polychlorinated biphenyls give an indication of the presence of industrial wastes containing mixtures of chlorinated byphenyl compounds having various percentages of chlorine. Organochlorine pesticides have a similar chemical structure. The PCBs cause skin disorders in humans and cancer in rats. They are stable and fire resistant and have good electrical insulation capabilities. They have been used in transformers, capacitors, brake linings, plasticizers, pumps, hydraulic fluids, inks, heat exchange fluids, canvas waterproofing, ceiling tiles, fluorescent light ballasts, and other products. They are not soluble in water but are soluble in fat. They cumulate in bottom sediment and in fish, birds, ducks, and other animals on a steady diet of food contaminated with the chemical. Concentrations up to several hundred and several thousand milligrams per liter have been found in fish, snapping turtles, and other aquatic life. Polybrominated biphenyl, a derivative of PCB, is more toxic than PCB. Aroclor is the tradename for a PCB mixture used in a pesticide. The manufacture of PCBs was prohibited in the United States in 1979 under the Toxic Substances Control Act of 1976. The use in transformers and electromagnets was banned after October 1985 if they pose an exposure risk to food or animal feed. Continued surveillance of existing equipment and its disposal is necessary for the life of the equipment. The toxicity of PCB and its derivatives appears to be due to its contamination with dioxins. The Food and Drug Administration (FDA) action levels are 1.5 mg/l in fat of milk and dairy products; 3 mg/l in poultry and 0.3 mg/l in eggs; and 2 mg/l in fish and shellfish. The MCL for drinking water is 0.0005 mg/l with zero as the EPA MCLG. The OSHA permissible 8-hr time-weighted average (TWA) airborne exposure limit is 0.5 mg/m^3 for PCBs containing 42 percent chlorine.[67] The National Institute of Occupational Safety and Health (NIOSH) recommended that the 8-hr TWA exposure by inhalation be limited to 1.0 $\mu g/m^3$ or less.[68] A level not exceeding 0.002 μg/l is suggested to protect aquatic life.[69] The PCBs are destroyed at 2000°F (1093°C) and 3 percent excess oxygen for 2 sec contact time. They are vaporized at 1584°F (862°C). The PCB contamination of well water has been associated with leakage from old submersible well pumps containing PCB in compacitors. These pumps were manufactured between 1960 and 1978, are oil cooled rather than water cooled, and have a two-wire lead rather than three-wire. Pumps using 220-volt service would not be involved.[70] Activated carbon adsorption and ozonation plus UV are possible water treatments to remove PCBs.

Polynuclear Aromatic Hydrocarbons Polynuclear aromatic hydrocarbons such as fluoranthene, 3,4-benzfluoranthene, 11,12-benzfluoranthene, 3,4-benzpyrene, 1,12-benzperyline, and indeno [1,2,3-*cd*] pyrene are known carcinogens and are potentially hazardous to humans. The WHO set a limit of 0.2 μg/l for the sum of these chemicals in drinking water, comparable in quality with unpolluted groundwater. Because of its carcinogenicity, a guideline value of 0.01 μg/l is proposed for benzo[*a*]pyrene in drinking water. It is also recommended that the use of cool-tar-based pipe linings be discontinued (ref. 27, Vol. 2, pp. 185–186).

Polysaccharides In soft drink manufacture, polysaccharides* in surface waters may be found in the water used. In waters of low pH, the polysaccharides come out of solution to form a white precipitate. The CO_2 in carbonated water is also sufficient to cause this. Coagulation and sedimentation or reverse osmosis treatment can remove polysaccharides.

Brewing water should ideally be low in alkalinity and soft but high in sulfates.[71]

Radioactivity The maximum contaminant levels for radioactivity in drinking water are given in Table 3-4. The exposure to radioactivity from drinking water is not likely to result in a total intake greater than recommended by the Federal Radiation Council. Naturally occurring radionuclides include Th-232, U-235, and U-238 and their decay series, including radon and radium 226 and 228. They may be found in well waters, especially those near uranium deposits. (Radium is sometimes found in certain spring and well supplies.)

*One of a group of carbohydrates.

Since these radionuclides emit alpha and beta radiation (as well as gamma), their ingestion or inhalation may introduce a serious health hazard, if found in well-water supplies.[72] Possible man-made sources of radionuclides in surface waters include fallout (in soluble form and with particulate matter) from nuclear explosions in precipitation and runoff, releases from nuclear reactors and waste facilities, and manufacturers. Radon is the major natural source of radionuclides.

Radon Radon is a natural decay product of uranium and is a byproduct of uranium used in industry and the manufacture of luminescent faces of clocks and instruments. It is also found in soil, rock, and well water and is readily released when water is agitated such as in a washing machine (clothes and dish), when water flows out of a faucet, and when water is sprayed from a shower head. Radon is particularly dangerous when released and inhaled in an enclosed space such as indoors. Radon-222 is emitted from tailings at uranium mill sites.

The EPA estimates that 10,000 pCi/l in water will result in a radon air concentration of about 1 pCi/l. The EPA has proposed a maximum contaminant level of 300 pCi/l for drinking water supplies.

Radon can be removed from water by aeration—packed tower or diffused air, filtration through granular activated carbon, ion exchange, and reverse osmosis. The concentration of radon in removal raises a disposal problem. See Indoor Air Quality, Chapter 11.

Selenium Selenium is associated with industrial pollution (copper smelting) and vegetation grown in soil containing selenium. It is found in meat and other foods. Selenium causes cancers and sarcomas in rats fed heavy doses.[55] Chronic exposure to excess selenium results in gastroenteritis, dermatitis, and central nervous system disturbance.[73] Selenium is considered an essential nutrient and may provide protection against certain types of cancer. Selenium in drinking water should not exceed the MCL of 0.05 mg/l. An intake of 25 or 50 μg/day is not considered harmful.

Silver The secondary MCL for silver in drinking water is 0.10 mg/l. Silver is sometimes used to disinfect small quantities of water and in home faucet "purifiers." Colloidal silver may cause permanent discoloration of the skin, eyes, and mucous membranes. A continuous daily dose of 400 μg of silver may produce the discoloration (argyria). Only about 10 percent of the ingested silver is absorbed (ref. 27, Vol. 2, p. 144).

Sodium Persons on a low-sodium diet because of heart, kidney, or circulatory (hypertension) disease or pregnancy should use distilled water if the water supply contains more than 20 mg/l of sodium and be guided by a physician's advice. The consumption of 2.0 liters of water per day is assumed. Water containing more than 200 mg/l sodium should not be used for drinking by those on a moderately restricted sodium diet. It can be tasted at this concentration when combined with other anions. Many groundwater supplies and most home-softened (using ion exchange) well waters contain too much sodium for persons on sodium-restricted diets. If the well water is low in sodium (less than 20 mg/l) but the water is softened by the ion exchange process because of excessive hardness, the cold-water system can be supplied by a line from the well that bypasses the softener and low-sodium water can be made available at cold-water taps. A home water softener adds 0.46 times the hardness removed as $CaCO_3$. Sodium can be removed by reverse osmosis, distillation, and cation exchange, but it is costly. A laboratory analysis is necessary to determine the exact amount of sodium in water. The WHO guideline for sodium in drinking water is 200 mg/l. Common sources of sodium, in addition to food, are certain well waters, ion exchange water-softening units, water treatment chemicals (sodium aluminate, lime-soda ash in softening, sodium hydroxide, sodium bisulfite, and sodium hypochlorite), road salt, and possibly industrial wastes. Sodium added in fluoridation and corrosion control is not significant.

Specific Electrical Conductance Specific electrical conductance is a measure of the ability of a water to conduct an electrical current and is expressed in micromhos per cubic centimeters of water at 77°F (25°C). Because the specific conductance is related to the number and specific chemical types of ions in solution, it can be used for approximating the dissolved-solids content in the water, particularly the mineral salts in solution if present. The higher the conductance, the more mineralized the water and its corrosivity. Different minerals in solutions give different specific conductance. Commonly, the amount of dissolved solids (in milligrams per liter) is about 65 percent of the specific conductance. This relationship is not constant from stream to stream or from well to well, and it may even vary in the same source with changes in the composition of the water. Specific conductance is used for the classification of irrigation waters. In general, waters of less than 200 μmho/cm^3 are considered acceptable, and conductance in excess of 300 μmho/cm^3 unsuitable. Good fresh waters for fish in the United States are reportedly under 1100 μmho/cm^3.[74] Wastewater with a conductivity up to 1200 to 4000 μmho/cm^3 may be acceptable for desert reclamation. Electrical conductivity measurements give a rapid approximation of the concentration of dissolved solids in milligrams per liter.

Sulfates The sulfate content should not exceed the secondary MCL of 250 mg/l. The WHO guideline is 400 mg/l (ref. 27, Vol. 1, p. 84). With zeolite softening, calcium sulfate or gypsum is replaced by an equal concentration of sodium sulfate. Sodium sulfate (or Glauber salts) in excess of 200 mg/l, magnesium sulfate (or Epsom salts) in excess of 390 to 1000 mg/l, and calcium sulfate in excess of 600 to 800 mg/l are laxative to those not accustomed to the water. Magnesium sulfate causes hardness; sodium sulfate causes foaming in steam boilers. Sulfate is increased when aluminum sulfate is used in coagulation. High sulfates also contribute to the formation of scale in boilers and heat exchangers. Concentrations of 300 to 400 mg/l cause a taste. Sulfates can be removed by ion exchange, distillation, reverse osmosis, or electrodialysis. Sulfates are found in surface waters receiving industrial wastes such as those from sulfate pulp mills, tanneries, and textile plants. Sulfates also occur in many waters as a result of leaching from gypsum-bearing rock.

***Total Dissolved Solids* (*TDS*)** The total solid content should be less than 500 mg/l; however, this is based on the industrial uses of public water supplies and not on public health factors. Higher concentrations cause physiological effects and make drinking water less palatable. Dissolved solids, such as calcium, bicarbonates, magnesium, sodium, sulfates, and chlorides, cause scaling in plumbing above 200 mg/l. The TDS can be reduced by distillation, reverse osmosis, electrodialysis, evaporation, ion exchange, and, in some cases, chemical precipitation. Water with more than 1000 mg/l of dissolved solids is classified as "saline," irrespective of the nature of the minerals present.[74a] The USGS classifies water with less than 1000 mg/l as fresh, 1000 to 3000 as slightly saline, 3000 to 10,000 as moderately saline, 10,000 to 35,000 as very saline, and more than 35,000 as briny.

1,1,1-Trichloroethane[52] This chemical is used as a cleaner and degreaser of metals. It generally gets into drinking water by improper waste disposal. This chemical has been shown to damage the liver, nervous system, and circulatory system of laboratory animals such as rats and mice exposed at high levels over their lifetimes. Some industrial workers who were exposed to relatively large amounts of this chemical during their working careers also suffered damage to the liver, nervous system, and circulatory system. Chemicals that cause adverse effects among exposed industrial workers and in laboratory animals may also cause adverse health effects in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for 1,1,1-trichloroethane at 0.2 mg/l to protect against the risk of adverse health effects observed in humans and laboratory animals.

Trichloroethylene[52] This chemical is a common metal-cleaning and dry-cleaning fluid. It generally gets into drinking water by improper waste disposal. This chemical has been shown to cause cancer in laboratory animals such as rats and mice when exposed at high levels over their lifetimes. Chemicals that cause cancer in laboratory animals may also increase the risk of cancer in humans exposed at lower levels over long periods of time. The EPA has set forth the enforceable drinking water standard for trichloroethylene at 0.005 mg/l to reduce the risk of cancer or other adverse health effects observed in laboratory animals.

Trihalomethanes Trihalomethanes (THMs) and other nonvolatile, higher molecular weight compounds are formed by the interaction of free chlorine with humic and fulvic substances and other organic precursors produced either by normal organic decomposition or by metabolism of aquatic biota. The precursor level is determined through testing by prechlorination of a sample and then analyzing the sample after seven days storage under controlled temperature and pH. A rapid surrogate THM measurement can be made using UV absorbent measurement. Two gas chromatographic analytic techniques are acceptable by the EPA for THM analysis. The THMs include chloroform (trichloromethane), bromoform (tribromomethane), dibromochloromethane, bromodichloromethane, and iodoform (dichloroiodomethane). Toxicity, mutagenicity, and carcinogenicity have been suspected as being associated with the ingestion of trihalomethanes. The EPA has stated that

> epidemiological evidence relating THM concentrations or other drinking water quality factors and cancer morbidity-mortality is not conclusive but suggestive. Positive statistical correlations have been found in several studies,* but causal relationships cannot be established on the basis of epidemiological studies. The correlation is stronger between cancer and the brominated THMs than for chloroform.[75,76]

Chloroform is reported to be carcinogenic to rats and mice in high doses and hence is a suspected human carcinogen. The Epidemiology Subcommittee of the National Research Council (NRC) says that cancer and THM should not be linked.[77] The Report on Drinking Water and Health, NRC Safe Drinking Water and Health, states: "A review of 12 epidemiological studies failed either to support or refute the results of positive animal bioassays suggesting that certain trihalomethanes, chloroform for example, may cause cancer in humans."[78] However, the National Drinking Water Advisory Council, based on studies in the review and evaluation by the National Academy of Sciences, the work done by the National Cancer Institute, and other research institutions within the EPA, has accepted the regulation of trihalomethanes on "the belief that chloroform in water does impose a health threat to the consumer" (ref. 79, p. 16). A standard of 100 μg/l for total THM has been established by the EPA for public water supplies serving 10,000 or more people. Reduction to 5 to 25 μg/l has been proposed. The WHO guideline for chloroform is 30 μg/l (ref. 27, Vol. 1, p. 77) and 35 μg/l for THM in Canada. For further discussion of the causes of THM formation, its control, and its removal, see (a) Prevention and Removal of Organic Chemicals and (b) Trihalomethanes, Removal and Control, this chapter.

*The reliability and accuracy of studies such as these are often subject to question.

Uranyl Ion This ion may cause damage to the kidneys. Objectionable taste and color occur at about 10 mg/l. It does not occur naturally in most waters above a few micrograms per liter. The taste, color, and gross alpha MCL will restrict uranium concentrations to below toxic levels; hence, no specific limit is proposed (ref. 69, p. 91).

Vinyl Chloride[52] This chemical is used in industry and is found in drinking water as a result of the breakdown of related solvents. The solvents are used as cleaners and degreasers of metals and generally get into drinking water by improper waste disposal. This chemical has been associated with significantly increased risks of cancer among certain industrial workers who were exposed to relatively large amounts of this chemical during their working careers. This chemical has also been shown to cause cancer in laboratory animals when exposed at high levels over their lifetimes. Chemicals that cause increased risk of cancer among exposed industrial workers and in laboratory animals also may increase the risk of cancer in humans exposed at lower levels over long periods of time. The EPA has set the enforceable drinking water standard for vinyl chloride at 0.002 mg/l to reduce the risk of cancer or other adverse health effects observed in humans and laboratory animals. Packed-tower aeration removes vinyl chloride.

Zinc The concentration of zinc in drinking water (goal) should be less than 1.0 mg/l. The MCL and the WHO guideline is 5.0 mg/l.[27] Zinc is dissolved by surface water. A greasy film forms in surface water containing 5 mg/l or more zinc upon boiling. More than 5.0 mg/l causes a bitter metallic taste and 25 to 40 mg/l may cause nausea and vomiting. At high concentrations, zinc salts impart a milky appearance to water. Zinc may contribute to the corrosiveness of water. Common sources of zinc in drinking water are brass and galvanized pipe and natural waters where zinc has been mined. Zinc from zinc oxide in automobile tires is a significant pollutant in urban runoff.[80] The ratio of zinc to cadmium may also be of public health importance. Zinc deficiency is associated with dwarfism and hypogonadism.[55] Zinc is an essential nutrient. The recommended daily dietary allowance is given in Table 1-19. It can be reduced by ion exchange, softening, reverse osmosis, and electrodialysis.

Drinking Water Additives

Potentially hazardous chemicals or contaminants may inadvertently be added directly or indirectly to drinking water in treatment, well drilling, and distribution. Other contaminants potentially may leach from paints, coatings, pumps, storage tanks, distribution system pipe and plumbing systems, valves, pipe fittings, and other equipment and products.

Chemicals (direct additives) used in water treatment for coagulation, corrosion control, and other purposes may contain contaminants such as heavy metals or organic substances that may pose a health hazard. In addition, significant concentrations of organic and inorganic contaminants (indirect additives) may leach or be extracted from various drinking water system components.

Since its inception, the EPA has maintained an advisory list of acceptable products for drinking water contact, but this function was transferred to the private sector on April 7, 1990. In 1985, the EPA provided seed funding for a consortium to establish a program for setting standards and for the testing, evaluation, inspection, and certification to control potentially hazardous additives. The consortium included the AWWA, the American Water Works Association Research Foundation (AWWARF), the Association of State Drinking Water Administrators (ASDWA), and the National Sanitation Foundation (NSF).

In 1988, the NSF published American National Standards Institute (ANSI)/NSF Standard 60, Drinking Water Treatment Chemicals—Health Effects, and ANSI/NSF Standard 61, Drinking Water System Components—Health Effects.[81] The ANSI approved NSF Standards 60 and 61 in May of 1989.

Third-party certification organizations, like the NSF, Underwriters Laboratories (UL), and the Safe Water Additives Institute,[82]* can certify products for compliance with the ANSI/NSF standards. In addition to the NSF listing of certified products, the AWWA plans to maintain and make available a directory of all products certified as meeting the ANSI/NSF standards.

In mid-1990 the ANSI announced a program to "certify the certifiers." Because each state regulates drinking water additives products, the ANSI program is expected to provide the basis for state acceptance of independent certification organizations to test and evaluate equipment and products for compliance with the standards. The ANSI program includes minimum requirements for certification agencies that address chemical and microbiological testing, toxicology review and evaluation, factory audits, follow-up evaluations, marking, contracts and policies, and quality assurance. Many state drinking water regulations and rules require independent third-party certification of additives products.

Water Quantity

The quantity of water used for domestic purposes will generally vary directly with the availability of the water, habits of the people, cost of water, number and type of plumbing fixtures provided, water pressure, air temperature, newness of a community, type of establishment, metering, and other factors. Wherever possible, the actual water consumption under existing or similar circumstances and the number of persons served should be the basis for the

*The NSF is accredited by the ANSI, UL has applied for accreditation, and the Safe Water Additives Institute is developing a program for ANSI review (*AWWA MainStream*, May 1991).

design of a water and sewage system. Special adjustment must be made for unaccounted-for water and for public, industrial, and commercial uses. The average per-capita municipal water use has increased from 150 gpd in 1960 to 168 gpd in 1975 and to 183 gpd in 1980. Approximately 70 gal is residential use, 50 gal industrial, 35 gal commercial, and 10 gal public and 18 gal is lost.[83] Included is water lost in the distribution system and water supplied for firefighting, street washing, municipal parks, and swimming pools. USGS estimated rural water use at 68 gpd in 1975 and 79 gpd in 1980.[84]

Table 3-14 gives estimates of water consumption at different types of places and in developing areas of the world. Additions should be made for car washing, lawn sprinkling, and miscellaneous uses. If provision is made for firefighting requirements, then the quantity of water provided for this purpose to meet fire underwriters' standards will be in addition to that required for normal domestic needs in small communities.

Developing Areas of the World Piped water delivery to individual homes and waterborne sewage disposal are not affordable in many developing countries. This calls for sequential or incremental improvements from centrally located hand pumps to water distribution systems. Social, cultural, and economic conditions, hygiene education, and community participation must be taken into account in project selection and design.[85,86] Community perception of needs, provision of local financial management, operation, and maintenance must be taken into consideration and assured before a project is started. The annual cost of water purchased from a water vendor may equal or exceed the cost of piped metered water. In addition, much time is saved where water must be hauled from a stream. Hand pumps, where used, should be reliable, made of corrosion-resistant materials, with moving parts resistant to abrasion, including sand, and readily maintained at the local level. A detailed analysis of hand pump tests and ratings has been made by Arlosoroff et al.[87] It is important to keep mechanical equipment to a minimum and to train local technicians. Preference should be given to drilled wells where possible. For surface-water supplies, slow sand filters are generally preferred over the more complex rapid sand filters.

Water Conservation

Water conservation can effect considerable saving of water with resultant reduction in water treatment and pumping costs and wastewater treatment. With water conservation, development of new sources of water and treatment facilities and their costs can be postponed or perhaps made unnecessary, and low-distribution system water pressure situations are less likely. However, the unit cost of water to the consumer may not be reduced; it may actually increase since the fixed cost will remain substantially the same. The revenue must still be adjusted to meet the cost of water production and distribution.

Water conservation can be accomplished, where needed, by a continuing program of leak detection and repair in the community distribution system

TABLE 3–14 Guides for Water Use in Design

Type of Establishment	gpd[a]
Residential	
Dwellings and apartments (per bedroom)	150
Rural	60
Suburban	75
Urban	180
Temporary Quarters	
Boarding houses	65
Additional (or nonresident boarders)	10
Campsites (per site), recreation vehicle with individual connection	100
Campsites, recreational vehicle, with comfort station	40–50
Camps without toilets, baths, or showers	5
Camps with toilets, without baths or showers	25
Camps with toilets and bathhouses	35–50
Cottages, seasonal with private bath	50
Day camps	15–20
Hotels	65–75
Mobile home parks (per unit)	125–150
Motels	50–75
Public Establishments	
Restaurants (toilets and kitchens)	7–10
Without public toilet facilities	$2\frac{1}{2}$–3
With bar or cocktail lounge, additional	2
Schools, boarding	75–100
Day with cafeteria, gymnasium, and showers	25
Day with cafeteria, without gymnasium and shower	15
Hospitals (per bed)	175–400
Institutions other than hospitals (per bed)	75–125
Places of public assembly	3–10
Turnpike rest areas	5
Turnpike service areas (per 10% of cars passing)	15–20
Prisons	120
Amusement and Commercial	
Airports (per passenger), add for employees and special uses	3–5
Car wash (per vehicle)	40
Country clubs, excluding residents	25
Day workers (per shift)	15–35
Drive-in theaters (per car space)	5
Gas station (per vehicle serviced)	10
Milk plant, pasteurization (per 100 lb of milk)	11–25
Movie theaters (per seat)	3
Picnic parks with flush toilets	5–10

TABLE 3–14 (*Continued*)

Type of Establishment	gpd[a]
Picnic parks with bathhouse, showers, bathrooms	20
Self-service laundries (per machine) (or 50 gal per customer)	400–500
Shopping center (per 1000 ft^2 floor area), add for employees, restaurants, etc.	250
Stores (per toilet room)	400
Swimming pools and beaches with bathhouses	10
Fairgrounds (based on daily attendance), also sports arenas	5
Farming (per Animal)	
Cattle or steer	12
Milking cow, including servicing	35
Goat or sheep	2
Hog	4
Horse or mule	12
Cleaning milk bulk tank, per wash	30–60
Milking parlor, per station	20–30
Liquid manure handling, cow	1–3
Poultry (per 100)	
Chickens	5–10
Turkeys	10–18
Cleaning and sanitizing equipment	4

Miscellaneous Home Water Use	Estimated (gal)
Toilet, tank, per use[b]	1.6–3.5
Toilet, flush valve 25 psi (pounds per square inch), per use[b]	1.6–3.5
Washbasin, gpm[b]	2–3
Bathtub	30/use
Shower, gpm[b]	2.5–3
Dishwashing machine, domestic, 15.5/load	9.5–
Garbage grinder, 2/day	1–
Automatic laundry machine, domestic	
34–57/load, top load	
22–33/load, front load	
Garden hose	
$\frac{5}{8}$ in., 25-ft head	200/hr
$\frac{3}{4}$ in., $\frac{1}{4}$ in. nozzle, 25-ft head	300/hr
Lawn sprinkler, 3000-ft^2 lawn, 1 in. per week	120/hr
Air conditioner, water-cooled, 3-ton, 8 hr per day	1850/week 2880/day

TABLE 3–14 (*Continued*)

Household Water Use	Percent	Municipal Water Use	Percent
Toilet flushing	36	Residential	38
Bathing	26	Industrial: factories	27
Drinking and cooking	5	Commercial: hospitals, restaurants	19
Dishwashing	6	Public: fires, parks	6
Clothes washing	15	Waste: leaks	10
Cleaning and miscellaneous	12		

Water Demand per Dwelling Unit: Surburban, Three-Bedrooms (BR)	Water Use (gpd)
Average day	300
Maximum day	600
Maximum hourly rate	1500
Maximum hourly rate with appreciable lawn watering	1800

Home Water System (Minimums)	2 BR	3 BR	4 BR	5 BR
Pump capacity, gal/hr	250	300	360	450
Pressure tank, gal minimum	42	82	82	120
Service line from pump, diameter (in.)[c]	$\frac{3}{4}$	$\frac{3}{4}$	1	$1\frac{1}{4}$

Other Water Use	Gallons
Fire hose, $1\frac{1}{2}$ in., $\frac{1}{2}$ in. nozzle, 70-ft head	2400/hr
Drinking fountain, continuous flowing	75/hr
Dishwashing machine, commercial	
Stationary rack type, 15 psi	6–9/min
Conveyor type, 15 psi	4–6/min
Fire hose, home, 10 gpm at 60 psi for 2 hr, $\frac{3}{4}$ in.	600/hr
Restaurant, average	35/seat
Restaurant, 24-hr	50/seat
Restaurant, tavern	20/seat
Gas station	500/set of pumps

Developing Areas of the World

One well or tap/200 persons; controlled tap or hydrant: Fordilla or Robovalve type

Average consumption, 5 gal/capita/day at well or tap, water carried

Water system design, 30 gal/capita/day (10 gal/capita is common) (50 gal is recommended)

Pipe size, 2 in. and preferably larger (1 and $1\frac{1}{2}$ in. common)

Drilled well, cased, 6–8 in. diameter

Water system pressure, 20 lb/in.^{2}

(Keep mechanical equipment to a minimum.)

TABLE 3–14 (*Continued*)

Developing Country[d]	Liters	Gallons
China	80	21
Africa	15–35	4–9
Southeast Asia	30–70	8–19
Western Pacific	30–90	8–24
Eastern Mediterranean	40–85	11–23
Europe (Algeria, Morocco, Turkey)	20–65	5–17
Latin America and Caribbean	70–190	19–51
World average	35–90	9–24

[a]Per person unless otherwise stated.
[b]Water conservation fixtures. See text.
[c]Service lines less than 50 ft long, brass or copper. Use next larger size if iron pipe is used. Use minimum $1\frac{1}{3}$-in. service with flush valves. Minimum well yield, 5 gal/min.
[d]Assumes hydrant or hand pump available within 200 m; 70 liters per capita per day (Lpcd) or more could mean house or central courtyard outlet.) Mechanical equipment kept at a minimum.

and in buildings; use of low water-use valves and plumbing fixtures; water pressure and flow control in the distribution system and in building services (orifices); universal metering and price adjustment; conservation practices by the consumer; and a rate structure that encourages conservation.

Leak detection activities would include metering water use and water production balance studies; routine leak detection surveys of the distribution system; investigation of water ponding or seepage reports and complaints; and reporting and prompt follow-up on leaking faucets, running flushometer valves and water closet ball floats, and other valves. Universal metering will make possible water balance studies to help detect lost water and provide a basis for charging for water use. Meters must be periodically tested for accuracy and read. However, centralized remote meter reading can simplify this task. Reduction in water use, perhaps 20 percent, may be temporary in some instances; many users may not economize.

Low water-use plumbing fixtures and accessories would include the low-flush water closets; water-saving shower head flow controls, spray taps, and faucet aerators; and water-saving clothes washers and dishwashers. In a dormitory study at a state university, the use of flow control devices (pressure level) on shower heads effected a 40 to 60 percent reduction in water use as a result of reducing the shower head flow rates from 5.5 gpm to 2.0 to 2.5 gpm.[88] Plumbing codes should require water-saving fixtures and pressure control in new structures and rehabilitation projects. For example, only water-efficient plumbing fixtures meeting the following standards are permitted to be sold or installed in New York State[89]*:

*The Washington Suburban Sanitary District plumbing code has similar requirements. (R. S. McGarry and J. M. Brusnighan, "Increasing Water and Sewer Rate Schedules: A Tool for Conservation," *J. Am. Water Works Assoc.*, September 1979, pp. 474–479.) The National Small Flows Clearinghouse, West Virginia University, reported in *Small Flows*, July 1991, that 12 states have adopted low-flow plumbing fixture regulations.

sink 3 gpm, lavatory faucet not greater than 2 gpm;
shower heads not greater than 3 gpm;
urinals and associated flush valve, if any, not greater than 1 gal of water per flush;
toilets and associated flush valve, if any, not greater than 1.6 gal of water per flush; and
drinking fountains, sinks, and lavatories in public restrooms with self-closing faucets.

Special fixtures such as safety showers and aspirator faucets are exempt, and the commissioner may permit use of fixtures not meeting standards if necessary for proper operation of the existing plumbing or sewer system.

On March 1, 1989, Massachusetts became the first state to require ultra-low-flow toilets using 1.6 gal per flush. the federal government adopted (effective January 1991). The following standards[90]:

Toilets	1.6 gal per flush
Urinals	1.0 gal per flush
Showerheads	2.5 gpm
Lavatory faucets	2.0 gpm
Kitchen faucets	2.5 gpm

An ultra-low-flush toilet using 0.8 gal per flush was found to perform equal to or better than the conventional toilet.[91] One might also add to the list of water conservation possibilities, where appropriate, use of the compost toilet, recirculating toilet, chemical toilet, incinerator toilet, and various privies. Air-assisted half-gallon flush toilets are also available.[92]

Pressure-reducing valves in the distribution system (pressure zones) to maintain a water pressure of 20 to 40 psi at fixtures will also reduce water use. A water saving of 6 percent can be expected at new single-family homes where water pressure in the distribution system is reduced from 80 to 30 to 40 psi based on HUD studies.[93,94] The potential water saving through pressure control is apparent from the basic hydraulic formulas

$$Q = VA \qquad Q = (2gpw)^{1/2} \times A \qquad Q = (2gh)^{1/2} \times A$$

where Q = cfs
V = fps
A = ft^2
g = 32.2 ft/sec/sec
p = lb/ft^2
w = lb/ft^3 (62.4)
h = ft of water

which show that the quantity of water flowing through a pipe varies with the velocity or the square root of the pressure head. For example, a pressure reduction from 80 to 40 psi will result in a flow reduction of 29 percent, but the actual water savings would probably be 6 percent, as noted above.

The success of water-use conservation also depends largely on the extent to which consumers are motivated. They can be encouraged to have leaking faucets and running toilets immediately repaired; not to waste water; to understand that a leak causing a $\frac{1}{8}$-in.-diameter stream adds up to 400 gal in 24 hr, which is about the amount of water used by a family of five or six in one day; to purchase a water-saving clothes washer and dishwasher; to add 2-quart bottles or a ''dam'' to the flush tank to see if the closet still flushes properly; to install water-saving shower heads and not use the tub; to install mixing faucets with single-lever control; and to install aerators on faucets. Consumer education and motivation must be a continuing activity. In some instances, reuse of shower, sink, and laundry wastewater for gardens is feasible.[95,96]

Water Reuse

An additional way of conserving drinking water and avoiding or minimizing large capital expenditures is to reduce or eliminate its use for nonpotable purposes by substituting treated municipal wastewater. This could increase the available supply for potable purposes at least cost and reduce the wastewater disposal problem. However, a distinctly separate nonpotable water system and monitoring protocol would be required.

Discussion of wastewater reuse should clearly distinguish between direct reuse and indirect reuse. In *direct reuse,* the additional wastewater treatment (such as storage, coagulation, flocculation, sedimentation, sand or anthracite filtration or granular activated-carbon filtration, and disinfection) is usually determined by the specific reuse. The wastewater is reclaimed for *nonpotable* purposes such as industrial process or cooling water, agricultural irrigation, groundwater recharge, desert reclamation, and fish farming; lawn, road median, tree farm, and park irrigation; landscape and golf course watering; and toilet flushing. See Chapter 4, Wastewater Reuse. The treated wastewater must *not* be used for drinking, culinary, bathing, or laundry purposes. The long-term health effects of using treated wastewater for potable purposes are not fully understood at this time and fail-safe, cost-effective treatment technology for the removal of all possible contaminants is not currently available.[97] In *indirect reuse,* wastewater receiving various degrees of treatment is discharged to a surface water or a groundwater aquifer where it is diluted and after varying detention periods may become a source of water for potable purposes after suitable treatment. *Recycling* is the reuse of wastewater, usually by the original user.

Direct municipal wastewater reuse, where permitted, would require a clearly marked dual water system, one carrying potable water and the other reclaimed wastewater. It has been estimated that the average person uses only about 25 to 55 gal of water per day for potable purposes.[97] The reclaimed water is usually bacteriologically safe but questionable insofar as other biological or organic and inorganic chemical content is concerned. A dye added to the reclaimed water would help avoid its inadvertent use for potable purposes. Okun emphasizes that the reclaimed or nonpotable water should (ref. 98)

> equal the quality of the potable systems that many communities now provide—the health hazard that results from the continuous ingestion of low levels of toxic substances over a period of years would not be present.

Advanced wastewater treatment, monitoring, and surveillance cannot yet in practice guarantee removal of all harmful substances (microcontaminants) from wastewater at all times; however, numerous projects are underway investigating reuse of water for potable purposes.[99]* More knowledge is needed concerning acute and long-term effects on human health of wastewater reuse.[100–102] In Windhoek, Namibia, Southwest Africa, reclaimed sewage, which is reported to contain no industrial wastes, blended with water from conventional sources has occasionally been used for drinking for many years without any apparent problems. The sewage is given very elaborate treatment involving some 18 unit processes.[103] Monitoring is done for *Salmonella, Shigella,* enteropathogenic *E. coli, Vibrio,* enterovirus, *Schistosoma,* viral hepatitis, meningitis, and nonbacterial gastroenteritis, in addition to turbidity and organic and inorganic chemicals. None of the pathogens was associated with the reclaimed wastewater.

More emphasis is needed on the removal of hazardous substances at the source and on adequate wastewater treatment prior to its discharge to surface and underground water supply sources. This will at least reduce the concentrations of contaminants discharged from urban and industrial areas and, it is hoped, the associated risks.

In any case, it is axiomatic that in general the cleanest surface and underground water source available should be used as a source of drinking water, and water conservation practiced, before a polluted raw water source is even considered, with cost being secondary. See also Wastewater Reuse, Chapter 4.

SOURCE AND PROTECTION OF WATER SUPPLY

General

The sources of water supply are divided into two major classifications: groundwater and surface water. To these should be added rainwater and demineralized water. The groundwater supplies include dug, bored, driven and

*The July 1985 issue of the *Journal of the American Water Works Association* as well as the articles given in ref. 99 are devoted to wastewater reuse.

drilled wells, rock and sand or earth springs, and infiltration galleries. The surface-water supplies include lake, reservoir, stream, pond, river, and creek supplies.

The location of groundwater supplies should take into consideration the recharge tributary wellhead area,[104,105] the probable sources and travel of pollution through the ground, the well construction practices and standards actually followed, depth of well casing and grouting, and the type of sanitary seal provided at the point where the pump line(s) pass out of the casing. These factors are explained and illustrated later.

Wellhead area has been defined under the 1986 Amendments to the Safe Drinking Water Act as ‘‘the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield.’’ The time of travel of a potential contaminant, distance, drawdown, flow boundaries, and assimilative capacity are critical factors in determining the wellhead protection area.[105,106] Some of the other hydrogeological considerations, in addition to well drawdown, radius of influence,* withdrawal rate, recharge area, and aquifer formation, are the hydraulic gradient, natural dilution, filtration, attenuation, and degradation of the contaminant in its movement through the zone of aeration (unsaturated zone) to the saturated zone and into the water table of the wellhead drainage area. These factors must be evaluated in the light of available topographic, geologic, and engineering information and the practicality of land-use controls, conservation easements, and dedication of land to parks to effectively prevent or adequately minimize the potential effects of contaminants on the recharge area. See earlier discussion under Sanitary Survey and Water Sampling.

The chemical quality of shallow groundwater (8–20 ft) and its quantity can be expected to vary substantially throughout the year and after heavy rains, depending on the soil depth and characteristics in the unsaturated zone above the water table. See also Water Cycle and Geology in this chpater and material that follows.

It is sometimes suggested that the top of a well casing terminate below the ground level or in a pit. This is not considered good practice except when the pit can be drained above flood level to the surface by gravity or to a drained basement. Frost-proof sanitary seals with pump lines passing out horizontally from the well casing are generally available. Some are illustrated later in Figures 3-7 through 3-10.

In order that the basic data on a new well may be recorded, a form such as the well driller's log and report shown in Figure 3-4 should be completed by the well driller and kept on file by the owner for future reference. A well for a private home should preferably have a capacity (well yield) of at least 500 gal/hr, but 300 gal/hr is usually specified as a minimum for domestic

*Circular only with flat water table, when drawdown cone of depression is 99 percent stabilized.

Well at .... In .... County of ....
Name of place   City, village or town

Owner .... P.O. Address ....

Depth of well ...... ft Diameter ...... in. Yield ...... gpm Was well disinfected? ...... yes or no

Amt. of casing above ground ...... in. Below ground ...... ft Well seal ...... cement grout

Draw a well diagram in the space provided below and show the depth and type of casing, the well seal, kind and thickness of formations penetrated, water bearing formations, diameter of drill holes with dotted lines and casing(s) with solid lines.

Well Diagram			Formations Penetrated
Diameter, in.		Depth in ft	Kind, thickness, and if water bearing
		Grade	
		25	
		50	
		75	
		100	
		150	
		200	
		250	

Remarks

Type of well ....
Drilling method ....
Was well dynamited? ....

Pumping Tests

Details	#1	#2	#3
Static water level, in feet below grade			
Pumping rate in gpm			
Pumping level in feet below grade			
Duration of test, in hours			

Water at end of test:
Clear ... Cloudy ... Turbid ...
Recommended depth of pump in well, ft below grade ... Capacity ...... gpm

Wells in sand & gravel:
Sand Eff. size ...... mm
Unif. Coef. ......
Length of screen ...... ft
Diam. of screen ...... in.
Type of screen ......
Screen openings ...... x ......

Comments:

Show cross-section of well & formations penetrated above. Draw a sketch of the property on the back of this sheet locating the well and sewage disposal systems within 200 ft, also land uses.

Drilling started ...... Completed ......

Well Driller ....
Signature

Figure 3-4 Well driller's log and report. *Well yield* is the volume of water per unit of time, such as gallons per minute, discharged from a well either by pumping to a stabilized drawdown or by free flow. The *specific capacity* of a well is the yield at a stabilized drawdown and given pumping rate, expressed as gallons per minute per foot of drawdown. chalked tape, electric probe, or known length of air line is used with pressure gauge. Test run is usually 4–8 hr for small wells; 24–72 hr for wells serving the public, or for 6 hr at a stabilized drawdown when pumping at 1.5 times the design pumping rate. See also Well Development in this chapter.

water use in serving a three-bedroom home. The long-term yield of a well is dependent on the seasonal static water level, other withdrawals from the aquifer, the recharge area and storage in the aquifer, and the hydraulic characteristics of the aquifer. Because of this and the uncertainty of when stabilized drawdown is reached, the determined well yield should be reduced to compensate for long-term use and possible decline of aquifer yield. Pumping tests should therefore ensure that the water level in the well returns to the original static level. See Tables 3-14 and 3-15 and Well Development in this chapter.

Surface-water supplies are all subject to continuous or intermittent pollution and must be treated to make them safe to drink. One never knows when the organisms causing typhoid fever, gastroenteritis, giardiasis, infectious hepatitis A, or dysentery, in addition to organic and inorganic pollutants, may be discharged or washed into the water source. The extent of the treatment required will depend on the results of a sanitary survey made by an experienced professional, including physical, chemical, and microbiological analyses. The minimum required treatments are coagulation, flocculation, sedimentation, filtration, and chlorination unless a conditional waiver is obtained from the regulatory agency. If more elaborate treatment is needed, it would be best to abandon the idea of using a surface-water supply and resort to a protected groundwater supply if possible and practical. Where a surface supply must be used, a reservoir or a lake that provides at least 30 days *actual* detention, that does not receive sewage, industrial, or agricultural pollution, and that can be controlled through ownership or watershed rules and regulations would be preferred to a stream or creek, the pollution of which cannot from a practical standpoint be controlled. There are many situations where there is no practical alternative to the use of polluted streams for water supply. In such cases, carefully designed water treatment plants providing multiple barriers must be provided.

Groundwater

About one-half of the U.S. population is dependent on groundwater for drinking and domestic purposes. Ninety-five percent of the rural population is almost entirely dependent on groundwater. Some 33 million people are served by individual, on-site well-water systems (1980 Census of Housing). These are not protected or regulated under the Safe Drinking Water Act. In view of this, protection of our groundwater resources must receive the highest priority. Elimination of groundwater pollution and protection of aquifers and their drainage areas by land-use and other controls require state and local regulations and enforcement.

It is estimated that at any one time there is 20 to 30 times more water stored underground than in all the surface streams and lakes. Protection and development of groundwater sources can significantly help meet the increasing water needs. Exploration techniques include use of data from USGS and state agencies, previous studies, existing well logs, gains or losses in stream

TABLE 3-15 Standards for Construction of Wells[a]

Water-Bearing Formation	Overburden	Oversize Drill Hole: Diameter	Oversize Drill Hole: Depth[b]	Cased Portion
1. Sand or gravel	Unconsolidated caving material; sand or sand and gravel	None required	None	2 in. minimum, 5 in. or more preferred
2. Sand or gravel	Clay, hardpan, silt, or similar material to depth of more than 20 ft	Casing size plus 4 in.	Minimum 20 ft	2 in. maximum, 5 in. or more preferred
3. Sand or gravel	Clay, hardpan, silt, or similar material containing layers of sand or gravel within 15 ft of ground surface	Casing size plus 4 in.	Minimum 20 ft	2 in. minimum, 5 in or more preferred
4. Sand or gravel	Creviced or fractured rock, such as limestone, granite, quartzite	Casing size plus 4 in.	Through rock formation	4 in. minimum
5. Creviced, shattered, or otherwise fractured limestone, granite, quartzite, or similar rock types	Unconsolidated caving material, chiefly sand or sand and gravel to a depth of 40 ft or more and extending at least 2000 ft in all directions from the well site	None required	None required	6 in. minimum
6. Creviced, shattered, or otherwise fractured limestone, granite, quartzite, or similar rock types	Clay, hardpan, shale, or similar material to a depth of 40 ft or more and extending at least 2000 ft in all directions from well site	Casing size plus 4 in.	Minimum 20 ft	6 in. minimum

TABLE 3-15 (*Continued*)

Well Diameter					
Uncased Portion	Well Screen Diameter[c]	Minimum Casing Length or Depth[b]	Liner Diameter (If Required)	Construction Conditions[b]	Miscellaneous Requirements
Does not apply	2 ft minimum	20 ft minimum; but 5 ft below pumping level[d]	2 in. minimum		
Does not apply	2 ft minimum	5 ft below pumping level[d]	2 in. minimum	Upper drill hole shall be kept at least one-third filled with clay slurry while driving permanent casing; after casing is in permanent position annular space shall be filled with clay slurry or cement grout.	An adequate well screen shall be provided where necessary to permit pumping sand-free water from the well.
Does not apply	2 ft minimum	5 ft below pumping level[d]	2 in. minimum	Annular space around casing shall be filled with cement grout.	
Does not apply	2 in. minimum	5 ft below over-burden of rock	2 in. minimum	Annular space around casing shall be filled with cement grout.	
6 in. preferred	Does not apply	Through caving overburden	4 in. minimum	Casing shall be firmly seated in the rock.	
6 in. preferred	Does not apply	Through overburden	4 in. minimum	Annular space around casing shall be grouted. Casing shall be firmly seated in rock.	

7. Creviced, shattered, or otherwise fractured limestone, granite, quartzite, or similar rock	Unconsolidated materials to a depth of less than 40 ft and extending at least 2000 ft in all directions	Casing size plus 4 in.	Minimum 40 ft	6 in. minimum
8. Sandstone	Any material except creviced rock to a depth of 25 ft or more	Casing size plus 4 in.	15 ft into firm sandstone or to 30 ft depth, whichever is greater	4 in. minimum
9. Sandstone	Mixed deposits mainly sand and gravel, to a depth of 25 ft or more	None required	None required	4 in. minimum
10. Sandstone	Clay, hardpan, or shale to a depth of 25 ft or more	Casing size plus 4 in.	Minimum 20 ft	4 in. minimum
11. Sandstone	Creviced rock at variable depth	Casing size plus 4 in.	15 ft or more into firm sandstone	6 in. minimum

TABLE 3-15 ***(Continued)***

Well Diameter		Minimum Casing Length or Depth[b]	Liner Diameter (If Required)	Construction Conditions[b]	Miscellaneous Requirements
Uncased Portion	Well Screen Diameter[c]				
6 in. preferred	Does not apply	40 ft minimum	4 in. minimum	Casing shall be firmly seated in rock. Annular space around casing shall be grouted.	If grout is placed through casing pipe and forced into annular space from the bottom of the casing, the oversize drill hole may be only 2 in. larger than the casing pipe.
4 in. preferred		Same as oversize drill hole or greater	2 in. minimum	Annular space around casing shall be grouted. Casing shall be firmly seated in sandstone.	Pipe 2 in. smaller than the drill hole and liner pipe 2 in. smaller than casing shall be assembled without couplings.
4 in. preferred		Through overburden into firm sandstone	2 in. minimum	Casing shall be effectively seated into firm sandstone.	
4 in. preferred		Through overburden into sandstone	2 in. minimum	Casing shall be effectively seated into firm sandstone. Oversized drill hole shall be kept at least one-third filled with clay slurry while driving permanent casing; after the casing is in the permanent position, annular space shall be filled with clay slurry or cement grout.	Pipe 2 in. smaller than the oversize drill hole and liner pipe 2 in. smaller than casing shall be assembled without couplings.

6 in. preferred	2 in. minimum, if well screen required to permit pumping sand-free water from partially cemented sandstone	15 ft into firm sandstone	4 in. minimum	Annular space around casing shall be filled with cement grout.	If grout is placed through casing pipe and forced into annular space from the bottom of the casing, the oversize drill hole may be only 2 in. larger than the casing pipe. Pipe 2 in. smaller than the drill hole and liner pipe 2 in. smaller than casing shall be assembled without couplings.

Source: Recommended State Legislation and Regulations, Public Health Service, Department of Health, Education, and Welfare, Washington, DC, July 1965.

Note: For wells in creviced, shattered, or otherwise fractured limestone, granite, quartzite, or similar rock in which the overburden is less than 40 ft and extends less than 2000 ft in all directions and no other practical acceptable water supply is available, the well construction described in line 7 of this table is applicable.

[a] Requirements for the proper construction of wells vary with the character of subsurface formations, and provisions applicable under all circumstances cannot be fixed. The construction details of this table may be adjusted, as conditions warrant, under the procedure provided by the Health Department and in the Note above.

[b] In the case of a flowing artesian well, the annular space between the soil and rock and the well casing shall be tightly sealed with cement grout from within 5 ft of the top of the aquifier to the ground surface in accordance with good construction practice.

[c] These diameters shall be applicable in circumstances where the use of perforated casing is deemed practicable. Well points commonly designated in the trade as $1\frac{1}{4}$-in. pipe shall be considered as being 2 ft nominal diameter well screens for purposes of these regulations.

[d] As used herein, the term *pumping level* shall refer to the lowest elevation of the surface of the water in a well during pumping, determined to the best knowledge of the water well contractor, taking into consideration usual seasonal fluctuations in the static water level and drawdown level.

flow, hydrogeologic mapping using aerial photographs, surface resistivity surveys electromagnetic induction surveys or other geophysical prospecting, and exploratory test wells.

A technique for water well location called *fracture-trace mapping* is reported to be a highly effective method for increasing the ratio of successful to unsuccessful well-water drilling operations and to greatly improve water yields (up to 50 times). Aerial photographs give the skilled hydrogeologist clues of the presence of a zone of fractures underneath the earth's surface. Clues are abrupt changes in the alignment of valleys, the presence of taller or more lush vegetation, the alignment of sink holes or other depressions in the surface, or the existence of shallow longitudinal depressions in the surface overtop of the fracture zone. The soil over fracture zones is often wetter and hence shows up darker in recently plowed fields. The aerial photograph survey is then followed by a field investigation and actual ground location of the fractures and potential well drilling sites.[107]

It has been suggested that all groundwater supplies be chlorinated. Exceptions may be properly located, constructed, and protected wells *not* in limestone or other channeled or fractured rock and where the highest water table level is at least 10 ft below ground level; where sources of pollution are more than 5000 ft from the well; and where there is a satisfactory microbiological history. Other criteria include soil permeability, rate and direction of groundwater flow, and underground drainage area to the well. Chlorination should be considered a factor of safety and not reason to permit poor well construction and protection.

Dug Well

A dug well is one usually excavated by hand, although it may be dug by mechanical equipment. It may be 3 to 6 ft in diameter and 15 to 35 ft deep, depending on where the water-bearing formation or groundwater table is encountered. Wider and deeper wells are less common. Hand pumps over wells and pump lines entering wells should form watertight connections, as shown in Figure 3-5 and Figure 3-6. Since dug wells have a relatively large diameter, they have large storage capacity. The level of the water in dug wells will lower at times of drought and the well may go dry. Dug wells are not usually dependable sources of water supply, particularly where modern plumbing is provided. In some areas, properly developed dug wells provide an adequate and satisfactory water supply. However, dug wells are susceptible to contamination deposited on or naturally present in the soil when subjected to heavy rains, particularly if improperly constructed. This potential hazard also applies to shallow bored, driven, and jetted wells. Water quality can be expected to change significantly.

Bored Well

A bored well is constructed with a hand- or machine-driven auger. Bored wells vary in diameter from 2 to 30 in. and in depth from 25 to 60 ft. A

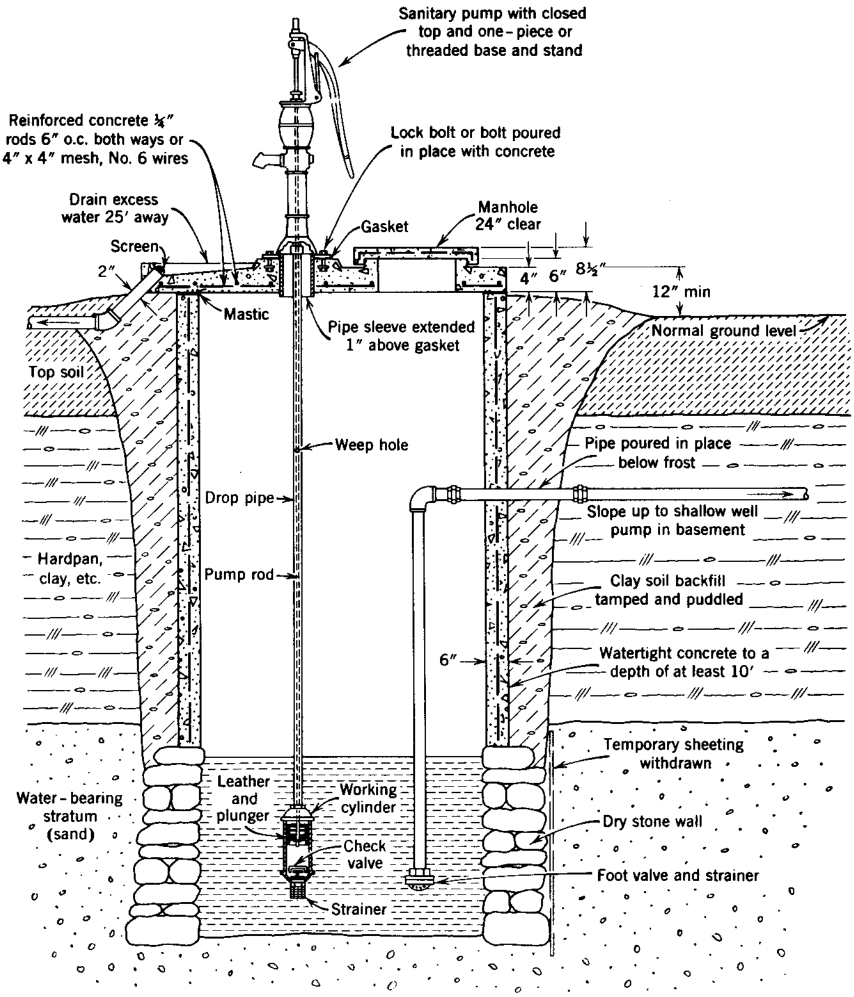


Figure 3-5 A properly developed dug well.

casing of concrete pipe, vitrified clay pipe, metal pipe, or plastic pipe is necessary to prevent the relatively soft formation penetrated from caving into the well. Bored wells have characteristics similar to dug wells in that they have small yields, are easily polluted, and are affected by droughts.

Driven and Jetted Well

These types of wells consist of a well point with a screen attached, or a screen with the bottom open, which is driven or jetted into a water-bearing formation found at a comparatively shallow depth. A series of pipe lengths are attached to the point or screen as it is forced into position. The driven

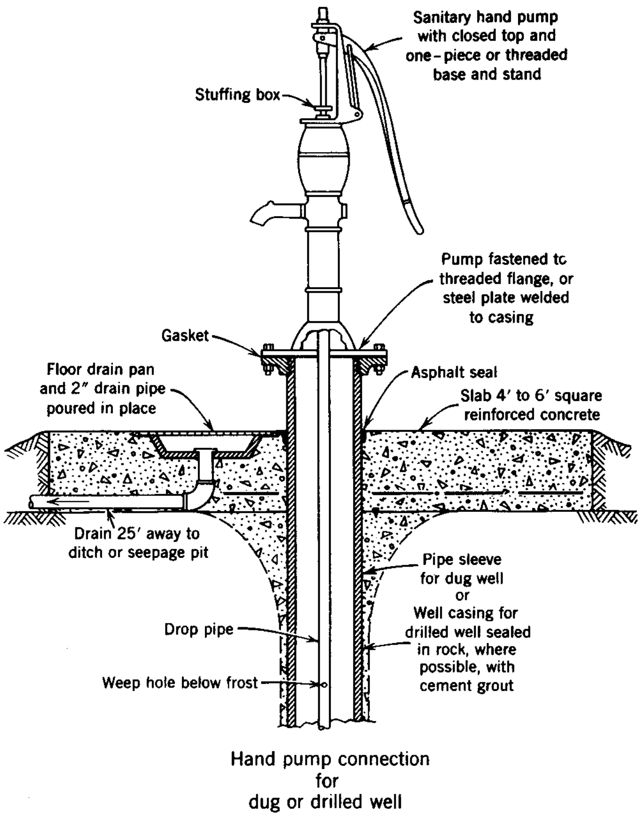


Figure 3-6 Sanitary hand pump and well attachment. Place 2 ft of gravel under slab where frost is expected.

well is constructed by driving the well point, preferably through at least 10 to 20 ft of casing, with the aid of a maul or sledge, pneumatic tamper, sheet pile driver, drive monkey, hand-operated driver, or similar equipment. In many instances, the casing is omitted, but then less protection is afforded the driven well, which also serves as the pump suction line. The jetted well is constructed by directing a stream of water at the bottom of the open screen, thereby loosening and flushing the soil up the casing to the surface as the screen is lowered. Driven wells are commonly between $1\frac{1}{4}$ and 2 in. in diameter and less than 50 ft in depth; jetted wells may be 2 to 12 in. in diameter and up to 100 ft deep, although larger and deeper wells can be constructed. In the small-diameter wells, a shallow well hand or mechanical suction pump is connected directly to the well. Large-diameter driven wells facilitate installation of the pump cylinder close to or below the water surface in the well at greater depth, in which case the hand pump must be located directly over the well. In all cases, however, care must be taken to see that the top of the well is tightly capped, the concrete pump platform extends 2 or 3 ft around the well pipe or casing, and the annular space between the well casing and drop pipe(s) is tightly sealed. This is necessary to prevent the entrance of unpurified water or other pollution from close to the surface.

A radial well is a combination dug-and-driven well in which horizontally driven well collectors radiate out from a central sump or core and penetrate into a water-bearing stratum.

Drilled Well

Studies have shown that, in general, drilled wells are superior to dug, bored, or driven wells and springs. But there are some exceptions. Drilled wells are less likely to become contaminated and are usually more dependable sources of water. When a well is drilled, a hole is made in the ground usually with a percussion (cable tool) or rotary (air or mud) drilling machine. Drilled wells are usually 4 to 12 in. in diameter or larger and may reach 750 to 1000 ft in depth or more. Test wells are usually 2 to 5 in. in diameter with a steel casing. A steel or wrought-iron casing is lowered as the well is drilled to prevent the hole from caving in and to seal off water of doubtful quality. Special plastic pipe is also used if approved. Lengths of casing should be threaded and coupled or properly field welded. The drill hole must, of course, be larger than the casing, thereby leaving an irregular space around the outside length of the casing. Unless this space or channel is closed by cement grout or naturally by formations that conform to the casing almost as soon as it is placed, pollution from the surface or crevices close to the surface or from polluted formations penetrated will flow down the side of the casing and into the water source. Water can also move up and down this annular space in an artesian well and as the groundwater and pumping water level changes.

The required well diameter is usually determined by the size of the discharge piping, fittings, pump, and motor placed inside the well casing. In general, for well yields of less than 100 gpm, a 6-in.-inside-diameter casing should be used; for 75 to 175 gpm an 8-in. casing; for 150 to 400 gpm a 10-in. casing; for 350 to 650 gpm a 12-in. casing; for 600 to 900 gpm a 14-in.-outside-diameter casing; for 850 to 1300 gpm a 16-in. casing; for 1200 to 1800 gpm a 20-in. casing; and for 1600 to 3000 gpm a 24-in. casing.[108] Doubling the diameter of a casing increases the yield up to only 10 to 12 percent.

When the source of water is water-bearing sand and gravel, a gravel well or gravel-packed well with screen may be constructed. Such a well will usually yield more water than the ordinary drilled well with a screen of the same diameter and with the same drawdown. A slotted or perforated casing in a water-bearing sand will yield only a fraction of the water obtainable through the use of a proper screen selected for the water-bearing material. On completion, the well should be developed and tested as noted below. A completed well driller's log should be provided to the owner on each well drilled. See Figure 3-4.

Only water well casing of clean steel or wrought iron should be used. Plastic pipe may be permitted. Used pipe is unsatisfactory. Standards for well casing are available from the American Society for Testing Materials, the American Iron and Steel Institute, and state health or environmental protection agencies.

Extending the casing at least 5 ft below the pumping water level in the well—or if the well is less than 30 ft deep, 10 ft below the pumping level—will afford an additional measure of protection. In this way the water is drawn from a depth that is less likely to be contaminated. In some sand and gravel areas, extending the casing 5 to 10 ft below the pumping level may shut off the water-bearing sand or gravel. A lesser casing depth would then be indicated, but in no instance should the casing be less than 10 ft, provided sources of pollution are remote and provision is made for chlorination. The recommended depth of casing, cement grouting, and need for double-casing construction or the equivalent are given in Table 3-15.

A vent is necessary on a well because, if not vented, the fluctuation in the water level will cause a change in air pressure above and below atmospheric pressure in a well, resulting in the drawing in of contaminated water from around the pump base over the well or from around the casing if not properly sealed. Reduced pressure in the well will also increase lift or total head and reduce volume of water pumped.

It must be remembered that well construction is a very specialized field. Most well drillers are desirous of doing a proper job for they know that a good well is their best advertisement. However, in the absence of a state or local law dealing with well construction, the enforcement of standards, and the licensing of well drillers, price alone frequently determines the type of well constructed. Individuals proposing to have wells drilled should therefore carefully analyze bids received. Such matters as water quality, well diameter, type and length of casing, minimum well yield, type of pump and sanitary seal where the pump line(s) passes through the casing, provision of a satisfactory well log, method used to seal off undesirable formations and cement grouting of the well, plans to pump the well until clear, and disinfection following construction should all be taken into consideration. See Figures 3-6 through 3-12.

Recommended water well protection and construction practices and standards are given in this text. More detailed information, including well construction and development, contracts, and specifications, is available in federal, state, and other publications.[109–113] A hydrogeologist or professional engineer can help assure proper location, construction, and development of a well, particularly for a public water supply. It has been estimated that the radius of the cone of depression of a well in fine sand is 100 to 300 ft, in coarse sand 600 to 1000 ft, and in gravel 1000 to 2000 ft. In a consolidated

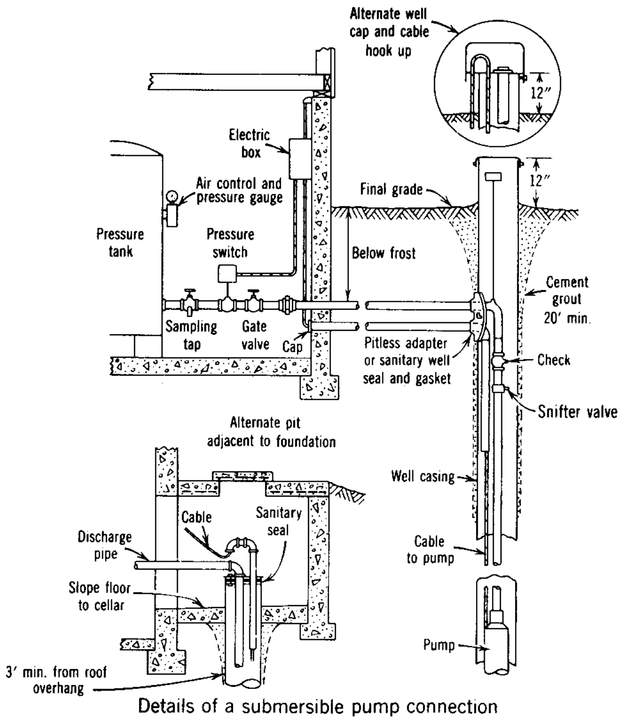


Figure 3-7 Sanitary well caps and seal and submersible pump connection.

formation, determination of the radius of the cone of depression requires a careful hydrogeological analysis. Remember, the cheapest well is not necessarily the best buy.

Well Development

Practically all well drilling methods, and especially the rotary drill method, cause smearing and compaction or cementing of clay, mud, and fine material on the bore hole wall and in the crevices of consolidated formations penetrated. This will reduce the sidewall flow of water into the well and hence the well yield. Various methods are used to remove adhering mud, clay, and fines and to develop a well to its full capacity. These include pumping, surging (valved surge device, solid surge device, pumping with surge device, air surge), and fracturing (explosives, high-pressure jetting, backwashing). Adding a polyphosphate or a nonfoaming detergent can also aid in removing adhering materials. The well development operation is continued until the discharge becomes practically clear of sand (5 ppm or less). Following development, the well should be tested to determine the dependable well yield. The well is then disinfected and the log completed.

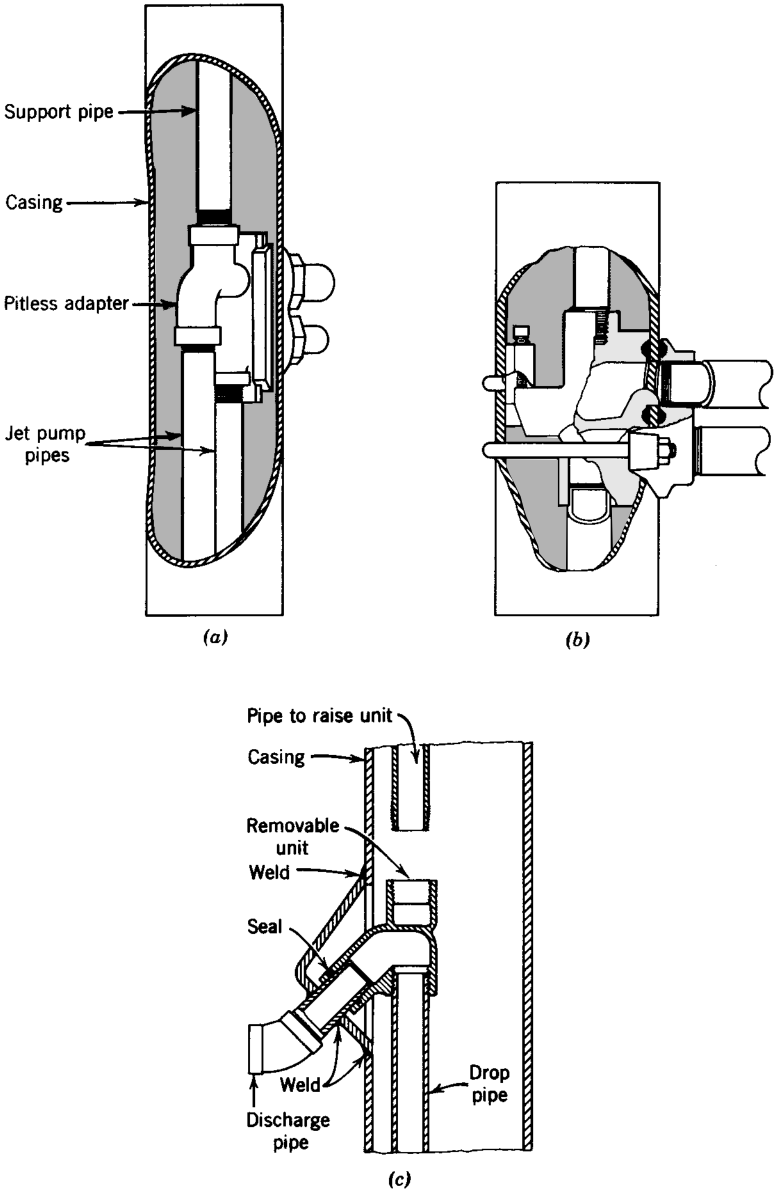


Figure 3-8 Pitless adapters. (*a*) Courtesy Martin Manufacturing Co., Ramsey, NJ. (*b*) Courtesy Williams Products Co., Joliet, IL. (*c*) Courtesy Herb Maass Service, Milwaukee, WI.

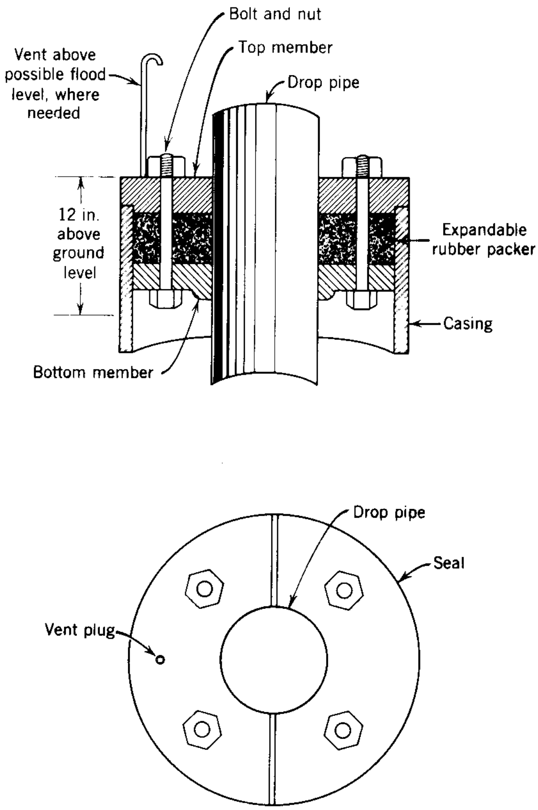


Figure 3-9 Sanitary expansion well cap.

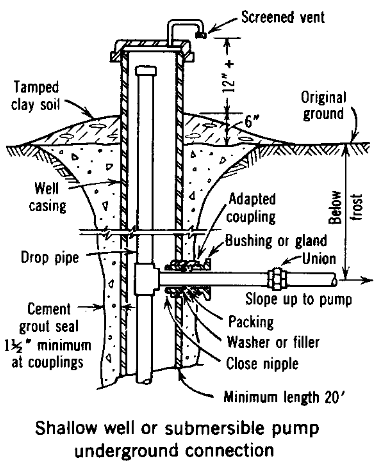


Figure 3-10 Improved well seal.

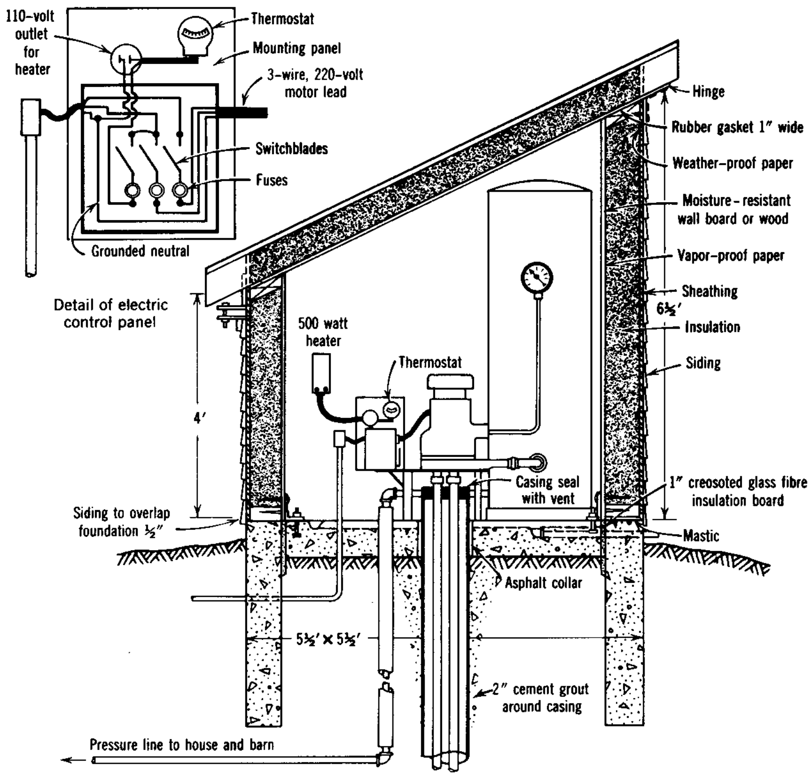


Figure 3-11 Insulated pumphouse. (*Source: Sewage Disposal and Water Systems on the Farm,* Extension Bulletin 247, University of Minnesota Extension Service, revised 1956. Reproduced with permission.)

Grouting

One of the most common reasons for contamination of wells drilled through rock, clay, or hardpan is failure to properly seal the annular space around the well casing. A proper seal is needed to prevent water movement between aquifers, protect the aquifers, and prevent entry of contaminated water from the surface or near the surface.

A contaminated well supply causes the homeowner or municipality considerable inconvenience and extra expense for it is difficult to seal off contamination after the well is drilled. In some cases, the only practical answer is to build a new well.

Proper *cement grouting* of the space between the drill hole and well casing, the annulus, where the overburden over the water-bearing formation is clay, hardpan, or rock, can prevent this common cause of contamination. (See Table 3-15.)

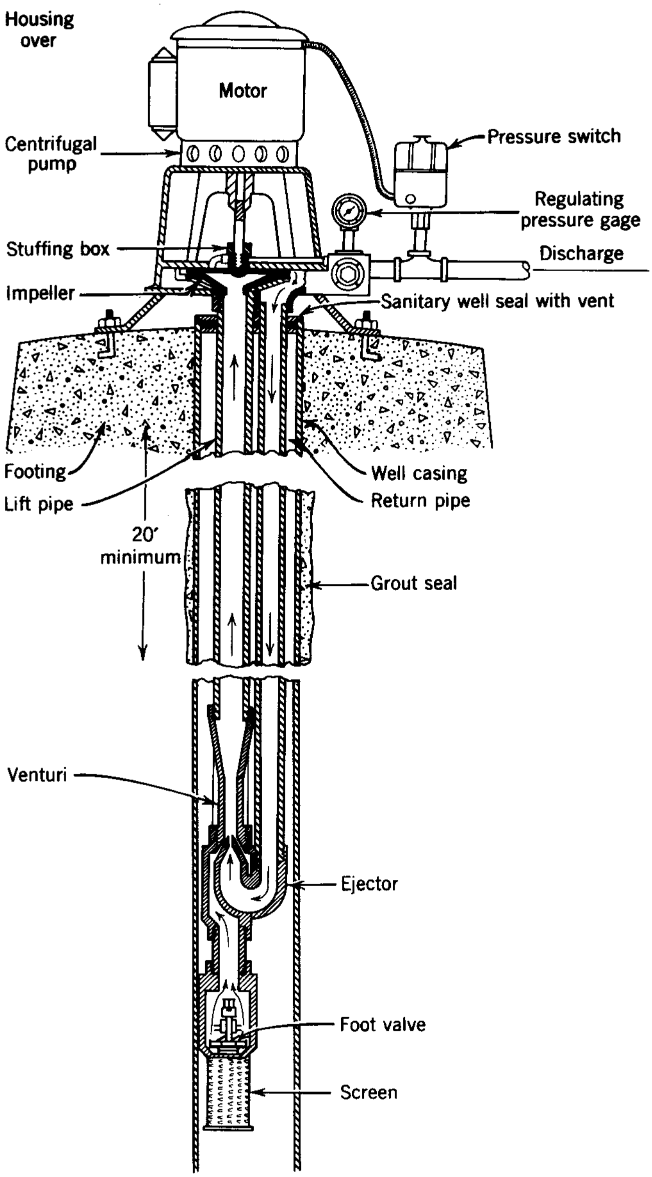


Figure 3-12 Sanitary well seal and jet pump.

There are many ways to seal well casings. The best material is neat cement grout.* However, to be effective, the grout must be properly prepared (a proper mixture is $5\frac{1}{2}$ to 6 gal of clean water to a bag of cement), pumped as one continuous mass, and placed upward from the bottom of the space to be grouted. An additive such as bentonite may be used to minimize shrinkage and increase fluidity, if approved.

The clear annular space around the outside of the casing couplings and the drill hole must be at least $1\frac{1}{2}$ in. on all sides to prevent bridging of the grout. Guides must be welded to the casing.

Cement grouting of a well casing along its entire length of 50 to 100 ft or more is good practice but expensive for the average farm or rural dwelling. An alternative is grouting to at least 20 ft below ground level. This provides protection for most installations, except in limestone and fractured formations. It also protects the casing from corrosion.

For a 6-in.-diameter well a 10-in. hole is drilled, if 6-in. welded pipe is used, to at least 20 ft or to solid rock if the rock is deeper than 20 ft. If 6-in. coupled pipe is used, a 12-in. hole will be required. From this depth the 6-in. hole is drilled deeper until it reaches a satisfactory water supply. A temporary outer casing, carried down to rock, prevents cave-in until the cement grout is placed.

Upon completion of the well, the annular space between the 6-in. casing and temporary casing or drill hole is filled from the bottom up to the grade with cement grout. The temporary pipe is withdrawn as the cement grout is placed—it is not practical to pull the casing after all the grout is in position.

The extra cost of the temporary casing and larger drill hole is small compared to the protection obtained. The casing can be reused as often as needed. In view of this, well drillers who are not equipped should consider adding larger casing and equipment to their apparatus.

A temporary casing or larger drill hole and cement grouting are not required where the entire earth overburden is 40 ft or more of silt or sand and gravel, which immediately close in on the total length of casing to form a seal around the casing; however, this condition is not common.

Drilled wells serving public places are usually constructed and cement grouted as explained in Table 3-15.

In some areas, limestone and shale beneath a shallow overburden represent the only source of water. Acceptance of a well in shale or limestone might be conditioned on an extended observation period to determine the sanitary quality of the water. Continuous chlorination should be required on satisfactory supplies serving the public and should be recommended to private individuals. However, chlorination should not be relied on to make a heavily

* Sand–cement grout, two parts sand to one part Portland cement by weight, with not more than 6 gal of water per sack of cement, may also be used. The curing time for neat cement is 72 hr; for high early strength cement, at least 36 hr.

contaminated well-water supply satisfactory. Such supplies should be abandoned and filled in with concrete or puddled clay unless the source of contamination can be eliminated.

Well drillers may have other sealing methods suitable for particular local conditions, but the methods described above utilizing a neat cement or sand–cement grout will give reasonably dependable assurance that an effective seal is provided, whereas this cannot be said of some of the other methods used. Driving the casing, a lead packer, drive shoe, rubber sleeves, and similar devices do not provide reliable annular space seals for the length of the casing.

Well Contamination—Cause and Removal

Well-water supplies are all too often improperly constructed, protected, or located, with the result that microbiological examinations show the water to be contaminated. Under such conditions, all water used for drinking or culinary purposes should first be boiled or adequately treated. Boiling will not remove chemical contaminants other than volatiles; treatment may remove some. If practical, abandonment of the well and connection to a public water supply would be the best solution. A second alternative would be investigation to find and remove the cause of pollution; however, if the aquifer is badly polluted, this may take considerable time. A third choice would be a new, properly constructed and located drilled well in a clean aquifer. See Travel of Pollution through the Ground, this chapter.

When a well shows the presence of bacterial contamination, it is usually due to one or more of four probable causes: lack of or improper disinfection of a well following repair or construction; failure to seal the annular space between the drill hole and the outside of the casing; failure to provide a tight sanitary seal at the place where the pump line(s) passes through the casing; and wastewater pollution of the well through polluted strata or a fissured or channeled formation. On some occasions, the casing is found to be only a few feet in length and completely inadequate. Chemical contamination usually means the aquifer has been polluted.

If a new well is constructed or if repairs are made to the well, pump, or piping, contamination from the work is probable. The well, pump, storage tank, and piping should be disinfected as explained in this chapter.

If a sewage disposal system is suspected of contamination, a dye such as water-soluble sodium or potassium fluorescein or ordinary salt can be used as a tracer. A solution flushed into the disposal system or suspected source may appear in the well water within 12 to 24 hr. It can be detected by sight, taste, or analysis if a connection exists. Samples should be collected every few hours and set aside for comparison. If the connection is indirect, fluoroscopic or chemical examination for the dye or chlorides is more sensitive. One part of fluorescein in 10 to 40 million parts of water is visible to the naked eye, and in 10 billion parts if viewed in a long glass tube or if concentrated in the laboratory. The chlorides in the well before adding salt should, of course, be known. Where chloride determinations are routinely made on water samples, sewage pollution may be apparent without making the salt test. Dye is not decolorized by passage through sand, gravel, or manure; it is slightly decomposed by calcareous soils and entirely decolorized by peaty formations and free acids, except carbonic acid.[114,115] A copper sulfate solution (300 mg/l), nonpathogenic bacteria and spores, radionuclides, strong electrolytes, and nonfluorescent dyes have also been used. Dyes include congo red, malachite green, rhodamine, pyranine, and photine.[116]

If the cause of pollution is suspected to be an underground seal where the pump line(s) passes through the side of the casing, a dye or salt solution or even plain water can be poured around the casing. Samples of the water can be collected for visual or taste test or chemical examination. The seal might also be excavated for inspection. Where the upper part of the casing can be inspected, a mirror or strong light can be used to direct a light beam inside the casing to see if water is entering the well from close to the surface. Sometimes it is possible to hear the water dripping into the well. Inspection of the top of the well will also show if the top of the casing is provided with a sanitary seal and whether the well is subject to flooding. See Figures 3-7 to 3-12.

The path of pollution entry can also be holes in the side of the casing, channels along the length of the casing leading to the well source, crevices or channels connecting surface pollution with the water-bearing stratum, or the annular space around the casing. A solution of dye, salt, or plain water can be used to trace the pollution, as previously explained.

The steps taken to provide a satisfactory water supply would depend on the results of the investigation. If a sanitary seal is needed at the top or side of the casing where the pump lines pass through, then the solution is relatively simple. On the other hand, an unsealed annular space is more difficult to correct. A competent well driller could be engaged to investigate the possibility of grouting the annular space and installing an inner casing or a new casing carefully sealed in solid rock. If the casing is found tight, it would be assumed that pollution is finding its way into the water-bearing stratum through sewage-saturated soil or creviced or channeled rock at a greater depth. It is sometimes possible, but costly, to seal off the polluted stratum and, if necessary, drill deeper.

Once a stratum is contaminated, it is very difficult to prevent future pollution of the well unless all water from such a stratum is effectively sealed off. Moving the offending sewage disposal system to a safe distance or replacing a leaking oil or gasoline tank is possible, but evidence of the pollution may persist for some time.

If a dug well shows evidence of contamination, the well sidewalls may be found to consist of stone or brick lining, which is far from being watertight. In such cases, the upper 6 to 10 ft should be removed and replaced with a poured concrete lining and platform. As an alternative, a concrete collar 6 to

12 in. thick, 6 to 10 ft deep could be poured around the *outside* of the stone or brick lining (see Figure 3-5). Take safety precautions (see *Safety* in Index).

Chemical contamination of a well and the groundwater aquifer can result from spills, leaking gasoline and oil tanks, or improper disposal of chemical wastes such as by dumping—on the ground in landfills—lagooning, or similar methods. Gasoline and oil tanks typically have a useful life of about 20 years, depending on the type of soils and tank coatings. Since many tanks have been in the ground 20 to 30 years or longer, their integrity must be uncertain and they are probably leaking to a greater or lesser degree. New tanks are not necessarily immune from leakage. If not already being done, oil, gasoline, and other buried tanks containing hazardous chemicals should be tested periodically and, of course, at the first sign of leakage promptly replaced with approved tanks. The number of tanks, surreptitious dumpings, discharges to leaching pits, and other improper disposals make control a formidable task. This subject is discussed further in this chapter; see (a) Groundwater Pollution Hazard and (b) Travel of Pollution through the Ground.

Unless all the sources of pollution can be found and removed, it is recommended that the well be abandoned and filled with neat cement grout, puddled clay, or concrete to prevent the pollution from traveling to other aquifers or wells. In some special cases and under controlled conditions, use of a slightly contaminated water supply may be permitted provided approved treatment facilities are installed. Such equipment is expensive and requires constant attention. If a public water supply is not available and a new well is drilled, it should be located and constructed as previously explained.

Spring

Springs are broadly classified as either rock springs or earth springs, depending on the source of water. To obtain satisfactory water, it is necessary to *find the source,* properly develop it, eliminate surface water, and prevent animals from gaining access to the spring area.

Protection and development of a source of water are shown in Figure 3-13. A combination of methods may also be possible under certain ground conditions and would yield a greater supply of water than either alone.

In all cases, the spring should be protected from surface-water pollution by constructing a deep diverting ditch or the equivalent above and around the spring. The spring and collecting basin should have a watertight top, preferably concrete, and water obtained by gravity flow or by means of a properly installed sanitary hand or mechanical pump. Access or inspection manholes, when provided, should be tightly fitted (as shown) and kept locked. Water from limestone or similar type channeled or fissured rock springs is not purified to any appreciable extent when traveling through the formation and hence may carry pollution from nearby or distant places. Under these circum-

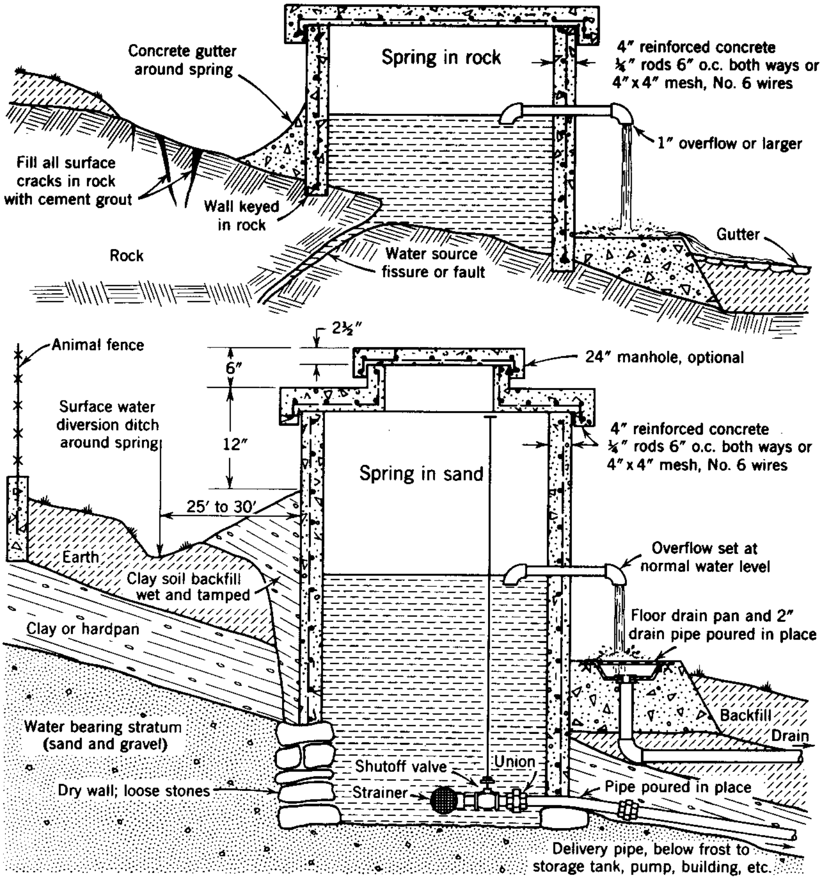


Figure 3-13 Properly constructed springs.

stances, it is advisable to have periodic bacteriological examinations made and chlorinate the water.

Infiltration Gallery

An infiltration gallery consists of a system of porous, perforated, or open-joint pipe or other conduit draining to a receiving well. The pipe is surrounded by gravel and located in a porous formation such as sand and gravel below the water table. The collecting system should be located 20 ft or more from a lake or stream or under the bed of a stream or lake if installed under expert supervision. It is sometimes found desirable, where possible, to intercept the flow of groundwater to the stream or lake. In such cases, a cofferdam, cutoff wall, or puddled clay dam is carefully placed between the collecting conduit and the lake or stream to form an impervious wall. It is not advisable to construct an infiltration gallery unless the water table is relatively stable and the water intercepted is free of pollution. The water-bearing strata should not contain cementing material or yield a very hard water, as it may clog the strata or cause incrustation of the pipe, thereby reducing the flow. An infiltration gallery is constructed similar to that shown in Figure 3-14. The depth of the collecting tile should be about 10 ft below the normal ground level, and below the lowest known water table, to assure a greater and more constant yield. An infiltration gallery may also be located at a shallow depth, above a highly mineralized groundwater, such as saline water, to collect the fresh or less mineralized water. An infiltration system consisting of horizontally perforated or porous radial collectors draining to a collecting well can also be designed and constructed where hydrogeological conditions are suitable, usu-

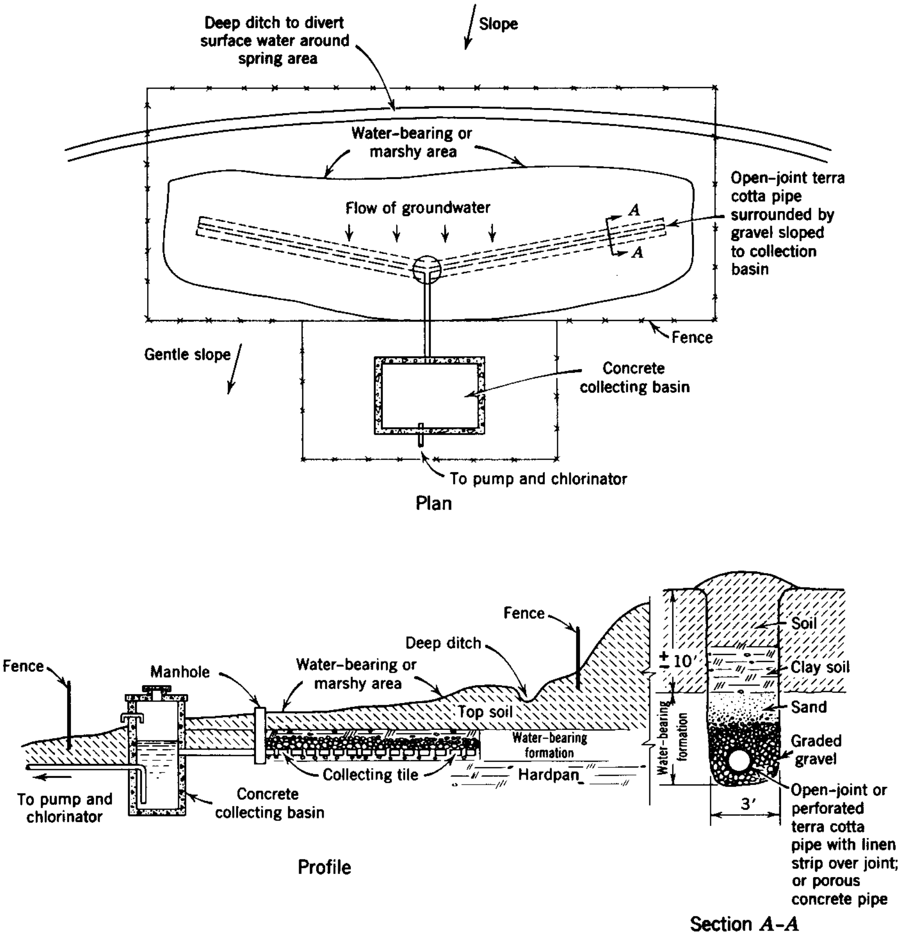


Figure 3-14 Development of a spring in a shallow water-bearing area.

ally under a stream bed or lake, or where a thin water-bearing stratum exists. The infiltration area should be controlled and protected from pollution by sewage and other wastewater and animals. Water derived from infiltration galleries should, at the minimum, be given chlorination treatment.

Cistern

A cistern is a watertight tank in which rainwater collected from roof runoff or other catchment area is stored. When the quantity of groundwater or surface water is inadequate or the quality objectionable and where an adequate municipal water supply is not available, a cistern supply may be acceptable as a limited source of water. Because rainwater is soft, little soap is needed when used for laundry purposes. On the other hand, rain will wash air pollutants, dust, dirt, bird and animal droppings, leaves, paint, and other material on the roof or in roofing materials or catchment area into the cistern unless special provision is made to bypass the first rainwater and filter the water. The bypass may consist of a simple manually or float-operated damper or switch placed in the leader drain. When in one position, all water will be diverted to a float control tank or to waste away from the building foundation and cistern; when in the other position, water will be run into the cistern. The filter will not remove chemical pollutants. If the water is to be used for drinking or food preparation, it should also be pointed out that because rainwater is soft and acidic, and therefore corrosive, hazardous concentrations of zinc from galvanized iron sheet roofing, gutters, and pipe and lead and copper from soldered copper pipe may also be released, in addition to cadmium.

The capacity of the cistern is determined by the size of the roof or catchment area, the probable water consumption, the maximum 24-hr rainfall, the average annual rainfall, and maximum length of dry periods. Suggested rainwater cistern sizes are shown in Figure 3-15. The cistern storage capacity given allows for a reserve supply, plus a possible heavy rainfall of $3\frac{1}{2}$ in. in 24 hr. The calculations assume that 25 percent of the precipitation is lost. Weather bureaus, the *World Almanac,* airports, water departments, and other agencies give rainfall figures for different parts of the country. Adjustment should therefore be made in the required cistern capacity to fit local conditions. The cistern capacity will be determined largely by the volume of water one wishes to have available for some designated period of time, the total volume of which must be within the limits of the volume of water that the roof or catchment area and annual rainfall can safely yield. Monthly average rainfall data can be expected to depart from the true values by 50 percent or more on occasion. The drawing of a mass diagram is a more accurate method of estimating the storage capacity, since it is based on past actual rainfall in a given area.

It is recommended that the cistern water be treated after every rain with a chlorine compound of at least 5 mg/l chlorine. This may be accomplished by adding five times the quantities of chlorine shown in Table 3-16, mixed in 5

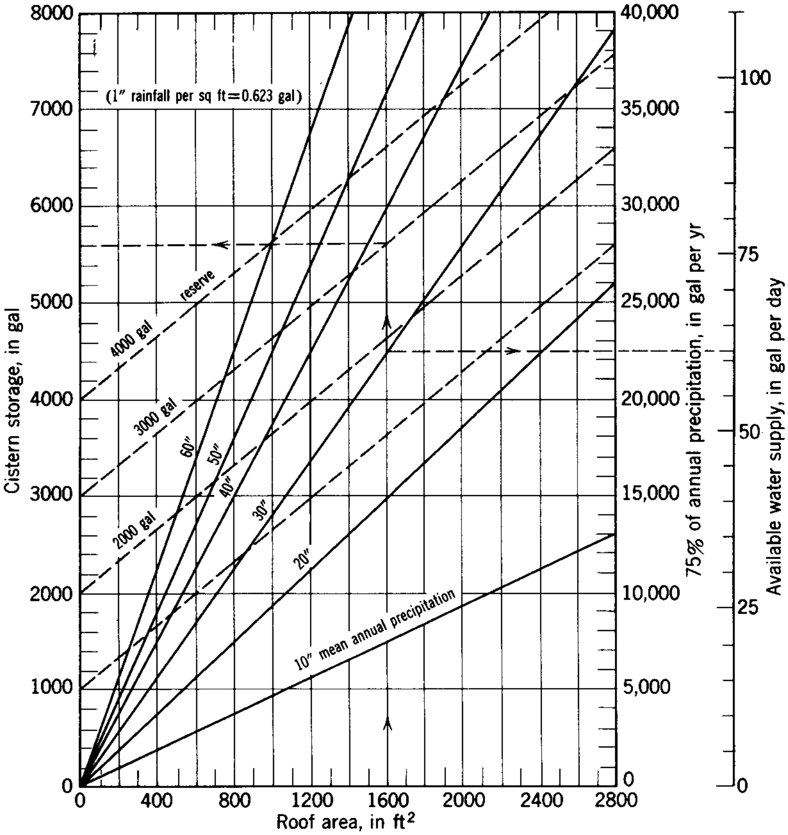


Figure 3-15 Suggested cistern storage capacity and available supply.

gal of water to each 1000 gal of water in the cistern. A stack or tablet chlorinator and carbonate (limestone) contact tank on the inlet to the cistern is advised for disinfection and acidity neutralization. In areas affected by air

TABLE 3-16 Quantity and Type of Chlorine to Treat 1000 gal of Clean Water at Rate of 1 mg/l

Chlorine Compound	Quantity
High test, 70% chlorine	$\frac{1}{5}$ oz or $\frac{1}{4}$ heaping tablespoon
Chlorinated lime, 25% chlorine	$\frac{1}{2}$ oz or 1 heaping tablespoon
Sodium hypochlorite	
14% chlorine	1 oz
10% chlorine	$1\frac{1}{3}$ oz
Bleach, $5\frac{1}{4}$ chlorine	$2\frac{3}{5}$ oz

pollution, fallout on the roof or catchment area will contribute chemical pollutants that may not be neutralized by limestone or chlorine treatment. Soft water flowing over galvanized iron roofs or through galvanized iron pipe or stored in galvanized tanks contains cadmium and zinc.[55]

Example With a roof area of 1600 ft^2, in a location where the mean annual precipitation is 30 in. and it is desired to have a reserve supply of 3000 gal, the cistern storage capacity should be about 5600 gal. This should yield an average annual supply of about 62 gal per day.

In some parts of the world, large natural catch basins are lined to collect rainwater. The water is settled and chlorinated before distribution. The amount of water is of course limited and may supplement groundwater, individual home cisterns, and desalinated water.

Domestic Well-Water Supplies—Special Problems[117]*

Domestic well-water supply problems are discussed below. The local health department and commercial water-conditioning companies may be of assistance to a homeowner.

Hard Water Hard water makes it difficult to produce suds or rinse laundry, dishes, or food equipment. Water hardness is caused by dissolved calcium and magnesium bicarbonates, sulfates, and chlorides in well water. Pipes clog and after a time equipment and water heaters become coated with a hard mineral deposit, sometimes referred to as lime scale. A commercial zeolite or synthetic resin water softener is used to soften water. The media must be regenerated periodically and disinfected with chlorine to remove contamination after each regeneration. Softeners do not remove contamination in the water supply. A filter should be placed ahead of a softener if the water is turbid. See also Water Softening, this chapter.

The sodium content of the water passing through a home water softener will be increased. Individuals who are on a sodium-restricted diet should advise their physician that they are using home-softened water since such water is a continual source of dietary sodium. A cold-water bypass line can be installed around the softener to supply drinking water and water for toilet flushing.

Turbidity or Muddiness This usually occurs in water from a pond, creek, or other surface source. Such water is polluted and requires coagulation, flocculation, sedimentation, filtration, and chlorination treatment. Wells sometimes become cloudy from cave-in or seepage from a clay or silt stratum but

*This section is adapted from ref. 117.

usually clear up with prolonged pumping. If the clay is in the colloidal state, coagulation, such as with aluminum sulfate (alum), is needed.

Sand filters can remove mud, dirt, leaves, foreign matter, and most bacteria, viruses, and protozoa if properly operated, but they may clog rapidly. Chlorination is also required to ensure destruction of pathogens. Charcoal, zeolite, or carbon filters are not suitable for this purpose, and, in addition, they clog. Iron and iron growths that sometimes cause turbidity in well water are discussed below. See also Filtration, this chapter.

Iron and Manganese in Well Water Iron and manganese may be found in water from deep wells and springs. In high concentrations it causes a bitter taste in tea or coffee. When exposed to the air, iron and manganese are oxidized and settle out. Red to brown or black (manganese) stains form on plumbing fixtures, equipment, and laundry. Chlorine bleach exacerbates the staining problem. Iron and manganese in solution (colloidal) form may be found in shallow wells, springs, and surface waters. In this form, the water has a faint red or black color.

A commercial home zeolite water softener removes 1.5 to 2.0 mg/l, and an iron removal filter removes up to 10 mg/l iron from well water devoid of oxygen. The water should *not* be aerated prior to zeolite filtration as this will cause precipitation of oxidized (ferric) iron rather than the exchange of sodium by ferrous iron, which is washed out as ferrous chloride when regenerated. An iron removal filter will also remove some hydrogen sulfide. The water softener is regenerated with salt water. The iron removal filter is backwashed to remove the precipitated iron and regenerated with potassium permanganate. Since potassium permanganate is toxic, it must all be flushed out before the treated water is used. The controlled addition of a polyphosphate can keep 1.0 to 2.0 mg/l iron in solution, but, as with the zeolite softener, sodium is also added to the water. Heating of water to 140 to 150°F (60–66°C) nullifies the effectiveness of polyphosphate.

With higher concentrations of iron, the water is chlorinated to oxidize the iron in solution and allowed a short contact period, but the water should then be filtered to remove the iron precipitate before it enters the distribution system. The pH of the water should be raised to above 7.0 if the water is acid; soda ash, added to the chlorine solution, is usually used for this purpose. Hydrogen peroxide or potassium permanganate will also oxidize the iron.

Another approach is to discharge the water to the air chamber of a pressure tank, or to a sprinkler over a cascade above a tank, but this will require double pumping. It is necessary to flush out the iron that settles in the tank and filter out the remainder. Air control is needed in a pressure tank. Air is admitted with the well water entering and air is vented from the tank. Manganese is also removed with iron treatment.

Injecting a chlorine solution into the water at its source, where possible, controls the growth of iron bacteria, if this is a problem. See also (a) Iron and Manganese Occurrence and Removal and (b) Iron Bacteria Control, this chapter. Before purchasing any equipment, seek expert advice and a proper demonstration should be sought.

Corrosive Water Water having a low pH or alkalinity and dissolved oxygen or carbon dioxide tends to be corrosive. Corrosive water dissolves metal, shortens the life of water tanks, discolors water, and clogs pipes. Iron corrosion causes rusty water; copper or brass pipe causes blue-green stains. Water can be made noncorrosive by passing it through a filter containing broken limestone, marble chips, or other acid neutralizers. The controlled addition of a polyphosphate, silicate, or soda ash to raise the water pH (commercial units are available) usually prevents metal from going into solution. The water remains clear and staining is prevented. However, bear in mind that a sodium polyphosphate would add sodium to the water, making it undesirable for individuals on a low-sodium diet. The use of low-lead solder (95:5 tin–antimony solder), plastic pipe, maintenance of water temperature below 140°F (60°C), and a glass-lined hot water storage tank will minimize the problems associated with corrosion in home plumbing.

Taste and Odors Activated-carbon filters or cartridges are normally used to remove undesirable tastes and odors from domestic water supplies, but they do not remove microbiological contamination. Hydrogen sulfide in water causes a rotten-egg odor; corrosion of iron, steel, and copper; and black stains on laundry and crockery. It can also be eliminated by aeration and chlorination followed by filtration. An activated-carbon filter is not efficient. The activated carbon will have to be replaced when its capacity has been exhausted. Filtration alone, through a pressure filter containing a special synthetic resin, also removes up to 5 mg/l hydrogen sulfide in most cases. The water in question should be used to check the effectiveness of a process before any equipment is purchased. See also Hydrogen Sulfide, Sources and Removal in this chapter.

Detergents Detergents in water can be detected visually, by taste, or by laboratory examination. When some detergents exceed 1 mg/l, foam appears in a glass of water drawn from a faucet. Detergents themselves have not been shown to be harmful, but their presence is evidence that wastewater from one's own sewage disposal system or from a neighbor's system is entering the water supply source. In such circumstances, the sewage disposal system may be moved, a well constructed in a new area, or the well extended and sealed into a deeper water-bearing formation not subject to pollution. There is no guarantee that the new water-bearing formation will not be or become polluted later. The solution of this problem is connection to a public water supply and/or a public sewer. A granular activated-carbon (GAC) filter may be used to remove detergent, but its effectiveness and cost should first be demonstrated. See also Methylene Blue Active Substances (MBAS), this chapter.

Salty Water In some parts of the country, salty water may be encountered. Since the salt water generally is overlain by fresh water, the lower part of the well in the salt water zone can be sealed off. But when this is done, the yield of the well is decreased.

Sometimes, waste salt water resulting from the backwashing of a home ion exchange water softener is discharged close to the well. Since salt water is not filtered out in seeping through the soil, it may find its way into the well. The best thing to do is to discharge the wastewater as far as possible and downgrade from the well or utilize a commercial water softener service. Salt water is corrosive; it will damage grass and plants and sterilize soil. Road salting or salt storage areas may also contribute to well pollution.

Special desalting units (using distillation, deionization, and reverse osmosis) are available for residential use, but they are of limited capacity and relatively expensive and pretreatment of the water may be needed. Complete information, including effectiveness with the water in question and annual cost, should be obtained before purchase. See Desalination, this chapter, for additional information.

Radon in Well Water See Indoor Air Quality, Chapter 11, and Radon, this chapter.

Gasoline or Fuel Oil in Water See (a) Removal of Gasoline, Fuel Oil, and Other Organics in an Aquifer and (b) Travel of Pollution through the Ground, this chapter.

Household Treatment Units *(*Point-of-Use and Point-of-Entry*)*

Sometimes a chlorinator, faucet filter (point-of-use unit), dwelling filter (point-of-entry unit), or UV light disinfection unit is suggested to make an on-site polluted water supply safe for drinking without regard to the type, amount, or cause of pollution. This is hazardous. Instead, every effort should first be made to identify the pollutant and remove the source. This failing, every effort should be made to obtain water from a public water system. As a last resort, a household treatment unit or bottled water may have to be used. But the treatment units do not remove all microbiological, chemical, and physical pollutants. Careful selection of the proper treatment unit, which will resolve the particular pollution problem, in addition to cost, required maintenance and operation control, must be considered.

Household treatment unit processes include filtration, UV light radiation, chlorination, granular or powdered activated-carbon filtration, reverse osmosis, cartridge filters, cation exchange, anion exchange, distillation, pasteurization,[118] and activated-alumina filtration as well as sand, porous stone, and ceramic filters. Each has limitations.

Ultraviolet light radiation and chlorination units are not considered satisfactory for the purification of surface-water supplies such as from ponds, lakes, and streams, which usually vary widely in physical, chemical, and microbiological quality, or for well or spring supplies, which may contain turbidity, color, iron, or organic matter. Pretreatment, usually including coagulation, flocculation, sedimentation, filtration, and disinfection or the equivalent, would be required to remove organic and inorganic contaminants that interfere with the effectiveness of the treatment. Chlorination and UV radiation treatment may be considered microbiologically acceptable only if the water supply is always clean, clear, and not subject to chemical or organic pollution and the units are operated as intended.* Certain controls are needed to ensure that the efficiency of the UV unit is not impaired by changes in light intensity, loss of power, rate of water flow, short circuiting, condition of the lamp, slime accumulation, turbidity, color, and temperature of the water.[119] Public Health Service 1974 standards state that acceptable UV units must have a flow rate of less than 0.2 gpm/effective inch of lamp, which must emit 2437 Å at an intensity of 4.85 UV watts/ft^2 at a distance of 2 in., or an equivalent ratio of lamp intensity to flow, with a minimum retention time of 15 sec at the maximum flow rate.[120] A flow control device, UV light-sensing device, alarm, and shutdown device are also needed.[121] Ultraviolet radiation units have application in the dairy, beverage, pharmaceutical, cosmetic, electronic, and food industries for the treatment of wash and cooling waters and for lowering the bacterial count in potable water used for soft drinks and bottled water. A chlorination unit requires inspection, solution replacement, and daily residual chlorine tests to ensure the unit operates as intended.

Most household filters contain activated carbon for the removal of organic substances. Taste and odor compounds are reduced, including chlorine, radon, and volatile halogenated organics such as trichloroethylene and carbon tetrachloride.[122] Sediment is trapped in the filter, and organic compounds, such as trihalomethanes resulting from chlorination, are removed to some extent. The activated-carbon filter cartridge needs periodic replacement, as recommended by the manufacturer. Microorganisms may grow in the filter and be released, but no harmful effects have been reported.[123] Many volatile organic compounds and radon (see Indoor Air Quality in Chapter 11) are also removed by boiling and aeration. A cartridge filter to remove particulates should precede the carbon filter if the raw water is turbid. It should be understood that the water to be filtered must be potable. Microbiological and inorganic contaminants in solution are not removed.

A reverse-osmosis filter can reduce the concentrations of fluoride, mercury, lead, nitrates, sodium, iron, sulfate, alkalinity, total dissolved solids, and similar substances that might be present in drinking water, but not radon (GAC is effective). Sediment and many organic compounds are also removed, but prefiltration through a filter that removes particulates is indicated if sediment

*Normal chlorination treatment and UV radiation treatment do not inactivate the *Giardia lamblia* and *Cryptosporidium* protozoan cysts.

is present to prevent premature membrane clogging, followed by an activated-carbon filter to remove taste and odor compounds and other organics.[124] Arsenic and uranium are also removed under certain operating conditions.[125] The unit should have an automatic shut-off valve. The filter membrane requires backwashing.*

An activated-alumina unit can reduce the fluorides, arsenic, barium, and nitrates if sulfates are not too high. Uranium is also reduced.[125] The unit requires periodic regeneration. The activated-alumina lead removal cartridge is effective in removing lead.[126]

Electric distillation units that boil and condense water are also available. These units remove most microorganisms and inorganic compounds, including lead, salt, and nitrates, but not volatile organic compounds like benzene and chloroform—their capacity is limited.

Special ion exchange cartridge filters can remove inorganic contaminants from drinking water, including fluoride, uranium, and arsenic.[125] Ion exchange units can be regenerated with sodium chloride.

Porous stone "candles" and unglazed porcelain Pasteur or Berkefield filters for microbiological control are available and can be attached to a faucet spigot. They may develop hairline cracks and become unreliable for the removal of pathogenic microorganisms. They should be scrubbed, cleaned, and sterilized in boiling water once a week. Portable pressure-type ceramic microfiltration units, with single or multiple candles, having a capacity to remove 0.2-μm particles (bacteria, protozoa, helminths, and fungi), but not all viruses or chemical contaminants, are also available.[127]

Environmental Protection Agency studies of home water treatment filter devices showed THM removals of 6 to 93 percent and total organic carbon removals of 2 to 41 percent, depending on the unit. In some cases, higher bacterial counts were found in the water that had passed through the filter.[128] A subsequent study showed similar results.[129] Another study of halogenated organic removal showed reductions ranging from 76 percent for a faucet-mount unit to 99 percent for several line bypass units.[130,131] These filter units do not remove nitrates, fluorides, or chlorides; do not soften water; remove little dissolved lead, iron, manganese, and copper; and do not remove microorganisms. They should not be used on any water supply that does not otherwise meet drinking water standards. The ability of a unit to remove the particular deleterious contaminants in the raw water should be confirmed with the manufacturer and the health department before purchase.† In general, reverse osmosis and distillation are most effective for inorganic contaminant reduction and granular activated carbon for organic contaminant removal.

*Typically, about 75 percent of the tap water put into the reverse-osmosis system is wasted. ("FACTS for Consumers," Federal Trade Commission, Washington, DC, August 1989, p. 2.)

†The National Sanitation Foundation, 3475 Plymouth Road, Ann Arbor, MI 48106, can provide a list of units certified for specific purposes. Also, The Water Quality Research Council, 4151 Naperville Road, Lisle, IL 60532.

Household treatment units have a limited flow capacity, which can be compensated for in part by incorporating a storage tank in the water system. Provision must be made for replacement or washing and disinfection of the filter element on a planned basis.

The satisfactory operation of a large number of household point-of-entry units in an area requires an effective management system, including monitoring, maintenance, and timely replacement of units or components and, in some instances, pre– and post–water treatment such as preclarification and postdisinfection.[132]

For a discussion of bottled water, see Bottled, Packaged, and Bulk Water, this chapter.

Desalination

Desalination or desalting is the conversion of seawater or brackish water to fresh water for potable and industrial purposes. The conversion of treated wastewater to potable water using modified desalination processes is also being considered, but health effects and cost questions must first be resolved. Desalination technology is being used or considered to remove contaminants from surface and underground waters, including inorganics, radionuclides, and THM precursors.

About seven-tenths of our globe is covered by seawater. The world's oceans have a surface area of 139,500,000 mi^2 and a volume of 317,000,000 mi^3.[133] The oceans contain about 97 percent of the world's water; brackish inland sites and polar ice make up 2.5 percent, leaving less than 0.5 percent fresh water to be used and reused for municipal, industrial, agricultural, recreational, and energy-producing purposes.[134] In addition, more than half of the earth's surface is desert or semidesert. Under circumstances where adequate and satisfactory groundwater, surface water, or rainwater is not available and a high-quality water is required but where seawater or brackish water is available, desalination may provide an answer to the water problem. However, construction and energy costs could be major deciding factors. Isolated resorts and communities might find desalination an acceptable option where practical.

Desalting plants are in use all over the world. The Office of Saline Water Research and Development reports 3500 plants worldwide with capacity of 3000 mgd in operation or under construction as of 1986.[135]

Seawater has a total dissolved solids (TDS) concentration of about 35,000 mg/l. About 78 percent is sodium chloride, 11 percent magnesium chloride, 6 percent magnesium sulfate, 4 percent calcium sulfate, with the remainder primarily potassium sulfate, calcium carbonate, and magnesium bromide, in addition to suspended solids and microbiological organisms. The U.S. Geological Survey classifies water with less than 1000 mg/l TDS as fresh, 1000 to 3000 mg/l as slightly saline, 3000 to 10,000 mg/l as moderately saline, 10,000 to 35,000 mg/l as very saline, and more than 35,000 mg/l as brine.

The U.S. Office of Technology Assessment defines potable water as generally having less than 500 ppm TDS (salt and/or dissolved solids), less brackish water as 500 to 3000 ppm, moderately brackish water as 3000 to 10,000 ppm, and highly brackish water as 10,000 to 35,000 ppm. [135] The source of brackish water may be groundwater or surface-water sources such as oceans, estuaries, saline rivers, and lakes. Its composition can be extremely variable, containing different concentrations of sodium, magnesium, sulfate, calcium, chloride, bicarbonate, fluoride, potassium, and nitrate. Iron, manganese, carbon dioxide, and hydrogen sulfide might also contribute to the variability of brackish water quality. Water in the Great Salt Lake or the Dead Sea is considered brine.

Desalting will remove dissolved salts and minerals such as chlorides, sulfates, and sodium, in addition to hardness. Nitrates, nitrites, phosphates, fluorides, ammonia, and heavy metals are also removed to some degree depending on the process. Very hard brackish water will require prior softening to make reverse osmosis or electrodialysis very effective.[136] Desalination is not normally used to remove iron, manganese, fluorides, calcium, or magnesium.

Some known methods for desalting water are as follows[137]:

Membrane Reverse osmosis; electrodialysis and electrodialysis reversal; transport depletion; piezodialysis.

Distillation Multistage flash distillation; multieffect multistage distillation; vapor compression; vertical tube distillation; solar humidification.

Crystallization Vacuum freezing–vapor compression; secondary refrigerant freezing; eutectic freezing; hydrate formation.

Chemical Ion exchange.

Distillation In distillation, seawater is heated to the boiling point and then into steam, usually under pressure, at a starting temperature of 250°F (121°C). The steam is collected and condensed in a chamber by coming into contact with tubes (condenser–heat exchanger) containing cool seawater. The heated saline water is passed through a series of distillation chambers in which the pressure is incrementally reduced and the water boils (made to ‘‘flash’’), again at reduced temperature, with the production of steam, which is collected as fresh water. The remaining, more concentrated, seawater (brine) flows to waste. In each step, the temperature of the incoming seawater is increased by the condenser–heat exchangers as it flows to the final heater. The wastewater (brine) and distilled water are also used to preheat the incoming seawater. This process is referred to as multistage flash distillation (MSF). There may be as many as 15 to 25 stages. A major problem is the formation of scale (calcium carbonate, calcium sulfate, and magnesium hydroxide) on the heat transfer surfaces of the pipe or vessel in which the seawater is permitted to boil. This occurs at a temperature of about 160°F (71°C), but scale can be greatly minimized by pretreating the seawater to remove either the calcium or the carbon dioxide. Distilled sea water normally has 5 to 50 mg/l salt. Most volatile substances are removed.

Vertical-tube distillation, multieffect multistage distillation, vapor compression distillation, and solar distillation are distillation variations. Solar humidification (distillation) depends on water evaporation at a rate determined by the temperature of the water and the prevailing humidity. The unit is covered with a peaked glass or plastic roof from which the condensate is collected. Distilled water is tasteless and low in pH if not aerated and adjusted before distribution.

Reverse Osmosis Normally, if salt water and fresh water are separated by a semipermeable membrane, the fresh water diffuses through to the salt water as if under pressure, actually osmotic pressure. The process is known as osmosis. In reverse osmosis, hydraulic pressures of 200 to 500 psi for brackish water and 800 to 1200 psi for seawater (ref. 135, pp. 14, 57) are applied to the concentrated salt water on one side of a special flat or cylindrical supported membrane, a spiral wound, or hollow-fiber unit. The life of the membrane decreases with increasing pressure. In the process, fresh water is separated out from the salt water into a porous or hollow channel from which the fresh water is collected. The concentration of TDS in the salt water flowing through the unit must be kept below the point at which calcium sulfate precipitation takes place. Some of the dissolved solids, 5 to 10 percent, will pass through the membrane, including total hardness, sulfates, chlorides, ammonium, chemical oxygen demand (COD) materials, color, bacteria, and viruses. Chlorinated methanes and ethanes, which are common solvents, are not removed by reverse osmosis; however, air stripping is effective.[138] An increase in the TDS will result in a small increase of solids in the fresh water.

In reverse osmosis, the salt water to be treated must be relatively clear and free of excessive hardness, iron, manganese, and organic matter to prevent fouling of the system membranes. The maximum water temperature must be between 86 and 122°F (30 and 50°C) depending on membrane type.[139] The pretreatment may consist of softening to remove hardness; coagulation and filtration (sand, anthracite, multimedia; cartridge, or diatomaceous earth) to remove turbidity, suspended matter, iron, and manganese; and filtration through activated-carbon columns to remove dissolved organic chemicals. Acid is used if necessary to lower the pH and prevent calcium carbonate and magnesium hydroxide scale. Citric acid is used to clean membranes of inorganics and chlorine bleach for organics removal. Special cleaners may be needed to remove silicates, sulfates, hydroxides, and sulfides. Chlorine might also be used to control biological growths on the membranes,[140] but prior filtration of water through GAC is necessary to protect membranes not resistant to chlorine and prevent the formation of trihalomethanes (bromoform). Salt, dissolved solids, some microorganisms, organic and colloidal materials, and other contaminants, including radiologic, are removed. Reverse-osmosis treated water usually requires posttreatment for pH adjustment, degasification

(H_2S and CO_2), corrosion adjustment, and disinfection, possibly further demineralization by ion exchange, and UV radiation disinfection for certain industrial waters. Other membrane processes include nanofiltration, ultrafiltration, and microfiltration.

Electrodialysis In electrodialysis the dissolved solids in the brackish water (less than 10,000 mg/l TDS) are removed by passage through a cell in which a direct electric current is imposed. Dissolved solids in the water contain positively charged ions (cations) and negatively charged ion (anions). The cations migrate to and pass through a special membrane allowing passage of the positive ions. Another special membrane allows the negative ions to pass through. The concentration of dissolved solids determines the amount of current needed. The process removes salt, other inorganic materials, and certain low-molecular-weight organics (ref. 135, pp. 14, 57). Operating pressures vary from 70 to 90 psi. The partially desalted–demineralized water is collected and the wastewater is discharged to waste. Maximum water operating temperature is 113°F (45°C).[139]

The plant size is determined in part by the desired amount of salt removal. However, a change in the TDS in the brackish water will result in an equal change in the treated water.[141] As in reverse osmosis, pretreatment of the brackish water is necessary to prevent fouling of the membranes and scale formation. Scaling or fouling of membranes is reported to be prevented in most units by reversing the electric current at 15- to 30-min intervals.[135] The cost of electricity limits the use of electrodialysis.

Transport depletion is a variation of the electrodialysis process. Piezodialysis is in the research stage; it uses a new membrane desalting process.

Ion Exchange In the deionization process, salts are removed from brackish water (2000 to 3000 mg/l TDS). Raw water passes through beds of special synthetic resins that have the capacity to exchange ions held in the resins with those in the raw water.

In the two-step process, at the first bed (acidic resin) sodium ions and other cations in the water are exchanged for cations (cation exchange) in the resin bed. Hydrogen ions are released and, together with the chloride ions in the raw water, pass through to the second resin bed as a weak hydrochloric acid solution. In the second resin bed, the chloride ions and other anions are taken up (anion exchange) from the water, are exchanged for hydroxide ions in the resin bed that are released, combine with the hydrogen ions to form water, and pass through with the treated water. The ion exchange beds may be in a series or in the same shell.

When the resins lose their exchange capacity and become saturated, the treatment of water is interrupted and the beds are regenerated, with acids or bases. The resins may become coated or fouled if the raw water contains excessive turbidity, microorganisms, sediment, color, organic matter including dissolved organics, hardness, iron, or manganese. In such cases, pretreatment to remove the offending contaminant is necessary. Chlorine in water would attack the cation resin and must also be removed prior to deionization.

Waste Disposal The design of a desalting plant must make provision for the disposal of waste sludge from pretreatment and also of the concentrated salts and minerals in solution removed in the desalting process. The amount or volume of waste is dependent on the concentration of salts and minerals in the raw water and the amount of water desalted. The percent disposed as waste concentrate from a reverse osmosis unit treating brackish water may be 20 to 50 percent, from a seawater unit 60 to 80 percent, from an electrodialysis unit 10 to 20 percent, and from a distillation unit 5 to 75 percent (ref. 135, pp. 25, 31).

The waste from mildly brackish water (1000 to 3000 mg/l TDS) will contain from 5000 to 10,000 mg/l (TDS). The waste from a seawater desalting plant can contain as much as 70,000 mg/l (TDS).[142]

The waste disposal method will usually be determined by the location of the plant and the site geography. Methods that would be considered include disposal to the ocean, inland saline lakes and rivers, existing sewer outfalls, injection wells or sink holes where suitable rock formations exist, solar evaporation ponds, lined or tight-bottom holding ponds, or artificially created lakes. In all cases, prior approval of federal (EPA) and state regulatory (water pollution and water supply) agencies having jurisdiction must be obtained. Surface and underground sources of drinking water and irrigation water must not be endangered. A possible use for the wastewater might be for regeneration of a community sodium zeolite softener.

Costs The Office of Water Research and Technology reported that the cost of desalted water from some 1036 desalting plants around the world is upward from 85 cents per 1000 gal, except where fuel is available at very low cost (ref. 137, p. 1). Costs in the United States are about $4 for seawater and $1 for brackish water per 1000 gal, compared to $0.40 for conventional sources (ref. 134, pp. i, 10). Costs in 1985 (capital and operating costs) were estimated to be $4 to $6 per 1000 gal for seawater distillation and reverse osmosis, and as much as $10 per 1000 gal for inefficient operations. Costs were estimated to be $2 to $2.50 per 1000 gal for brackish water, reverse osmosis, and electrodialysis treatment, with conventional treatment at approximately $0.40 to $2 per 1000 gal.[135]

An analysis was made by Miller[143] of 15 municipalities in the western United States demineralizing brackish water by reverse osmosis, electrodialysis, or ion exchange and combinations thereof. Flows varied from 0.13 to 7.18 mgd and TDS from 941 to 3236 mg/l. The demineralization cost varied from $0.37 to $1.56 per 1000 gal. Reverse osmosis was found to be the least costly process by most of the communities. Reverse osmosis plant construction and operating costs for seawater desalting were reported to be usually less than for distillation.[144] This may not be the case, however, where large volumes of seawater are to be distilled and where a convenient source of heat energy is available,[145] such as from a power plant or incinerator or where fuel costs are low. In another report the energy break-even point of the reverse osmosis and electrodialysis treatment of brackish water and wastewater was approximately 1200 mg/l. Electrodialysis was more energy efficient below 1200 mg/l and reverse osmosis above that level.[134]

Construction and operating cost comparisons must be made with care. They are greatly influenced by location; material, labor, and energy costs; size; TDS concentration; and amount of pollutants such as suspended and other dissolved solids in the water to be desalted. Waste disposal and water distribution are additional factors usually considered separately.

General The use of desalted water usually implies a dual water distribution and plumbing system, one carrying the potable desalted water and the other carrying nonpotable brackish water or seawater. Obviously, special precaution must be taken to prevent interconnections between these two water systems. The brackish water or seawater may be used for firefighting, street flushing, and possibly toilet flushing.

The finished desalted water requires pH adjustment for corrosion control (lime, sodium hydroxide) and disinfection prior to distribution. It must contain not more than 500 mg/l total dissolved solids to meet drinking water standards. Up to 1000 mg/l dissolved solids might be acceptable in certain circumstances. Other standards would apply if the desalted water is used for industrial purposes. The EPA considers a groundwater containing less than 10,000 mg/l TDS as a potential source of drinking water.[146]

Indirect benefits of desalting brackish water may include the purchase of less bottled water, use of less soap and detergents, no need for home water softeners and water-conditioning agents, and fewer plumbing and fixture repairs and replacements due to corrosion and scale buildup.[147]

TREATMENT OF WATER—DESIGN AND OPERATION CONTROL

Surface Water

The quality of surface water depends on the watershed area drained, land use, location and sources of natural and man-made pollution, and natural agencies of purification, such as sedimentation, sunlight, aeration, nitrification, filtration, and dilution. Since these are variable, they cannot be depended on to continuously purify water effectively. However, large reservoirs providing extended storage permit natural purification to take place, but short-circuiting and direct contamination must be avoided. In addition, increasing urbanization, industrialization, and intensive farming have caused heavy organic and inorganic chemical discharges to streams, which are not readily removed by the usual water treatment. Treatment consisting of coagulation, flocculation, sedimentation, rapid sand filtration, and chlorination has little effect on some chemical contaminants noted. Because of these factors and to reduce risk, heavily polluted surface waters should be avoided as drinking water supplies, if possible, and upland protected water sources should be used and preserved consistent with multipurpose uses in the best public interest (ref. 148, p. 238):

> The American Water Works Association (AWWA) is dedicated to securing drinking water from the highest quality sources available and protecting those sources to the maximum degree possible.

The growing demand for use of reservoirs for recreational purposes requires that the public understand the need for strict controls to prevent waterborne diseases and watershed disturbance. Involved are added capital and maintenance and operating costs that may increase the charges for the water and use of the recreational facilities, if the multipurpose uses are permitted.

Treatment Required

The treatment required is dependent on the federal and state regulations and on the probable changing physical, chemical, and microbiological quality of the water source. This emphasizes the importance of adequate meteorological and hydrological information, the sanitary survey previously discussed, and its careful evaluation. The evaluation should take into consideration the existing land-use zoning and probable development. Water treatment plants should not have to bear the total burden and cost of elaborate treatment because of water pollution of its source water. The water purveyor should therefore take an active role in stream, lake, and land-use classifications and be aware of all existing and proposed industrial and municipal wastewater outlets and nonpoint pollution sources. The pollution from these sources should ideally be eliminated or minimized to the extent possible and adequately treated. Continual supervision and enforcement of watershed, land-use, and wellhead area protection rules and regulations must be assured.

The EPA rules, based on the 1986 Amendments to the Safe Drinking Water Act, require the following[149]:

1. Surface water complete filtration treatment if
   a. fecal coliforms exceed 20 per 100 ml or
   b. total coliforms exceed 100 per 100 ml in more than 10 percent of the measurements for the previous 6 months, calculated each month.
2. Minimum sampling frequency for fecal or total coliforms per week of
   a. 1 for systems serving fewer than 501 people,
   b. 2 for systems serving 501 to 3300,
   c. 3 for systems serving 3301 to 10,000,
   d. 4 for systems serving 10,001 to 25,000, and
   e. 5 for systems serving 25,000 or more.

3. Turbidity measurements every 4 hr; once a day for systems serving less than 501 people. Filtration treatment is required if turbidity level exceeds 5 NTU unless the state determines that the event is unusual.
4. Treatment to achieve at least 99.9 percent removal or inactivation of *Giardia lamblia* cysts (also *Cryptosporidium*) and 99.99 percent removal or inactivation of viruses, also *Legionella*.
5. Maintenance of disinfecting residuals in the distribution system—not less than 0.2 mg/l chlorine in at least 95 percent of the samples tested.
6. A watershed protection program; annual sanitary survey; absence of waterborne disease outbreaks; compliance with the total coliform and trihalomethane maximum contaminant levels (MCLs); turbidity of 0.5 NTU in 95 percent of monthly measurements; certified operators; and increased monitoring and reporting.

People expect the water to be safe to drink, attractive to the senses, soft, nonstaining, and neither scale forming nor corrosive to the water system. The various treatment processes used to accomplish these results are briefly discussed under the appropriate headings below. In all cases, the water supply must meet the federal and state drinking water standards.[150] The untrained individual should not attempt to design a water treatment plant, for life and health will be jeopardized. This is a job for a competent sanitary engineer. Submission and approval of plans and specifications are usually required by the regulatory agency.[151] Computerized control of water treatment and distribution is considered essential to a greater or lesser degree, dependent on the operator skills and immediate availability of manufacturer assistance.

Disinfection

The more common chemicals used for the disinfection of drinking water are chlorine (gas and hypochlorite), chlorine–ammonia, chlorine dioxide, and ozone. Chlorine is discussed below; the others are discussed in relation to the removal or reduction of objectionable tastes and odors and trihalomethanes. Ozone and chlorine dioxide are receiving greater attention as primary disinfectants and chlorine–ammonia for maintenance of a residual in the distribution system. Other disinfectants that may be used under certain circumstances include UV radiation,* bromine, iodine, silver, and chlorinated lime. See also Household Treatment Units, this chapter.

The National Research Council–National Academy of Science, in a study of disinfectants, concluded that there had not been sufficient research under actual water treatment conditions for the reactions of disinfectants and their byproducts to be adequately understood and that the chemical side effects of

*UV disinfection is being used as a primary disinfectant more in Europe (approximately 2000), with free chlorine for residual maintenance. (R. L. Wolfe, "Ultraviolet Disinfection of Potable Water," *Environ. Sci. Technol.*, June 1990, pp. 768–772.)

disinfectants "should be examined in detail."[152]* There is need to identify the byproducts associated with the use of not only chlorine but also chloramines, ozone, and chlorine dioxide and their health significance.

Chlorination is the most common method of destroying the disease-producing organisms that might normally be found in water used for drinking in the United States. The water so treated should be relatively clear and clean with a pH of 8.0 or less and an average monthly MPN of coliform bacteria of not more than 50/100 ml.† Clean lake and stream waters and well, spring, and infiltration gallery supplies not subject to significant pollution can be made of safe sanitary quality by continuous and effective chlorination, but surface sources also usually require complete filtration treatment to protect against viruses, bacteria, protozoa, and helminths. The effectiveness of chlorine is dependent on the water pH, temperature, contact time, water clarity, and absence of interfering substances.

Operation of the chlorinator should be automatic, proportional to the flow of water, and adjusted to the temperature and chlorine demand of the water. A standby source of power and a spare machine including chlorine should be on the line. A complete set of spare parts for the equipment will make possible immediate repairs. The chlorinator should provide for the positive injection of chlorine and be selected with due regard to the pumping head and maximum and minimum water flow to be treated. The point of chlorine application should be selected to provide a contact time of 2 hr for surface water receiving free residual chlorination treatment and 3 hr with combined residual chlorination. A lesser time may be accepted for groundwater (ref. 151, p. 57). The chlorinator should have a capacity to provide at least 2 mg/l free chlorine residual after 30 min contact at maximum flow and chlorine demand.

Hypochlorinators are generally used to feed relatively small quantities of chlorine as 1 to 5 percent sodium or calcium hypochlorite solution. Positive feed machines are fairly reliable and simple to operate. Hypochlorite is corrosive and may produce severe burns. It should be stored in its original container in a cool, well-ventilated, dry place. Gas machines usually feed larger quantities of chlorine and require certain precautions as noted below. Hypochlorination is discussed in Chapter 9 under Disinfection. Chlorine addition, with either a hypochlorinator or gas machine, should be proportional to the flow, direct or through corrosion-resistant piping; iron or steel piping or

*Greenburg points out that "the health effects of their (chlorine dioxide and ozone) reaction products, particularly the chlorite ion from chlorine dioxide and oxidized organic compounds from ozone are uncertain" and adds that "if unequivocal safety information becomes available, changes from chlorine to chlorine dioxide or ozone may be indicated but only if the manipulation of chlorination methods proves incapable of minimizing carcinogen hazard." (A. E. Greenburg, "Public Health Aspects of Alternative Water Disinfectants," *J. Am. Water Works Assoc.*, January 1981, pp. 31–33.)

†Suggested criteria include total coliform $<$100/100 ml, fecal coliform $<$20/100 ml, turbidity $<$1–5 NTU, color 15 units, chlorine demand $\not>$2 mg/l, plus others.

fittings should not be used. Note that the addition of an acid such as ferric chloride to sodium hypochlorite will release chlorine gas.

Gas Chlorinator

When a dry feed gas chlorinator or a solution feed gas chlorinator is used, the chlorinator and liquid chlorine cylinders should be located in a separate gas-tight room that is mechanically ventilated to provide one air change per minute, with outside switch and the exhaust openings at floor level opposite the air inlets at ceiling level. Exhaust ducts must be separate from any other ventilating system of ducts and extend to a height and location that will not endanger the public, personnel, or property and ensure adequate dispersion. The door to the room should have a shatter-resistant glass inspection panel at least 12 in. square, and a chlorine gas mask, or preferably self-contained breathing apparatus, approved by the NIOSH, available just outside of the chlorinator and chlorine cylinder room. Vapor from a plastic squeeze bottle containing aqua ammonia will produce a white cloud at a chlorine leak.* The chlorine canister-type of mask is only suitable for low concentrations of chlorine in air and only for a brief period. It does not supply oxygen. The self-contained breathing apparatus† with full-face piece (pressure demand) with at least 30-min capacity meeting NIOSH standards is usually required. It can be used during repairs and for high concentrations of chlorine. A factory-built chlorinator housing, completely equipped, is available.

The temperature around the chlorine cylinders should be cooler than the temperature of the chlorinator room to prevent condensation of chlorine in the line conducting chlorine or in the chlorinator. Cylinders must be stored at a temperature below 140°F.[153]‡ A platform scale is needed for the weighing of chlorine cylinders in use to determine the pounds of chlorine used each day and anticipate when a new cylinder will be needed. Cylinders should be in a safety bracket or chained to prevent being tipped. They should be connected to a manifold to allow chlorine to be drawn from several cylinders at a time and to facilitate cylinder replacement without interrupting chlorination. It is advisable to not draw more than 35 to 40 lb of chlorine per day at a continuous rate from a 100- or 150-lb cylinder to prevent clogging by chlorine ice. Liquid chlorine comes in 100- and 150-lb cylinders, in 1-ton containers, and in 16- to 90-ton rail-tank cars. Smaller cylinders, as little as 1 lb, are available. The major factors affecting withdrawal rates are ambient air tem-

*In an emergency, do not try to neutralize chlorine; leave this to the professionals. Call CHEMTREC at 800-424-9300 or the nearest supplier or producer. The permissible 8 hr concentration exposure is 1 ppm, 3 ppm for 15 min.

†At least two units are recommended, including worker protective clothing.

‡The fusible plugs are designed to soften or melt at a temperature between 158 and 165°F (70 and 74°C). The chlorinator should have automatic shutoff if water pressure is lost or if chlorine piping leaks or breaks. See ref. 153.

perature and size and type cylinder. The normal operating temperature is 70°F (21°C).

A relatively clear source of water of adequate volume and pressure is necessary to prevent clogging of injectors and strainers and ensure proper chlorination at all times. The water pressure to operate a gas chlorinator should be at least 15 psi and about three times the back pressure (water pressure at point of application plus friction loss in the chlorine solution hose and a difference in elevation between the point of application and the chlorinator) against which the chlorine is injected. About 40 to 50 gpd of water is needed per pound of chlorine to be added. Residual chlorine recorders and alarms and chlorine feed recorders provide additional protection and automatic residual chlorine control.

Testing for Residual Chlorine

The recommended field tests for measuring residual chlorine in water are the *N*,*N*-diethyl-*p*-phenylenediamine (DPD) colorimetric and the stabilized neutral orthotolidine (SNORT) methods.[154] The DPD and amperometric titration methods are approved by the EPA. In any case, all tests should be made in accordance with accepted procedures such as in *Standard Methods for the Examination of Water and Wastewater.*[29]

The DPD test procedure for residual chlorine measurement and the Free Available Chlorine Test, syringaldazine (FACTS) test procedure are reported to be equivalent. The FACTS and amperometric procedures are also equivalent.[155] A comprehensive evaluation of residual chlorine, chlorine dioxide, and ozone measurement methods is available.[156] The use of dry reagents is recommended for the DPD test as the liquid form is unstable. High concentrations of iron and manganese and dirty glassware cause interference with residual chlorine readings. The evaluation should be read immediately to also minimize interference from chloramines.

Chlorine Treatment for Operation and Microbiological Control

To ensure that only properly treated water is distributed, it is important to have a competent and trustworthy person in charge of the chlorination plant. He or she should keep daily records showing the gallons of water treated, the pounds of chlorine or quarts of chlorine solution used and its strength, the gross weight of chlorine cylinders if used, the setting of the chlorinator, the time residual chlorine tests made, the results of such tests, and any repairs or maintenance, power failures, modifications, or unusual occurrences dealing with the treatment plant or water system. Where large amounts of chlorine are needed, the use of ton containers can effect a saving in cost, as well as in labor, and possibly reduce chlorine gas leakage, although if a chlorine leak does occur, it can be of major consequence.

The required chlorine dosage should take into consideration the appearance as well as the quality of a water. Pollution of the source of water, the type of microorganisms likely to be present, the pH of the water, contact time, interfering substances, temperature, and degree of treatment a water receives are all very important. Disinfection effectiveness is also dependent on the absence of turbidity, less than 1 NTU.

The chlorine residual that will give effective disinfection of a relatively demand-free *clear* water has been studied by Butterfield[157] and others. The germicidal efficiency of chlorine is primarily dependent on the percent-free chlorine that is in the form of hypochlorous acid (HOCl), which in turn is dependent on the pH, contact time, and temperature of the water, as can be seen in Table 3-17. Hypochlorous acid is about 80 to 150 times more effective than the hypochlorite ion, 150 times more effective than monochloramine, and 80 times more effective than dichloramine. The percentage of hypochlorous acid is the major factor determining destruction or inactivation of enteric bacteria and amebic cysts.[158] *Giardia* cysts are almost always present in raw sewage.

In a review of the literature, Greenberg and Kupka concluded that a chlorine dose of at least 20 mg/l with a contact time of 2 hr is needed to adequately disinfect a biologically treated sewage effluent containing tubercle bacilli.[159]

Laboratory studies by Kelly and Sanderson indicated that

> depending on pH level and temperature, residual chlorine values of greater than 4 ppm, with 5-min contact, or contact periods of at least 4 hours with a residual chlorine value of 0.5 ppm, are necessary to inactivate viruses, and that the recommended standard for disinfection of sewage by chlorine (0.5 ppm residual after 15-min contact) does not destroy viruses (ref. 160, p. 16).

Another study showed that inactivation of partially purified poliomyelitis virus in water required a free-residual chlorine after 10 min of 0.05 mg/l at a pH of 6.85 to 7.4. A residual chloramine value of 0.50 to 0.75 mg/l usually inactivated the virus in 2 hr.[161]* Destruction of coxsackievirus required 7 to 46 times as much free chlorine as for *E. coli*.[163] Infectious hepatitis virus was not inactivated by 1.0 mg/l total chlorine after 30 min or by coagulation, settling, and filtration (diatomite), but coagulation, settling, filtration, and chlorination to 1.1 mg/l total and 0.4 mg/l free chlorine was effective.[159] Bush and Isherwood suggest the following (ref. 164):

> The use of activated sludge with abnormally high sludge volume index followed by sand filtration may produce the kind of control necessary to stop virus. Chlo-

*In ref. 162, Weidenkopf reported on Polio 1 inactivation by free chlorine as 0.1 mg/l at pH 6.0 and 0.53 mg/l at pH 8.5.

TABLE 3-17 Chlorine Residual for Effective Disinfection of Demand-Free Water (mg/l)

	Approximate Percent at 32–68°F[b]		Bactericidal Treatment[a]		Cysticidal Treatment Free Available Chlorine after 30 min		
pH	HOCl	OCl^-	Free Available Chlorine after 10 min, 32–78°F	Combined Available Chlorine after 60 min, 32–78°F	36–41°F[c]	60°F[c]	78°F[b]
5.0	—	—	—	—	—	2.3	—
6.0	98–97	2–3	0.2	1.0	7.2	—	1.9[d]
7.0	83–75	17–25	0.2	1.5	10.0	3.1	2.5[d]
7.2	74–62	26–38	—	—	—	—	2.6[d]
7.3	68–57	32–43	—	—	—	—	2.8[d]
7.4	64–52	36–48	—	—	—	—	3.0[d]
7.5	58–47	42–53	—	—	14.0[d]	4.7	3.2[d]
7.6	53–42	47–58	—	—	—	—	3.5[d]
7.7	46–37	53–64	—	—	16.0[d]	6.0	3.8[d]
7.8	40–32	60–68	—	—	—	—	4.2[d]
8.0	32–23	68–77	0.4	1.8	22.0	9.9	5.0[d]
9.0	5–3	95–97	0.8	Reduce pH of water	—	78.0	20.0[d]
10.0	0	100	0.8	to below 9.0	—	761	170[d]

Note: Free chlorine = HOCl. Free available chlorine = HOCl + OCl^-. Combined available chlorine = chlorine bound to nitrogenous matter as chloramine. Only free available chlorine or combined available chlorine is measured by present testing methods; therefore, to determine actual free chlorine (HOCl), correct reading by percent shown above. "Chlorine residual," as the term is generally used, is the combined available chlorine and free available chlorine, or total residual chlorine. When the chlorine–ammonia ratio reaches 15:1 or 20:1 and $pH < 4.4$, nitrogen trichloride is formed; it is acrid and highly explosive. Ventilate.

Viricidal treatment requires a free available chlorine of 0.53 mg/l at pH 7 and 5 mg/l at pH 8.5 in 32°F demand-free water. For water at a temperature of 77–82.4°F and pH 7–9, a free available chlorine of 0.3 mg/l is adequate. (See *Manual for Evaluating Public Drinking Water Supplies,* PHS Pub. 1820, Environmental Control Administration, Cincinnati, OH, 1969.) At a pH 7 and temperature of 77°F at least 9 mg/l combined available chlorine is needed with 30 min contact time. Turbidity should be less than one turbidity unit. The above results are based on studies made under laboratory conditions using water free of suspended matter and chlorine demand.

[a] Ref. 157.

[b] *Water Treatment Plant Design*, American Water Works Association, New York, 1969, pp. 153, 165; E. W. Moore, "Fundamentals of Chlorination of Sewage and Waste," *Water Sewage Works,* 130–136 (March 1951).

[c] S. L. Chang, "Studies on *Endamoeba histolytica," War Med.,* **5,** 46 (1944); see also W. Brewster Snow, "Recommended Chlorine Residuals for Military Water Supplies," *J. Am. Water Works Assoc.,* **48,** 1510 (December 1956).

[d] Approximations. All residual chlorine results reported as milligrams per liter. One milligram per liter hypochlorous acid gives 1.35 mg/l free available chlorine as HOCl and OCl^- distributed as noted above. The HOCl component is the markedly superior disinfectant, about 80–150 times more effective than the hypochlorite ion (OCl^-).

rination with fivetenths parts per million chlorine residual for an eight hour contact period seems adequate to inactivate Coxsackie virus.

Malina[165] summarized the effectiveness of water and wastewater treatment processes on the removal of viruses. The virus concentration in untreated municipal wastewater was found to range from about 200 plaque-forming units per liter (PFU/l) in cold weather to about 7000 in warm months in the United States, with 4000 to 7000 PFU/1 common. In contrast, the virus concentration in South Africa was found to be greater than 100,000 PFU/1. Virus removal in wastewater is related in part to particulate removal. Possible virus removal values by various wastewater treatment systems are as follows:

Primary sedimentation	0–55%
Activated sludge	64–99%
Contact stabilization	74–95%
Trickling filters	19–94%d
Stabilization ponds	92–100%
Coagulation–flocculation	86–100%
Chlorine (as final treatment)	99–100%
Iodine	100%
Ozone	100%
Anaerobic digestion	62–99%

Chemical coagulation, with adequate concentrations of aluminum sulfate or ferric chloride, of surface water used as a source of drinking water or of wastewater that has received biological treatment can remove 99 percent of the viruses. Hepatitis A virus, rotavirus, and poliovirus removal of 98.4 to 99.7 percent was also achieved in a pilot plant by softening during Ca^{2+} and Mg^{2+} hardness reduction.[166] A high pH of 10.8 to 11.5, such as softening with excess lime, can achieve better than 99 percent virus removal, but pH adjustment is then necessary.

Filtration using sand and/or anthracite following coagulation, flocculation, and settling can remove 99 percent or more of the viruses, but some viruses penetrate the media with floc breakthrough and turbidity at low alum feed.[166,167] Diatomaceous earth filtration can remove better than 98 percent of the viruses, particularly if the water is pretreated. Activated-carbon adsorption is not suitable for virus removal. The infectivity of hepatitis A virus is destroyed by 2.0 to 2.5 mg/l free residual chlorine. Reverse osmosis and ultrafiltration, when followed by disinfection, can produce a virus-free water. However, it has been found that both enteroviruses and rotaviruses could be isolated from water that received complete treatment containing more than 0.2 mg/l free chlorine, less than one coliform bacteria per 100 ml, and turbidity of less than 1 NTU.[168] The WHO states that a contaminated source water may be considered adequately treated for viruses infectious to humans if it has a turbidity of 1 NTU or less and is disinfected to provide a free residual chlorine of at least 0.5 mg/l after a contact period of at least 30 min at a pH below 8.0 (ref. 27, Vol. 1, p. 28).

A conventional municipal biological wastewater treatment plant can produce an effluent with less than 10 PFU/l. When followed by conventional water treatment incorporating filtration and chlorination, a virus-free water can be obtained.[165]

The product of the contact time (*t*) in minutes and free residual chlorine, or other approved disinfectant, in milligrams per liter (*C*) produces a value that is a measure of the adequacy of disinfection. The $C \cdot t$ value for a particular organism will vary with the water pH, temperature, degree of mixing, turbidity, and presence of interfering substances, in addition to disinfectant concentration and contact time. For example, a turbidity less than 1 to 5 NTUs and a free chlorine as HOCl (that penetrates the cell wall of microorganisms and destroys their nucleic acid) are necessary. A smaller $C \cdot t$ value is effective at lower pH and at higher temperature.[169] The $C \cdot t$ value effective to inactivate 99.9 percent of the *Giardia* cyst will also inactivate 99.99 percent or greater of the bacteria and viruses at a given pH and temperature.

For protozoa (*Giardia lamblia*) a $C \cdot t$ value of 150 to 200 at pH 8.0 or less is required with water at 50°F (10°C). Experimental results based on animal infectivity data show that a 99.99 percent cyst inactivation can be obtained at $C \cdot t$ values of 113 to 263, at pH 6, temperature 33°F (0.5°C), and chlorine concentration of 0.56 to 3.93 mg/l for 39 to 300 min. At pH 8, temperature 33°F (0.5°C), chlorine concentration of 0.49 to 3.25 mg/l, and contact time of 132 to 593 min, the $C \cdot t$ values varied from 159 to 526. If a large enough $C \cdot t$ value can be maintained to ensure adequate *Giardia* cyst disinfection to EPA satisfaction, then filtration may not be required.[170]

Chlorine dioxide can achieve 99.9 percent *Giardia lamblia* inactivation at $C \cdot t$ values of 63, in water at 34°F (1°C) or less, to 11 at 77°F (25°C) or greater. Inactivation using ozone is achieved at $C \cdot t$ values of 2.9, in water at 34°F (1°C) or less, to 0.48 at 77°F (25°C) or greater. These $C \cdot t$ values also achieve greater than 99.99 percent inactivation of enteric viruses. See state regulatory agency for required $C \cdot t$ values to inactivate *Giardia lamblia* and enteric viruses using chlorine, chloramine, chlorine dioxide, and ozone.

Naegleria fowleri cyst is a pathogenic flagellated protozoan. It causes primary amebic meningoencephalitis, a rare disease generally fatal to humans. See Health Considerations, Chapter 9. The organism is free living, nonparasitic, found in soil and water. *Naegleria gruberi,* a nonpathogenic strain, was used in experimental inactivation studies. At pH 5.0 the *N. gruberi* cyst was inactivated in 15.8 to 2.78 min by 0.45 to 2.64 mg/l free chlorine residual at 25°C (77°F). At pH 7.0 it was inactivated in 21.5 to 2.9 min by 0.64 to 3.42 mg/l; and at pH 9.0 in 11.5 to 2.36 min by 15.4 to 87.9 mg/l residual chlorine. Also, it was reported that *Acanthamoeba* sp. 4A cysts (pathogenic) were inactivated after 24 hr by an initial chlorine dose of 8.0 mg/l but ending with a chlorine residual of 6.0 mg/l. *Naegleria fowleri* was reported to be inactivated by 4 mg/l chlorine residual in 10 min at a temperature of 77°F

(25°C) and a pH of 7.2 to 7.3.[171] *Giardia lamblia* cysts are inactivated in 60 min by 2.0 mg/l free chlorine residual at pH 6.0 and 41°F (5°C); in 60 min by 2.5 mg/l free chlorine at pH 6.0, 7.0, and 8.0 and 60°F (15°C); in 10 min by 1.5 mg/l free chlorine at pH 6.0, 7.0, and 8.0 and 77°F (25°C); and in 30 min by 6.2 mg/l total chlorine at pH 7.9 and 37°F (3°C).[172]

Entamoeba histolytica cysts are inactivated by 2 mg/l free chlorine in 15 min at a temperature of 68°F (20°C) and pH 7.0,[171,173,174] by 2.5 mg/l free chlorine in 10 min at a temperature of 86°F (30°C) and pH 7.0,[171,173,175] by 5.0 mg/l free chlorine in 15 min at a temperature of 50°F (10°C) and pH 7.0,[171,173,174] and by 7.0 mg/l free chlorine in 10 to 15 min at a temperature of 86°F (30°C) and pH 9.0.[171,173,175]

The removal of nematodes requires prechlorination to produce 0.4 to 0.5 mg/l residual after a 6-hr retention period followed by settling. The pathogenic fungus *Histoplasma capsulatum* can be expected in surface-water supplies, treated water stored in open reservoirs, and improperly protected well-water supplies. Fungicidal action is obtained at a pH of 7.4 and at a water temperature of 78.8°F (26°C) with 0.35 mg/l free chlorine after 4 hr contact and with 1.8 mg/l free chlorine after 35 min contact. Complete rapid sand filter treatment completely removed all viable spores even before chlorination.[176]

Cysts of *E. histolytica* and *Giardia lamblia* (also worms and their eggs) are removed by conventional water treatment, including coagulation, flocculation, sedimentation, and filtration (2–6 gpm/ft^2). Direct and high-rate filtration, diatomaceous earth filtration with good precoat (1 kg/m^2), and special cartridge filters ($<7 \times 8$-μm pore size) can also be effective. The slow sand filter is also considered effective. Pressure sand filtration is not reliable. The inactivation of *Giardia lamblia* by free chlorine is similar to that for *E. histolytica*.[177]

Coliform bacteria can be continually found in a chlorinated surface-water supply (turbidity 3.8 to 84 units, iron particles, and microscopic counts up to 2000 units) containing between 0.1 and 0.5 mg/l of free residual chlorine and between 0.7 and 1.0 mg/l total residual chlorine after more than 30 min contact time.[178]

It is evident from available information that the coliform index may give a false sense of security when applied to waters subject to intermittent doses of pollution. The effectiveness of proper disinfection, including inactivation of viruses, other conditions being the same, is largely dependent on the freedom from suspended material and organic matter in the water being treated. Treated water having a turbidity of less than 5 NTU (ideally less than 0.1), a pH less than 8, and an HOCl residual of 1 mg/l after 30 min contact provides an acceptable level of protection.[179]

Free residual chlorination is the addition of sufficient chlorine to yield a free chlorine residual in the water supply in an amount equal to more than 85 percent of the total chlorine present. When the ratio of chlorine to ammonia is 5:1 (by weight), the chlorine residual is all monochloramine; when the ratio reaches 10:1, dichloramine is also formed; when the ratio reaches

15:1 or 20:1, nitrogen trichloride is formed, reaching a maximum at pH less than 4.5 and at a higher pH in polluted waters. Nitrogen trichloride as low as 0.05 mg/l causes an offensive and acrid odor that can be removed by carbon, aeration (natural or forced draft), exposure to sunlight, or forced ventilation indoors.[180] It can titrate partly as free chlorine and is also highly explosive. The reaction of chlorine in water is shown in Figure 3-16.

The minimum free chlorine residual at distant points in the distribution system should be 0.2 to 0.5 mg/l. Combined chlorine residual, if use is approved, should be 1.0 to 2.0 mg/l at distant points in the distribution system (ref. 151, p. 57).

In the presence of ammonia, organic matter, and other chlorine-consuming materials, the required chlorine dosage to produce a free residual will be high. The water is then said to have a high chlorine demand. With free residual chlorination, water is bleached, and iron, manganese, and organic matter are oxidized by chlorine and precipitated, particularly when the water is stored in a reservoir or basin for at least 2 hr. Most taste- and odor-producing compounds are destroyed; the reduction of sulfates to taste- and odor-producing sulfides is prevented; and objectionable growths and organisms in the mains are controlled or eliminated, provided a free chlorine residual is maintained in the water. An indication of accidental pollution of water in the mains is also obtained if the free chlorine residual is lost, provided chlorination is not interrupted.

The formation of trihalomethanes and other chloro-organics, their prevention, control, and removal, and the use of other disinfectants are discussed later in this chapter.

Distribution System Contamination

Once a water supply distribution system is contaminated with untreated water, the presence of coliform organisms may persist for an extended period of

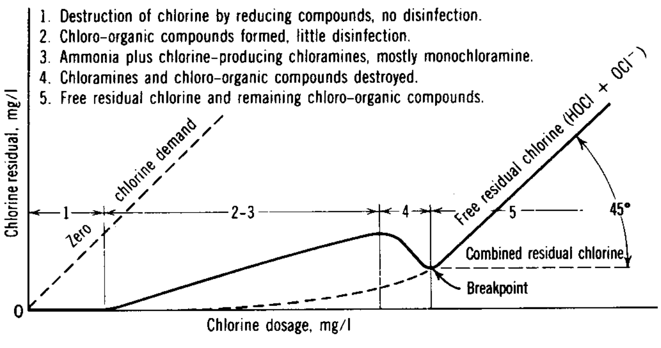


Figure 3-16 Reaction of chlorine in water. (Adapted from *Manual of Instruction for Water Plant Chlorinator Operators,* New York State Department of Health, Albany, NY.)

time. A surface-water supply or an inadequately filtered water supply may admit into a distribution system organic matter, minerals, and sediment, including fungi, algae, macroscopic organisms, and microscopic organisms. These flow through or settle in the mains or become attached and grow inside the mains when chlorination is marginal or inadequate to destroy them. Suspended matter and iron deposits will intermingle with and harbor the growths. Hence, the admission of contaminated water into a distribution system, even for a short time, will have the effect of inoculating the growth media existing inside the mains with coliform and other organisms. Elimination of the coliform organisms will therefore involve removal of the growth media and harborage material, which is not always readily possible, and disinfectant penetration. Bacteriological control of the water supply is lost until the biofilm and incrustation harboring coliform and other organisms are removed, unless a free chlorine residual of at least 0.2 to 0.4 mg/l is maintained in active parts of a distribution system. Even this may be inadequate if unfiltered water is admitted or if contaminants or particulates are released in the distribution system, such as after fire flows.

If a positive temporary program of continuous heavy chlorination at the rate of 5 to 10 mg/l, coupled with routine flushing of the main, is maintained, it is possible in most cases to eliminate the coliform on the inside surface of the pipes[181] and hence the effects of accidental contamination in 2 to 3 weeks or less. If a weak program of chlorination is followed, with chlorine dosage of less than 5 mg/l, the contamination may persist for an extended period of time. The rapidity with which a contaminated distribution system is cleared will depend on many factors: admission of only low-turbidity filtered water; uninterruption of chlorination even momentarily; the chlorine dosage and residual maintained in the entire distribution system; the growths in the mains and degree of pipe incrustation and their removal; conscientiousness in flushing the distribution system; the social, economic, and political deterrents; and, mostly, the competency of the responsible individual. A solution to main bacterial growths might be main cleaning and relining. The deterioration of water quality in a distribution system may be due to biological, physical, and chemical factors. The causes are usually complex and require laboratory participation and evaluation of data to identify possible causes and action measures. Species identification may be helpful in determining the significance of coliform-positive samples collected from a water system.[182] Physical analyses may include temperature, suspended and attached solids, chemical analyses including iron, dissolved oxygen, pH, alkalinity, nitrate and nitrite ions, ammonium, microbiological analyses including heterotrophic and direct microscopic counts, and residual chlorine over the long term.[183]

Plain Sedimentation

Plain sedimentation is the quiescent settling or storage of water, such as would take place in a reservoir, lake, or basin, without the aid of chemicals, preferably for a month or longer, particularly if the source water is a sewage-polluted river water. This natural treatment results in the settling out of suspended solids; reduction of hardness, ammonia, lead, cadmium, and other heavy metals; breakdown of organic chemicals and fecal coliform; removal of color (due to the action of sunlight); and die-off of pathogenic microorganisms principally because of the unfavorable temperature, lack of suitable food, and sterilizing effect of sunlight. Certain microscopic organisms, such as protozoa, consume bacteria, thereby aiding in purification of the water. Experiments conducted by Sir Alexander Houston showed that polluted water stored for periods of 5 weeks at 32°F (0°C), 4 weeks at 41°F (5°C), 3 weeks at 50°F (10°C), or 2 weeks at 64.4°F (18°C) effected the elimination of practically all bacteria.[184] A bacteria and virus removal of 80 to 90 percent can be expected after 10 to 30 days storage.[185] Plain sedimentation, however, has some disadvantages that must be taken into consideration and controlled. The growth of microscopic organisms causing unpleasant tastes and odors is encouraged, and pollution by watershed surface wash, fertilizers, pesticides, recreational uses, birds and animals, sewage, and industrial wastes may occur unless steps are taken to prevent or reduce these possibilities. Although subsidence permits bacteria, including pathogens, to die off, it also permits bacteria to accumulate and grow in reservoir bottom mud under favorable conditions. In addition, iron and manganese may go into solution, carbon dioxide may increase, and hydrogen sulfide may be produced.

Presettling basins or upflow roughing filters are sometimes used to eliminate heavy turbidity or pollution and thus better prepare the water for treatment by coagulation, flocculation, settling, and filtration. Ordinarily, at least two basins are provided to permit one to be cleaned while the other is in use. A capacity sufficient to give a retention period of at least two or three days is desirable. When heavily polluted water is to be conditioned, provision can be made for preliminary coagulation at the point of entrance of the water into the basins followed by chlorination or other disinfection at the exit. Consideration must be given to the possible formation of trihalomethanes and their prevention.

Microstraining

Microstraining is a process designed to reduce the suspended solids, insects, and nuisance organisms, including plankton, in a water. The filtering surface may consist of very finely woven fabrics of stainless steel, nylon, bronze, or other resistant material on a revolving drum. Water flows into the drum, which is closed at the other end, and out through the filtering surface. Applications to water supplies are primarily the clarification of relatively clean surface waters low in true color and colloidal turbidity, in which microstraining and disinfection constitute the pretreatment, before water coagulation and clarification, ahead of slow or rapid sand filters and diatomite filters. Removal of the more common types of algae have been as high as 95 percent. Washwater consumption by the outside cleaning jets may run from 1 to 3 percent of the flow through the unit. The wastewater is collected and carried off by a trough in the upper part of the drum for proper disposal. Blinding of the fabric rarely occurs but may be due to inadequate washwater pressure or the presence of bacterial slimes. Cleansing is readily accomplished with commercial sodium hypochlorite.[186] Small head losses and low maintenance costs may make the microstrainer attractive for small installations.

Unit sizes start at about $2\frac{1}{2}$ ft in diameter by 2 ft wide. These have a capacity varying between 50,000 and 250,000 gpd depending on the type and amount of solids in the water and the fabric used. Larger units have capacities in excess of 10 mgd.

Coagulation, Flocculation, and Settling

Adding a coagulant such as alum (aluminum sulfate) to water permits particles to come together and results in the formation of a flocculent mass, or floc, which enmeshes and agglomerates microorganisms, suspended particles, and colloidal matter, removing and attracting these materials in settling out. Removal of 90 to 99 percent of the bacteria and viruses and more than 90 percent of the protozoa and phosphate can be expected.[185] Total organic carbon and THM precursors and around 80 percent of the color and turbidity are also removed. The common coagulants used, in addition to alum, are copperas (ferrous sulfate), ferric sulfate, ferric chloride, sodium aluminate, pulverized limestone, bentonite, and clays. Sodium silicate and polyelectrolytes, including polymers, are also used at times as coagulant aids to improve coagulation and floc strength, usually resulting in less sludge and lower chemical dosages. The use of ozone as a microflocculant has also led to the need for less alum.

Proper respiratory protection should be provided for water plant operators handling water treatment plant chemicals, including chlorine and fluoride. Safety professionals, safety equipment suppliers, and chemical manufacturers can be of assistance. All chemicals must meet EPA purity standards. See Drinking Water Additives, this chapter.

To adjust the chemical reaction (alkalinity and pH) for improved coagulation, it is sometimes necessary to first add soda ash, hydrated lime, quicklime, or sulfuric acid. Color is best removed at a pH of 6.0 to 6.5. The mixing of the coagulant is usually done in two steps. The first step is rapid or flash mix and the second is slow mix, during which flocculation takes place. Rapid mix is a violent agitation for a few seconds, not more than 30 sec, and may be accomplished by a mechanical agitator, pump impeller and pipe fittings, baffles, hydraulic jump, Parshall flume, in-line mixer, or other means. Slow mix and flocculation are accomplished by means of baffles or a mechanical paddle mixer to promote formation of a floc and provide a detention of at least 30 min with a flow-through velocity of 0.5 to 1.5 fpm. The flocculated water then flows to the settling basin designed to provide a retention of 4 to

6 hr, an overflow rate of about 500 gpd/ft^2 of area, or 20,000 gpd/ft of weir length. The velocity through the basin should not exceed 0.5 fpm. Cold water has a higher viscosity than warm water, hence the rate of particle or floc settling is much less in cold water; this must be taken into consideration in the design of a sedimentation basin. It is always recommended that mixing tanks and settling basins be at least two in number to permit cleaning and repairs without completely interrupting the water treatment, even though mechanical cleaning equipment is installed for sludge removal.

For the control of coagulation, jar tests are made in the laboratory to determine the approximate dosage of the chemicals (not laboratory grade) used, at the actual water temperature, that appear to produce the best results.[187,188] The best pH and coagulant and coagulant aid are also determined. Then, with this as a guide, the chemical dosing equipment, dry feed or solution feed, is adjusted to add the desired quantity of chemical proportional to the flow of water treated to give the best results. See Figure 3-20 later in the chapter. The dosages may be further adjusted or refined based on actual operating conditions. Aluminum breakthrough is minimized with coagulation pH control at the prevailing water temperature. It should be remembered that the algal level in a surface-water source will affect the dissolved-oxygen, carbon dioxide, and pH levels in the raw water and produce changes between night and day.

Zeta potential is also used to control coagulation. It involves determination of the speed at which particles move a given distance through an electric field caused by a direct current passing through the raw water. Best flocculation takes place when the charge approaches zero, giving best precipitation when a coagulant such as aluminum sulfate, assisted by a polyelectrolyte (polymer) if necessary, is added. Polymers may contain hazardous impurities. Quality control specifications should be met.

The addition of a polymer, silicate, and special clays may assist coagulation and clarification of certain waters as previously noted. A faster settling and more filterable floc is reported, which is less affected by temperature change or excessive flows. Less plugging of filters, longer filter runs, more consistent effluent turbidity, less backwash water, less sludge volume, and easier dewatering of sludge are claimed for polymer, clay–alum treatment.[189,190] Surface wash is found necessary with use of a clay-polymer and high-rate filtration.

Another device for coagulating and settling water consists of a unit in which the water, to which a coagulant has been added, is introduced near the bottom, mixes with recirculated sludge, and flows upward through a blanket of settled floc. The clarified water flows off at the top. Sludge is drawn off at the bottom. These basins are referred to as upflow suspended-solids contact clarifiers. The detention period used in treating surface water is 4 hr, but may be as little as $1\frac{1}{2}$ to 2 hr depending on the quality of the raw water. The normal upflow rate is 1440 gpd/ft^2 of clarifier surface area and the overflow rate is 14,400 gpd per foot of weir length. A major advantage claimed, where applicable, is a reduction of the detention period and hence savings in space. Disadvantages include possible loss of sludge blanket with changing water temperature and variable water quality.

Tube settlers are shallow tubes, usually inclined at an angle of approximately 60° from horizontal. Flow is up through the tubes that extend from about middepth to a short distance below the water surface and are inclined in the direction of water flow. Solids settle in the tube bottom, should slide down against the flow, and accumulate on the bottom of the basin. Effective operation requires laminar flow, adequate retention, nonscouring velocities, and floc particle settling with allowance for sludge accumulation and desludging at maximum flow rates.[191] Pilot plant studies are advisable prior to actual design and construction. Algal growths may clog tubes. Inclined plate settlers are similar to the tube settlers except that 45° to 60° inclined plates are used instead of tubes; the settled sludge slides down the smooth plates (plastic) opposite the direction of flow; the water enters through the sides and flows upward. If the depth is adequate, tube and inclined plate settlers can be used in existing settling basins to increase their capacity and improve their efficiency.

Filtration

Filters are of the slow sand, rapid sand, or other granular media (including multimedia) and pressure (or vacuum) type. Each has application under various conditions. The primary purpose of filters is to remove suspended materials, although microbiological organisms and color are also reduced. Of the filters mentioned, the slow sand filter is recommended for use at small communities, in developing areas, and in rural places, where adaptable. A rapid sand filter is not recommended because of the rather complicated control required to obtain satisfactory results unless competent supervision and operation can be ensured. This precaution also applies to package plants. The pressure filter, including the diatomaceous earth type, is commonly used for the filtration of industrial water supplies and swimming pool water; it is not generally recommended for the treatment of drinking water, except where considered suitable under the conditions of the proposed use. Variations of the conventional rapid sand filter, which may have application where raw water characteristics permit, are direct filtration, deep-bed filtration (4 to 8 ft media depth and 1.0 to 2.0 mm media size), high-rate filtration (up to 10 gpm/ft^2), declining flow rate filtration, and granular activated-carbon filters. In all cases, their feasibility and effectiveness should first be demonstrated by pilot plant studies at the site.

Slow Sand Filter

A slow sand filter consists of a watertight basin, usually covered, built of concrete, and equipped with a rate controller and loss-of-head gauge. The basin holds a special sand 30 to 48 in. deep that is supported on a 12- to 18-in. layer of graded gravel placed over an underdrain system that may consist of open-joint, porous, or perforated 2- to 4-in.-diameter pipe or conduit spaced no greater than 3 ft. The velocity in the underdrain system should not exceed 0.75 fps. The sand should have an effective size of 0.25 to 0.35 mm and a uniformity coefficient not greater than 2.5. Operation of the filter is controlled so that filtration will take place at a rate of 1 to 4 million gallons per acre per day, with 2.5 million gallons as an average rate. This would correspond to a filter rate of 23 to 92 gal/ft^2 of sand area per day or an average rate of 57 gal. A rate up to 10 million gallons may be permitted by the approving authority if justified.

From a practical standpoint, the water that is to be filtered should have low color, less than 30 units, and low coliform concentration (less than 1000 per 100 ml) and be low in suspended matter and algae, with a low turbidity not exceeding an occasional 50 units; otherwise, the filter will clog quickly. A plain sedimentation basin, roughing filter, or other pretreatment ahead of the filter can be used to reduce the suspended matter, turbidity, and coliform concentration of the water if necessary. It could also serve as a balancing tank. A loss-of-head gauge should be provided on the filter to show the resistance the sand bed offers to the flow of water through it and to show when the filter needs cleaning, usually 30 to 60 days, more or less, depending on raw water quality and filter rate. This is done by draining the water down to 6 in. below the surface of the sand bed and scraping about 1 in. of sand with adhering particles and *schmutzdecke* off the top of the bed. The sand is washed and replaced when the depth of sand is reduced to about 24 in. A scraper or flat shovel is practical for removing the top layer of clogged sand with the aid of a motorized cart. The sand surface can also be washed in place by a special washer traveling over the sand bed. Filtered water is readmitted to a depth of several inches above the sand to prevent scour when placed in operation. Slow sand filters should be constructed in pairs as a minimum. These filters, *operated without interruption,* are easily controlled and, when followed by disinfection, produce a consistently satisfactory water. The filtration process is primarily biological rather than chemical/physical.

A well-operated plant will remove 98 to 99.5 percent of the coliform bacteria, protozoa, and viruses as well as some organic and inorganic chemicals in the raw water (after a biological film has formed on the surface and within the sand bed). Effluent turbidity of less than 1.0 NTU and coliform of 1 per 100 ml or less can be regularly obtained. Chlorination of the filtered water is necessary to destroy microorganisms passing through the filter and growing or entering the storage basin and water system. This type plant will also remove about 25 to 40 percent of the color in the untreated water. Chlorination of the sand filter itself is desirable either continuously or periodically to destroy microorganisms growing within the sand bed, supporting gravel, or underdrain system. Continuous prechlorination at a rate that produces 0.3 to 0.5 mg/l in the water on top of the filter will not harm the filter film; it will increase the length of the filter run. A high chlorine residual (5 mg/l) is detrimental. Filtration to waste 6 hr to 2 weeks after cleaning is required, depending on the age of the filter, particulate matter in the raw water, and filtrate quality.[192] In any case, continuous postchlorination should be provided.

A slow sand filter suitable for a small rural water supply is shown in Figure 3-17. Details relating to design are given in Table 3-18. The rate of filtration in this filter is controlled by selecting an orifice and filter area that will deliver not more than 50 gal/ft^2 of filter area per day, thus preventing excessive rates of filtration that could endanger the quality of the treated water. Where competent and trained personnel are available, the rate of flow can be controlled by manipulating a gate or butterfly valve on the effluent line from each filter, provided a Venturi, orifice, triangular weir, or other suitable meter, with indicating and preferably recording instruments, is installed on the outlet to measure the rate of flow. The valve can then be adjusted to give the desired rate of filtration until the filter needs cleaning. Another practical method of controlling the rate of filtration is by installing a float valve on the filter effluent line, as shown in Figure 3-18. The valve is actuated by the water level in a float chamber, which is constructed to maintain a reasonably constant head over an orifice in the float chamber that would yield the desired filter rate of flow. A hydraulically operated float can be connected to a control valve by tubing and located at some distance from the valve. A solenoid valve can accomplish the same type of control. A modulating float valve is more sensitive to water level control than the ordinary float valve. A remote float-controlled weighted butterfly valve, with spring-loaded packing glands and stainless steel shafts is described by Riddick.[193] A special rate control valve can also be used if it is accurate within the limits of flow desired. The level of water over the orifice or filter outlet must be *above* the top of the sand to prevent the development of a negative head. If a negative head is permitted to develop, the mat on the surface of the sand may be broken and dissolved air in the water may be released in the sand bed, causing the bed to become air bound. At least 3 in. of water over the sand or a flexible influent hose will minimize any possible disturbance of the sand when water from the influent line falls into the filter. Postchlorination should be provided. A cartridge-type tablet or stack chlorinator may meet the needs in a rural situation. The filter should operate without interruption to produce uniform results, and daily operation reports should be kept.

Rapid Sand (Granular Media) Filter

A rapid sand gravity filter, also referred to as a granular media and mechanical filter, is shown in Figure 3-19. Two important accessories to a conventional rapid sand filter are the loss-of-head gauge and the rate controller. The loss-of-head gauge shows the frictional resistance to the flow of water through the sand, laterals, and orifices. When this reaches about 7 ft with sand and 5 ft with a dual media, it indicates that the filter needs to be backwashed. The rate controller is constructed to automatically maintain a uniform predeter-

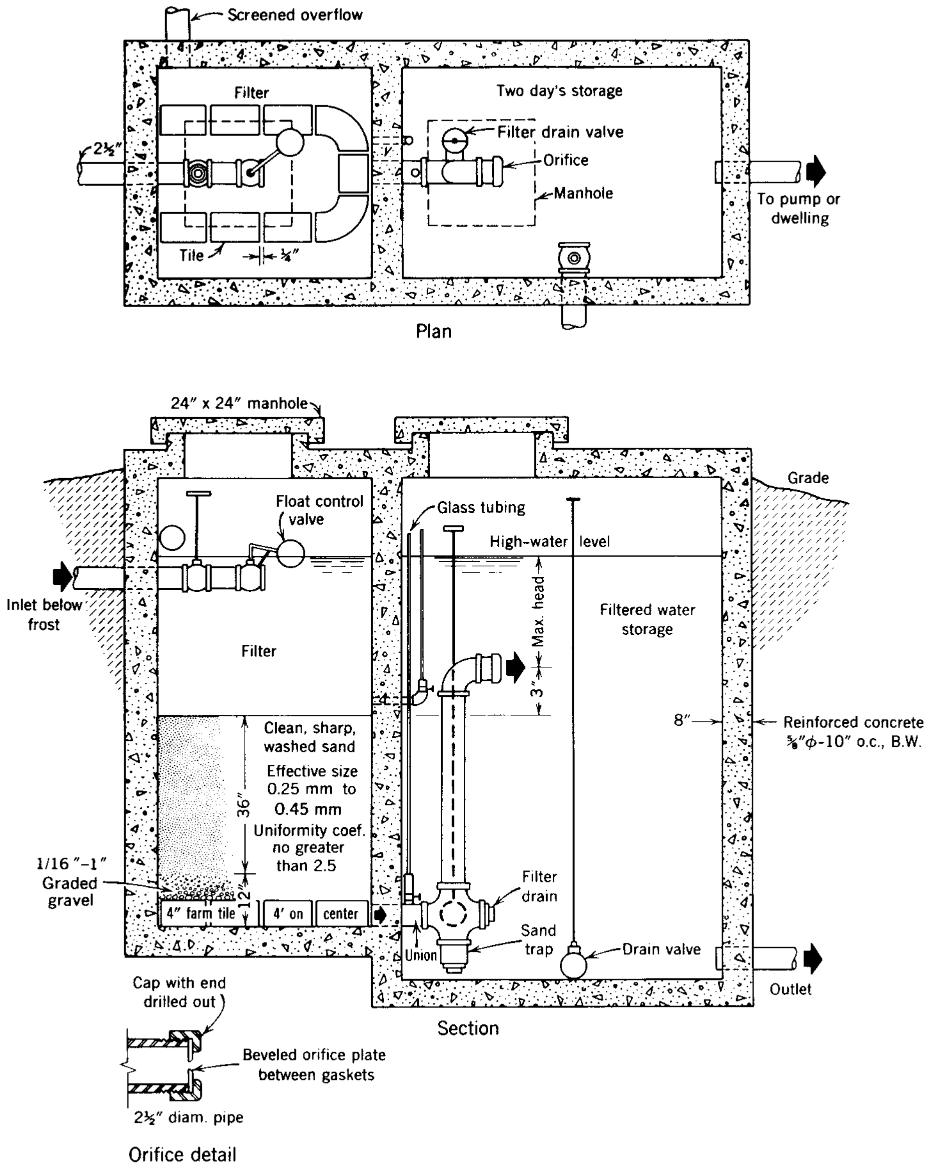


Figure 3-17 Slow sand filter for a small water supply. Minimum of two units. The difference in water level between the two glass tubes represents the frictional resistance to the flow of water through the filter. When this difference approaches the maximum head and the flow is inadequate, the filter needs cleaning. To clean, scrape the top 1 in. of sand bed off with a mason's trowel, wash in a pan or barrel, and replace clean sand on bed. Float control valve may be omitted where water on filter can be kept at a desirable level by gravity flow or an overflow valve. Add a meter, venturi, or other flow-measuring device on the inlet to the filter. Rate of flow can also be controlled by maintaining a constant head with a weighted float valve over an orifice or weir. See 3-18. Filtered water should be disinfected before use. Allow sufficient head room for cleaning the filter. Separation of the filter box from the filtered water storage clear well is usually required by health officials for public water supplies. Thoroughly ventilate filter box and water storage tank before entering and during occupancy.

TABLE 3-18 Orifice Flow for Selected Orifice Diameters

Maximum Head, (ft of water)	Maximum Flow by Orifice Diameter[a] (gpd)[b]														
	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{7}{8}$	1
1	67	149	266	597	1,060	1,660	2,390	3,240	4,240	5,370	6,640	8,010	9,550	13,030	17,000
$1\frac{1}{2}$	82	183	326	732	1,305	2,040	2,930	3,990	5,220	6,580	8,130	9,850	11,700	15,950	20,800
2	96	213	380	852	1,520	2,370	3,410	4,650	6,060	7,680	9,480	11,480	14,300	18,600	24,200
$2\frac{1}{2}$	107	236	421	945	1,680	2,620	3,780	5,150	6,720	8,500	10,500	12,680	15,100	20,600	26,800
3	116	259	462	1,036	1,840	2,880	4,140	5,640	7,380	9,130	11,520	13,920	16,550	22,600	29,500
$3\frac{1}{2}$	126	279	498	1,120	1,990	3,100	4,470	6,060	7,950	10,050	12,420	14,900	17,900	24,300	30,700
4	135	300	534	1,200	2,125	3,330	4,790	6,530	8,520	10,800	13,300	16,100	19,150	26,100	34,000
$4\frac{1}{4}$	145	322	574	1,290	2,290	3,580	5,160	7,020	9,150	11,600	14,350	17,300	20,600	28,000	36,600
5	150	333	594	1,332	2,370	3,700	5,340	7,260	9,480	12,000	14,800	17,950	21,400	29,000	38,700
$5\frac{1}{2}$	157	350	624	1,400	2,490	3,890	5,600	7,620	9,960	12,600	15,550	18,850	22,400	30,500	39,300
6	164	366	650	1,460	2,600	4,070	5,850	7,980	10,400	13,150	16,250	19,900	23,400	31,800	41,500
$6\frac{1}{2}$	169	376	672	1,510	2,680	4,180	6,030	8,220	10,700	13,580	16,750	20,200	24,200	32,800	42,800

Note: The loss of head through a clean filter is about 3 in.; hence add 3 in. to the ''maximum head'' in the table and sketch to obtain the indicated flow in practice. A minimum 3–4 ft of water over the sand is advised. Example: To find the size of a filter that will deliver a maximum of 500 gpd: From above, a filter with a $\frac{1}{8}$-in. orifice and a head of water of 3 ft 9 in. will meet the requirements. Filtering at the rate of 50 gpd/ft^2 of filter area, the required filter area is 500 gpd/[50 gal/(ft^2)(day)] = 10 ft^2. Provide at least 2 days storage capacity.

[a] In inches.

[b] No loss head through sand and gravel or pipe is assumed; flow is based on $Q = C_d VA$, where $V = \sqrt{2gh}$ and $C_d = 0.6$, with free discharge. (Design filter for twice the desired flow to ensure an adequate delivery of water as the frictional resistance in the filter to the flow builds up. *Use two or more units in parallel.*)

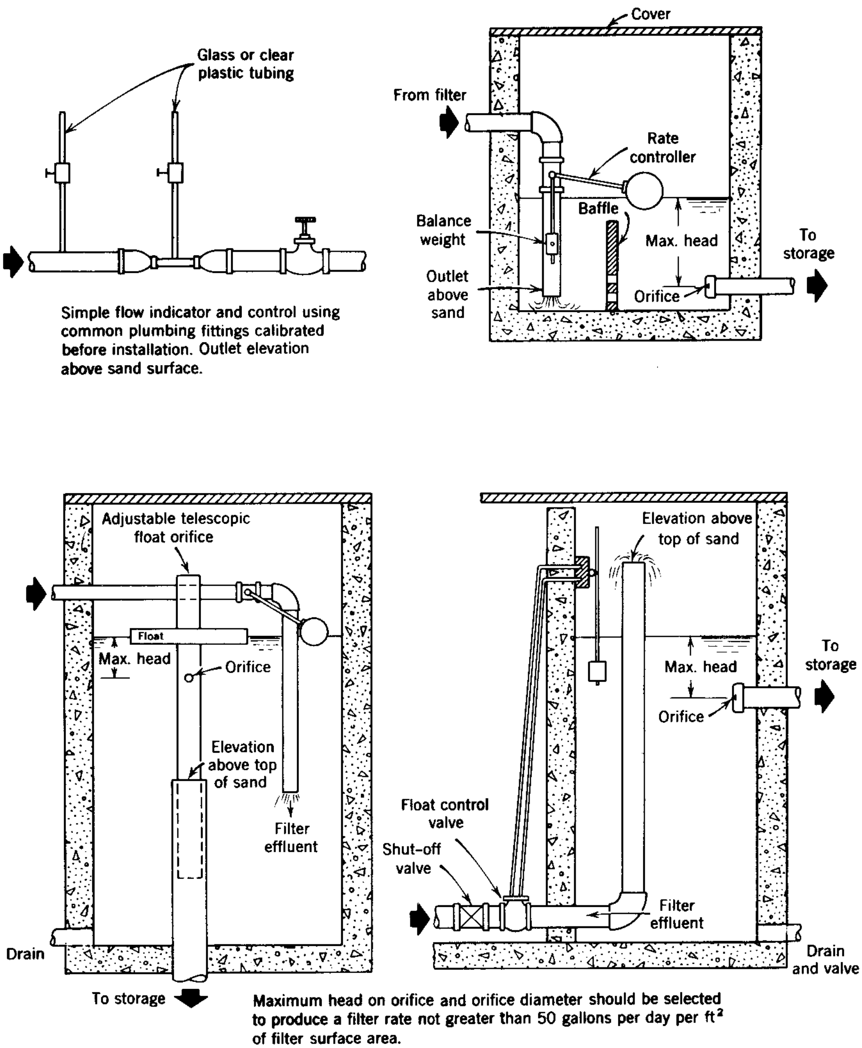


Figure 3-18 Typical devices for the control of the rate of flow or filtration. Plant capacity: 50 to 100 percent greater than average daily demand, with clear well.

mined rate of filtration through the filter, usually about 3 gpm/ft^2, until the filter needs cleaning. Disturbance of filter rate, interruption, or excessive head loss may cause breakthrough of suspended particles and filter floc. (A turbidimeter should be used to monitor effluent.) Filter design and operation should reduce the possible magnitude of filter fluctuations.[194] A filter rate of 3 to 4 gpm/ft^2 or higher may be permitted with skilled operation if pretreatment can ensure that the water on the filter has a turbidity of less than about 10 NTU, and preferably 3 units, and the coliform concentration is less than 2.2. Sand

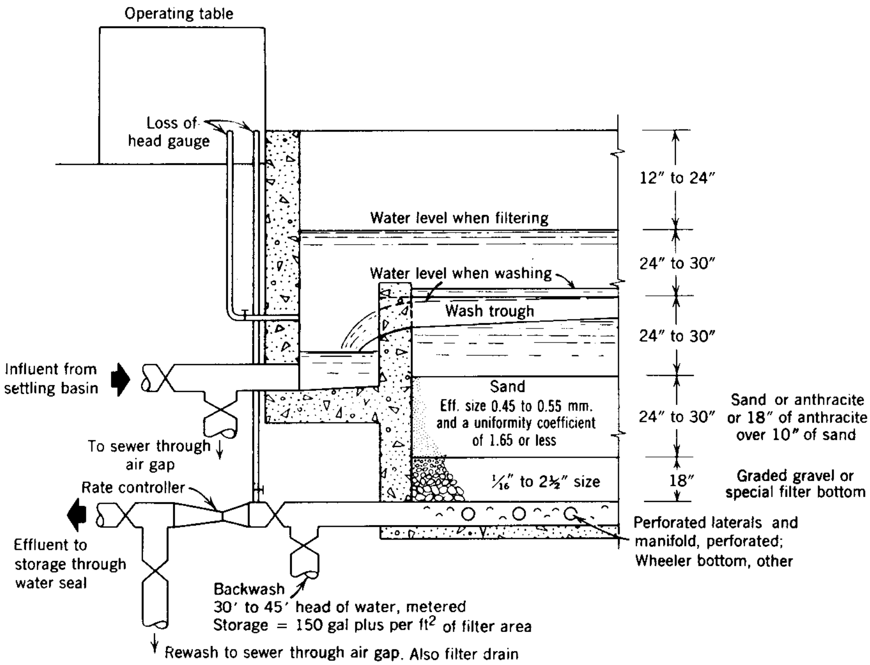


Figure 3-19 Essential parts of a rapid sand filter. The minimum total depth is 8½ ft, 12 ft preferred.

$$\text{Rate of filtration} = \frac{7.48}{\text{minutes for water in filter to fall 1 ft}}$$

Fill filter with water, shut off influent, and open drain

Backwash time = 10–15 min minimum, until water entering through is clear
Normal washwater usage = 2–2.5% or less of water filtered
Sand expansion = 40–50% = 33.6–36 in. for 24-in. sand bed
= 25–35% for dual media, anthracite, and sand

$$\text{Rate of backwash} = \frac{7.48}{\text{minutes for water in filter to rise 1 ft}}$$

Lower water level to sand, slowly open backwash valve, 20–25 gpm/ft^2 minimum (32–40 in. rise/min).

Orifice area = 0.25–0.30% of filter area
Lateral area = 2 × orifice area
Manifold area = 1.5–2 × total area of laterals

for the higher rate would have an effective size of 0.5 to 0.7 mm or higher, a uniformity coefficient of 1.5 to 2.0, and a greater sand depth. A larger effective size anthracite on top in a dual-media filter improves the length of filter runs but permits deeper penetration of solids and requires more effective backwash and cleaning.

The rate controller is omitted in a declining-rate filter. A gate valve or orifice is used in its place. An acceptable rate of flow (filtration) is set at the start of a run but decreases as the head loss increases. The use of this concept is recommended in developing countries and other areas where skilled operators are not generally available.[195] See also Slow Sand Filter (filtration rate control) in this chapter and Table 3-18.

In a combination anthracite over sand bed filter (dual media), use is made of the known specific gravity of crushed anthracite of 1.35 to 1.75 and the specific gravity of sand of 2.5 to 2.65. The relative weight of sand in water is three times that of anthracite. The anthracite effective size is 0.9 to 1.1 and uniformity coefficient 1.6 to 1.8. The sand effective size is 0.45 to 0.55 and uniformity coefficient 1.5 to 1.7. Anthracite grains can be twice as large as sand grains; after backwashing, the sand will settle in place before the anthracite in two separate layers.[196] High-rate sand–anthracite filters require careful operating attention and usually use of a filter conditioner to prevent floc passing through while at the same time obtaining a more uniform distribution of suspended solids throughout the media depth. Longer filter runs, such as two to three times the conventional filter, at a rate of 4 to 6 gpm/ft^2 and up to 8 or 10 gpm/ft^2 and less washwater are reported. A mixed or multimedia may consist of anthracite on top, effective size 0.95 to 1.0 mm and uniformity coefficient 1.55 to 1.75; silica sand in the middle, effective size 0.45 to 0.55 and uniformity coefficient 1.5 to 1.65; and garnet sand* on the bottom, effective size 0.2 to 0.35 mm and uniformity coefficient 1.6 to 2.0. Total media depth is 24 to 48 in. Under the same conditions, filter runs will increase with dual media and increase further with mixed media over single-media sand. The turbidity of the effluent can be expected to be less than 0.5 NTU in a well-operated plant. Granular activated-carbon media (GAC) in place of sand and anthracite can function both as an adsorbent of organics and as a filter medium, but backwash rates will have to be reduced and carefully controlled. If the organics are synthetic chemicals, frequent regeneration will be required. If the organics are taste- and odor-producing compounds, activated carbon may remain effective for several years. The GAC will dechlorinate water that has been chlorinated.

Treatment of the raw water by coagulation, flocculation, and settling to remove as much as possible of the pollution is usually necessary and an important preliminary step in the rapid sand filtration of water. Without coagulation, virus removal is very low. The settled water, in passing to the filter, carries with it some flocculated suspended solids, color, and microorganisms. This material forms a mat on top of the sand that aids greatly, together with adsorption on the bed granular material, in the straining and removal of other suspended matter, color, and microorganisms, but this also causes rapid clogging of the sand. Special arrangement is therefore made in the design for

*Garnet sand has a specific gravity of 4.0–4.2.

washing the filter (every 48–72 hours depending on the head loss) by forcing water backward up through the filter at a rate that will provide a sand expansion of 40 to 50 percent based on the backwash rate, water temperature, and sand effective size. For example, with a 0.4-mm-effective-size sand, a 40 percent sand expansion requires a washwater rate rise of 21 in./min with 32°F (0°C) water and a rise of $32\frac{1}{2}$ in. with water at 70°F (21°C).[197] The dirty water is carried off to waste by troughs built in above the sand bed 5 to 6 ft apart. Separate air laterals in the underdrain system can increase the backwash efficiency. A system of water jets or rakes or a $1\frac{1}{2}$- to 2-in. pressure line at 45 to 75 psi with a hose connection (including vacuum breaker) should be provided to scour the surface of the sand to assist in loosening and removing the material adhering to it, in the pores of the sand on the surface, and in the filter depth. Air scour or wash is also very effective for cleaning the entire bed depth, especially in beds 4 to 6 ft deep. A backwash rate of 10 gpm/ft^2 may be acceptable with an anthracite or granular activated-carbon bed. Effective washing of the sand is essential. Backwash should start when the turbidity begins to rise above 0.1 to 0.2 NTU, not after the turbidity reaches 1.0 NTU. Before being placed back into sevice the filter effluent should be sent to waste for 5 to 20 min to reestablish filtration efficiency. Aluminum in the filtered water should be less than 0.15 mg/l. Filters that have been out of service should be backwashed before being returned to service. The filter sand should be inspected periodically. Its condition can be observed by lowering the water level below the sand and looking for mounds and craters, debris on the surface, or cracks on the surface or along the walls. Depth samples of the sand may also be taken for laboratory observation. During the washing operation the samples should be inspected for uneven turbulence and the presence of small lumps known as mud balls. Any of these conditions requires further investigation and correction. A conventional rapid sand filter plant flow diagram and unit processes are shown in Figure 3-20.

When properly operated, a filtration plant, including coagulation, flocculation, and settling, can be expected to remove 90 to 99.9 percent of the bacteria, protozoa, and viruses,[185] a great deal of the odor and color, and practically all of the suspended solids. Adequate pretreatment is essential. Nevertheless, chlorination must be used to ensure that the water leaving the plant is safe to drink. Construction of a rapid sand filter should not be attempted unless it is designed and supervised by a competent environmental engineer. Pilot plant studies, including preliminary treatment for heavily polluted water, may be required to ensure the proposed treatment will produce a water meeting drinking water standards at all times. Adequate coagulation, flocculation, and settling, in addition to granular media filtration and disinfection, are necessary to ensure the removal of bacteria, protozoa (*Giardia* and *E. histolytica* cyst), and viruses. Improper pH control can result in weak floc and passage of dissolved coagulant.

A flow diagram of a typical treatment plant is shown in Figure 3-21.

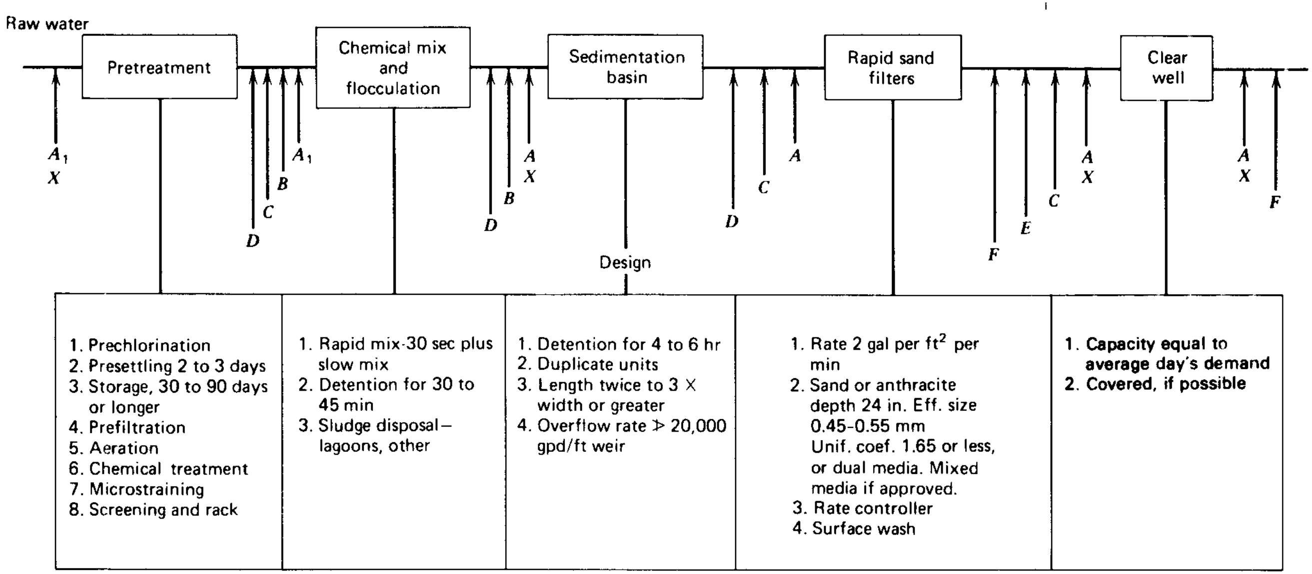


Figure 3-20 Conventional rapid sand filter plant flow diagram. Possible chemical combinations:
A: Chlorine. A_1 Eliminate if THMs formed.
B: Coagulant; aluminum sulfate (pH 5.5–8.0), 10 to 50 mg/l; ferric sulfate (pH 5.0–11.0), 10 to 50 mg/l; ferrous sulfate (pH 8.5–11.0), 5 to 25 mg/l; ferric chloride (pH 5.0–11.0); sodium aluminate, 5 to 20 mg/l; activated silica, organic chemicals (polyelectrolytes).
C: Alkalinity adjustment; lime, soda ash, or polyphosphate.
D: Activated carbon, potassium permanganate.
E: Dechlorination; sulfur dioxide, sodium sulfite, sodium bisulfite, activated carbon.
F: Fluoridation treatment.
X: Chlorine dioxide, ozone, chlorine-ammonia.
Note that the chlorinator should be selected to postchlorinate at 3 mg/l. Provide for a dose of 3 mg/l plus chlorine demand for groundwater. Additional treatment processes may include softening (ion exchange, lime-soda, excess lime and recarbonation), iron and manganese removal (ion exchange, chemical oxidation and filtration, ozone oxidation, sequestering), organics removal (activated carbon, superchlorination, ozone oxidation), and demineralization (distillation, electrodialysis, reverse osmosis, chemical oxidation and filtration, freezing).

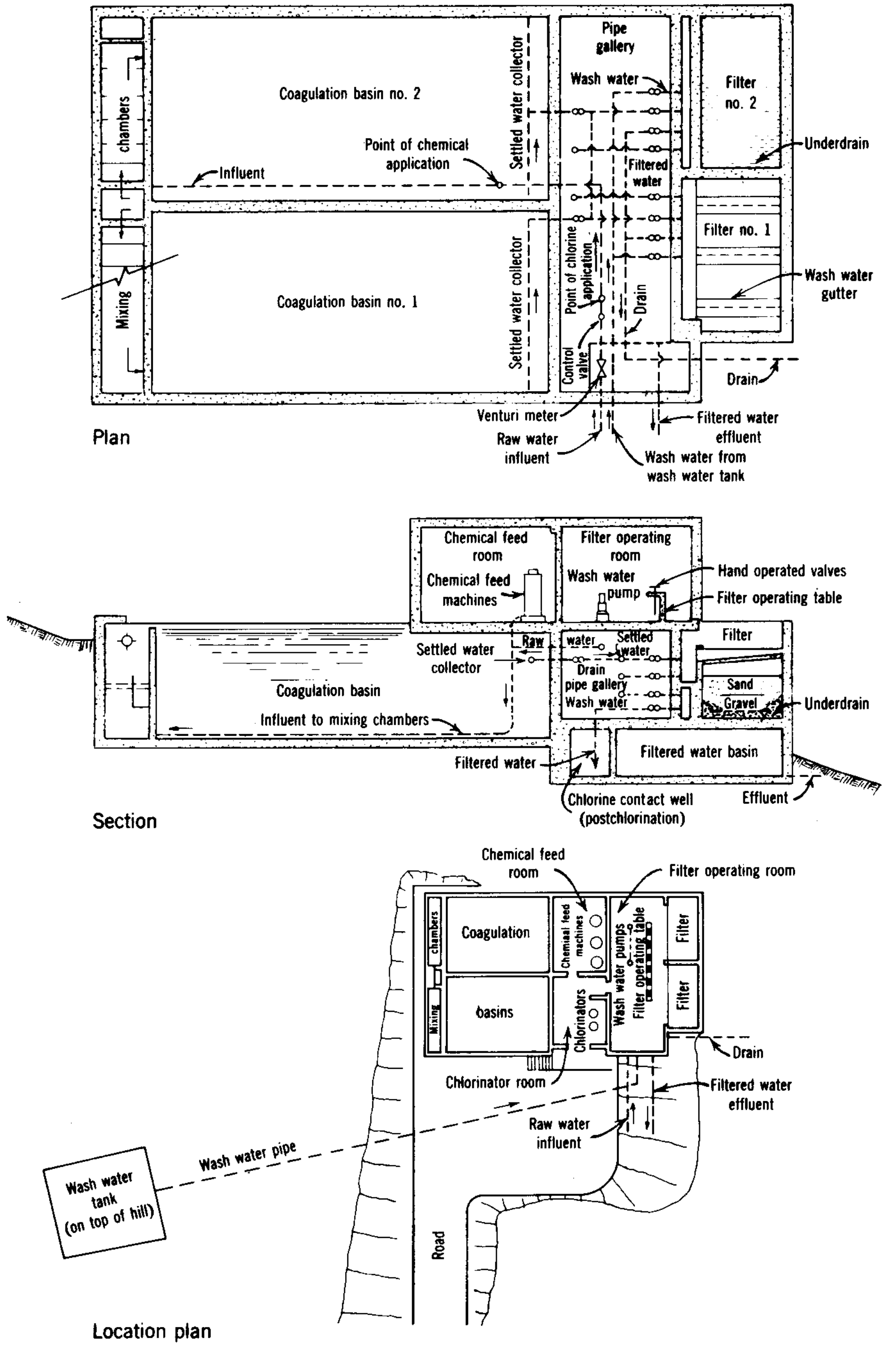


Figure 3-21 Flow diagram of typical treatment plant. This plant is compactly arranged and adaptable within a capacity range of 0.25 to 1.0 mgd. Operation is simple as the emphasis is on manual operation with only the essentials in mechanical equipment provided. Design data are described in the text. (*Source: Water Treatment Plant Design,* American Water Works Association, New York, 1969. Copyright 1969 by the American Water Works Association. Reprinted with permission.)

Direct Filtration

Direct filtration of waters with low suspended matter and turbidity, color, coliform organisms, and plankton, and free of paper fiber, has been attractive because of the lower cost in producing a good quality water, if substantiated by prior pilot plant studies reflecting seasonal variations in raw water quality. Direct filtration removals of bacteria, viruses, and turbidity tend to be more erratic than with conventional treatment.[198] In direct filtration, the sedimentation basin is omitted. The unit processes prior to filtration (dual or mixed media) may consist of only rapid mix, rapid mix and flocculation, or rapid mix and contact basin (1-hour detention) without sludge collector. A flocculation or contact basin is recommended for better water quality control. Rapid sand filtration with coagulation and flocculation is reported to remove 90 to 99 percent of the viruses, bacteria, and protozoa.[185] A polymer is normally used in addition to a coagulant. Direct filtration is a good possibility[199] if

1. the raw water turbidity and color are each less than 25 units,
2. the color is low and the maximum turbidity does not exceed 200 NTU, or
3. the turbidity is low and the maximum color does not exceed 100 units.

The presence of paper fiber or of diatoms in excess of 1000 areal standard units per milliliter (asu/ml) requires that settling (or microscreening) be included in the treatment process chain. Diatom levels in excess of 200 asu/ml may require the use of special coarse coal on top of the bed in order to extend filter runs. Coliform MPNs should be low. Filter rates of 4 to 5 gpm/ft^2 and as high as 15 gpm/ft^2 may produce satisfactory results with some waters, but caution is advised. Decreased chemical dosage, and hence sludge production but increased filter washwater, will usually result in reduced net cost as compared to conventional treatment.[200] Surface wash, subsurface wash, or air scour is required.[151] Good pretreatment and operation control are essential.

Pressure Sand Filter

A pressure filter is similar in principle to the rapid sand gravity filter except that it is completely enclosed in a vertical or horizontal cylindrical steel tank through which water under pressure is filtered. The normal filtration rate is 2 gpm/ft^2 of sand. Higher rates are used. Pressure filters are most frequently used in swimming pool and industrial plant installations and for precipitated iron and manganese removal. It is possible to use only one pump to take water from the source or out of the pool (and force it through the filter and directly into the plant water system or back into the pool), which is the main advantage of a pressure filter. This is offset by difficulty in introducing chemicals under pressure, inadequate coagulation facilities, and lack of adequate settling. The appearance of the water being filtered and the condition of the sand cannot be seen; the effectiveness of backwashing cannot be observed; the safe rate of filtration may be exceeded; and it is difficult to look inside the filter for the purpose of determining loss of sand or anthracite, need for cleaning, replacing of the filter media, and inspection of the washwater pipes, influent, and effluent arrangements. Because of these disadvantages and weaknesses, a pressure filter is not considered dependable for the treatment of contaminated water to be used for drinking purposes. It may, however, have limited application for small, slightly contaminated water supplies and for turbidity removal if approved. In such cases, the water should be coagulated and flocculated in an open basin before being pumped through a pressure filter. This will require double pumping. Pressure filters are not used to filter surface water or other polluted water or following lime-soda softening.

Diatomaceous Earth Filter

The pressure-filter type consists of a closed steel cylinder inside of which are suspended septa, the filter elements. In the vacuum type, the septa are in an open tank under water that is recirculated with a vacuum inside the septa. Normal rates of filtration are 1 to $1\frac{1}{2}$ gpm/ft^2 of element surface. To prepare the filter for use, a slurry or filter aid (precoat) of diatomaceous earth is introduced with the water to be treated at a rate of about $1\frac{1}{2}$ oz/ft^2 of filter septum area, which results in about $\frac{1}{16}$ in. depth of media being placed evenly on the septa, and the water is recirculated for at least 3 min before discharge. Then more filter aid (body feed) is continuously added with the water to maintain the permeability of the filter media. Use of a cationic polymer enhances the removal of bacteria and viruses. The rate of feed is roughly 2 to 3 mg/l per unit of turbidity in the water. Filter aid comes in different particle sizes. It forms a coating or mat around the outside of each filter element. Because of smaller media pore size, it is more efficient than sand in removing from the water suspended matter and organisms such as protozoal cysts (which cause amebiasis and giardiasis), cercariae (which cause schistosomiasis), flukes (which cause paragonimiasis and clonorchiasis), and worms (which cause dracunculiasis, ascariasis, and trichuriasis). Expected bacteria removal is 90 to 99 percent, viral 95 percent, and protozoan 99 percent.[185] These organisms, except for *Giardia* cysts, are not common in the United States. Effluent turbidity of 0.10 NTU or less is normal with proper operation.

The diatomite filter has found its greatest practical application in swimming pools, iron removal for groundwaters, and industrial and military installations. It has a special advantage in the removal of oil from condensate water, since the diatomaceous earth is wasted. It should not be used to treat a public water supply unless pilot plant study results on the water to be treated meet the regulatory agency requirements. The filter should not be used to treat raw water with greater than 2400 MPN per 100 ml, 30 turbidity units, or 3000 areal standard microscopic units per 100 ml. It does not remove color or taste- and odor-producing substances. In any case, disinfection is considered a necessary adjunct to filtration.

A major weakness in the diatomite filter is that failure to add diatomaceous earth to build up the filtering mat, either through ignorance or negligence, will render the filter entirely ineffective and give a false sense of security. In addition, the septa will become clogged and require replacement or removal and chemical cleaning. During filtration, the head loss through the filter should not exceed 30 lb/in.^{2}, thereby requiring a pump and motor with a wide range in the head characteristics (ref. 151, p. 55). The cost of pumping water against this higher head is therefore increased. Diatomite filters cannot be used where pump operation is intermittent, as with a pressure tank installation, for the filter cake will slough off when the pump stops, unless sufficient continuous recirculation of 0.1 gpm/ft^2 of filter area is provided by a separate pump. A reciprocating pump should not be used. Head loss should not exceed a vacuum of 15 in. of mercury in a vacuum system (ref. 151, pp. 48–50).

The filter is backwashed by reversing the flow of the filtered water back through the septa, thereby forcing all the diatomite to fall to the bottom of the filter shell, where it is flushed to waste. Only about 0.5 percent of the water filtered is used for backwash when the filter run length equals the theoretical or design length. As with other filters, the diatomite filter must be carefully operated by trained personnel in order to obtain dependable results, where its use is approved.

Package Water Treatment Plant

These plants are usually predesigned gravity rapid sand filter plants. They are compact and include chemical feeders, coagulation, flocculation, and/or settling, filtration, and water conditioning if needed. Filter design rates are usually 3 to 5 gal/ft^2. Provision must be made for adequate sludge storage and removal and for chlorine contact time. Because of variable raw water quality, it is necessary to first demonstrate that a water of satisfactory sanitary quality can be produced under all conditions. Since these plants include automated equipment, it is essential that a qualified operator be available to make treatment adjustments as needed. Approval of the regulatory agency is usually required.

Water Treatment Plant Wastewater and Sludge

Water treatment plant sludge from plain sedimentation and coagulation–flocculation settling basins and backwash wastewater from filters are required by the Clean Water Act (PL 92–500) to be adequately treated prior to discharge to a surface-water course. Included are softening treatment sludge, brines, iron and manganese sludge, and diatomaceous earth filter wastes. The wastes are characteristic of substances in the raw water and chemicals added in water treatment; they contain suspended and settleable solids, including organic and inorganic chemicals as well as trace metals, coagulants (usually aluminum hydroxide), polymers, clay, lime, powdered activated carbon, and other materials. The aluminum could interfere with fish survival and growth.

The common waste treatment and disposal processes include sand sludge drying beds where suitable, lagooning where land is available, natural or artificial freezing and thawing, chemical conditioning of sludge using inorganic chemicals and polymers to facilitate dewatering, and mechanical dewatering by centrifugation, vacuum filtration, and pressure filtration.[201]

Sludge dewatering increases sludge solids to about 15 to 20 percent. The use of a filter press involves a sludge thickener, polymer, sludge decant, lime, retention basin, addition of a precoat, and mechanical dewatering by pressure filtration. The filter cake solids concentration is increased to 40 percent. The use of a polymer with alum for coagulation could reduce the amount of alum used to less than one-fifth, the cost of coagulant chemicals by one-third, and the sludge produced by over 50 percent. Lime softening results in large amounts of sludge, increasing with water hardness. Recovery and recycling of lime may be economical at large plants. Sludge may be disposed of by lagooning, discharge to a wastewater treatment plant, or mechanical dewatering and landfilling, depending on feasibility and regulations.[202] Brine wastes may be discharged at a controlled rate to a stream if adequate dilution is available or to a sanitary sewer if permitted.

The ultimate disposal of sludge can be a problem in urban areas and land disposal where the runoff or leachate might be hazardous to surface or underground waters. Sludge analyses may be required for sludge disposal approval.

Causes of Tastes and Odors

Tastes and odors in water supplies are caused by oils, minerals, gases, organic matter, and other compounds and elements in the water. Some of the common causes are oils and products of decomposition exuded by algae and some other microorganisms; wastes from gas plants, coke ovens, paper mills, chemical plants, canneries, tanneries, oil refineries, and dairies; high concentrations of iron, manganese, sulfates, and hydrogen sulfide in the water; decaying vegetation such as leaves, algae, weeds, grasses, brush, and moss in the water; and chlorine compounds and high concentrations of chlorine. The control of taste and odor-producing substances is best accomplished by eliminating or controlling the source when possible. When this is not possible or practical, study of the origin and type of the tastes and odors should form the basis for the necessary treatment.

Control of Microorganisms

For the most part, microorganisms that cause tastes and odors are harmless. They are visible under a microscope and include plankton, fungi, bacteria, viruses, and others. Plankton are aquatic organisms; they include algae, protozoa, rotifers, copepods, and certain larvae. Phytoplankton are plant plankton. Zooplankton are animal plankton that feed on bacteria and small algae. Crenothrix, gallionella, and leptothrix, also known as iron bacteria, can also be included. *Thiobacillus thiooxidans* and sulfur bacteria have been implicated in the corrosion of iron. Phytoplankton, including algae, contain chlorophyll; utilize carbon, nitrogen, phosphorus, and carbon dioxide in water; produce oxygen; are eaten by zooplankton; and serve as a basic food for fish. All water is potentially a culture medium for one or more kinds of algae. Bacteria and algae are dormant in water below a temperature of about 48°F (10°C). Heavy algal growths cause a rise in pH and a decrease in water hardness during the day and the opposite at night.

Crenothrix and leptothrix are reddish-brown, gelatinous, stringy masses that grow in the dark inside distribution systems or wells carrying water devoid of oxygen but containing iron in solution. Control, therefore, may be effected by the removal of iron from the water before it enters the distribution system, maintenance of pH at 8.0 to 8.5, increase in the concentration of dissolved oxygen in the water above about 2 mg/l, or continuous addition of chlorine to provide a free residual chlorine concentration of about 0.3 mg/l, or 0.5 to 1.0 mg/l total chlorine. Chemical treatment of the water will destroy and dislodge growths in the mains, with resulting temporary intensification of objectionable tastes and odors, until all the organisms are flushed out of the water mains. A consumer information program should precede the treatment. Iron bacteria may grow in ditches draining to reservoirs. Copper sulfate dosage of 3 mg/l provides effective control.[203] The slime bacteria known as actinomycetes are also controlled by this treatment.

High water temperatures, optimum pH values and alkalinities, adequate food such as mineral matter (particularly nitrates, phosphorus, potassium, and carbon dioxide), low turbidities, large surface area, shallow depths, and sunlight favor the growth of plankton. Exceptions are diatoms, such as asterionella, which grow also in cold water at considerable depth without the aid of light. Fungi can also grow in the absence of sunlight. Extensive growths of anabaena, oscillaria, and microcystis resembling pea green soup are encouraged by calcium and nitrogen. Protozoa such as synura are similar to algae, but they do not need carbon dioxide; they grow in the dark and in cold water. The blue-green algae do not require direct light for their growth, but green algae do. They are found in higher concentrations within about 5 ft of the water surface.

Sawyer[204] has indicated that any lake having, at the time of the spring overturn, inorganic phosphorus greater than 0.01 mg/l and inorganic nitrogen greater than 0.3 mg/l can be expected to have major algal blooms. Reduction of nutrients therefore should be a major objective, where possible. In a reservoir, this can be accomplished by minimizing the entrance of nutrients such as farm and forest drainage, by watershed control, by removal of aquatic weeds before the fall die-off, and by draining the hypolimnion (the zone of stagnation) during periods of stratification since this water stratum has the highest concentration of dissolved minerals and nutrients. See also (a) Aquatic Weed Control and (b) Reservoir Management, Intake Control, and Stratification, this chapter.

Inasmuch as the products of decomposition and the oils given off by algae cause disagreeable tastes and odors, preventing their growth will remove the cause of difficulty. Where it is practical to cover storage reservoirs to exclude light, this is the easiest way to prevent the growth of those organisms that require light and cause difficulty. Where this is not possible, copper sulfate, potassium permanganate, or chlorine can be applied to prevent the growth of the organisms. A combination of chlorine, ammonia, and copper sulfate has also been used with good results. However, in order that the proper chemical dosage required may be determined, it is advisable to make microscopic examinations of samples collected at various depths and locations to determine the type, number, and distribution of organisms and the chemical crystal size for maximum contact. This may be supplemented by laboratory tests using the water to be treated and the proposed chemical dose before actual treatment. In New England, diatoms usually appear in the spring; blue-green algae appear between the diatoms and green algae. Shallow areas usually have higher concentrations of algae.

In general, the application of about $2\frac{1}{2}$ lb of copper sulfate per million gallons of water treated at intervals of two to four weeks between April and October in the temperate zone will prevent difficulties from most microorganisms. A chelating agent such as citric acid improves the performance of the copper sulfate in a high-alkalinity water. Follow-up treatment with potassium permanganate will also kill and oxidize the algae. More exact dosages for specific microorganisms are given in Table 3-19. The required copper sulfate dose can be based on the volume of water in the upper 10 ft of a lake or reservoir, as most plankton are found within this depth. Bartsch[205] suggests an arbitrary dosage related to the alkalinity of the water being treated. A copper sulfate dosage of $2\frac{3}{4}$ lb per million gallons of water in the reservoir is recommended when the methyl orange alkalinity is less than 50 mg/l. When the alkalinity is greater than 40 mg/l, a dosage of 5.4 lb per acre of reservoir surface area is recommended (ref. 203, p. 234). Higher doses are required for the more resistant organisms. The dose needed should be based on the type of algae making their appearance in the affected areas, as determined by periodic microscopic examinations. An inadequate dosage is of very little value and is wasteful. Higher dosages than necessary have caused wholesale fish destruction. For greater accuracy, the copper sulfate dose should be increased by $2\frac{1}{2}$ percent for each degree of temperature above 59°F (15°C) and 2 percent for each 10 mg/l organic matter. Consideration must also be given to the dosage applied to prevent the killing of fish. If copper sulfate is evenly distributed, in the proper concentration, and in accordance with Table 3-20, there should be very little destruction of fish. Fish can withstand higher

TABLE 3-19 Dosage of Copper Sulfate to Destroy Microorganisms

Organism	Taste, Odor, Other	Dosage (lb/10^6 gal)
Diatomaceae (Algae)	(Usually brown)	
Asterionella	Aromatic, geranium, fishy	1.0–1.7
Cyclotella	Faintly aromatic	Use chlorine
Diatoma	Faintly aromatic	—
Fragilaria	Geranium, musty	2.1
Meridon	Aromatic	—
Melosira	Geranium, musty	1.7–2.8
Navicula	—	0.6
Nitzchia	—	4.2
Stephanodiscus	Geranium, fishy	2.8
Synedra	Earthy, vegetable	3.0–4.2
Tabellaria	Aromatic, geranium, fishy	1.0–4.2
Chlorophyceae (Algae)	(Green algae)	
Cladophora	Septic	4.2
Closterium	Grassy	1.4
Coelastrum	—	0.4–2.8
Conferva	—	2.1
Desmidium	—	16.6
Dictyosphaerium	Grassy, nasturtium, fishy	Use chlorine
Draparnaldia	—	2.8
Entomophora	—	4.2
Eudorina	Faintly fishy	16.6–83.0
Gloeocystis	Offensive	—
Hydrodictyon	Very offensive	0.8
Miscrospora	—	3.3
Palmella	—	16.6
Pandorina	Faintly fishy	16.6–83.0
Protococcus	—	Use chlorine
Raphidium	—	8.3
Scenedesmus	Vegetable, aromatic	8.3
Spirogyra	Grassy	1.0
Staurastrum	Grassy	12.5
Tetrastrum	—	Use chlorine
Ulothrix	Grassy	1.7
Volvox	Fishy	2.1
Zygnema		4.2
Cyanophyceae (Algae)	(Blue-green algae)	
Anabaene	Moldy, grassy, vile	1.0
Aphanizomenon	Moldy, grassy, vile	1.0–4.2
Clathrocystis	Sweet, grassy, vile	1.0–2.1
Coelosphaerium	Sweet, grassy	1.7–2.8
Cylindrosphermum	Grassy	1.0
Gloeocopsa	(Red)	2.0
Microcystis	Grassy, septic	1.7
Oscillaria	Grassy, musty	1.7–4.2
Rivularia	Moldy, grassy	—

TABLE 3-19 (*Continued*)

Organism	Taste, Odor, Other	Dosage ($lb/10^6$ gal)
Protozoa		
Bursaria	Irish moss, salt marsh, fishy	—
Ceratium	Fishy, vile (red-brown)	2.8
Chlamydomonas	—	4.2–8.3
Cryptomonas	Candied violets	4.2
Dinobryon	Aromatic, violets, fishy	1.5
Entamoeba histolytica (cyst)	—	Use chlorine 5–25 mg/l
Euglena	—	4.2
Glenodinium	Fishy	4.2
Mallomonas	Aromatic, violets, fishy	4.2
Peridinium	Fishy, like clam shells, bitter taste	4.2–16.6
Synura	Cucumber, musk melon, fishy	0.25
Uroglena	Fishy, oily, cod liver oil	0.4–1.6
Crustacea		
Cyclops	—	16.6
Daphnia	—	16.6
Schizomycetes		
Beggiatoa	Very offensive, decayed	41.5
Cladothrix	—	1.7
Crenothrix	Very offensive, decayed	2.8–4.2
Leptothrix	Medicinal with chlorine	—
Sphaerotilis natans	Very offensive, decayed	3.3
Thiothrix (sulfur bacteria)		Use chlorine
Fungi		
Achlya	—	—
Leptomitus	—	3.3
Saprolegnia	—	1.5
Miscellaneous		
Blood worm	—	Use chlorine
Chara	—	0.8–4.2
Nitella flexilis	Objectionable	0.8–1.5
Phaetophyceae	(Brown algae)	—
Potamogeton	—	2.5–6.7
Rhodophyceae	(Red algae)	—
Xantophyceae	(Green algae)	—

Note: Chlorine residual 0.5 to 1.0 mg/l will also control most growths, except melosira, cysts of *Entamoeba histolytica,* Crustacea, and Synura (2.9 mg/l free).

concentrations of copper sulfate in hard water. If a heavy algal crop has formed and then copper sulfate applied, the decay of algae killed may clog the gills of fish and reduce the supply of oxygen to the point that fish will die of asphyxiation, especially at times of high water temperatures. Tastes

TABLE 3-20 Dosage of Copper Sulfate and Residual Chlorine That If Exceeded May Cause Fish Kill

Fish	Copper Sulfate		Free Chlorine (mg/l)	Chloramine (mg/l)
	$lb/10^6$ gal	mg/l		
Trout	1.2	0.14	0.10 to 0.15	0.4
Carp	2.8	0.33	0.15 to 0.2	0.76 to 1.2
Suckers	2.8	0.33		
Catfish	3.5	0.40		
Pickerel	3.5	0.40		
Goldfish	4.2	0.50	—	0.25
Perch	5.5	0.67		
Sunfish	11.1	1.36	—	0.4
Black bass	16.6	2.0		
Minnows	—	—	0.4	0.76–1.2
Bullheads	—	—	—	0.4
Trout fry	—	—	—	0.05–0.06
Gambusia	—	—	—	0.5–1.0

and odors are of course also intensified. Certain blue-green algae* may produce a toxin that is lethal to fish and animals. Other conditions may also be responsible for the destruction of fish. For example, a lower dissolved oxygen, a pH value below 4 to 5 or above 9 to 10, a free ammonia or equivalent of 1.2 to 3 mg/l, an unfavorable water temperature, a carbon dioxide concentration of 100 to 200 mg/l or even less, free chlorine of 0.15 to 0.3 mg/l, chloramine of 0.4 to 0.76 mg/l, 0.5 to 1.0 mg/l hydrogen sulfide and other sulfides, cyanogen, phosphine, sulfur dioxide, and other waste products are all toxic to fish.[206]† Even a chlorine residual of greater than 0.1 mg/l may be excessive.[207] Lack of food, overproduction, and species survival also result in mass "fish kills." The total chlorine residual to protect fish in the "full-channel mixing zone" should not exceed 0.005 mg/l.

Copper sulfate may be applied in several ways. The method used usually depends on such things as the size of the reservoir, equipment available, proximity of the microorganisms to the surface, reservoir inlet and outlet arrangement, and time of year. One of the simplest methods of applying copper sulfate is the burlap-bag method. A weighed quantity of crystals (bluestone) is placed in a bag and towed at the desired depth behind a rowboat or, preferably, motor-driven boat. The copper sulfate is then drawn through the water in accordance with a planned pattern, first in one direction in parallel

*Some belonging to the genera *Microcystis* and *Anabaena. Prymnesium parvum* is incriminated in fish mortality in brackish water. Marine dinoflagellates *Gymnodinium* and *Gonyaulax* toxins cause death of fish and other aquatic life.

†Trout are usually more sensitive.

lanes about 25 ft apart and then at right angles to it so as to thoroughly treat the entire body of water, including shallow areas. The rapidity with which the chemical goes into solution may be controlled by regulating the fabric of the bag used, varying the velocity of the boat, using crystals of large or small size, or combinations of these variables. In another method, a long wedge-shaped box (12 × 6 in.) is attached vertically to a boat. Two bottom sides have double 24-mesh copper screen openings 1 ft high; one has a sliding cover. Copper sulfate is added to a hopper at the top. The rate of solution of copper sulfate is controlled by raising or lowering the sliding cover over the screen, by the boat speed, and by the size of copper sulfate crystals used. Where spraying equipment is available, copper sulfate may be dissolved in a barrel or tank carried in the boat and sprayed on the surface of the water as a $\frac{1}{2}$ or 1 percent solution. Pulverized copper sulfate may be distributed over large reservoirs or lakes by means of a mechanical blower carried on a motor-driven boat. Larger crystals are more effective against algae at lower depths. Where water flows into a reservoir, it is possible to add copper sulfate continuously and proportional to the flow, provided fish life is not important. This may be accomplished by means of a commercial chemical feeder, an improvised solution drip feeder, or a perforated box feeder wherein lumps of copper sulfate are placed in the box and the depth of submergence in the water is controlled to give the desired rate of solution. In the winter months, when reservoirs are frozen over, copper sulfate may be applied if needed by cutting holes in the ice 20 to 50 ft apart and lowering and raising a bag of copper sulfate through the water several times. If an outboard motor is lowered and rotated for mixing, holes may be 1000 ft apart. Scattering crystals on the ice is also effective in providing a spring dosage when this is practical. Dosage should limit copper to less than 1 mg/l in the water treatment plant effluent. Potassium permanganate crystals may be used where copper sulfate is ineffective.

It is possible to control microorganisms in a small reservoir, where chlorine is used for disinfection and water is pumped to a reservoir, by maintaining a free residual chlorine concentration of about 0.3 mg/1 in the water. However, chlorine will combine with organic matter and be used up or dissipated by the action of sunlight unless the reservoir is covered and there is a sufficiently rapid turnover of the reservoir water. Where a contact time of 2 hr or more can be provided between the water and disinfectant, the chlorine–ammonia process may be used to advantage. Chlorine may also be added as chloride of lime or in liquid form by methods similar to those used for the application of copper sulfate.

Mackenthum[203] cautions that the control of one nuisance may well stimulate the occurrence of another under suitable conditions and necessitate additional control actions. For example, the control of algae may lead to the growth of weeds. Removal of aquatic weeds may promote the growth of phytoplankton or bottom algae such as chara. The penetration of sunlight is thereby facilitated, but nutrients are released by growth and then decay of chara. The primary emphasis should be elimination of nutrients.

Gnat flies sometimes lay their eggs in reservoirs. The eggs develop into larvae, causing consumer complaints of worms in the water. The best control measure is covering the reservoir or using fine screening to prevent the entrance of gnats.

Zebra Mussel and Its Control

The zebra mussel is 1 to 2 in. (2.5–5 cm) long. An adult female can release 30,000 to 40,000 eggs per year. The eggs hatch into larvae (veligers) in several days, drift with the currents, hatch within 3 weeks, and attach themselves to any hard surface such as water intakes, boat and ship hulls, rock reefs, and canals, where they grow. Waters having less than 15 mg/l calcium, pH less than 6.5, temperatures below 45°F (7°C) or above 90°F (32°C), and salinity greater than 600 mg/l chloride ion limit growth. The mussels mature in about two years and have a life span of three to five years, depending on the environment. A major concern is the accumulation of the zebra mussels inside industrial plant, power plant, and drinking water intakes, causing restriction in flows and eventual clogging. Flows of 3.3 to 5.0 ft/sec (1.0–1.5 m/s) prevent attachment of the mussel, but infestation has extended to intake screens, raw water wells, settling tanks, condensers, and cooling towers. The mussel imparts a very disagreeable taste to drinking water when it dies.

The zebra mussel is believed to have been introduced into the United States via the St. Lawrence River and the Great Lakes through international ship freshwater ballast discharges. This practice is prohibited but is not entirely effective. The mussels are spreading to inland waters by attachment to recreation boats and by waterfowl carrying the veligers.

Suggested control measures include location of water intakes under sand, cleanable screens, mechanical scraping or pigging of intake pipes, electrical currents, certain sound frequencies, flushing intakes with hot water [113–131°F (45–55°C)] for not less than 10 min, oxygen deprivation, chlorine if trihalomethane production is not a problem, and ozone injection. Dual cleanable intake lines may be needed.

Although the zebra mussel improves water clarity (it filters about 1 liter of water per day and consumes phytoplankton and organic material), it deprives fish of algae and other food. The problems created, prevention or treatment, and costs involved remain to be fully resolved.[207a–207c]

Aquatic Weed Control

The growth of aquatic plants (and animals) is accelerated in clear water by nutrients in the water and bottom sediment and when the temperature of the surface water is about 59°F (15°C). Vegetation that grows and remains below the water surface does not generally cause difficulty. Decaying submergent, emergent, and floating aquatic vegetation as well as decaying leaves, brush, weeds, grasses, and debris in the water can cause tastes and odors in water supplies. The discharge of organic wastes from wastewater treatment plants, overflowing septic tank systems, storm sewers, and drainage from lawns, pastures, and fertilized fields contains nitrogen and phosphorus, which promote algal and weed growth. The contribution of phosphorus from sewage treatment plants and septic tank systems can be relatively small compared to that from surface runoff. Unfortunately, little can be done to permanently prevent the entrance of all wastes and drainage or destroy growths of rooted plants, but certain chemical, mechanical, and biological methods can provide temporary control.

Reasonably good temporary control of rooted aquatic plants may be obtained by physically removing growths by dredging; wire or chain drags, rakes, and hand pulling; and mechanical cutting. Winter drawdown and deepening of reservoirs, lakes, and ponds edges to a depth of 2 ft or more will prevent or reduce plant growths. Weeds that float to the surface should be removed before they decay. Sandy, gravelly, rocky, or clayey bottoms inhibit plant growths.

Where it is possible, the water level should be drained or lowered 3 to 6 ft to expose the affected areas of the reservoir for about 1 month during the freezing winter months, followed by drying the weeds and roots and clearing and removal. Drying out the roots and burning and removing the ash are effective for a number of years. Flooding 3 ft or more above normal is also effective where possible.

Biological control with plant-eating fish, such as white amur or grass carp, is illegal in many states. They eat aquatic insects and other invertebrates and are detrimental to other fish and water quality.

As a last resort, aquatic weeds may be controlled by chemical means. Tastes and odors may result if the water is used for drinking purposes; the chemical may kill fish and persist in the bottom mud, and it may be hazardous to the applicator. The treatment must be repeated annually or more often, and heavy algal blooms may be stimulated, particularly if the plant destroyed is allowed to remain in the water and return its nutrients to the water. Chemical use should be restricted and permitted only after careful review of the toxicity to humans and fish, the hazards involved, and the purpose to be served. Copper sulfate should not be used for the control of aquatic weeds, except for algae, since the concentration required to destroy the vegetation will assuredly kill any fish present in the water and probably exceed permissible levels in drinking water. Diquat and endothal have been approved by the EPA, if applied according to directions. Diquat use requires a 10-day waiting period. Endothal use requires a waiting period of 14 days with the amine salt formulation and 7 days with the potassium or sodium salts formulation.[208] The health and conservation departments should be consulted prior to any work. A permit is usually required. See also Control of Aquatic Weeds in Chapter 9.

Other Causes of Tastes and Odors

In new reservoirs, clearance and drainage reduce algal blooms by removing organic material beneficial to their growth. Organic material, which can cause anaerobic decomposition, odors, tastes, color, and acid conditions in the water, is also removed. If topsoil is valuable, its removal may be worthwhile.

Some materials in water cause unpleasant tastes and odors when present in excessive concentrations, although this is not a common source of difficulty. Iron and manganese, for example, may give water a bitter, astringent taste. In some cases, sufficient natural salt is present, or salt water enters to cause a brackish taste in well water. It is not possible to remove the salt in the well water without going to great expense. Elimination of the cause by sealing off the source of the salt water, groundwater recharge with fresh water, or controlling pump drawdown is sometimes possible.

Other causes of tastes and odors are sewage and industrial or trade wastes and spills. Sewage would have to be present in very large concentrations to be noticeable in a water supply. If this were the case, the dissolved oxygen in the water receiving the sewage would most probably be used up, with resultant nuisance conditions. On the other hand, the billions of microorganisms introduced, many of which would cause illness or death if not removed or destroyed before consumption, are the greatest danger in sewage pollution. Trade or industrial wastes introduce in water suspended or colloidal matter, dissolved minerals and organic chemicals, vegetable and animal organic matters, harmful bacteria, and other materials that are toxic and produce tastes and odors. Of these, the wastes from steel mills, paper plants, and coal distillation (coke) plants have proved to be the most troublesome in drinking water, particularly in combination with chlorine. Tastes produced have been described as ‘‘medicinal,’’ ‘‘phenolic,’’ ‘‘iodine,’’ ‘‘carbolic acid,’’ and ‘‘creosote.’’ Concentrations of 1 part phenol to 500 million parts of water will cause very disagreeable tastes even after the water has traveled 70 miles.[209] The control of these tastes and odors lies in the prevention and reduction of stream pollution through improved plant operation and waste treatment. Chlorine dioxide has been found effective in treating a water supply not too heavily polluted with phenols. The control of stream pollution is a function and responsibility of federal and state agencies, municipalities, and industry. Treatment of water supplies to eliminate or reduce objectionable tastes and odors is discussed separately below.

Sometimes high uncontrolled doses of chlorine produce chlorinous tastes and chlorine odors in water. This may be due to the use of constant feed equipment rather than a chlorinator, which will vary the chlorine dosage proportional to the quantity of water to be treated. In some installations, chlorine is added at a point that is too close to the consumers, and in others, the dosage of chlorine is marginal or too high or chlorination treatment is used where coagulation, filtration, and chlorination should be used instead. Where superchlorination is used and high concentrations of chlorine remain in the water, dechlorination with sodium sulfite, sodium bisulfite, sodium thiosulfate, sulfur dioxide, or activated carbon is indicated. Sulfur dioxide is most commonly used in manner similar to that used for liquid chlorine and with the same precautions; dosage must be carefully controlled to avoid lowering the pH and dissolved oxygen, as reaeration may then be necessary.

Methods to Remove or Reduce Objectionable Tastes and Odors

Some of the common methods used to remove or reduce objectionable tastes and odors in drinking water supplies, not in order of their effectiveness, are as follows:

1. free residual chlorination or superchlorination,
2. chlorine–ammonia treatment,
3. aeration or forced-draft degasifier,
4. application of activated carbon,
5. filtration through granular activated-carbon or charcoal filters,
6. coagulation and filtration of water (also using an excess of coagulant),
7. control of reservoir intake level,
8. elimination or control of source of trouble,
9. chlorine dioxide treatment,
10. ozone treatment,
11. potassium permanganate treatment,
12. hydrogen sulfide removal, and
13. removal of gasoline, fuel oil, and other organics.

Bench and pilot studies over a representative period of time are advised, including laboratory studies, possible treatment or combinations of treatment, and source control.

Free Residual Chlorination Free residual chlorination will destroy, by oxidation, many taste- and odor-producing substances and inhibit growths inside water mains. Biochemical corrosion is also prevented in the interior of water mains by destroying the organisms associated with the production of organic acids. The reduction of sulfates to objectionable sulfides is also prevented. However, chloro-organics (THMs), which are suspected of being carcinogenic, may be formed, depending on the precursors in the water treated, pH, temperature, contact time, and point of chlorination.

Nitrogen trichloride is formed in water high in organic nitrogen when a very high free chlorine residual is maintained. It is an explosive, volatile, oily liquid that is removed by aeration or carbon. Nitrogen trichloramine exists below pH 4.5 and at higher pH in polluted waters. See Chlorine Treatment for Operation and Microbiological Control, this chapter.

Chlorine–Ammonia Treatment In practice, chlorine–ammonia treatment is the addition of about three or four parts chlorine to one part ammonia. Ammonia is available as a liquid and as a gas in 50-, 100-, and 150-lb cylinders. The ammonia is added a few feet ahead of the chlorine. Nitrogenous organic compounds reduce the effectiveness of inorganic chloramines and give misleading residual readings. Chloramines are weak disinfectants. Chloramine (monochloramine) concentration should be increased by 25 and contact time 100 times to obtain the same effectiveness as free chlorine disinfection. Because of this, chlorine–ammonia treatment is not recommended as the primary disinfectant. The disinfection efficiency of chloramines decreases with increases in pH. Chloramines prevent chlorinous tastes due to the reaction of chlorine with taste-producing substances in water. However, other taste and odor compounds may develop. An excess of ammonia can cause bacterial growth in the extremities of distribution systems. Chloramines may stimulate the growth of algae and bacteria in open reservoirs and will interfere with the maintenance of a free chlorine residual if insufficient chlorine is used. Chloramines are toxic to fish, including tropical fish, if not removed prior to use. Hospitals should also be informed that chloramines may adversely affect dialysis patients. Soft-drink manufacture may also be affected.

Chloroform is not formed as in free residual chlorination; but other chloroorganic compounds that may cause adverse health effects are formed.[210] Free residual chlorination followed by dechlorination and then chlorination of the water distributed is sometimes practiced with good bacteriological control.[211] Chlorine–ammonia treatment of the filtered water to maintain a chloramine residual in the distribution system, instead of a free residual, is sometimes used to minimize trihalomethane formation, but microbiological quality must not be compromised.

Aeration Aeration is a natural or mechanical process of increasing the contact between water and air for the purpose of releasing entrained gases, adding oxygen, and improving the chemical and physical characteristics of water. Some waters, such as water from deep lakes and reservoirs in the late summer and winter seasons, cistern water, water from deep wells, and distilled water, may have an unpleasant or flat taste due to a deficient dissolved-oxygen content. Aeration will add oxygen to such waters and improve their taste. In some instances, the additional oxygen is enough to make the water corrosive. Adjustment may be needed. Free carbon dioxide and hydrogen sulfide will be removed or reduced, but tastes and odors due to volatile oils exuded by algae are not effectively removed.[212] Aeration is advantageous in the treatment of water containing dissolved iron and manganese in that oxygen will change or oxidize the dissolved iron and manganese to insoluble ferric and manganic forms that can be removed by settling, contact, and filtration. It is also useful to remove carbon dioxide before lime–soda ash softening.

Aeration is accomplished by allowing the water to flow in thin sheets over a series of steps, weirs, splash plates, riffles, or waterfalls; by water sprays in fine droplets; by allowing water to drip out of trays, pipes, or pans that have been slotted or perforated with $\frac{3}{16}$- to $\frac{1}{2}$-in. holes spaced 1 to 3 in. on centers to maintain a 6-in. head; by causing the water to drop through a series of trays containing 6 to 9 in. of coke or broken stones; by means of spray nozzles; by using air-lift pumps; by introducing finely divided air in the water; by permitting water to trickle over 1 × 3-in. cypress wood slats with $\frac{1}{2}$- to $\frac{3}{4}$-in. separations in a tank through which air is blown up from the bottom; by forced or induced draft aeration; and by similar means. Water is applied at the rate of 1 to 5 gpm/ft^2 of total tray area (ref. 151, p. 65). Coke will become coated, and hence useless if the water is not clear, if the coke is not replaced. Slat trays are usually 12 in. apart.

Louvered enclosures are necessary for protection from wind and freezing. Many of these methods are adaptable to small rural water supplies, but care should be taken to protect the water from insects and accidental or willful contamination. Screening of the aerator is necessary to prevent the development of worms. Aerated water must be chlorinated before distribution for potable purposes. Corrosion control may also be necessary.

Activated Carbon—Powdered and Granular The sources of raw material for activated carbon include bituminous coal, lignite, peat, wood, bone, petroleum-based residues, and nut shells. The carbon is activated in an atmosphere of oxidizing gases such as CO_2, CO, O_2, steam, and air at a temperature of between 572 and 1832°F (300–1000°C), usually followed by sudden cooling in air or water. The micropores formed in the carbonized particles contribute greatly to the adsorption capacity of the activated carbon. Granular carbon can be reactivated by heat treatment as, for example, in a multihearth furnace at a temperature of 1508 to 1706°F (820–930°C) in a controlled low-oxygen steam atmosphere, where dissolved organics in the carbon pores are volatilized and released in gaseous form. The regenerated carbon is cooled by water quenching.[213] In any case, the spent carbon, whether disposed of in a landfill or incinerator or regenerated, must be handled so as not to pollute the environment.

Granular activated-carbon (GAC) filters (pressure type) are used for treating water for soft drinks and bottled drinking water. The GAC filter beds are used at water treatment plants to remove taste- and odor-producing compounds as well as color and synthetic organic chemicals suspected of being carcinogenic. Colloids interfere with adsorption if not removed prior to filtration. The GAC filters or columns normally follow conventional rapid sand filters but can be used alone if a clear, clean water is being treated.

Granular activated carbon is of limited effectiveness in the removal of trihalomethane precursor compounds. It is effective for only a few weeks.[214] In contrast, GAC beds for taste and odor control need regeneration every three to six years.[215] When the GAC bed becomes saturated with the contaminant being removed, the contaminant appears in the effluent (an event known as breakthrough) if the GAC is not replaced or regenerated.

Activated carbon in the powdered form is used quite generally and removes by adsorption, if a sufficient amount is used, practically all tastes and odors found in water. The powdered carbon may be applied directly to a reservoir as a suspension with the aid of a barrel and boat (as described for copper sulfate) or released slowly from the bag in water near the propeller, but the reservoir should be taken out of service for one to two days, unless the area around the intake can be isolated. The application of copper sulfate within this time will improve the settling of the carbon.

Doses vary from 1 to 60 lb or more of carbon to 1 million gallons of water, with 25 lb as an average. In unusual circumstances, as much as 1000 lb of carbon per million gallons of water treated may be needed, but cost may make this impractical. Where a filtration plant is provided, carbon is fed by means of a standard chemical dry-feed machine or as a suspension to the raw water, coagulation basin, or filters. However, carbon can also be manually applied directly to each filter bed after each wash operation. Ten to 15 min contact time between the carbon and water being treated and good mixing will permit efficient adsorption of the taste and color compounds. Activated carbon is also used in reservoirs and settling basins to exclude sunlight causing the growth of algae. This is referred to as ‘‘blackout’’ treatment. The dosage of carbon required can be determined by trial and error and tasting the water or by a special test known as the ‘‘threshold odor test,’’ which is explained in *Standard Methods*.[29] If the water is pretreated with chlorine, after 15 to 20 min the activated carbon will remove up to about 10 percent of its own weight of chlorine; hence, they should *not* be applied together. Careful operation control can make possible prompt detection of taste- and odor-producing compounds reaching the plant and the immediate application of corrective measures.

The GAC filters are usually $2\frac{1}{2}$ to 3 ft deep and operate at rates of 2 to 5 gpm/ft^2. They are supported on a few inches of sand. Pressure filters containing sand and activated carbon are used on small water supplies. The GAC columns are up to 10 ft deep. The water, if not clear, must be pretreated by conventional filtration, including coagulation and clarification.

Charcoal Filters Charcoal filters, either of the open-gravity or closed-pressure type, are also used to remove substances causing tastes and odors in water. The water so treated must be clear, and the filters must be cleaned, reactivated, or replaced when they are no longer effective in removing tastes and odors. Rates of filtration vary from 2 to 4 gpm/ft^2 of filter area, although rates as high as 10 gpm/ft^2 are sometimes used. Trays about 4 ft^2 containing 12 in. of coke are also used. The trays are stacked about 8 in. apart, and the quantity is determined by the results desired.

Coagulation Coagulation of turbidity, color, bacteria, organic matter, and other material in water followed by flocculation, settling, and then filtration will also result in the removal of taste- and odor-producing compounds, particularly when activated carbon is included. The use of an excess of coagulants will sometimes result in the production of a better tasting water. In any case, a surface-water supply should be treated to produce a very clear water so as to remove the colloids, which together with volatile odors account for the taste and odors of most finished waters.[216]

Reservoir Management, Intake Control, and Stratification The quality of reservoir and lake water varies with the depth, season of the year or temperature, wave action, organisms and food present, condition of the bottom, clarity of the water, and other factors. Stratification is more likely to be pronounced in deep-water bodies. Lakes are classified as eutrophic (productive) or oligotrophic (unproductive).

Temperature is important in temperate zones. At a temperature of 39.2°F (4°C), water is heaviest, with a specific gravity of 1.0. Therefore, in the fall of the year, the cool air will cause the surface temperature of the water to drop, and when it reaches 39.2°F, this water, with the aid of wind action, will move to the bottom and set up convection currents, thereby forcing the bottom water up. Then in the winter the water may freeze, and conditions will remain static until the spring, when the ice melts and the water surface is warmed. A condition is reached when the entire body of water is at a temperature of about 39.2°F, but a slight variation from this temperature, aided by wind action, causes an imbalance, with the bottom colored, turbid water deficient in oxygen (usually also acidic and high in iron, manganese, and nutrient matter) rising and mixing with the upper water. The warm air will cause the temperature of the surface water to rise, and a temporary equilibrium is established, which is upset again with the coming of cold weather. This phenomenon is known as reservoir turnover. In a shallow reservoir or lake, less than about 25 ft deep, wind action rather than water density induces water mixing.

In areas where the temperature does not fall below 39.2°F and during warm months of the year, the water in a deep reservoir or lake will be stratified in three layers: the top mixed zone (epilimnion), which does not have a permanent temperature stratification and which is high in oxygen and algae; the middle transition zone (metalimnion or thermocline), in which the drop in temperature equals or exceeds 1.8°F (1°C) per meter and oxygen decreases; and the bottom zone of stagnation (hypolimnion), about one-half or more of the depth, which is generally removed from surface influence. The hypolimnion is cold, below 54°F (12°C), and often deficient in oxygen. The metalimnion is usually the source of the best quality water. The euphotic zone, in the epilimnion, extends to the depth at which photosynthesis fails to occur because of inadequate light penetration. The reservoir or upper lake layer or region, in which organic production from mineral substances takes place because of light penetration, is called the trophogenic region. The layer in the hypolimnion in which the light is deficient and in which nutrients are released by dissimilation (the opposite of assimilation) is called the tropholytic region. Hydrogen sulfide, manganese, iron, and ammonia may occur at the bottom, making for poor-quality, raw water.

A better quality water can usually be obtained by drawing from different depth levels, except during reservoir turnover. To take advantage of this, provision should be made in deep reservoirs for an intake tower with inlets at different elevations so that the water can be drawn from the most desirable level. Where an artificial reservoir is created by the construction of a dam, it is usually better to waste surplus water through a bottom blowoff rather than over a spillway; then stagnant hypolimnion bottom water, usually the colder water except in the winter, containing decaying organic matter (hydrogen sulfide), phosphorus, color, manganese, iron, and silt, can be flushed out.

Chlorine Dioxide Treatment Chlorine dioxide treatment was originally developed to destroy tastes produced by phenols. However, it is also a strong disinfectant over a broad pH range and effective against other taste-producing compounds such as from algae, decaying vegetation, and industrial wastes. It also oxidizes iron and manganese and aids in their removal.

Chlorine dioxide is manufactured at the water plant where it is to be used. Sodium chlorite solution and chlorine water are usually pumped into a glass cylinder where chlorine dioxide is formed and from which it is added to the water being treated, together with the chlorine water previously acidified with hydrochloric acid. A gas chlorinator is needed to form chlorine water, and for a complete reaction with full production of chlorine dioxide, the pH of the solution in the glass reaction cylinder must be less than 4.0, usually 2 to 3. Where hypochlorinators are used, the chlorine dioxide can be manufactured by adding hypochlorite solution, a dilute solution of hydrochloric acid, and a solution of sodium chlorite in the glass reaction cylinder so as to maintain a pH of less than 4.0. Three solution feeders are then needed. Cox (ref. 187, pp. 121–122) gives the theoretical ratio of chlorine to sodium chlorite as 1.0 to 2.57 with chlorine water or hypochlorite solution and sodium chlorite to chlorine dioxide produced as 1.0 to 0.74. A chlorine dioxide dosage of 0.2 to 0.3 mg/1 will destroy most phenolic taste-producing compounds. Chlorine dioxide does not react with nitrogenous compounds or other organic materials in solution having a chlorine demand. Chloramine and trihalomethane formation is prevented or reduced provided free chlorine is not present. It is an effective disinfectant, about equivalent to hypochlorous acid. In contrast to free chlorine, chlorine dioxide efficiency increases as the pH increases: Chlorine dioxide is a more efficient bactericide and virucide at pH 8.5 to 9.0 than at pH 7.0.[217] Chlorine dioxide may have to be supplemented by chlorine to maintain an effective residual in the distribution system. The EPA requires that chlorine dioxide residual oxidants be controlled so that the sum of chlorine dioxide, chlorite ion, and chlorate ion does not exceed 0.5 to 1.0 mg/l. The chlorite ion is said to be very toxic. Because of this and other uncertainties, caution is urged. Chlorine dioxide is a very irritating gas and is more toxic than chlorine. It explodes on heating. The permissible 8-hour exposure concentration is 0.1 ppm and 0.3 ppm for 15 min.[218]

Ozone Treatment Ozone in concentrations of 1.0 to 1.5 mg/1 has been used for many years as a disinfectant and as an agent to remove color, taste, and odors from drinking water.[219] It effectively eliminates or controls color, taste, and odor problems not amenable to other treatment methods; controls disinfection byproducts formation; and improves flocculation of surface waters in low concentrations. Doses of 5 mg/l are reported to interfere with flocculation and support bacterial growths. Ozone also oxidizes and permits iron and manganese removal by settling and filtration and aids in turbidity removal. About 2 mg/l or less is required.[220] Like chlorine, ozone is a toxic gas. Source water quality affects ozonation effectiveness. Pilot plant studies are indicated.

In contrast to chlorine, ozone is a powerful oxidizing agent over a wide pH and temperature range. It is an excellent virucide, is effective against amoebic and *Giardia* cysts, and destroys bacteria, humic acid, and phenols. The potential for the formation of chlorinated organics such as THMs is greatly reduced with preozonation; the removal of soluble organics in coagulation is also reported to be improved.[221] Ozone is reported to be 3100 times faster and more effective than chlorine in disinfection.[222] Ozone attacks the protein covering protecting a microorganism; it inactivates the nucleic acid, which leads to its destruction. Ozonation provides no lasting residual in treated water but increases the dissolved oxygen; it has a half-life of about 20 min in 70°F (21°C) distilled water. Ozone is more expensive as a disinfectant than either chlorine or chlorine dioxide. The disadvantage of no lasting residual can be offset by adding chlorine or chlorine–ammonia to maintain a chlorine residual in the distribution system.

New products can also be formed during the ozonation of wastewaters; not all low-molecular-weight organic compounds are oxidized completely to CO_2 and H_2O. Careful consideration must be given to the possibility of the formation of compounds with mammalian toxicity during ozonation of drinking water.[223]

However, at least one study concludes that the probability of potentially toxic substances being formed is small.[222] Ozone disinfection before chloramination yielded less than 1 μg/l total trihalomethane.[224]

Ozone must be generated at the point of use; it cannot be stored as a compressed gas. Although ozone can be produced by electrolysis of perchloric acid and by UV lamps, the practical method for water treatment is by passage of dry, clean air between two high-voltage electrodes. Pure oxygen can be added in a positive-pressure injection system. High-purity oxygen will produce about twice the amount of ozone from the same ozonator at the same electrical input.[225] The ozonized air is injected in a special mixing and contact chamber (30 min) with the water to be treated. The space above the chamber must be carefully vented, after its concentration is reduced, using an ozone-destruct device to avoid human exposure, as ozone is very corrosive and toxic.

The vented ozone may contribute to air pollution. It should not exceed 0.12 ppm in the ambient air. As with chlorine, special precautions must be taken in the storage, handling, piping, respiratory protection, and housing of ozone. Exhaust air and plant air must be continuously monitored. The permissible 8-hr exposures are 0.1 and 0.3 ppm for 15 min (ref. 152, p. 15). Exposure to 0.05 ppm 24 hr/day, 7 days/week, is reported to be detrimental. Greater than 0.1 ppm calls for investigation. A concentration of 10,000 ppm is lethal in 1 min; 500 ppm is lethal after 16 hr.

The generation of ozone results in the production of heat, which may be utilized for heating.

Hydrogen Sulfide, Sources and Removal Hydrogen sulfide is undesirable in drinking water for aesthetic and economic reasons. Its characteristic "rotten-egg" odor is well known, but the fact that it tends to make water corrosive to iron, steel, stainless steel, copper, and brass is often overlooked. The permissible 8-hr occupational exposure to hydrogen sulfide is 20 ppm, but only 10 min for 50 ppm exposure.[226] Death is said to result at 300 ppm. See Safety, Chapter 4. As little as 0.2 mg/l in water causes bad taste and odor and staining of photographic film.

The sources of hydrogen sulfide are both chemical and biological. Water derived from wells near oil fields or from wells that penetrate shale or sandstone frequently contain hydrogen sulfide. Calcium sulfate, sulfites, and sulfur in water containing little or no oxygen will be reduced to sulfides by anaerobic sulfur bacteria or biochemical action, resulting in liberation of hydrogen sulfide. This is more likely to occur in water at a pH of 5.5 to 8.5, particularly in water permitted to stand in mains or in water obtained from close to the bottom of deep reservoirs. Organic matter often contains sulfur that, when attacked by sulfur bacteria in the absence of oxygen, will release hydrogen sulfide. Another source of hydrogen sulfide is the decomposition of iron pyrites or iron sulfide.

The addition of 2.0 to 4 mg/l copper sulfate or the maintenance of at least 0.3 mg/l free residual chlorine in water containing sulfate will inhibit biochemical activity and also prevent the formation of sulfides. The removal of H_2S already formed is more difficult, for most complete removal is obtained at a pH of around 4.5. Aeration removes hydrogen sulfide, but this method is not entirely effective; carbon dioxide is also removed, thereby causing an increase in the pH of the water, which reduces the efficiency of removal. Therefore, aeration must be supplemented. Aeration followed by settling and filtration is an effective combination. Chlorination alone can be used without precipitation of sulfur, but large amounts, theoretically 8.4 mg/l chlorine to each milligram per liter of hydrogen sulfide, would be needed. The alkalinity (as $CaCO_3$) of the water is lowered by 1.22 parts for each part of chlorine added. Chlorine in limited amounts, theoretically 2.1 mg/l chlorine for each milligram per liter of hydrogen sulfide, will result in formation of flowers of sulfur, which is a fine colloidal precipitate requiring coagulation and filtration for removal. If the pH of the water is reduced to 6.5 or less by adding an acid to the water or a sufficient amount of carbon dioxide as flue gas, for example, good hydrogen sulfide removal should be obtained. But pH adjustment to reduce the aggressiveness of the water would be necessary. Another removal combination is aeration, chlorination, and filtration through an activated-carbon pressure filter. Pilot plant studies are indicated.

Pressure tank aerators, that is, the addition of compressed air to hydropneumatic tanks, can reduce the entrained hydrogen sulfide in well water from 35 to 85 percent, depending on such factors as the operating pressures and dissolved oxygen in the hydropneumatic tank effluent.[227] The solubility of air in water increases in direct proportion to the absolute pressure. Carbon dioxide is not removed by this treatment. Air in the amount of 0.005 to 0.16 ft^3/gal water and about 15 min detention is recommended, with the higher amount preferred. The air may be introduced through perforated pipe or porous media in the tank bottom or with the influent water. Unoxidized hydrogen sulfide and excess air in the tank must be bled off. Air-relief valves or continuous air bleeders can be used for this purpose. It is believed that oxidation of the hydrogen sulfide through the sulfur stage to alkaline sulfates takes place, since observations show no precipitated sulfur in the tank. Objections to pressure tank aerators are milky water caused by dissolved air and corrosion. The milky water would cause air binding or upset beds in filters if not removed.

A synthetic resin has been developed that has the property of removing hydrogen sulfide with pH control. It can be combined with a resin to remove hardness so that a low-hardness water can be softened and deodorized. The resin is manufactured by Rohm and Haas Company (Philadelphia, PA).

Removal of Gasoline, Fuel Oil, and Other Organics in an Aquifer Leaking storage tanks and piping (50 percent of old tanks leak after 20 years), overflow from air vent or in filling, or accidental spillage near a well may cause gasoline or fuel oil to seep into an aquifer. Correction requires on-site studies and identification, location, and elimination of the cause. Removal of the source is a first and immediate step, followed possibly by pumping out and recovery of the contaminant, bioremediation, or other measures, based on the site geology, soils, and plume.

Sometimes lowering the pump or drop pipe intake in a well may help if this is possible. However, the contaminant is likely to coat or fill soil pore spaces and persist in the contaminated zone a long time. Gasoline and oil tend to adhere to soil particles by surface tension and attraction, particularly in the unsaturated soil zone until dissipated through adsorption, dispersion, diffusion, and ion exchange[228] or flushed out or broken down by soil microorganisms. The gasoline, benzene, or fuel oil will gradually collect on the groundwater surface and in the well and can be skimmed off over a period of time. Denser liquids, such as chlorinated solvents, tend to move down through the groundwater.

A well contaminated by gasoline or fuel oil might be rehabilitated by extended pumping after removal of the source. The objective would be to create a cone of depression so that the zone of influence due to pumping encompasses the underground contaminated area or plume. This is not very effective if a large area is involved. Many withdrawal wells would be needed. One pump would lower the water table around the well to create a cone of depression; another with the intake close to the water surface in the well serves as an oil or gasoline skimmer. Of course, the contaminated water pumped must be treated before disposal. Continual leaching of gasoline and oil or other contaminant in pore spaces, on soil particles in both the saturated and unsaturated zones, and in rock fractures and faults can be expected for some time. The process may be expedited, under professional direction, by purging and the use of nontoxic, biodegradable detergents; however, it may not be completely effective in restoring the aquifer.

An aquifer was cleaned by treatment of the water from extraction wells using a combination of high-temperature air stripping, biological treatment, and granular activated-carbon filtration. Volatile organics, nonvolatile organics, and trace metals were removed. Soluble organics and some nonvolatile organics were destroyed.[229] Different options should be compared.

Soils contaminated with gasoline from underground storage tanks have been successfully treated by excavating and stockpiling when mixed with bacteria specifically cultivated for petroleum decomposition. Nutrients were applied to enhance growth and soil piles turned intermittently to ensure adequate concentrations of oxygen and soil/bacteria mixing. Spraying of a ditch contaminated by diesel oil with a solution of bacteria and nutrients was also successful.[230]

An activated-carbon filter will remove small amounts of oil or gasoline from a contaminated water supply. It may become expensive if large quantities must be removed and the activated carbon replaced frequently. Air stripping is effective for the removal of petroleum products but is more suitable for large water systems. Air stripping may also be used to decontaminate an unsaturated sandy soil. Preheated air is injected through injection wells and released through venting wells. Vacuum wells may also be used to extract volatile contaminants in unsaturated loose soil.

Ozone has also been found effective in removing volatile organic chemicals from drinking water, including 1,1-dichloroethene, 1,1,2-tetrachloroethene, trichloroethene, vinyl chloride, chlordane, polychlorinated biphenyls, and toxaphene. The treatment may include UV–ozone, UV–hydrogen peroxide, and ozone–hydrogen peroxide.[231]

Treatment methods for the removal of synthetic organic chemicals are also discussed later in this chapter.

Containment of a chemical contaminant in the aquifer may also be possible. This may be accomplished by the use of barriers such as a bentonite slurry trench, grout curtain, sheet piling, or freshwater barrier and by the provision of an impermeable cap over the offending source if it cannot be removed. The method used would depend on the problem and the hydrogeological conditions. However, there are many uncertainties in any method used, and no barrier can be expected to be perfect or maintain its integrity forever.

Bioremediation and Aquifer Restoration In situ aerobic microbial degradation, also referred to as bioremediation, biorestoration, or bioreclamation, has also been used to treat soil contaminated with biodegradable, nonhalogenated organics. The process is complex in view of the many variables and unknowns. In general, as much as possible of the contaminated water and surface soil is removed; oxygen, nutrients such as nitrogen and phosphorus, enzymes, and/or bacteria are added, then reinjected through injection wells and recirculated. Favorable soil conditions include neutral pH, high soil permeability, and 50 to 75 percent moisture content.[232–234]

Progress is also being made in the use of genetically engineered microorganisms to break down (metabolize) pentachlorophenol (PCP) compounds into water carbon dioxide and cell protoplasm. Microorganisms are also being engineered to break down other toxic chemicals.[235] Naturally occurring soil bacteria that use hydrocarbons for food may be present at shallow depths and possibly in soil at greater depths.[236]

The decontamination procedure should be tailored to the soils and pollutants present and their characteristics. Competent prior background information—including interviews; hydrogeological, land-use, and soil investigations; microbiological and chemical analyses; laboratory bench-scale studies; and well monitoring—are usually necessary to characterize the problem, determine the best remediation treatment, and evaluate effectiveness. Aerial photographs, topographic maps, and nearby well logs are valuable aids. It is also important to know the hydraulic conductivity of the affected formation(s), depth to groundwater, direction of groundwater flow, and types and extent of contamination. Adequate hydraulic conductivities are required to obtain in situ bioreclamation. The feasibility of biodegradation is determined in the laboratory using soil samples from several locations on the site.[237]

Iron and Manganese Occurrence and Removal

Iron in excess of 0.3 to 0.5 mg/l will stain laundry and plumbing fixtures and cause water to appear rusty. When manganese is predominant, the stains will be brown or black. Neither iron nor manganese is harmful in the concentrations found in water. Iron may be present as soluble ferrous bicarbonate in alkaline well or spring waters; as soluble ferrous sulfate in acid drainage waters or waters containing sulfur; as soluble organic iron in colored swamp waters; as suspended insoluble ferric hydroxide formed from iron-bearing well waters, which are subsequently exposed to air; and as a product of pipe corrosion producing red water.

Most soils, including gravel, shale, and sandstone rock, and most vegetation contain iron and manganese in addition to other minerals. Decomposing organic matter in water, such as in the lower levels of reservoirs, removes the dissolved oxygen usually present in water. This anaerobic activity and acidic condition dissolves mineral oxides, changing them to soluble compounds. Water containing carbon dioxide or carbonic acid, chlorine, or other oxidizing agent will have the same effect. In the presence of air or dissolved oxygen in water, soluble ferrous bicarbonate and manganous bicarbonate will change to insoluble ferric iron and manganic manganese, which will settle out in the absence of interfering substances. Ferrous iron and manganous manganese may be found in the lower levels of deep reservoirs, flooding soils, or rock containing iron and manganese or their compounds; hence, it is best to draw water from a higher reservoir level but below the upper portion, which supports microscopic growths like algae. This requires the construction and use of multiple-gate intakes, as previously mentioned. Consideration must be given to vertical circulation, such as in the spring and fall when the ferrous iron and manganous manganese are brought into contact with dissolved oxygen and air and convert to the insoluble state and settle out, if not drawn out in the intake.

The presence of as little as 0.1 mg/l iron in a water will encourage the growth of such bacteria as leptothrix and crenothrix. Carbon dioxide also favors their growth. These organisms grow in distribution systems and cause taste, odor, and color complaints. Mains, service lines, meters, and pumps may become plugged by the crenothrix growths. Gallionella bacteria can grow in wells and reduce capacity. Complaints reporting small gray or brownish flakes or masses of stringy or fluffy growths in water would indicate the presence of iron bacteria. The control of iron bacteria in well water is also discussed under (a) Control of Microorganisms, Iron and Manganese Occurrence and Removal, and (c) Corrosion Cause and Control, this chapter.

Corrosive waters that are relatively free of iron and manganese may attack iron pipe and house plumbing, particularly hot-water systems, causing discoloration and other difficulties. Such corrosion will cause red water, the control of which is discussed separately.

Iron and manganese can be removed by aeration or oxidation with chlorine, chlorine dioxide, ozone, potassium permanganate, or lime and lime–soda softening followed by filtration. A detention of at least 20 min may be required following aeration if the raw water is high in manganese or iron. Manganese can also be removed by filtration through manganese green sand capped with at least 6 in. of anthracite, but potassium permanganate is added ahead of the filter. Iron and manganese can be kept in solution (sequestered) if present in combination or individually at a concentration of 1 mg/l or less. Sodium silicates may be used to sequester up to 2 mg/l iron and/or manganese in well water prior to air contact (ref. 151, pp. 68–70). Each method has limitations and requirements that should be determined by on-site pilot plant studies. A summary of processes used to remove iron and manganese is given in Table 3-21.

Most of the carbon dioxide in water is removed by aeration; then the iron is oxidized and the insoluble iron is removed by settling or filtration. If organic matter and manganese are also present, the addition of lime or chlorine will assist in changing the iron to an insoluble form and hence simplify its removal.

TABLE 3-21 Processes of Iron and Manganese Removal

Treatment Process	Oxidation Required	Character of Water	Equipment Required	pH Range Required	Chemicals Required	Remarks
1. Aeration, sedimentation, filtration	Yes	Iron alone in absence of appreciable concentrations of organic matter	Aeration, settling basin, sand filter	>7	None	Easily operated, no chemical control required
2. Aeration, contact oxidation, sedimentation, sand filtration	Yes	Iron and manganese loosely bound to organic matter but no excessive carbon dioxide or organic acid content	Contact aerator of coke, gravel, or crushed pyrolusite; settling basin; sand filter	>7 for iron removal, 7.5–10 for manganese	None	Double pumping required; easily controlled
3. Aeration, contact filtration	Yes	Iron and manganese bound to organic matter but no excessive organic acid content	Aerator and filter bed of manganese-coated sand, Birm, crushed pyrolusite ore, or manganese zeolite	>7 for iron removal, 7.5–10 for manganese	Lime for manganese removal	Double pumping required unless air compressor or ''sniffler'' valve used to force air into water; limited air supply adequate; easily controlled
4. Contact filtration	Yes, but not by aeration	Iron and manganese bound to organic matter but no excessive carbon dioxide or organic acid content	Filter bed of manganese-coated sand, Birm, crushed pyrolusite ore, or manganese zeolite	>7 for iron removal, >8.5 for manganese	Filter bed reactivated or oxidized with chlorine at intervals or with potassium permanganate applied continuously	Single pumping; aeration not required
5. Catalytic action, aeration, sedimentation, filtration	Yes	Manganese in combination with organic matter	Closed pyrolusite bed, aerator, second open-contact bed, sand filter	>7	None	Manganese changed to manganous hydroxide by catalytic action in absence of air, then oxidized

6. Aeration, chlorination, sedimentation, sand filtration	Yes	Iron and manganese loosely bound to organic matter	Aerator and chlorinator or chlorinator alone, settling basin, sand filter	7–8	Chlorine or potassium permanganate	Required chlorine dose reduced by previous aeration, but chlorination alone permits single pumping
7. Aeration, lime treatment, sedimentation, sand filtration	Yes	Iron and manganese in combination with organic matter; organic acids	Effective aerator, lime feeder mixing basin, settling basin, sand filter	8.5–10	Lime	pH control required
8. Aeration, coagulation and lime treatment, sedimentation, sand filtration	Yes	Colored turbid surface water containing iron and manganese combined with organic matter	Conventional rapid sand filtration plant	8.5–9.6	Lime and ferric chloride or ferric sulfate, or chlorinated copperas, or lime and copperas	Complete laboratory control required
9. Zeolite softening	No	Well water devoid of oxygen, containing <0.5 ppm iron and manganese for each 17.0 ppm hardness removed	Conventional sodium zeolite unit, with manganese zeolite unit (or equivalent) for treatment of by-passed water	>6.5	None added continuously but bed is regenerated at intervals with salt solution	Only soluble ferrous and manganese bicarbonate can be removed by base exchange, so aeration or double pumping not required
10. Lime treatment, sedimentation, sand filtration	No	Soft well water devoid of oxygen, containing iron as ferrous bicarbonate	Lime feeder, enclosed mixing and settling tanks, pressure filter	8.1–8.5	Lime	Iron precipitated as ferrous carbonate in absence of oxygen; minimizes or prevents corrosion; double pumping not required

Source: C. R. Cox, *Operation and Control of Water Treatment Processes,* WHO Monograph Series, No. 49, World Health Organization, Geneva, 1964, pp. 212–213. Reproduced with permission.

The open coke-tray aerator is a common method to oxidize and remove iron and manganese. Two or more perforated wooden trays containing about 9 in. of coke are placed in tiers. A 20- to 40-min detention basin is provided beneath the stack of trays; there the heavy precipitate settles out. The lighter precipitate is pumped out with the water to a pressure filter, where it is removed. Carbon dioxide and hydrogen sulfide are liberated in the coke-tray aerator, and when high concentrations of carbon dioxide are present, it may be necessary to supplement the treatment by the addition of soda ash, caustic soda, or lime to neutralize the excess carbon dioxide to prevent corrosion of pipelines.

Open slat-tray aerators operate similarly to the coke-tray type but are not as efficient; however, they are easier to clean than the coke tray, and there is no coke to replace. When the trays are enclosed and air under pressure is blown up through the downward falling spray, a compact unit is developed in which the amount of air can be proportioned to the amount of iron to be removed. Theoretically, 0.14 mg/l oxygen is required to precipitate 1 mg/l iron. The unit may be placed indoors or outdoors.

Another method for iron removal utilizes a pressure tank with a perforated air distributor near the bottom. Raw water admitted at the bottom of the pressure tank mixes with the compressed air from the distributor and oxidizes the iron present. The water passes to the top of a pressure tank, at which point air is released and automatically bled off. The amount of air injected is proportioned to the iron content by a manually adjusted needle valve ahead of a solenoid valve on the air line.[238]

At a pH of 7.0, 0.6 parts of chlorine removes 1 part iron and 0.9 parts alkalinity. At a pH of 10.0, 1.3 parts of chlorine removes 1 part of manganese and 3.4 parts alkalinity.[239]

Corrosion Cause and Control

Internal Pipe Corrosion Internal pipe corrosion usually occurs in unlined metal distribution system piping and building plumbing in contact with soft water of low hardness, pH, and alkalinity containing carbon dioxide and oxygen. In serious cases, water heaters are damaged, the flow of water is reduced, the water is red or rusty where unprotected iron pipe is used, and the inside surface of pipe and fittings is dissolved, with consequent release of trace amounts of possibly harmful chemicals and weakening or pitting of pipe. Dissolved iron may be redeposited as tubercules with a reduction of pipe diameter and water flow. Biochemical changes take place in pipe where iron bacteria such as crenothrix and leptothrix use iron in their growth. High water velocities, carbon dioxide, dissolved solids, and high water temperatures [(140–150°F) (60–66°C)] all accelerate corrosion. Free chlorine residual less than 2 mg/l in water at pH 7 to 8 results in minimal corrosion. However, significant metal leaching (copper, cadmium, zinc, and lead) can occur in home water systems served with private wells when the water has high pH and hardness.

Although much remains to be learned concerning the mechanism of corrosion, a simple explanation as related to iron may aid in its understanding. Water in contact with iron permits the formation of soluble ferrous oxide and hydrogen gas. Gaseous hydrogen is attracted to the pipe and forms a protective film if allowed to remain. But gaseous hydrogen combines with oxygen usually present in "aggressive" water, thereby removing the protective hydrogen film and exposing the metal to corrosion. High water velocities also remove the hydrogen film. In addition, ferrous oxide combines with the water and part of the oxygen usually present to form ferric hydroxide when the carbonate concentration is low, which redeposits in other sections of pipe or is carried through with the water. When the carbonate concentration is high, ferrous carbonate is formed. Another role is played by carbon dioxide. It has the effect of lowering the pH of the water since more hydrogen ions are formed, which is favorable to corrosion.

Pipe Materials and Corrosion Lined steel and ductile iron pipe, asbestos–cement, wood-stave, plastic, vitrified clay, and concrete pressure pipe are corrosion resistant.* Plastic pipe may be polybutylene (PB), polyethylene (PE), or polyvinyl chloride (PVC). The PVC pipe comes in diameters of $\frac{1}{2}$ to 30 in., 10 to 20 ft lengths, and 100 to 235 psi working pressures. It is very resistant to corrosion. Fiberglass-reinforced plastic pipe is available in diameters up to 144 in. and lengths up to 60 ft. Polyethylene pipe comes in 18 to 120 in. diameters and 20 ft lengths. Fiber–epoxy pipe comes in 20 ft lengths and 2 to 12 in. diameters and is easily installed. It combines light weight with high tensile and compressive strength. The pipe withstands pressures of 300 psi, electrolytic attack, as well as embrittlement associated with cold temperatures and aging. Ductile iron pipe comes in diameters of 4 to 54 in. and for pressures of 250 to 350 psi. Concrete pressure pipe withstands pressures of 400 psi and is available in diameters from 16 to 60 in. With soft waters, calcium carbonate tends to be removed from new concrete, cement-lined, and asbestos-cement pipe for the first few years. Salt used in deicing can seep through the ground and greatly weaken reinforced concrete pipe and corrode the steel. Wood-stave, vitrified clay, and concrete pipes have limited applications. Iron and steel pipes are usually lined or coated with cement, tar, paint, epoxy, or enamel, which resist corrosion provided the coating is unbroken. Occasionally, coatings spall off or are imperfect, and isolated corrosion takes place. It should be remembered that even though the distribution system is corrosion resistant, corrosive water should be treated to protect household plumbing systems.

Polycyclic aromatic carbons, some of which are known to be carcinogenic, are picked up from bituminous lining of the water distribution system, not

*See the AWWA/ANSI C104/A 21.4–85 Standard for Cement-Mortar Lining for Ductile-Iron Pipe and Fittings for water. Thermoplastic pipe should have the National Sanitation Foundation seal of approval. The AWWA standards C900-89 and C905 apply to 4- to 12-in. PVC pipe.

from oil-derived tarry linings. On general principles, bituminous linings are being discontinued in England by the Department of the Environment.[241] The WHO recommends that polynuclear aromatic hydrocarbon (PAH) levels in drinking water not exceed 10 to 50 μg/l, the levels found in unpolluted groundwater. Since some PAHs are carcinogenic in laboratory animals and may be carcinogenic in humans, the WHO also recommends that the use of coal-tar based and similar materials for pipe linings and coatings on water storage tanks *should be discontinued.* This recommendation was made with the knowledge that food contributes almost 99 percent of the total exposure to PAHs and that drinking water contributes probably less than 1 percent (ref. 27, Vol. 1, p. 67). Tetrachloroethylene can leach from vinyl-toluene-lined asbestos–cement pipe at dead-end or low-flow sections. The health risk is considered negligible.[242] Petroleum distillates, such as gasoline, can pass through PB and PE pipe and impart taste and odor to drinking water, but PVC pipe is penetrated to a lesser extent by gasoline. The PE, PB, PVC, asbestos–cement, and plastic joining materials may permit permeation by lower molecular weight organic solvents or petroleum products. The manufacturer should be consulted as to whether pipe may pass through contaminated soil.[243] See also Drinking Water Additives, this chapter.

Corrosion Control The control of corrosion involves the removal of dissolved gases, treatment of the water to make it noncorrosive, building up of a protective coating inside pipe, use of resistant pipe materials or coating, cathodic protection, the insulation of dissimilar metals, prevention of electric grounding on water pipe, and control of growths in the mains. Therefore, if the conditions that are responsible for corrosion are recognized and eliminated or controlled, the severity of the problem will be greatly minimized. The particular cause(s) of corrosion should be determined by proper chemical analyses of the water as well as field inspections and physical tests. The applicable control measures should then be employed.

The gases frequently found in water and that encourage corrosion are oxygen and carbon dioxide. Where practical, as in the treatment of boiler water or hot water for a building, the oxygen and carbon dioxide can be removed by heating or by subjecting the water, in droplets, to a partial vacuum. Some of the oxygen is restored if the water is stored in an open reservoir or storage tank.

Dissolved oxygen can also be removed by passing the water through a tank containing iron chips or filings. Iron is dissolved under such conditions, but it can be removed by filtration. The small amount of oxygen remaining can be treated and removed with sodium sulfite. Ferrous sulfate is also used to remove dissolved oxygen.

All carbon dioxide except 3 to 5 mg/l can be removed by aeration, but aeration also increases the dissolved-oxygen concentration, which in itself is detrimental. Sprays, cascades, coke trays, diffused air, and zeolite are used to remove most of the carbon dioxide. A filter rate of 25 gpm/ft^2 in coke trays

6 in. thick may reduce the carbon dioxide concentration from 100 to 10 mg/l and increase pH from about 6.0 to 7.0.[244] The carbon dioxide remaining, however, is sufficient to cause serious corrosion in water having an alkalinity caused by calcium carbonate of less than about 100 mg/l. It can be removed where necessary by adding sodium carbonate (soda ash), lime, or sodium hydroxide (caustic soda). With soft waters having an alkalinity greater than 30 mg/l, it is easier to add soda ash or caustic soda in a small water system to eliminate the carbon dioxide and increase the pH and alkalinity of the water. The same effect can be accomplished by filtering the water through broken limestone or marble chips. Well water that has a high concentration of carbon dioxide but no dissolved oxygen can be made noncorrosive by adding an alkali such as sodium carbonate, with pH adjusted to 8.1 to 8.4. Soft waters that also have a low carbon dioxide content (3 to 5 mg/l) and alkalinity (20 mg/l) may need a mixture of lime and soda ash to provide both calcium and carbonate for the deposition of a calcium carbonate film.*

Sodium and calcium hexametaphosphate, tetrasodium pyrophosphate, zinc phosphates, sodium silicate (water glass), lime, caustic soda, and soda ash are used to build up an artificial coating inside of pipe. Health department approval of chemical use and pilot plant studies are usually required. The sodium concentration in drinking water is increased when sodium salts are added.

Sodium hexametaphosphate dissolves readily and can be added alone or in conjunction with sodium hypochlorite by means of a solution feeder. Concentrated solutions of metaphosphate are corrosive. A dosage of 5 to 10 mg/l is normally used for 4 to 8 weeks until the entire distribution system is coated, after which the dosage is maintained at 1 to 2 mg/l with pH maintained at 7.2 to 7.4. The initial dosage may cause precipitated iron to go into solution with resultant temporary complaints, but flushing of the distribution system will minimize this problem. Calcium metaphosphate is a similar material, except that it dissolves slowly and can be used to advantage where this property is desirable. Inexpensive and simple pot-type feeders that are particularly suitable for small water supplies are available. Sodium pyrophosphate is similar to sodium hexametaphosphate. All these compounds are reported to coat the interior of the pipe with a film that protects the metal, prevents lime scale and red water trouble, and resists the corrosive action of water. However, heating of water above 140 to 150°F (60–66°C) will nullify any beneficial effect. The phosphate in these compounds may stimulate biological growths in mains. In any case, the corrosion control method used should be monitored to determine its effectiveness.

*One grain per gallon (17.1 mg/l) of lime, caustic soda, and soda ash remove, respectively, 9.65, 9.55, and 7.20 mg/l free CO^2; the alkalinity of the treated water is increased by 23.1, 21.4, and 16.0 mg/l, respectively. One milligram per liter of chlorine decreases alkalinity (as $CaCO^3$) 0.7 to 1.4 mg/l and 1 mg/l alum decreases natural alkalinity 0.5 mg/l.

Sodium silicate in solution is not corrosive to metals and can easily be added to a water supply with any type of chemical feeder to form calcium silicate, provided the water contains calcium. Doses vary between 25 and 240 lb/million gal, 70 lb being about average. The recommendations of the manufacturer should be followed in determining the treatment to be used for a particular water.

Adjustment of the pH and alkalinity of a water so that a thin coating is maintained on the inside of piping will prevent its corrosion. Any carbon dioxide in the water must be removed before this can be done, as previously explained. Lime* is added to water to increase the alkalinity and pH so as to come within the limits shown in Figure 3-22. The approximate dosage may be determined by the "marble test," but the Langelier saturation index, Ryznar index, and Enslow stability indicator discussed below are more accurate methods. Under these conditions, calcium carbonate is precipitated from the water and deposited on the pipe to form a protective coating, provided a velocity of 1.5 to 3.0 fps is maintained to prevent heavy precipitation near the point of treatment and none at the ends of the distribution system. The addition of 0.5 to 1.5 mg/l metaphosphate will help obtain a more uniform calcite coating throughout the distribution system. The addition of lime must be carefully controlled so as not to exceed a pH of 8.0 to 8.5 to maintain chlorination disinfection effectiveness. Calcium carbonate is less soluble in hot water than in cold water. It should be remembered that the disinfecting capacity of chlo-

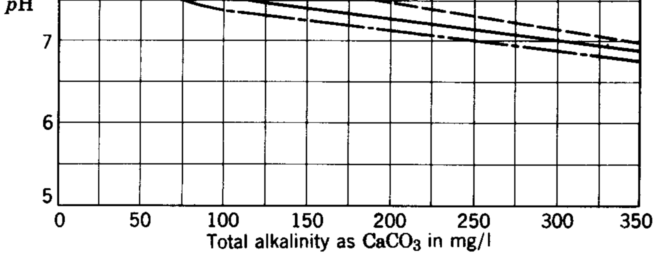


Figure 3-22 Solubility of $CaCO_3$ at 71°F (Baylis curve). (*Source:* C. R. Cox, *Water Supply Control,* Bulletin No. 22, New York State Department of Health, Albany, NY, 1952, p. 185.)

*At a pH above 8.3, calcium carbonate is soluble to 13–15 mg/l.

rine (HOCl) decreases as the pH increases; hence, the free available chlorine concentration maintained in the water should be increased with the higher pH. See Table 3-17. Also note that soft corrosive water with a high pH will increase corrosion of copper and zinc; old, yellow brass plumbing can be dezincified and galvanizing can be removed from iron pipe.[245]

The Langelier saturation index (the difference between the measured pH and the calculated pH) can be used to determine the point of calcium carbonate stability for corrosion control with waters having an alkalinity greater than 35 to 50 mg/l. A positive Langelier index is indicative primarily of calcium carbonate (scale) deposition; a negative index number is indicative of increasing water corrosivity with −2.0 considered high. Slightly positive is the goal. The point of calcium carbonate stability is also indicated by the Ryznar index. A Ryznar index number of less than about 6.0 is indicative primarily of the start of calcium carbonate (scale) deposition; an index number greater than 6.0 to 7.0 is indicative of increasing water corrosivity. Other measures are the Enslow stability indicator and the aggressiveness index. The Caldwell–Lawrence diagram[246] is useful for solving water-conditioning problems, but raw water concentration of calcium, magnesium, total alkalinity, pH, and TDS values must be known. See *Standard Methods*[29] for procedures. Do not rely on only one method.

The AWWA recognizes the coupon test to measure the effects of physical factors and substances in water on small sections of stainless steel and galvanized iron inserted in a water line for 90 days. Measurement of the weight loss due to corrosion or weight gained due to scale formation can thus be determined under the actual use conditions. The gain on stainless steel should not exceed 0.05 mg/cm^2; the loss from the galvanized iron should not exceed 5.0 mg/cm^2. Temperature, pH, velocity, dissolved oxygen, and water quality affect corrosion rates. Coupons should preferably remain in the pipe for 1 year or longer. The test does not show the inside condition of the pipe.[247]

The danger of lead or zinc poisoning and off-flavors due to copper plumbing can be greatly reduced when corrosive water is conducted through these pipes by simply running the water to waste in the morning. This will flush out most of the metal that has had an opportunity to go into solution while standing during the night. Maintenance of a proper balance between pH, calcium carbonate level, and alkalinity as calcium carbonate is necessary to reduce and control lead corrosion by soft aggressive water. Formation and then *maintenance* of a carbonate film are necessary. See Figure 3-22. In a soft, corrosive water, sodium hydroxide can be used for pH adjustment and sodium bicarbonate for carbonate addition. Lead pipe should not be used to conduct drinking water. Low lead solders and use of plastic pipe and glass-lined water heaters will minimize the problems associated with corrosion in the home. See Lead, this chapter.

Biochemical actions such as the decomposition of organic matter in the absence of oxygen in the dead end of mains, the reduction of sulfates, the biochemical action within tubercles, and the growth of crenothrix and leptothrix, all of which encourage corrosion in mains, can be controlled by the maintenance of at least 0.3 mg/l free residual chlorine in the distribution system.

External Pipe Corrosion External corrosion of underground pipe may be caused by stray direct electric currents; buried defective electric, telephone, and TV cables and grounding connections to water mains; grounding of household systems, appliances, and equipment; direct current welding equipment; acidic soils; abrasions and breaks in external coating; anaerobic bacteria; and dissimilar metals in contact. Stray currents from electric trolleys and subways also contribute to the problem. Soil around pipe serves as the electrolyte and the pipe serves as the conductor.

Corrosion caused by electrolysis or stray direct electric currents can be prevented by making a survey of the piping and removing grounded electrical connections and defective electric cables. Moist soils will permit electric currents to travel long distances. A section of nonconducting pipe in dry soil may confine the current. In the vicinity of power plants, this problem is very serious and requires the assistance of the power company involved.

Where dissimilar metals are to be joined, a plastic, hard rubber, or porcelain fitting can be used to separate them. It must be long enough to prevent the electric charge from jumping the gap. A polyethylene tube or encasement around cast-iron and ductile iron pipe and mastic, coal-tar enamel, epoxy, or similar coating protected with a wrapping will protect pipe from corrosive soil.

Corrosion of water storage tanks and metal pipelines can be controlled by providing "cathodic protection," in which a direct current is imposed to make the metal (cathode) more electronegative than an installed anode. But repainting of the metal above the water line in a water storage tank with an approved coating is necessary. Consult with the provider of cathodic protection equipment. A number of galvanic anodes, which are higher in the galvanic electromotive series,* such as magnesium or zinc, may be used adjacent to pipelines. The higher metal in the electromotive series will be the anode and will corrode; the lower metal (the pipe) is the cathode. The current flows from the anode to the cathode. The moist soil serves as the electrolyte. Eventually, the anode will have to be replaced.

Well Clogging and Cleaning A common problem with wells in anaerobic zones is the reduction in production capacity, usually due to clogging of the formation or incrustation of the well screen openings. This may be due to mineral scale precipitation formed around the screen and on the screen; to

*Galvanic series from most active to least active: sodium, magnesium, zinc, aluminum, steel, iron, lead, tin, brass, copper, nickel, silver, gold, platinum.

bacteria that oxidize iron such as crenothrix, leptothrix, and gallionella; and plugging when silt, fine sand, and clay build up in the formation or gravel pack around the well screen. Anaerobic waters may contain sulfides or iron and possibly manganese. If sulfates predominate, the water will contain sulfides. Iron bacteria are found where dissolved oxygen and dissolved iron are present. The source may also be surface water contamination.

As much information as possible should be obtained concerning the well-water characteristics to suggest a possible cause of reduced well capacity before any unclogging work is done. Chemical analysis of a representative water sample and a marble test or calculation of the Langelier saturation index or Ryznar index can show if calcium carbonate could precipitate out on the well screen or if iron or manganese and incrustations are present. Comparison with analyses made when the well was new may provide useful information. High bacterial plate counts may indicate organic growths in or on the well screen. Microscopic examination can show if iron bacteria or other objectionable growths are present.[248]

Treatment methods include the use of acids to dissolve mineral scale and bacterial iron precipitate, but care is necessary to minimize corrosion of the well, screen, and pump. Chlorination (sodium hypochlorite) to disinfect a well will also remove and retard growth of the iron bacteria. A 1-mg/l copper sulfate solution or a quaternary ammonium compound might also be effective. Sodium polyphosphates have been found effective in unplugging wells caused by clay and silt particles.[249] Repeat treatment is usually needed, including well surging to purge the well screen and adjacent aquifer.

Water Softening

Water softening is the removal of minerals causing hardness from water. For comparative purposes, one grain per gallon of hardness is equal to 17.1 mg/l. Water hardness is caused primarily by the presence of calcium bicarbonate, magnesium bicarbonate (carbonate hardness), calcium sulfate (gypsum), magnesium sulfate (epsom salts), calcium chloride, and magnesium chloride (noncarbonate hardness) in solution. In the concentrations usually present these constituents are not harmful in drinking water. The presence of hardness is demonstrated by the use of large quantities of soap in order to make a lather*; the presence of a gritty or hard curd in laundry or in a basin; the formation of hard chalk deposits on the bottom of pots and inside of piping causing a reduced water flow; and the lowered efficiency of heat transfer in boilers

*With a water hardness of 45 mg/l the annual per-capita soap consumption was estimated at 29.23 lb; with 70 mg/l hardness, soap consumption was 32.13 lb; with 298 mg/l hardness, soap consumption was 39.89 lb; and with 555 mg/l, soap consumption was 45.78 lb. (M. L. Riehl, *Hoover's Water Supply and Treatment,* National Lime Association, Washington, DC, April 1957.)

caused by the formation of an insulating scale. Hard water is not suitable for use in boilers, laundries, textile plants, and certain other industrial operations where a zero hardness of water is needed.

In softening water the lime or lime–soda ash process, zeolite process, and organic resin process are normally used. In the lime–soda ash method, the soluble bicarbonates and sulfates are removed by conversion to relatively insoluble forms. In the zeolite process, the calcium and magnesium are replaced with sodium, forming sodium compounds in the water that do not cause hardness but add to the sodium content. With synthetic organic resins, dissolved salts can be almost completely removed. Table 3-22 gives ion exchange values. Caustic soda can also remove both carbonate and noncarbonate hardness, but it is more costly.

Lime–soda ash softening requires the use of lime to convert the soluble bicarbonates of calcium and magnesium (carbonate hardness) to insoluble calcium carbonate and magnesium hydroxide, which are precipitated. Prior aeration of excess lime is needed to remove carbon dioxide if it is present in the raw water. The soluble calcium and magnesium sulfate and chlorides (noncarbonate hardness) are converted to insoluble calcium carbonate and magnesium carbonate by the addition of soda ash and lime and precipitated. Lime softening will also remove 90 to 99 percent of the bacteria and viruses but does not remove the need for disinfection. The sodium chloride and sodium sulfate formed remain in the water. Excess lime is needed to achieve a pH of about 9.5 to precipitate calcium carbonate, and a pH of about 11 is needed to precipitate magnesium hydroxide when it is greater than about 40 mg/l. Then pH adjustment is needed to control calcium carbonate precipitation on filters and in the distribution system. Carbon dioxide gas is usually added (recarbonation) to change the calcium hydroxide to calcium carbonate to improve precipitation and to adjust the pH to 8.6 or less in the finished water. Carbon dioxide is usually produced by the burning of gas, oil, coke, or coal. A coagulant such as aluminum sulfate (filter alum), ferrous sulfate (copperas), ferric sulfate, or sodium aluminate is usually used to coagulate and settle the compounds formed, followed by filtration to remove turbidity and color. Large volumes of sludge with high water content are produced. Disposal may present a problem. Options include reclamation and land disposal. The lime–soda ash method is not suitable for softening small quantities of water because special equipment and technical control are necessary. The process is more economical for softening moderately hard water. As water hardness increases, the lime requirement increases, which makes the zeolite process more attractive. The lime–soda ash process is usually controlled to reduce hardness to about 50 to 80 mg/l.

The zeolite and synthetic resin softening methods are relatively simple ion exchange processes that require little control. Only a portion of the hard water need be passed through a zeolite softener since a water of zero hardness is produced by the zeolite filter. The softener effluent can be mixed with part of the untreated water to produce a water of about 50 to 80 mg/l hardness.

TABLE 3-22 Ion Exchange Materials and Their Characteristics

Exchange Material	Exchange Capacity (grains/ft^3)	Effluent Content	Regeneration Material	Remarks
Natural zeolites	3000–5,000	Sodium bicarbonate, chloride, sulfate	0.37–0.45 lb salt per 1000 grains hardness removed	Ferrous bicarbonate and manganous bicarbonate also removed from well water devoid of oxygen, pH of water must be 6.0–8.5, moderate turbidity acceptable. Use 5–10% brine solution. Saturated brine is about 25%.
Artificial zeolites	9000–12,000	Sodium bicarbonate, chloride,	0.37–0.45 lb salt per 1000 grains hardness removed	
Carbonaceous zeolites	9000–12,000	Carbon dioxide and acids, sodium chloride and sulfate	0.37–0.45 lb salt per 1000 grains hardness removed	Acid waters may be filtered. CO_2 in effluent removed by aeration, acid by neutralization with bypassed hard water or addition of caustic soda.
Synthetic organic resins	10,000–30,000	Carbon dioxide and acids	0.2–0.3 lb salt per 1000 grains hardness removed	Dissolved salts are removed by resins. To remove CO_2 and acids, add soda ash or caustic soda, or CO_2 by aeration, and acids by synthetic resin filtration.

Note: One gallon of saturated brine weighs 10 lb and contains $2\frac{1}{2}$ lb of salt. Hardness is caused by calcium bicarbonate, magnesium bicarbonate, calcium sulfate, magnesium sulfate, and calcium chloride. Natural zeolite is more resistant to waters of low pH than artificial zeolite. Natural zeolite is also known as greensand.

The calcium and magnesium in water to be treated replace the sodium in the zeolite filter media, and the sodium passes through with the treated water. This continues until the sodium is used up, after which the zeolite is regenerated by bringing a 5 to 10 percent solution of common salt in contact with the filter media. Units are available to treat the water supply of a private home or a community. Water having a turbidity of more than 5 units will coat the zeolite grains and reduce the efficiency of a zeolite softener. Iron in the ferric form and organic substances are also detrimental. Iron or manganese or iron plus manganese should not exceed 0.3 mg/l. Pretreatment to remove turbidity, organic matter, and iron would be indicated. The filters are not less than 3 ft deep. Downward-flow filters generally operate at rates between 3 and 5 gpm/ ft^2; upward-flow filters operate at 4 to 6 gpm/ft^2. The maximum rate should not exceed 7 gpm/ft^2.

Synthetic resins for the removal of salts by ion exchange are discussed under Desalination in this chapter. Consideration must be given to the disposal of the brine waste from the ion exchange process.

Small quantities of water can be softened in batches for laundry purposes by the addition of borax, washing soda, ammonia, or trisodium phosphate. Frequently, insufficient contact time is allowed for the chemical reaction to be completed, with resultant unsatisfactory softening.

Lime softening removes arsenic, barium, cadmium, chromium, fluoride, lead, mercury, selenium, radioactive contaminants, copper, iron, manganese, and zinc.

The extent to which drinking water is softened should be evaluated in the light of the relationship of soft water to cardiovascular diseases. In view of the accumulating evidence, the wisdom of constructing municipal softening plants is being questioned. There is evidence associating the ingestion of sodium with cardiovascular diseases, kidney disease, and cirrhosis of the liver. See Hardness and Sodium, in this chapter and Cardiovascular Diseases in Chapter 1.

Fluoridation

Since about 1943 fluorides have been added to public water supplies in controlled amounts to aid in the reduction of tooth decay. The compounds commonly used are sodium fluoride (NaF), sodium silicofluoride (Na_2SiF_6), and hydrofluosilicic acid (H_2SiF_6), also called fluosilicic acid. They are preferred because of cost, safety, and ease of handling. Ammonium silicofluoride may be used in conjunction with chlorine where it is desired to maintain a chloramine residual in the distribution system, if permitted by the regulatory agency. Calcium fluoride (fluospar) does not dissolve readily. Hydrofluoric acid is hazardous; unsealed storage containers should be vented to the atmosphere. Backflow devices are required on all fluoride and water feed lines.

Solution and gravimetric or volumetric dry feeders are used to add the fluoride, usually after filtration treatment and before entry into the distribution system. Fluoride solutions for small water systems are usually added by means of a small positive-feed displacement pump. Corrosion-resistant piping must be used. Calcium hypochlorite and fluoride should not be added together as a calcium fluoride precipitate would be formed. Fluoride compounds should not be added before lime–soda ash or ion exchange softening. Personnel handling fluorides are required to wear protective clothing. Proper dust control measures, including exhaust fans, must be included in the design where dry feeders are used. Dosage must be carefully controlled.

The average annual per-capita cost of fluoridation of a public water supply is small. Softened water should be used to prepare a sodium fluoride solution whenever the hardness, as calcium carbonate, of the water used to prepare the solution is greater than 75 mg/l, or even less. This is necessary to prevent calcium and magnesium precipitation, which clogs the feeder. Small quantities of water can be softened by ion exchange or polyphosphates may be used.[250] See Fluorides in this chapter and Dental Caries in Chapter 1.

Removal of Inorganic Chemicals

The sources, health effects, permissible concentrations, and control measures related to certain inorganic chemicals are also discussed under the appropriate headings in Figure 1-2 and earlier in this chapter under Chemical Examinations. Fundamental to the control of toxic inorganic chemicals in drinking water is a sanitary survey and identification of the sources, types, and amounts of pollutants followed by their phased elimination as indicated, *starting at the source*. Watershed and land-use controls are usually the best preventive measures in both the short term and long term, coupled with point and nonpoint source control.

Table 3-23 summarizes treatment methods for the removal of inorganic chemicals from drinking water. Several are discussed in some detail below.

Arsenic Removal Inorganic arsenic in water occurs naturally in two oxidation states, arsenite [As(III)] and arsenate [As(V)]. Arsenate is a negatively charged molecule and is relatively easy to remove since it strongly adsorbs onto the surface of metal hydroxide particles. Arsenite, however, is more difficult to remove due to its neutral charge. If the water being treated contains only arsenite (or enough that achieving the MCL is questionable) the treatment should begin with an oxidation step to convert all inorganic arsenic to arsenate. Oxidation is effectively achieved using simple chlorination, ozonation, or use of potassium permanganate.

For surface water systems with a conventional process using either ferric or alum coagulation, arsenic is easily removed during the coagulation–semination process. Groundwater systems (with or without disinfection) will likely choose one of the following treatment processes, which will all achieve greater than 95% removal:

TABLE 3-23 Most Effective Treatment Methods for Inorganic Contaminant Removal

Contaminant	Most Effective Methods	Contaminant	Most Effective Methods
Arsenic As^{3+}	Ferric sulfate coagulation, pH 6–8	Fluoride	Ion exchange with activated alumina or bone char media
	Alum coagulation, pH 6–7	Lead	Ferric sulfate coagulation, pH 6–9
	Excess lime softening		Alum coagulation, pH 6–9
	Oxidation before treatment required		Lime softening
			Excess lime softening
As^{5+}	Ferric sulfate coagulation, pH 6–8	Mercury	
	Alum coagulation, pH 6–7	Inorganic	Ferric sulfate coagulation, pH 7–8
	Excess lime softening		
Barium	Lime softening, pH 10–11	Organic	Granular activated carbon
	Ion exchange	Nitrate	Ion exchange
		Selenium	
Cd^{3+}	Ferric sulfate coagulation, above pH 8	Se^{4+}	Ferric sulfate coagulation, pH 6–7
	Lime softening		Ion exchange
	Excess lime softening		Reverse osmosis
Chromium		Se^{6+}	Ion exchange
Cr^{3+}	Ferric sulfate coagulation, pH 6–9		Reverse osmosis
	Alum coagulation, pH 7–9	Silver	Ferric sulfate coagulation, pH 7–9
	Excess lime softening		Alum coagulation, pH 6–8
	Ferrous sulfate coagulation, pH 7–9.5		Lime softening
Cr^{6+}			Excess lime softening

Source: T. J. Sorg, "Treatment Techniques for the Removal of Inorganic Contaminants from Drinking Water," *Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations,* U.S. Environmental Protection Agency, Cincinnati, OH, May 1977, p. 3.

- Sorption process (ion exchange or adsorption onto an iron, aluminum, or copper media)
- Precipitation process (coagulation followed by filtration)
- Membrane process (nanofiltration or reverse osmosis)

The final choice of treatment technology will depend on several factors, including the availability of sewers to handle waste brine; the presence of competing ions such as nitrate and sulfate; the number of bed-volumes of an adsorbent media (i.e., useful life); and the presence of other constituents such as hardness or TDS. Following an assessment of the most appropriate technology, pilit studies should be conducted to confirm the treatment efficacy prior to full-scale implementation.[251]

Cadmium Removal Cadmium removal of greater than 90 percent can be achieved by iron coagulation at about pH 8 and above. Greater percentage removal is obtained in higher turbidity water. Lime and excess lime softening remove nearly 100 percent cadmium at pH 8.7 to 11.3. Ion exchange treatment with cation exchange resin should remove cadmium from drinking water. Powdered activated carbon is not efficient and granular activated carbon will remove 30 to 50 percent. Reverse osmosis may not be practical for cadmium removal.[252]

Lead Removal Normal water coagulation and lime softening remove lead—99 percent for coagulation at pH 6.5 to 8.5 and for lime softening at pH 9.5 to 11.3. Turbidity in surface water makes particulate lead removal easier by coagulation, flocculation, settling, and filtration. Powdered activated carbon removes some lead; GAC effectiveness is unknown; and reverse osmosis, electrodialysis, and ion exchange should be effective.[252] Lead in the soluble form may be removed by reverse osmosis or distillation.

Nitrate Removal Treatment methods for the removal of nitrates from drinking water include chemical reduction, biological denitrification, anion exchange, reverse osmosis, distillation, and electrodialysis. Ion exchange is the most practical method. At one community water system,* the water has approximately 200 mg/l total dissolved solids; the nitrate–nitrogen levels are reduced from 20 to 30 mg/l to less than 2 mg/l.[253,254] Little plant-scale data are otherwise available. Reverse osmosis and electrodialysis are effective (40 to 95 percent), but these methods are more costly than ion exchange.

*Garden City Park Water District, Garden City, NY. Nitrates have also been reduced in Bridgewater, MA, since 1979 and in McFarland, CA, since 1983. ("Letters," *AWWA MainStream,* January 1986, p. 2.)

Fluoride Removal Treatment methods for the removal of fluorides from drinking water have been summarized by Sorg.[254] They include high (250–300 mg/l) alum doses, activated carbon at pH 3.0 or less; lime softening if sufficient amounts of magnesium (79 mg/l to reduce fluoride from 4 to 1.5 mg/l) are present or added for coprecipitation with magnesium hydroxide; ion exchange using activated alumina, bone char, or granular tricalcium phosphate; and reverse osmosis. Of these methods, alum coagulation and lime softening are not considered practical. Reverse osmosis has not been demonstrated on a full-scale basis for this purpose, but ion exchange has. Activated alumina and bone char have been successfully used, but the former is the method of choice for the removal of fluoride from drinking water.[255]

Selenium Removal Selenium is predominantly found in water as selenite and selenate. Selenite can be removed (40–80 percent) by coagulation with ferric sulfate, depending on the pH, coagulant dosage, and selenium concentration. Alum coagulation and lime softening are only partially effective, 15 to 20 percent and 35 to 45 percent, respectively. Selenite and selenate are best removed by ion exchange, reverse osmosis, and electrodialysis, but the effectiveness of these methods in removing selenium has not been demonstrated in practice.[251]

Radionuclide Removal Coagulation and sedimentation are very effective in removing radioactivity associated with turbidity and are fairly effective in removing dissolved radioactive materials—with certain exceptions. The type of radioactivity, the pH of the treatment process, and the age of the fission products in the water being treated must be considered. For these reasons, jar-test studies are advised before plant-scale operation is initiated. A comprehensive summary of the effectiveness of different chemical treatment methods with various radionuclides is given by Straub.[256] The effectiveness of rapid and slow sand filtration, lime–soda ash softening, ion exchange, and other treatment processes is also discussed.

Studies for military purposes show that radioactive materials present in water as undissolved turbidity can be removed by coagulation, hypochlorination, and diatomite filtration. Soluble radioisotopes are then removed by ion exchange using a cation exchange column followed by an anion exchange column operated in series. Hydrochloric acid is used for regenerating the cation resin and sodium carbonate the anion resin. The standard Army vapor compression distillation unit is also effective in removing radioactive material from water.[257] Groundwater sources of water can generally be assumed to be free of fallout radioactive substances and should, if possible, be used in preference to a surface-water source[257] in emergency situations. However, radionuclides can travel great distances in groundwater.

Kosarek[258] reviewed the water treatment processes used to reduce dissolved radium contamination to an acceptable level (5 pCi/l or less) in water for industrial and municipal purposes. Processes for industrial water uses are selective membrane mineral extraction, reverse osmosis, barium sulfate co-precipitation, ion exchange, activated alumina, lime–soda ash softening, and sand filtration. Processes for municipal water uses are reverse osmosis, ion exchange, lime–soda ash softening, aeration, greensand filtration, and sand filtration. Aeration, greensand filtration, and sand filtration have low radium removal efficiency. Lime–soda ash has a 50 to 85 percent efficiency; the other remaining processes have an efficiency of 90 to 95 percent or better. A manganese dioxide coated fiber filter can effectively remove radium from drinking water by adsorption.[259]

Packed tower aerators can remove more than 95 percent of the radon and conventional cascading tray aerators better than 75 percent.[260] Radon is effectively removed from well water by GAC adsorption. However, as in other processes, the spent carbon and other solid and liquid wastes collected present a disposal problem because of the radioactive materials retained in the waste. Possible waste disposal options for treatment plant solid and liquid wastes containing radium, if approved by the regulatory authority, include sanitary sewers, storm sewers, landfills, and land spreading. Conditions for disposal must be carefully controlled.[261]

Uranium can be removed from well water to a level as low as 1 μg/l using conventional anion exchange resins in the chloride form. Gamma radiation buildup in the system does not appear to be significant.[262] Treatment methods to remove uranium from surface waters and groundwaters include iron coagulation (80–85 percent), alum coagulation (90–95 percent), lime softening (99 percent), cation exchange (70–95 percent), anion exchange (99 percent), activated alumina (99 percent), granular activated carbon (90+ percent), and reverse osmosis (99 percent).[263]

The EPA is considering the setting of MCLs for certain radionuclides in water and a proposal of best available treatment (BAT) technologies to achieve the MCLs and MCLGs. Radon MCLs may fall between 300 and 4000 pCi/l in water, equivalent to about 0.03 to 0.4 pCi/l in air. The BATs given are aeration and GAC. Radium-226 and Ra-228 MCLs may fall between 2 and 20 pCi/l each. The BATs given are cation exchange, lime softening, and reverse osmosis. Uranium MCLs may fall between 5 and 40 pCi/l. The BATs given are coagulation/filtration, reverse osmosis, anion exchange, and lime softening. Beta particle and photon emitter MCL concentrations may be equal to the risk posed by a 4-mrem effective dose equivalent. The BATs given for betas are reverse osmosis and ion exchange (mixed bed).[263a]

Prevention and Removal of Organic Chemicals

As noted for inorganic chemicals, the control of organic chemicals in drinking water should start with a sanitary survey to identify the sources, types, and amounts of pollutants, followed by their phased elimination as indicated by the associated hazard. Included would be watershed use regulation and protection, watershed management to minimize turbidity and organic and inorganic runoff, vigorous compliance with the national and state water and air pollution elimination objectives, enforcement of established water and air classification standards, and complete effective drinking water treatment under competent supervision. It is obvious that selection of the cleanest available protected source of water supply, for the present and the future, would greatly minimize the problems associated not only with organic chemicals but also with inorganic, physical, and microbiological pollution. In any case, water treatment plants must be upgraded where needed to consistently produce a water meeting the national drinking water standards.

Trihalomethanes, Removal and Control The halogenated, chloro-organic compounds* include the trihalomethanes: trichloromethane (chloroform), bromodichloromethane, dibromochloromethane, and tribromomethane (bromoform). These chlorination byproducts are formed by the reaction of *free* chlorine with certain organic compounds in water. The major cause of trihalomethane (THM) formation in chlorinated drinking water is believed to be humic and fulvic substances (natural organic matter in soil, peat, other decay products of plants and animals, and runoff) and simple low-molecular-weight compounds not removed by conventional filtration treatment—all referred to as precursors. Treatment to remove turbidity should remove high-molecular-weight compounds. Low-molecular-weight compounds are best reduced by GAC treatment. Chlorination of municipal wastewater also results in the formation of halo-organics, but their concentration is very low when combined chlorine is formed,[264] which is usually the case. However, chloramination produces other yet undefined chloro-organic compounds. The reaction is dependent on chlorine dose, pH, temperature, and contact time. The point of chlorination, to avoid precursors, is critical in drinking water treatment to minimize or prevent the formation of THMs. Total trihalomethane concentration in treated water has been found to be higher in the summer, after reservoir turnover, and lowest in the winter. It is also related to the presence of phytoplankton and correlates well with chlorine demand of untreated water, but not with organic carbon and chloroform extract.[265] The potential for THM formation in groundwater was found to be strongly correlated with total organic carbon (TOC) concentration, ammonia, iron, and manganese, but very few sources were found to exceed 100 μg/l.[265a]

Prechlorination with long contact periods and sunlight increases the formation of THMs, as does increased chlorine dosage and the addition of chlorine prior to coagulation and settling. Preozonation is effective in oxidizing in part naturally present organic compounds, thereby reducing the potential for THM production after subsequent postchlorination. Alternative disinfectants are chloramines and chlorine dioxide as well as potassium permanganate

*Halogenated organics are organic compounds that contain one or more halogens—fluorine, chlorine, bromide, iodine, and astatine.

and ultraviolet radiation if approved. Ozone and chloramine treatment is reported to produce only about 2 percent of the THMs produced by free chlorine.

Granular activated carbon has been found to be of limited effectiveness in removing precursor materials; GAC is effective for only a few weeks.[266] In contrast, GAC for taste and odor control needs regeneration every three to six years.[267] It is not efficient for the removal of THMs once formed. Treatment to remove suspended, colloidal, and dissolved materials by coagulation, flocculation, settling, and filtration should precede GAC treatment if used for taste and odor control. The same holds true for the removal of synthetic organic chemicals so as not to coat and reduce the adsorptive capacity of the carbon. Such treatment will also remove most THM precursors, as previously noted.

Recommended Standards for Water Works summarizes recommended practice in the ''Policy Statement on Trihalomethane Removal and Control for Public Water Supplies'' (ref. 151, pp. xix–xx).

> Trihalomethanes (THMs) are formed when free chlorine reacts with organic substances, most of which occur naturally. These organic substances (called ''precursors''), are a complex and variable mixture of compounds. Formation of THMs is dependent on such factors as amount and type of chlorine used, temperature, concentration of precursors, pH, and contact time. Approaches for controlling THMs include:
>
> 1. Control of precursors at the source.
>   a. Selective withdrawal from reservoirs—varying depths may contain lower concentrations of precursors at different times of the year.
>   b. Plankton Control—Algae and their oils, humic acid, and decay products have been shown to act as THM precursors.
>   c. Alternative sources of water may be considered, where available.
> 2. Removal of THM precursors and control of THM formation.
>   a. Moving the point of chlorination to minimize THM formation.
>   b. Removal of precursors prior to chlorination by optimizing:
>   (1) Coagulation/flocculation including sedimentation and filtration
>   (2) Precipitative softening/filtration
>   (3) Direct filtration
>   c. Adding oxidizing agents such as potassium permanganate, ozone or chlorine dioxide to reduce or control THM formation potential.
>   d. Adsorption by powdered activated carbon (PAC).
>   e. Lowering the pH to inhibit the reaction rate of chlorine with precursor materials. Corrosion control may be necessary.
> 3. Removal of THM.
>   a. Aeration—by air stripping towers.
>   b. Adsorption by:
>   (1) Granular Activated Carbon (GAC)
>   (2) Synthetic Resins

4. Use of Alternative Disinfectants—Disinfectants that react less with THM precursors may be used as bacteriological quality of the finished water is maintained. Alternative disinfectants may be less effective than free chlorine, particularly with viruses and parasites. Alternative disinfectants, when used, must be capable of providing an adequate distribution system residual. Use of alternative disinfectants may also produce possible health effects and must be taken into consideration. The following alternative disinfectants may be used:
   a. Chlorine Dioxide
   b. Chloramines
   c. Ozone

Using various combinations of THM controls and removal techniques may be more effective than a single control or a treatment method.

Any modifications to existing treatment process must be approved by the reviewing authority. Pilot plant studies are desirable.

The maximum contaminant level for total THMs in drinking water in the United States is 100 μg/l. The goal is 10 to 25 μg/l. The Canadian maximum acceptable level is 350 μg/l.[268]The WHO has set a guideline for chloroform only at 30 μg/l; several countries have set limits of 25 to 250 μg/l for the sum of four specific THMs (ref. 27, Vol. 1, p. 77).

Synthetic Organic Chemicals and Their Removal The major sources of synthetic organic chemical pollution (also inorganic pollution in many places) are industrial wastewater discharges; air pollutants; municipal wastewater discharges; runoff from cultivated fields, spills, and waste storage sites; and leachate from sanitary landfills, industrial and commercial dump sites, ponds, pits, and lagoons. Illegal dumping and coal-tar-based pipe coating and linings may also contribute organics. Both surface waters and groundwaters may be affected. It cannot be emphasized enough that *control of all pollutants must start at the source,* including raw-material selection, chemical formulation, and manufacturing process control. Separation of floating oils and collection of low-solubility, high-density compounds in traps on building drains and improved plant housekeeping could reduce pollutant discharges and recover valuable products. Such actions would reduce the extent of needed plant upgrading, sophisticated wastewater treatment and control, burden on downstream aquatic life and water treatment plants, and hence risks to the consumer associated with the ingestion of often unknown hazardous or toxic chemicals.

Waters containing a mixture of organic chemicals and soluble metals are difficult to treat and require special study.

The more common water treatment methods considered to reduce the concentration of volatile organic chemicals (VOCs) and other synthetic organic chemicals (SOCs) in drinking water sources are aeration and adsorption through GAC. Other possible methods include ozonation, oxidation, osmosis, ion exchange, and ultrafiltration.[269] However, before a treatment method is selected and because of the many variables involved, characterization of the organic contaminants involved and bench-scale and pilot plant studies of aeration and GAC are generally required to be carried out with the actual water to be treated to determine the effectiveness of a process and the basis for design. This is also necessary to determine the GAC adsorption capacity before exhaustion and its reactivation cost. Organics have different adsorptive characteristics on GAC. It should also be noted that bench-scale tests using strongly basic anion exchange resins showed that most organics present in surface water can be removed.[270] Conventional coagulation, flocculation, sedimentation, and sand filtration treatment does not remove VOCs to any significant extent.

Aeration (air stripping) will remove many VOCs. Methods include diffused air in which air is forced up through the falling water spray, packed tower with forced or induced draft, waterfall, mechanical surface aerators, cascade aeration, tray aeration, and air-lift pump. The extent to which aeration is successful will depend on the concentration, temperature, solubility, and volatility of the compounds in the water. The rate of removal depends on the amount of air used, contact time, and temperature of the air and water. Removals of 95 to 99 percent have been reported. Very low efficiencies are obtained at freezing temperatures. Aeration is usually more effective for removing the lighter, more volatile SOCs such as found in groundwater. The GAC is more effective for removal of heavier SOCs found in surface water. Compounds reported to be removed by aeration include trichloroethylene, carbon tetrachloride, tetrachloroethylene, benzene, toluene, napthalene, biphenyl methyl bromide, bromoform, chloroform, dibromochloromethane, bromodichloromethane, methylene chloride, vinyl chloride, sodium fluoroacetate, dichloroethylene, dichloroethane, perchloroethylene, and others. The potential for air pollution and its control must be considered. Synthetic organic chemicals, referred to as refractory compounds, resist decomposition and removal. Corrosion control is usually required after aeration. Airborne contamination, including worm growth in the aerator, must be guarded against.

Granular activated carbon is considered the best available broad-spectrum adsorber of SOCs and appears to be indicated where nonvolatile organics are present. The carbon is similar in size to filter sand. Adsorption is a complex process. It is influenced by the surface area of the carbon grains, the material being adsorbed or concentrated (adsorbate), the pH and temperature of the water being treated, the mixture of compounds present, and the nature of the adsorbent—that is, the carbon grain structure, surface area, and pores. The smaller the grain size within the range of operational efficiency, the greater the rate of adsorption obtained.[271,272] Disposal of spent carbon may be a problem.

The EPA has designated packed-tower aeration and GAC filtration as the BAT for the removal of regulated VOCs. The exception is vinyl chloride, for which packed-tower aeration is the preferred technology. The GAC treatment is considered more costly than air stripping (ref. 233, pp. 157–171).

Treatment consisting of coagulation, filtration, and powdered activated carbon is reported[273,274] to remove 85 to 98 percent endrin, 90 to 98 percent 2,4-D, and 30 to 99 percent lindane at dosages of 5 to 79 mg/l. Reverse osmosis is also effective in removing organics, including pesticides, with proper design and membrane selection. Highly colored waters and iron can coat GAC and interfere with its adsorption of VOCs.

WATER SYSTEM DESIGN PRINCIPLES*

Water Quantity

The quantity of water upon which to base the design of a water system should be determined in the preliminary planning stages. Future water demand is based on social, economic, and land-use factors, all of which can be expected to change with time. (See Chapter 2.) Population projections are a basic consideration. They are made using arithmetic, geometric, and demographic methods and with graphical comparisons with the growth of other comparable cities or towns of greater population.[23,275] Adjustments should be made for hospital and other institution populations, industries, fire protection, military reservations, transients, and tourists as well as for leakage and unaccounted-for water, which may amount to 10 to 15 percent or more. Universal metering is necessary for an accounting.

Numerous studies have been made to determine the average per-capita water use for water system design. Health departments and other agencies have design guides, and standard texts give additional information. In any case, the characteristics of the community must be carefully studied and appropriate provisions made. See Water Quantity and Quality, this chapter, for average water uses.

Design Period

The design period (the period of use for which a structure is designed) is usually determined by the future difficulties to acquire land or replace a structure or pipeline, the cost of money, and the rate of growth of the community or facility served. In general, large dams and transmission mains are designed to function for 50 or more years; wells, filter plants, pumping stations, and distribution systems for 25 years; and water lines less than 12 in. in diameter

*Refer to *Recommended Standards for Water Works*, Great Lakes–Upper Mississippi River Board of State Public Health and Environmental Managers, Health Research Inc., Health Education Services Division, Albany, NY, 1987. See also state and design publications.

for the full future life. When interest rates are high or temporary or short-term use is anticipated, a lesser design period would be in order. Fair, et al.[23] suggest that the dividing line is in the vicinity of 3 percent per annum. Treatment of water, design, and operation control has been discussed earlier.

Watershed Runoff and Reservoir Design

Certain basic information, in addition to future water demand, is needed upon which to base the design of water works structures. Long-term precipitation, stream flow data, and groundwater information are available from the U.S. Geological Survey and state sources, but these seldom apply to small watersheds. Precipitation data for specific areas are also available from the National Oceanic and Atmospheric Administration, local weather stations, airports, and water works. Unit hydrographs, maximum flows, minimum flows, mass diagrams,* characteristics of the watershed, precipitation, evaporation losses, percolation, and transpiration losses should be considered for design purposes and storage determinations when these are applicable.

Watershed runoff can be estimated in different ways. The rational method for determining the maximum rate of runoff is given by the formula

$$Q = AIR$$

where Q = runoff, ft^3/sec
A = area of the watershed, acres
R = rate of rainfall on the watershed, in./hr
I = imperviousness ratio, that is, the ratio of water that runs off the watershed to the amount precipitated on it

The ratio I will vary from 0.01 to 0.20 for wooded areas; from 0.05 to 0.25 for farms, parks, lawns, and meadows depending on the surface slope and character of the subsoil; from 0.25 to 0.50 for residential semirural areas; from 0.05 to 0.70 for suburban areas; and from 0.70 to 0.95 for urban areas having paved streets, drives, and walks.[276] For maximum storms

$$R = 360/t + 30$$

for ordinary storms in eastern United States

$$R = 105/t + 15$$

*A plot of the summation of accumulated stream inflow in million gallons vs. the summation of the mean daily demand in years (25 or more if stream flow data are available) to determine the required (available) storage to meet the daily demand.

for San Francisco

$$R = 7/\sqrt{t}$$

for New Orleans

$$R = 56/(t + 5)^{0.85}$$

and for St. Louis

$$R = 19/\sqrt{t}$$

where t is time (duration) of rainfall in minutes.[277]

Another formula for estimating the average annual runoff by Vermuelé may be written as

$$F = R - (11 + 0.29R)\ (0.035)T - 0.65)$$

where F = annual runoff, in.
R = annual rainfall, in.
T = mean annual temperature, °F

This formula is reported to be particularly applicable to streams in northern New England and in rough mountainous districts along the Atlantic Coast.[278] For small water systems, it is suggested that design be based on the year of minimum rainfall or on about 60 percent of the average.

In any reservoir storage study, it is important to take into consideration the probable losses due to seepage, outflows, evaporation from water surfaces during the year, and loss in storage capacity due to sediment accumulation if the sediment cannot be released during high inflow. This becomes very significant in small systems when the water surfaces exceed 6 to 10 percent of the drainage area.[279] In the North Atlantic states, the annual evaporation from land surfaces averages about 40 percent, while that from water surfaces is about 60 percent of the annual rainfall.[280] A more general relationship of monthly transpiration and evaporation to mean monthly air temperature is given in Figures 4-26 and 4-27. The watershed water loss due to land evaporation and transpiration is significant and hence must be taken into consideration when determining precipitation minus losses.

The minimum stream flow in New England has been estimated to yield 0.2 to 0.4 cfs/mi^2 of tributary drainage and an annual yield of 750,000 gpd/mi^2 with storage of 200 to 250 $\times$ 10^6 gal/mi^2. New York City reservoirs located in upstate New York have a dependable yield of about 1 mgd/mi^2 of drainage area. For design purposes, long-term rainfall and stream flows should be used and a mass diagram constructed. See Figure 3-24 later.

Groundwater runoff at the 70 percent point (where flow is equaled or exceeded 70 percent of the time) for the United States land area averaged a yield of 0.23 mgd/mi^2. In the Great Lakes Basin, 25 to 75 percent of the annual flow of streams is derived from groundwater seepage.[281]

The feasibility of implementing watershed rules and regulations should have a high priority in the selection of a water supply source. The management of land use and the control of wastewater discharges, including stormwater drainage on a watershed from urban, suburban, and rural areas, are necessary. Erosion and the input of sediment and organic and inorganic materials such as oils, pesticides, heavy metals, road salt, and other synthetic chemicals must be adequately minimized. Of course, these factors will affect the water quality and reservoir eutrophication, treatment required, and overall quality of the water source. Development of a reservoir should, if possible, include removal of rich organic topsoil from the site to conserve the resource and delay the development of anaerobic conditions.

Intakes and Screens

Conditions to be taken into consideration in design of intakes include high- and low-water stages; navigation or allied hazards; floods and storms; floating ice and debris; water velocities, surface and subsurface currents, channel flows, and stratification; location of sanitary, industrial, and storm sewer outlets; and prevailing wind direction.

Small communities cannot afford elaborate intake structures. A submerged intake crib, or one with several branches and upright tee fittings anchored in rock cribs 4 to 10 ft above the bottom, is relatively inexpensive. The inlet fittings should have a coarse strainer or screen with about 1-in. mesh. The total area of the inlets should be at least twice the area of the intake pipe and provide an inlet velocity less than 0.5 fps. Low-entrance velocities reduce ice troubles and are less likely to draw in fish or debris. Sheet ice over the intake structure also helps avoid anchor ice or frazil ice. If ice clogging of intakes is anticipated, provision should be made for an emergency intake or injecting steam, hot water, or compressed air at the intake. Backflushing is another alternative that may be incorporated in the design. Fine screens at intakes will become clogged; hence, they should not be used unless installed at accessible locations that will make regular cleaning simple. Duplicate stationary screens in the flow channel with $\frac{1}{8}$- to $\frac{3}{8}$-in. corrosion-resistant mesh can be purchased.

Some engineers have used slotted well screens in place of a submerged crib intake for small supplies. The screen is attached to the end of the intake conduit and mounted on a foundation to keep it off the bottom, and, if desired, crushed rock or gravel can be dumped over the screen. For example, a 10-ft section of a 24-in.-diameter screen with $\frac{1}{4}$-in. openings is said to be able to handle 12 mgd at an influent velocity of less than 0.5 fps. Attachment to the foundation should be made in such a way that removal for inspection is possible.

In large installations, intakes with multiple-level inlet ports are provided in deep reservoirs, lakes, or streams to make possible depth selection of the best water when the water quality varies with the season of the year and weather conditions. Special bottom outlets should be provided in reservoirs to make possible the flushing out of sediment and accumulated organic matter during periods of high inflow.

For a river intake, the inlet is perpendicular to the flow. The intake structure is constructed with vertical slotted channels before and after the bar racks and traveling screens for the placement of stop planks if the structure needs to be dewatered. Bar racks, 1 × 6 in. vertical steel, spaced 2 to 6 in. apart, provided with a rake operated manually or mechanically, keep brush and large debris from entering. This may be followed by a continuous slow-moving screen traveling around two drums, one on the bottom of the intake and the other above the operating floor level. The screen is usually a heavy wire mesh with square openings $\frac{3}{8}$ to 1 in.; it is cleaned by means of water jets inside that spray water through the screen, washing off debris into a wastewater trough. In cold-weather areas, heating devices such as steam jets are needed to prevent icing and clogging of the racks and screens. Intake velocities should be maintained at less than 5 fps.

Pumping

When water must be pumped from the source or for transmission, electrically operated pumps (at least two) should have gasoline or diesel standby units having at least 50 percent of the required capacity. If standby units provide power for pumps supplying chlorinators and similar units, the full 100 percent capacity must be provided where gravity flow of water will continue during the power failure.

The distribution of water usually involves the construction of a pumping station, unless one is fortunate enough to have a satisfactory source of water at an elevation to provide a sufficient flow and water pressure at the point of use by gravity. The size pump selected is based on whether hydropneumatic storage (steel pressure tank for a small system), ground level, or elevated storage is to be used; the available storage provided; the yield of the water source; the water usage; and the demand. Actual meter readings should be used, if available, with consideration being given to future plans, periods of low or no usage, and maximum and peak water demands. Metering can reduce water use by 25 percent or more. Average water consumption figures must be carefully interpreted and considered with required fire flows. If the water system is to also provide fire protection, then elevated storage is practically essential, unless ground-level storage with adequate pumps is available.

The capacity of the pump required for a domestic water system with elevated storage is determined by the daily water consumption and volume of the storage tank. Of course, where the topography is suitable, the storage tank can be located on high ground, although the hydraulic gradient necessary to meet the highest water demand may actually govern. The pump should be of such capacity as to deliver the average daily water demand to the storage tank in 6 to 12 hr. In very small installations, the pump chosen may have a capacity to pump in 2 hr all the water used in one day. This may be desirable when the size of the centrifugal pump is increased to 60 gpm or more and the size of the electric motor to 5 to 10 hp or more, since the efficiencies of these units then approach a maximum. On the other hand, larger transmission lines, if not provided, would be required in most cases to accommodate the larger flow, which would involve increased cost. Due consideration must also be given to the increased electrical demand and the effects this has. A careful engineering analysis should be made.

Pumping stations should be at least 3 ft above the 100-year flood level or the highest known level, whichever is higher. They should be secured and weather protected.

Distribution Storage Requirements

Water storage requirements should take into consideration the peak daily water use, the maximum-day demand plus the required fire flow, the capacity of the normal and standby pumping equipment, the availability and capacity of auxiliary power, the probable duration of power failure, and the promptness with which repairs can be made. Additional considerations include land use, topography, pressure needs, distribution system capacity, special demands, and the increased cost of electric power and pumps to meet peak demands.

Water storage is necessary to help meet peak demands, fire requirements, and industrial needs; to maintain relatively uniform water pressures; to eliminate the necessity for continuous pumping; to make pumping possible when the electric rate is low; and to use the most economical pipe sizes. Surges in water pressure due to water hammer are also dissipated. Other things being equal, a large-diameter shallow tank is preferable to a deep tank of the same capacity. It is less expensive to construct, and water pressure fluctuations on the distribution system are less. The cost of storage compared to the decreased cost of pumping, the increased fire protection and possibly lowered fire insurance rate, the greater reliability of water supply, and the decreased probability of negative pressures in the distribution system will be additional factors in making a decision.

In general, it is recommended that water storage equal not less than one-half the total daily consumption, with at least one-half the storage in elevated tanks. A preferred minimum storage capacity would be a two-day average use plus fire flow or the maximum-day usage plus fire requirements less the daily capacity of the water plant and system for the fire flow period.

Another basis is

> to provide sufficient water storage capacity to supply the maximum daily rate for a 4-hr period without depleting storage by more than one-half. Additionally, the minimum amount of storage that usually should be reserved for fire protection and other emergencies is one-third of system storage (ref. 282, p. 7).

Hudson[283] suggests the provision of two tank outlets, one to withdraw the top third of tank water for general purposes and a second outlet at the bottom of the tank to withdraw the remaining two-thirds of tank water if needed to supply building sprinkling systems in developed areas with high-rise apartments, industries, shopping centers, office complexes, and the like. In small communities, real estate subdivisions, institutions, camps, and resorts, elevated storage should be equal to at least 1 full day's requirements during hot and dry months when lawn sprinkling is heavy. Two or three days storage is preferred. The amount of water required during peak hours of the day may equal 15 to 25 percent of the total maximum daily consumption. This amount in elevated storage will meet peak demands, but not fire requirements. Some engineers provide storage equal to 20 to 40 gal/capita, or 25 to 50 percent of the total average daily water consumption. A more precise method for computing requirements for elevated storage is to construct a mass diagram. Two examples are shown in Figures 3-23 and 3-24. Fire requirements should be taken into consideration.[284]

It is good practice to locate elevated tanks near the area of greatest demand for water and on the side of town opposite from where the main enters. Thus, peak demands are satisfied with the least pressure loss and smallest main sizes. All distribution reservoirs should be covered; provided with an overflow that will not undermine the footing, foundation, or adjacent structures; and provided with a drain, water-level gauge, access manhole with overlapping cover, ladder, and screened air vent.

Water storage tanks are constructed of concrete, steel, or wood. Tanks may be constructed above or partly below ground, except that under all circumstances the manhole covers, vents, and overflows must be well above the normal ground level and the bottom of the tank above groundwater or flood water. Good drainage should be provided around the tank. Tanks located partly below ground must be at a higher level than any sewers or sewage disposal systems and not closer than 50 ft. Vents and overflows should be screened and the tanks covered to keep out dust, rain, insects, small animals, and birds. A cover will also prevent the entrance of sunlight, which tends to warm the water and encourage the growth of algae. Manhole covers should be locked and overlap at least 2 in. over a 2- to 6-in. lip around the manhole. Partly below-ground storage is usually less costly and aesthetically more acceptable than elevated storage.*

Properly constructed reinforced concrete tanks ordinarily do not require waterproofing. If tanks are built of brick or stone masonry, they should be carefully constructed by experienced craftsmen and only hard, dense material laid with full Portland cement mortar joints used. Two $\frac{1}{2}$-in. coats of 1:3 Portland cement mortar on the inside, with the second coat carefully troweled,

*For small concrete reservoir construction details, see *Manual of Individual Water Supply Systems*, U.S. EPA, Washington, DC, 1973, pp. 127–128.

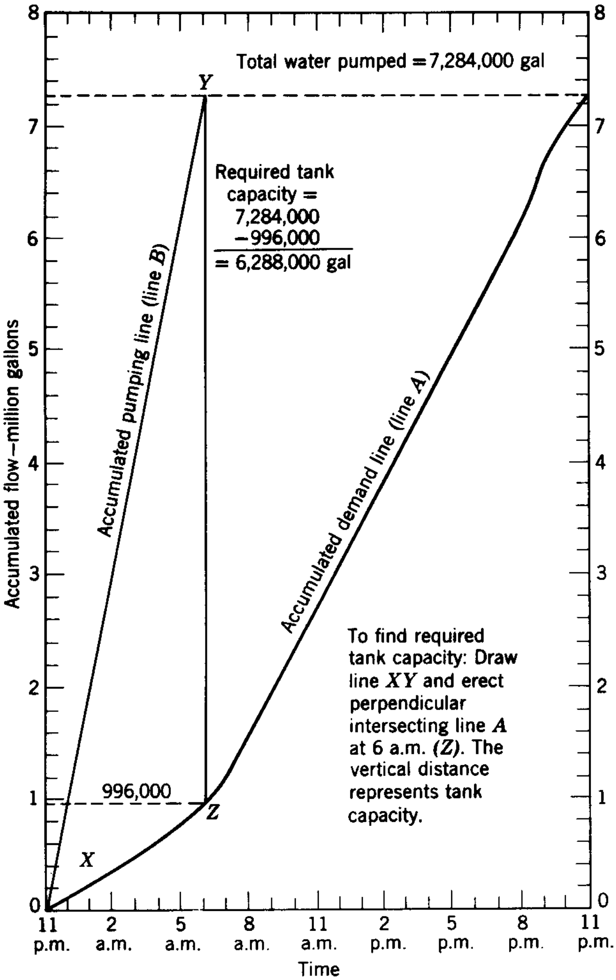


Figure 3-23 Mass diagram for determining capacity of tank when pumping 7 hr, from 11 p.m. to 6 a.m. (*Source:* J. E. Kiker, Jr., "Design Criteria for Water Distribution Storage," *Public Works,* March 1964, pp. 102–104. This illustration originally appeared in the March 1964 issue of *Public Works®*, published by Public Works Journal Corporation, 200 South Broad Street, Ridgewood, NJ 07450. © 2002 Public Works Journal Corporation. All rights reserved.)

should make such tanks watertight. A newly constructed concrete or masonry tank should be allowed to cure for about one month, during which time it should be wetted down frequently. The free lime in the cement can be neutralized by washing the interior with a weak acid, such as a 10 percent muriatic acid solution, or with a solution made up of 4 lb of zinc sulfate per gallon of water and then flushed clean.

Wooden elevated storage tanks are constructed of cypress, fir, long-leaf yellow pine, or redwood. They are relatively inexpensive and easily assembled and need not be painted or given special treatment; their normal life is 15 to

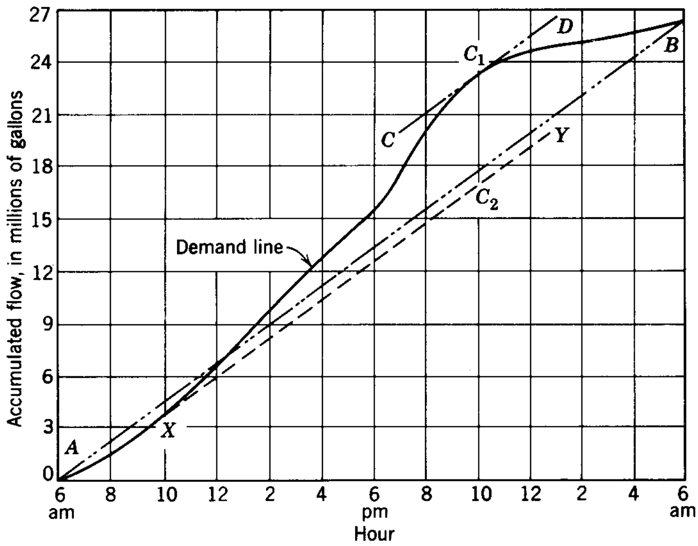


Figure 3-24 Mass diagram of storage requirements. The cumulative demand curve is plotted from records or estimates and the average demand line, *AB*, drawn between its extremities. Lines *CD* and *XY* are drawn parallel to line *AB* and tangent to the curve at points of greatest divergence from the average. At C_1 (the point of maximum divergence), a line is extended down the coordinate to line *XY*. This line, C_1C_2, represents the required peak-hour storage: in this case, it scales to 6.44×10^6 gal. (*Source:* G. G. Schmid, "Peak Demand Storage," *J. Am. Water Works Assoc.*, April 1956. Copyright 1956 by the American Water Works Association. Reprinted with permission.)

20 years. Wooden tanks are available with capacities up to 500,000 gal. The larger steel tanks start at 5000 to 25,000 gal; they require maintenance in order to prolong their life. Reinforced prestressed concrete tanks are also constructed. Underground fiberglass reinforced plastic tanks are also available up to a capacity of 25,000 to 50,000 gal. Tanks having exterior lead-based paint needing repair present special problems regarding removal and prevention of air pollution.

Steel standpipes, reservoirs, and elevated tanks are made in a variety of sizes and shapes. As normally used, a standpipe is located at some high point to make available most of its contents by gravity flow and at adequate pressure; a reservoir provides mainly storage. A standpipe has a height greater than its diameter; a reservoir has a diameter greater than its height. Both are covered, except when a reservoir is a natural body of water. The altitude of elevated tanks, standpipes, and reservoirs is usually determined, dependent on topography, to meet special needs and requirements. Elevated tanks rising more than 150 ft above the ground or located within 15,000 ft of a landing area and in a 50-mile-wide path of civil airways, must meet the requirements of the Civil Aeronautics Administration.

Peak Demand Estimates

The maximum hourly or peak-demand flow upon which to base the design of a water distribution system should be determined for each situation. A small residential community, for example, would have characteristics different from a new realty subdivision, central school, or children's camp. Therefore, the design flow to determine distribution system capacity should reflect the pattern of living or operation, probable water usage, and demand of that particular type of establishment or community. At the same time, consideration should be given to the location of existing and future institutions, industrial areas, suburban or fringe areas, highways, shopping centers, schools, subdivisions, and direction of growth. In this connection, reference to the city, town, or regional comprehensive or master plan, where available, can be very helpful. Larger cities generally have a higher per-capita water consumption than smaller cities, but smaller communities have higher percentage peak-demand flow than larger communities.

The maximum hourly domestic water consumption for cities with a population above 50,000 will vary from about 200 to 700 percent of the average-day annual hourly water consumption; the maximum hourly water demand in smaller cities will probably vary from 300 to 1000 percent of the average-day annual hourly water consumption. The daily variation is reported to be 150 to 250 percent and the monthly variation 120 to 150 percent of the average annual daily demand in small cities.[285] A survey of 647 utilities serving populations of 10,000 or more in 1970 found the mean maximum daily demand to be 1.78 times the average day, with a range of 1.00 to 5.22. Studies in England showed that the peak flow is about 10 times the average flow in cities with a population of 5000.[286] It can be said that the smaller and newer the community, the greater the probable variation in water consumption from the average will be.

Various bases have been used to estimate the probable peak demand at real estate subdivisions, camps, apartment buildings, and other places. One assumption for small water plants serving residential communities is to say that, for all practical purposes, almost all water for domestic purposes is used in 12 hr.[287] The maximum hourly rate is taken as twice the maximum daily hourly rate, and the maximum daily hourly rate is $1\frac{1}{2}$ times the average maximum hourly rate. If the average maximum monthly flow is $1\frac{1}{2}$ times the average monthly annual flow, then the maximum hour's consumption rate is 9 times the average daily hourly flow rate.

Another basis used on Long Island is maximum daily flow rate = 4 times average daily flow rate; maximum 6-hr rate = 8 times average daily flow rate; and maximum 1-hr rate = $9\frac{1}{2}$ times average daily flow rate.[288]

A study of small water supply systems in Illinois seems to indicate that the maximum hourly demand rate is 6 times the average daily hourly consumption.[289]

An analysis by Wolff and Loos[290] showed that peak water demands varied from 500 to 600 percent over the average day for older suburban neighborhoods with small lots; to 900 percent for neighborhoods with $\frac{1}{4}$- to $\frac{1}{2}$-acre lots; and to 1500 percent for new and old neighborhoods with $\frac{1}{3}$- to 3-acre lots. Kuranz,[291] Taylor,[292] and many others[293] have also studied the variations in residential water use.

The results of a composite study of the probable maximum momentary demand are shown in Figure 3-25. It is cautioned, however, that for other than average conditions the required supply should be supplemented as might be appropriate for fire flows, industries, and other special demands.

Peak flows have also been studied at camps, schools, apartment buildings, highway rest areas, and other places.

The design of water requirements at toll road and superhighway service areas introduces special considerations that are typical for the installation. It

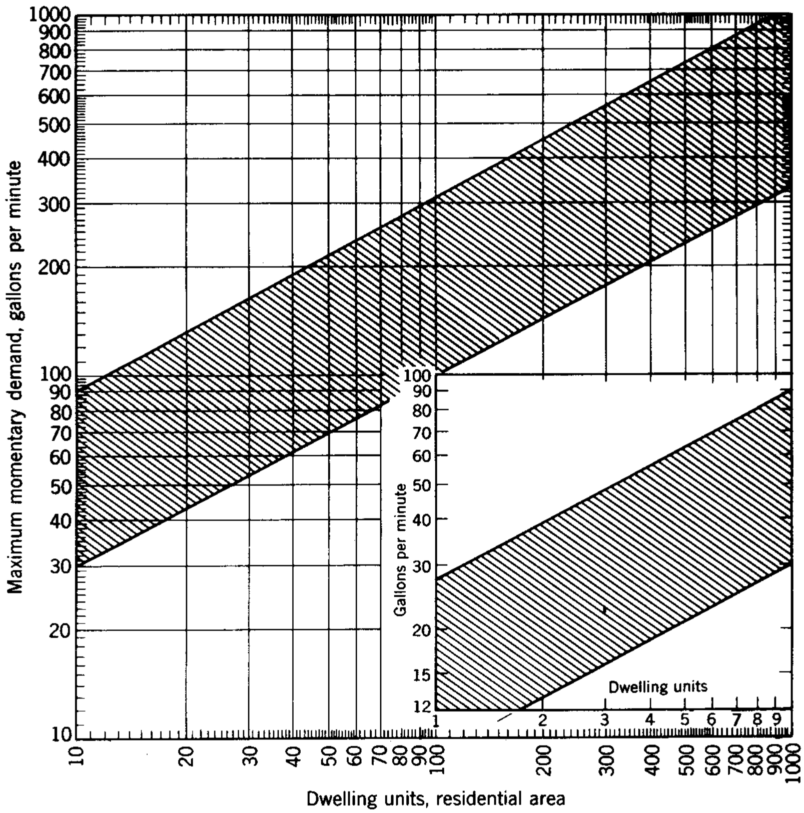


Figure 3-25 Probable maximum momentary water demand.

is generally assumed that the sewage flow equals the water flow. In one study of national turnpike and highway restaurant experience, the extreme peak flow was estimated at 1890 gpd per counter seat and 810 gpd per table seat; the peak day was taken as 630 gpd per counter seat and 270 gpd per table seat.[294] In another study of the same problem, the flow was estimated at 350 gpd per counter seat plus 150 gpd per table seat.[295] The flow was 200 percent of the daily average at noon and 160 percent of the daily average at 6 p.m. It was concluded that 10 percent of the cars passing a service area will enter and will require 15 to 20 gal per person. A performance study after 1 year of operation of the Kansas Turnpike service areas showed that 20 percent of cars passing service areas will enter; there will be $1\frac{1}{2}$ restaurant customers per car; average water usage will be 10 gal per restaurant customer, of which 10 percent is in connection with gasoline service; and plant flows may increase four to five times in a matter of seconds.[296]

Peak flows for apartment-type buildings can be estimated using the curves developed by Hunter.[297] Figure 3-26 and Tables 3-24 and 3-25 can be used in applying this method. Additions should be made for continuous flows. This method may be used for the design of small water systems, but the peak flows determined will be somewhat high.

At schools, peak flows would occur at recess and lunch periods and after gym classes. At motels, peak flows would occur between 7 and 9 a.m. and between 5 and 7 p.m.

It must be emphasized that actual meter readings from a similar type establishment or community should be used whenever possible in preference to an estimate. Time spent to obtain this information is a good investment, as each installation has different characteristics. Hence, the estimates and procedures mentioned here should be used as a guide to supplement specific studies and aid in the application of informed engineering judgment. Peak demands and per-capita daily water use can be expected to decline as water-saving plumbing fixtures and devices come into general use.

Distribution System Design Standards

As far as possible, distribution system design should follow usual good waterworks practice and provide for fire protection[284,298] (see also ref. 151, pp. 110–116). Mains should be designed on the basis of velocities of 4 to 6 fps with maximums of 10 to 20 fps, the rates of water consumption (maximum daily demand), and fire demand, plus a residual pressure of not less than 35 psi or more than 100 psi using the Hazen and Williams coefficient $C = 100$, with a normal working pressure of about 60 psi.

Air release valves or hydrants are provided as necessary where air can accumulate in the transmission lines, and blowoffs are provided at low drain points. These valves must not discharge to below-ground pits unless provided with a gravity drain to the surface above flood level. As far as possible, dead ends should be eliminated or a blowoff provided, and mains should be tied together at least every 600 ft. Lines less than 6 in. in diameter should gen-

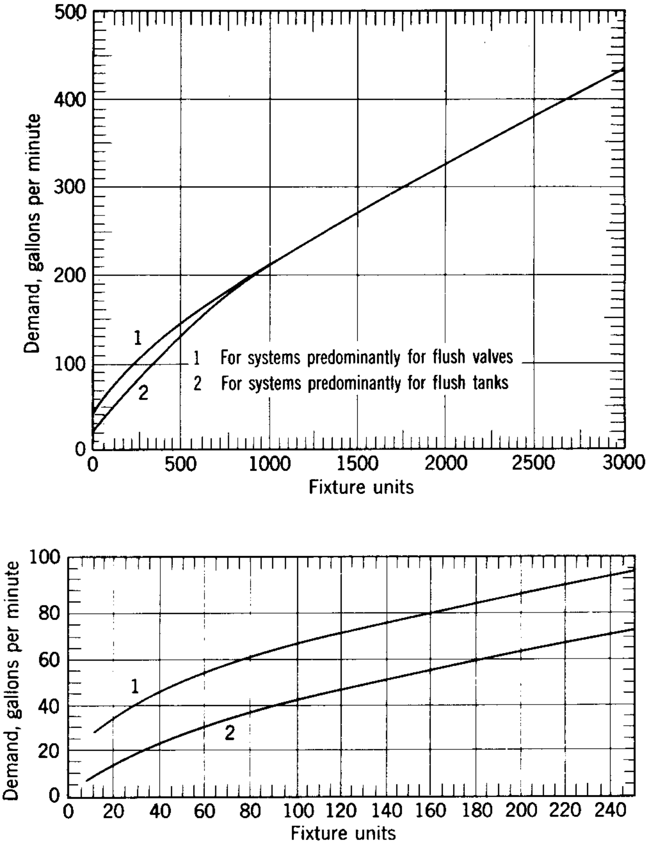


Figure 3-26 Estimate curves for demand load. (Source: R. B. Hunter, "Water-Distributing Systems for Buildings," Report BMS 79, National Bureau of Standards for Building Materials and Structures, November 1941.)

erally not be considered, except for the smallest system, unless they parallel secondary mains on other streets. In new construction 8-in. pipe should be used. In urban areas 12-in. or larger mains should be used on principal streets and for all long lines that are not connected to other mains at intervals close enough for proper mutual support. Although the design should aim to provide a pressure of not less than 35 psi in the distribution system during peak-flow periods, 20 psi minimum may be acceptable. A minimum pressure of 60 to 80 psi is desired in business districts, although 50 psi may be adequate in small villages with one- and two-story buildings. Thrust blocks and joint restraints must be provided on mains where indicated such as at tees, bends, plugs, and hydrants.

Valves are spaced not more than 500 ft apart in commercial districts and 800 ft in other districts and at street intersections. A valve book, at least in

TABLE 3-24 Demand Weight of Fixtures in Fixture Units[a]

Fixture or Group[b]	Occupancy	Type of Supply Control	Weight in Fixture Units[c]
Water closet	Public	Flush valve	10
		Flush tank	5
Pedestal urinal	Public	Flush valve	10
Stall or wall urinal	Public	Flush valve	5
		Flush tank	3
Lavatory	Public	Faucet	2
Bathtub	Public	Faucet	4
Shower head	Public	Mixing valve	4
Service sink	Office, etc.	Faucet	3
Kitchen sink	Hotel or restaurant	Faucet	4
Water closet	Private	Flush valve	6
		Flush tank	3
Lavatory	Private	Faucet	1
Bathtub	Private	Faucet	2
Shower head	Private	Mixing valve	2
Bathroom group	Private	Flush valve for closet	8
		Flush tank for closet	6
Separate shower	Private	Mixing valve	2
Kitchen sink	Private	Faucet	2
Laundry trays (1–3)	Private	Faucet	3
Combination fixture	Private	Faucet	3

Source: R. B. Hunter, *Water-Distributing System for Buildings,* Report No. BMS 79, National Bureau of Standards Building Materials and Structures, November 1941.

[a]For supply outlets likely to impose continuous demands, estimate continuous supply separately and add to total for fixtures.

[b]For fixtures not listed, weights may be assumed by comparing the fixture to a listed one using water in similar quantities and at similar rates.

[c]The given weights are for total demand. For fixtures with both hot and cold water supplies, the weights for maximum separate demands may be taken as three-fourths the listed demand for supply.

triplicate, should show permanent ties for all valves, number of turns to open completely, left- or right-hand turn to open, manufacturer, and dates valves operated. A valve should be provided between each hydrant and street main.

Hydrants should be provided at each street intersection and spacing may range generally from 350 to 600 ft, depending on the area served for fire protection and as recommended by the state Insurance Services Office. The connection to the street main should be not less than 6 in. in diameter. Operating nuts and direction of operation should be standard on all hydrants and conform with AWWA standards. Hydrants should be set so that they are easily accessible to fire department pumpers; they should not be set in depressions,

TABLE 3-25 Flow Rate and Required Pressure

Fixture	Flow Pressure[a] (psi)	Flow Rate (gpm)
Ordinary basin faucet	8	3.0
Self-closing basin faucet	12	2.5
Sink faucet		
$\frac{3}{8}$ in.	10	4.5
$\frac{1}{2}$ in.	5	4.5
Bathtub faucet	5	6.0
Laundry-tub cock, $\frac{1}{2}$ in.	5	5.0
Shower	12	5.0
Ball cock for closet	15	3.0
Flush valve for closet	10–20	15–40[b]
Flush valve for urinal	15	15.0
Garden hose, 50 ft and sill cock	30	5.0
Dishwashing machine, commercial	15–30	6–9

Source: Report of the Coordinating Committee for a National Plumbing Code, U.S. Department of Commerce, Washington, DC, 1951.

[a]Flow pressure is the pressure in the pipe at the entrance to the particular fixture considered. Some codes permit 8 psi for faucet fixtures and lesser flow rates.

[b]Wide range due to variation in design and type of flush-valve closets. (See Table 11-7 for fixture supply pipe diameters. See also Table 3-14.)

in cutouts, or on embankments high above the street; pumper outlets should face directly toward the street; with respect to nearby trees, poles, and fences, there should be adequate clearance for connection of hose lines. Hydrants should be painted a distinguishing color so that they can be quickly spotted at night. Hydrant drains shall not be connected to or located within 10 ft of sanitary sewers or storm drains.

Main breaks occur longitudinally and transversely. Age is not a factor. Breaks are associated with sewer and other construction, usually starting with a leaking joint. The leak undermines the pipe making a pipe break likely due to beam action. Sometimes poor quality control in pipe manufacture contributes to the problem. Good pipe installation practice, including bedding and joint testing, followed by periodic leak surveys will minimize main leaks and breaks. Unavoidable leakage should not exceed 70 gal per 24 hr per mile of pipe per inch of pipe diameter. A loss of 1000 to 3000 gal per mile of main is considered reasonable.

Water lines are laid below frost, separated from sewers a minimum horizontal distance of 10 ft and a vertical distance of 18 in. Water lines may be laid closer horizontally in a separate trench or on an undisturbed shelf with the bottom at least 18 in. above the top of the sewer line under conditions acceptable to the regulatory agency. It must be recognized that this type of construction is more expensive and requires careful supervision during construction. Mains buried 5 ft are normally protected against freezing and external loads.

The selection of pipe sizes is determined by the required flow of water that will not produce excessive friction loss. Transmission mains for small water systems more than 3 to 4 miles long should not be less than 10 to 12 in. in diameter. Design velocity is kept under 5 fps and head loss under 3 ft/1000 ft. If the water system for a small community is designed for fire flows, the required flow for domestic use will not cause significant head loss. On the other hand, where a water system is designed for domestic supply only, the distribution system pipe sizes selected should not cause excessive loss of head. Velocities may be $1\frac{1}{2}$ to $5\frac{1}{2}$ fps. In any case, a special allowance is usually necessary to meet water demands for fire, industrial, and other special purposes.

Design velocities as high as 10 to 15 fps are not unusual, particularly in short runs of pipe. The design of water distribution systems can become very involved and is best handled by a competent sanitary engineer. When a water system is carefully laid out, without dead ends, so as to divide the flow through several pipes, the head loss is greatly reduced. The friction loss in a pipe connected at both ends is about one-quarter the friction loss in the same pipe with a dead end. The friction loss in a pipe from which water is being drawn off uniformly along its length is about one-third the total head loss. Also, for example, an 8-in. line will carry 2.1 times as much water as a 6-in. line for the same loss of head.*

Where possible, a water system that provides adequate fire protection is highly recommended. This is discussed further below. The advantages of fire protection should at the very least be compared with the additional cost of increased pipe size and plant capacity, water storage, and the possible reduced fire insurance rate. If, for example, the cost of 8-in. pipe is only 20 percent more per foot than 6-in. pipe, the argument for the larger diameter pipe, where needed, is very persuasive since the cost of the trench would be the same. In any case, only pipes and fittings that have a permanent-type lining or inner protective surface should be used.

Small Distribution Systems

In some communities where no fire protection is provided, small-diameter pipe may be used. In such cases, a 2-in. line should be no more than 300 ft long, a 3-in. line no more than 600 ft, a 4-in. line no more than 1200 ft, and

*A 6-in. line carries 2.9 times as much as a 4-in. line; an 8-in. line carries 6.2 times as much as a 4-in. line; a 12-in. line carries 18 times as much as a 4-in. line, 6.2 times as much as a 6-in. line, and 2.9 times as much as an 8-in. line. The discharges vary as the 2.63 power of the pipe diameters being compared, based on the Hazen-Williams formula. See flow charts, nomograms, or Table 3-30.

a 6-in. line no more than 2400 ft. If lines are connected at both ends, 2- or 3-in. lines should be no longer than 600 ft; 4-in. lines are not more than 2000 ft.

Transmission lines for rural areas have been designed for peak momentary demands of 2 to 3 gpm per dwelling unit and for as low as 0.5 gpm per dwelling unit with storage provided on the distribution system to meet peak demands. Adjustments are needed for constant or special demands and for population size. For example, Figure 3-25 shows a probable maximum demand of 3 to 9 gpm per dwelling unit for 10 dwelling units, 1 to 3.2 gpm per dwelling unit for 100 dwelling units, and 0.33 to 1.1 gpm per dwelling unit for 1000 dwelling units.

A general rule of thumb is that a 6-in. main can be extended only 500 ft if the average amount of water of 1000 gpm is to be supplied for fire protection or about 2000 ft if the minimum amount of 500 gpm is to be supplied.

The minimum pipe sizes and rule-of-thumb guides mentioned above are not meant to substitute for distribution system hydraulic analysis but are intended for checking or rough approximation. Use of the equivalent pipe method, the Hardy Cross method, or one of its modifications should be adequate for the small distribution system. Computer analysis methods are used for large-distribution-system analysis.[299]

Fire Protection

Many factors enter into the classification of municipalities (cities, towns, villages, and other municipal entities) for fire insurance rate-setting purposes.

The Insurance Services Office, their state representatives, and other authorized offices use the *Fire Suppression Rating Schedule*[300] to classify municipalities with reference to their fire defenses. This is one of several elements in the development of property fire insurance rates.

The municipal survey and grading work formerly performed by the National Board of Fire Underwriters, then by the American Insurance Association, as well as that formerly performed by authorized insurance-rating organizations are continued under the Insurance Services Office. Credit is given for the facilities provided to satisfy the needed fire flows of the buildings in the municipality.[300] (Since this discussion is intended only for familiarization purposes, the reader interested in the details of the grading system is referred to the references cited in this section for further information.)

An adequate water system provides sufficient water to meet peak demands for domestic, commercial, and industrial purposes as well as for firefighting. For fire suppression rating, the water supply has a weight of 40 percent; the fire department, 50 percent; and receiving and handling fire alarms, 10 percent. The water system rating considers the adequacy of the supply works, mains and hydrant spacing, size and type of hydrants, and inspection and condition of hydrants.

To be recognized for fire protection, a water system must be capable of delivering at least 250 gpm at 20 psi at a fire location for at least 2 hr with consumption at the maximum daily rate. The method of determining the needed fire flow for a building is given in the *Fire Suppression Rating Schedule*.[300] The needed fire flow will vary with the class of construction, its combustibility class, openings and distance between buildings, and other factors. Table 3-26 shows the needed duration for fire flow. The needed fire flow for a community of one- and two-family dwellings varies from 500 gpm for buildings over 100 ft apart to 1500 gpm where buildings are less than 11 ft apart (ref. 284, p. 8). There should be sufficient hydrants within 1000 ft of a building to supply its needed fire flow. Each hydrant with a pumper outlet and within 300 ft of a building is credited at 1000 gpm; 301 to 600 ft, 670 gpm; and 601 to 1000 ft, 250 gpm.

Where possible, water systems should be designed to also provide adequate fire protection, and old systems should be upgraded to meet the requirements. This will also help ensure the most favorable grading, classification, and fire insurance rates. Improvements in a water system resulting in a better fire protection grade and classification would generally be reflected in a reduced fire insurance rate on specifically rated commercial properties, although other factors based on individual site evaluation may govern. However, this is not always the case in ‘‘class-rated properties’’ such as dwellings, apartment houses, and motels. It generally is not possible to justify the cost to improve the fire protection class *solely* by the resulting savings in insurance premiums.[301] Nevertheless, the greater safety to life and property makes the value of improved fire protection more persuasive.

It is prudent for the design engineer to follow the state Insurance Services Office requirements.[300]

One must be alert to ensure that fire protection programs do not include pumping from polluted or unapproved sources into a public or private water system main through hydrants or blowoff valves. Nor should bypasses be constructed around filter plants or provision made for ‘‘emergency’’ raw-water connections to supply water in case of fire. In *extreme emergencies,* the health department might permit a temporary connection under certain conditions, but in any case the water purveyor must immediately notify every consumer not to drink the water or use it in food or drink preparation unless first boiled or disinfected as noted at the end of this chapter.

TABLE 3-26 Needed Duration for Fire Flow

Needed Fire Flow (gpm)	Needed Duration (hr)
$\leq$2500	2
3000	3
3500	3
$\geq$4000	4

Source: Fire Suppression Rating Schedule, Insurance Services Office, New York, 1980.

Cross-Connection Control

There have been numerous instances of illness caused by cross-connections.[302–304] A discussion of water system design would not be complete without reference to cross-connection control and backflow prevention. The goal is to have no connection between a water of drinking water quality (potable) and an unsafe or questionable (nonpotable) water system or between a potable system and any plumbing, fixture, or device whereby nonpotable water might flow into the potable water system.

A *cross-connection* is any physical connection between a potable water system and a nonpotable water supply; any waste pipe, soil pipe, sewer, drain; or any direct or indirect connection between a plumbing fixture or device whereby polluted water or contaminated fluids including gases or substances might enter and flow back into the potable water system. Backflow of nonpotable water and other fluids into the potable water system may occur by backpressure or backsiphonage. In *backpressure* situations, the pressure in the nonpotable water system exceeds that in the potable water system. In *backsiphonage,* the pressure in the potable water system becomes less than that in the nonpotable water system due to a vacuum or reduced pressure developing in the potable water system. Backflow prevention is also discussed in Chapter 11.

Negative or reduced pressure in a water distribution or plumbing system may occur when a system is shut off or drained for repairs, when heavy demands are made on certain portions of the system causing water to be drawn from the higher parts of the system, or when the pumping rate of pumps installed on the system (or of fire pumps or fire pumpers at hydrants) exceeds the capacity of the supply line to the pump. Backpressure may occur when the pressure in a nonpotable water system exceeds that in the potable water system, such as when a fire pumper at a dock or marina pumps nonpotable water into a hydrant or when a boiler chemical feed pump is directly connected to the potable water system.

The more common acceptable methods or devices to prevent backflow are air gap separation (as shown in Chapter 9, Figures 9-2, 9-5, and 9-6), backpressure units as shown in Figures 3-27 and 3-28, and vacuum breakers.[284] The non-pressure-type vacuum breaker is always installed on the atmospheric side of a valve and is only intermittently under pressure, such as when a flushometer valve is activated (see Figure 11-13). The pressure-type vacuum breaker is installed on a pressurized system and will function only when a vacuum occurs. It is spring loaded to overcome sticking and is used only where authorized. The vacuum breaker is not designed to provide protection against backflow resulting from backpressure and should not be installed where backpressure may occur.

The barometric or atmospheric loop that extends 34 to 35 ft above the highest outlet is not acceptable as a backflow preventer because a backpressure due to water, air, steam, hot water, or other fluid can negate its purpose.

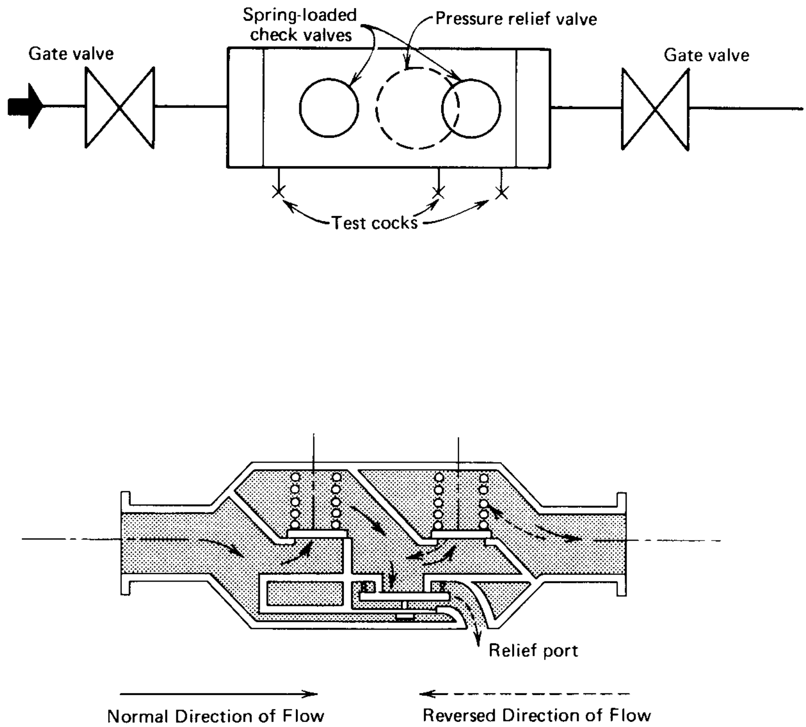


Figure 3-27 Reduced pressure zone backflow preventer—principle of operation. Malfunctioning of check or pressure-relief valve is indicated by discharge of water from relief port. Preferred for hazardous facility containment. (*Source: Cross-Connection Control,* EPA-430/9-73-002, U.S. EPA, Water Supply Division (WSD), Washington, DC, 1976, p. 25.)

The swing joint, four-way plug valve, three-way two-port valve, removable pipe section, and similar devices are not reliable as nonpotable water can enter the potable water system at the time they are in use.[305,306]

An elevated or ground-level tank providing an air gap, the reduced pressure zone backflow preventer, and the double-check-valve assembly are generally used on public water system service connections to prevent backflow into the distribution system. The vacuum breaker is usually used on plumbing fixtures and equipment.

An approved backflow preventer or air break should be required on the water service line to every building or structure using or handling any hazardous substance that might conceivably enter the potable water system. In addition, building and plumbing codes should prohibit cross-connections within buildings and premises and require approved-type backflow preventers on all plumbing, fixtures, and devices that might cause or permit backflow. It is the responsibility of the designing engineer and architect, the building and

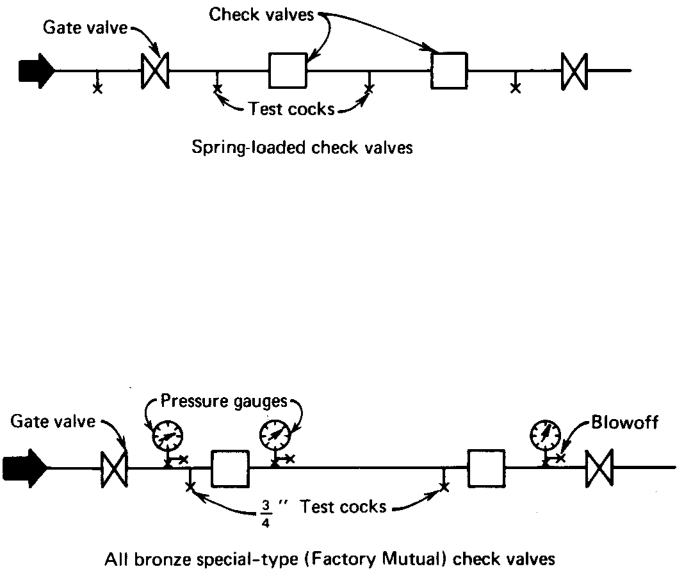


Figure 3-28 Double check valve–double gate valve assembly. For aesthetically objectionable facility containment.

plumbing inspector, the waterworks official, and the health department to prevent and prohibit possibilities of pollution of public and private water systems.

There are two major aspects to a cross-connection control program. One is protection of the water distribution system to prevent its pollution. The other is protection of the internal plumbing system used for drinking and culinary purposes to prevent its pollution.

The water purveyor has the responsibility to provide its customers with water meeting drinking water standards. This requires control over unauthorized use of hydrants, blowoffs, and main connections or extensions. It also means requirement of a backflow prevention device at the service connection (containment) of all premises where the operations or functions on the premises involve toxic or objectionable chemical or biological liquid substances or use of a nonpotable water supply, which may endanger the safety of the distribution system water supply through backflow. However, although these precautions may protect the water system, it is also necessary to protect the consumers on the premises using the water for drinking and culinary purposes. This responsibility is usually shared by the water purveyor, the building and plumbing department, the health department, and the owner of the structure, depending on state laws and local ordinances. The AWWA Policy Statement on Cross-Connection states, in part, that the "water purveyor must take reasonable precaution to protect the community distribution system from the hazards originating on the premises of its customers that may degrade the water in the community distribution system" (ref. 307, p. 8). The water purveyor has been held legally responsible for the delivery of safe water to the consumer and the Safe Drinking Water Act bases compliance with federal standards on the quality of water coming out of the consumer's tap. Under these circumstances, a cross-connection control program is needed in every community having a public water system to define and establish responsibility and ensure proper installation and adequate inspection, maintenance, testing, and enforcement.

A comprehensive cross-connection control program should include the following:[308,309]

1. an implementation ordinance that provides the legal basis for the development and complete operation of the program;
2. the adoption of a list of devices acceptable for specific types of cross-connection control;
3. the training and certification of qualified personnel to test and ensure devices are maintained;
4. the establishment of a suitable set of records covering all devices;
5. periodic seminars wherein supervisory, administrative, political, and operating personnel, as well as architects, consulting engineers, and building officials, are briefed and brought up-to-date on the reason for the program as well as on new equipment in the field; and
6. An inspection program with priority given to potentially hazardous connections.

In some states, the legal basis for the adoption of a local cross-connection ordinance is a state law or sanitary code; hence, consultation with the state health department or other agency having jurisdiction is advised in the development of a local ordinance and program. Model ordinances and instruction manuals are available.[310]* Enforcement is best accomplished at the local level.[311,312]

Implementation of a control program requires, in addition to the above, that a priority system be established. Grouping structures and facilities served as ''Hazardous,'' ''Aesthetically Objectionable,'' and ''Nonhazardous'' can make inspection manageable and permit concentration of effort on the more serious conditions. Estimating the cost of installing backflow prevention devices is helpful in understanding what is involved and obtaining corrections. Some devices are quite costly. An inspection program, with first priority to hazardous situations, is followed by review of findings with the local health department public health engineer or sanitarian, official notification of the customer, request for submission and approval of plans, establishment of a correction timetable, inspection and testing of the backflow device when in-

*See also local building and plumbing codes.

stalled, enforcement action if indicated, follow-up inspections, and testing of installed devices. The program progress should be reviewed and adjusted as needed every six months.[313]

Some practical applications of backflow prevention devices are illustrated and discussed in Chapters 9 and 11.

Hydropneumatic Systems

Hydropneumatic or pressure-tank water systems are suitable for small communities, housing developments, private homes and estates, camps, restaurants, hotels, resorts, country clubs, factories, and institutions and as booster installations. In general, only about 10 to 20 percent of the total volume of a pressure tank is actually available. Hydropneumatic tanks are usually made of $\frac{3}{16}$-in. or thicker steel and are available in capacities up to 10,000 or 20,000 gal. Tanks should meet American Society of Mechanical Engineers (ASME) code requirements. Small commercial-size tanks are 42, 82, 120, 144, 180, 220, 315, 525, and 1000 gal. Smaller tanks are available precharged with air.

The required size of a pressure tank is determined by peak demand, the capacity of the pump and source, the operating pressure range, and air volume control (available water). See Peak-Demand Estimates, this chapter. The capacity of well and pump should be at least 10 times the average daily water consumption rate, and the gross tank volume in gallons should be at least 10 times the capacity of the pump in gallons per minute (ref. 151, p. 107). The EPA suggests that the pump capacity for private dwellings be based on the number of fixtures in a dwelling, as shown in Table 3-27. The Water System Council recommends a 7-min peak-demand usage for one- to four-bedroom homes and suggests a storage of 15 gpd per dwelling unit.[314]

TABLE 3-27 Recommended Pump Capacity for Private Dwellings

Number of Fixtures	Recommended Pump Capacity (gpm)
2–7	7–8
8	8–9
10	9–11
12	10–12
14–16	11–13
18–20	12–14

Source: Manual of Individual Water Systems, EPA-570/9-82-004, U.S. Environmental Protection Agency, Office of Drinking Water, Washington, DC, October 1982, p. 99.

A simple and direct method for determining the recommended volume of the pressure storage tank and size pump to provide is given by Figure 3-29. This figure is derived from Boyle's law and is based on the formula

$$Q = \frac{Q_m}{1 + P_1/P_2}$$

where Q = pressure-tank volume, gal
Q_m = 15-min storage at the maximum hourly demand rate
P_1 = minimum absolute operating pressure (gauge pressure plus 14.7 lb/in.^{2})
P_2 = maximum absolute pressure[315]

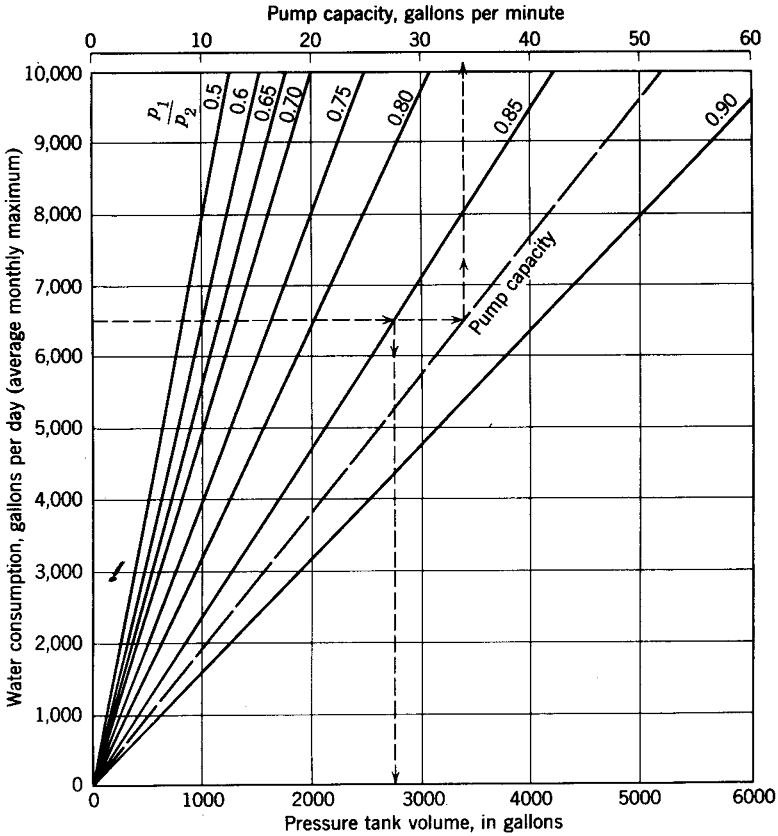


Figure 3-29 Chart for determining pressure storage tank volume and pump size. Pressure tank volume provides 15-min storage. (*Source:* J. A. Salvato, Jr., "The Design of Pressure Tanks for Small Water Systems," *J. Am. Water Works Assoc.,* June 1949, pp. 532–536. Reprinted by permission. Copyright © 1949 by the American Water Works Association.)

The pump capacity given on the curve is equal to 125 percent of the maximum hourly demand rate. The maximum hourly demand is based on the following but should be determined for each situation:

$$\text{Average daily rate} = \frac{\text{Average water use per day}}{\text{1440 min/day in gpm}} \quad \text{based on annual water use}$$

$$\text{Average maximum monthly rate} = 1.5 \times \text{average daily rate}$$

$$\text{Maximum hourly demand rate} = 6 \times \text{average maximum monthly rate or } 9 \times \text{average daily rate}$$

$$\text{Instantaneous rate (pump capacity)} = 1.25 \times \text{maximum hourly demand rate, or } 11.25 \times \text{average daily rate}$$

The pressure tank is assumed to be just empty when the pressure gauge reads zero. Figure 3-29 can also be used for larger or smaller flows by dividing or multiplying the vertical and horizontal axes by a convenient factor. The required pressure tank volume can be reduced proportionately if less than 15-min storage is acceptable. For example, it can be reduced to one-third if 5-min storage is adequate, or to $\frac{1}{15}$ if 1-min storage is adequate. Also, if the water consumption in Figure 3-29 is $\frac{1}{10}$ of 6500 gpd, that is 650 gpd, the corresponding pressure tank volume would be $\frac{1}{10}$ of 2800 gal, or 280 gal. The pump capacity would be $\frac{1}{10}$ of 34 gpm, or 3.4 gpm. But if all water is used in 12 hours, as in a typical residential dwelling, double the required pump capacity, which in this case would be 6.8 gpm. The larger pump is usually provided in small installations for faster pressure tank recovery and to meet momentary demands that are more likely to vary widely than in large installations. See text above and Table 3-27, also Figures 3-25 and 3-26. An example for a larger system is given under Design of Small Water Systems, this chapter.

The water available for distribution is equal to the difference between the dynamic head (friction plus static head) and the tank pressure. Because of the relatively small quantity of water actually available between the usual operating pressures, a higher initial (when the tank is empty) air pressure and range are sometimes maintained in a pressure tank to increase the water available under pressure. When this is done, the escape of air into the distribution system is more likely. Most home pressure tanks come equipped with a pressure switch and an automatic air volume control (Figure 3-30), which is set to maintain a definite air-water volume in the pressure tank at previously established water pressures, usually 20 to 40 psi. Air usually needs to be added to replace that absorbed by the water to prevent the tank from becoming waterlogged. Small pressure tanks are available with a diaphragm inside that

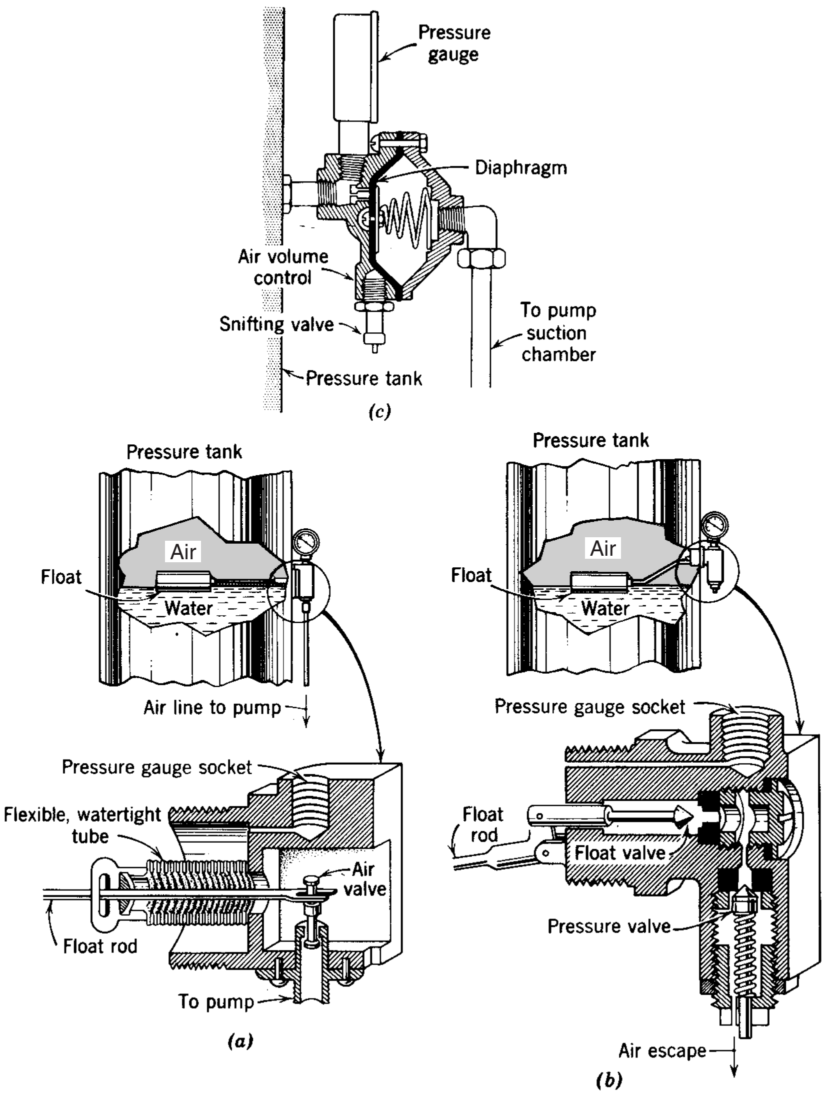


Figure 3-30 Pressure-tank air volume controls: (*a*) shallow-well type for adding air; (*b*) deep-well type for air release—used with submersible and piston pumps; (*c*) diaphragm-type in position when pump is not operating (used mostly with centrifugal pump). Small air precharged pressure tanks with a diaphragm to separate air and water are replacing air-volume controls. *Source: Pumps and Plumbing for the Farmstead,* Tennessee Valley Authority, Agriculture and Engineering Development Division, November 1940.)

separates air from the water, thereby minimizing this problem. Some manufacturers, or their representatives, increase the pressure tank storage slightly by precharging the tank with air. With deep-well displacement and submersible pumps, an excess of air is usually pumped with the water, causing the pressure tank to become airbound unless an air-release or needle valve is installed to permit excess air to escape.

In large installations an air compressor is needed, and an air-relief valve is installed at the top of the tank. A pressure-relief valve should also be included on the tank. See Figure 3-31.

Where a well yield (source) is inadequate to meet water demand with a pressure tank, then gravity or in-well storage, an additional source of water, or double pumping with intermediate storage, may be considered. Intermediate ground-level storage can be provided between the well pump and the pressure-tank pump. The well pump will require a low-water cutoff and *its capacity must be related to the dependable well yield*. The intermediate storage tank (tightly covered) should have a pump stop-and-start device to control the well pump and a low-water sensor to signal depletion of water in the intermediate storage tank. A centrifugal pump would pump water from the intermediate tank to a pressure tank, with a pressure switch control, and thence to the distribution system.

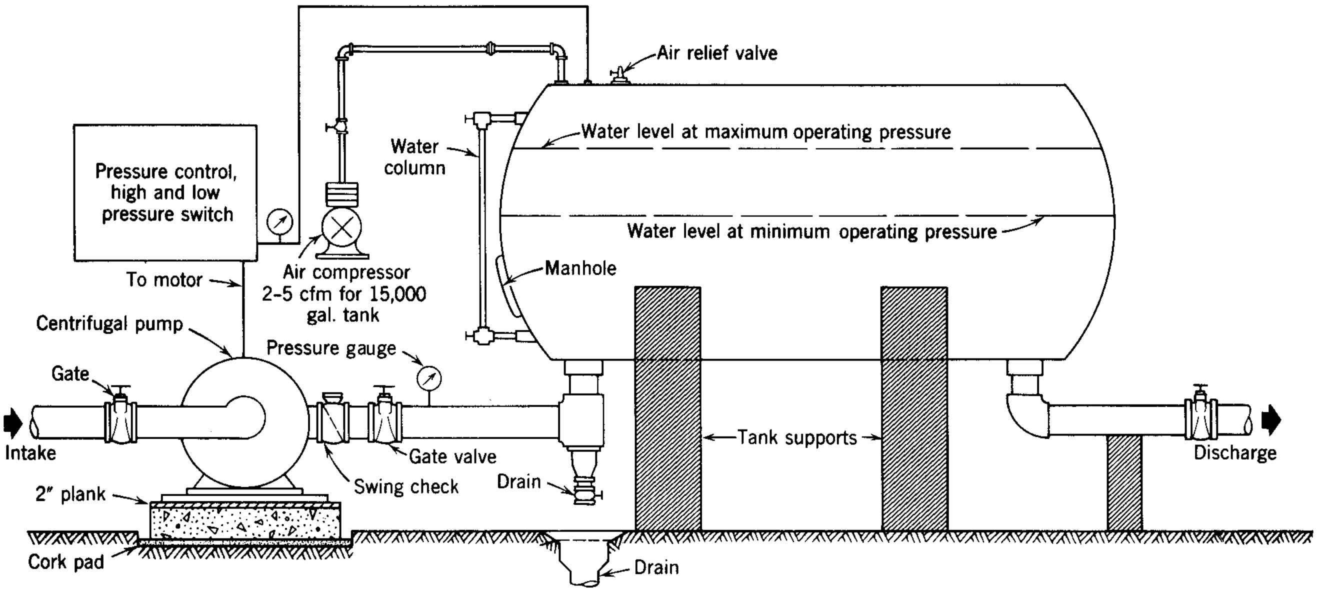
Low-rate pumping to elevated storage, a deeper well to provide internal storage, or an oversize pressure tank may be possible alternatives to intermediate ground-level storage, depending on the extent of the problem and relative cost.

Pumps

The pump types commonly used to raise and distribute water are referred to as positive displacement, including reciprocating, diaphragm, and rotary; centrifugal, including turbine, submersible, and ejector jet; air lift; and hydraulic ram. Pumps are classified as low lift, high lift, deep well, booster, and standby. Other types for rural and developing areas include the chain and bucket pump and hand pump.

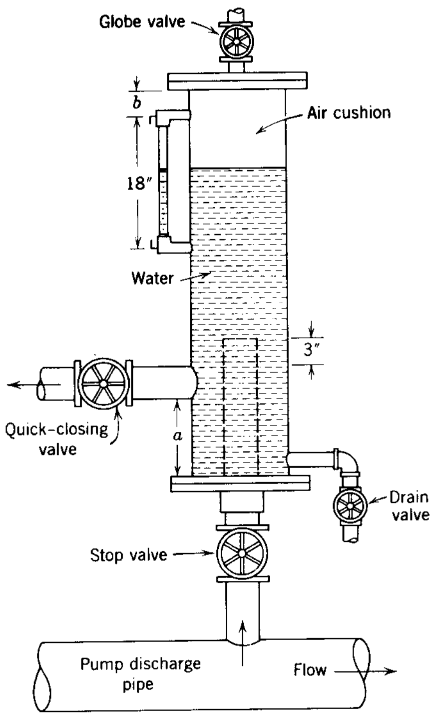
Displacement Pump

In reciprocating displacement pumps, water is drawn into the pump chamber or cylinder on the suction stroke of the piston or plunger inside the pump chamber and then the water is pushed out on the discharge stroke. This is a simplex or single-acting reciprocating pump. An air chamber (Figure 3-32) should be provided on the discharge side of the pump to prevent excessive water hammer caused by the quick-closing flap or ball valve; by the quick closing or opening of a gate valve, float valve, or pressure-reducing valve; and the sudden shutdown of a pump. The air chamber or other surge suppressor will protect piping and equipment on the line and will tend to even



Note: Use special rubber hose fitting between pump and pressure tank for quiet operation.

Figure 3-31 Typical large pressure tank installation.



Air Chamber Dimensions

Discharge Pipe	Inside Diameter of Air Chamber	Total Height	*a*	*b*
2″	8″	3′0″	4″	9″
2½″	8″	3′6″	4″	12″
3″	10″	4′0″	5″	15″
4″	10″	5′0″	6″	21″
5″	12″	6′0″	6″	27″
6″	16″	7′0″	6″	33″

Figure 3-32 Air chamber dimensions for reciprocating pumps. (*Source: Water Supply and Water Purification,* T.M. 5-295, War Department, Washington, DC, 1942.)

out the intermittent flow of water. See Water Hammer, this chapter. Reciprocating pumps are also of the duplex type wherein water is pumped on both the forward and backward stroke, and of the triplex type, in which three pistons pump water. The motive power may be manual; a steam, gas, gasoline, or oil engine; an electric motor; or a windmill. The typical hand pump and deep-well plunger or piston pumps over wells are displacement pumps.

A rotary pump is also a displacement pump, since the water is drawn in and forced out by the revolution of a cam, screw, gear, or vane. It is not used to any great extent to pump water.

Displacement pumps have certain advantages over centrifugal pumps. The quantity of water delivered does not vary with the head against which the pump is operating but depends on the power of the driving engine or motor. A pressure-relief valve is necessary on the discharge side of the pump to prevent excessive pressure in the line and possible bursting of a pressure tank or water line. They are easily primed and operate smoothly under suction lifts as high as 22 ft. Practical suction lifts at different elevations are given in Table 3-28.

Displacement pumps are flexible and economical. The quantity of water pumped can be increased by increasing the speed of the pump, and the head can vary within wide limits without decreasing the efficiency of the pump. A displacement pump can deliver relatively small quantities of water as high as 800 to 1000 ft. Its maximum capacity is 300 gpm, although horizontal piston pumps are available in sizes of 500 to 3000 gpm. The overall efficiency of a plunger pump varies from 30 percent for the smaller sizes to 60 to 90 percent for the larger sizes with electric motor drive. It is particularly suited to pumping small quantities of water against high heads and can, if necessary, pump air with water. This type of pump is no longer widely used.

Centrifugal Pump, Also Submersible and Turbine

There are several types of centrifugal pumps; the distinction lies in the design of the impeller. They include radial, mixed, and axial flow, turbine, close-coupled, submersible, and adjustable blade impeller pumps. Water is admitted into the suction pipe or pump casing and is rotated in the pump by an impeller inside the pump casing. The energy is converted from velocity head primarily into pressure head. In the submerged multistage, turbine-type pump used to pump water out of a well, the centrifugal pump is in the well casing below

TABLE 3-28 Atmospheric Pressure and Practical Suction Lift

Elevation Above Sea Level		Atmospheric Pressure		Design Suction Life (ft)		
ft	miles	lb/in.^{2}	ft of water	Displacement Pump	Centrifugal Pump	Turbine Pump
0	—	14.70	33.95	22	15	28
1,320	$\frac{1}{4}$	14.02	32.39	21	14	26
2,640	$\frac{1}{2}$	13.33	30.79	20	13	25
3,960	$\frac{3}{4}$	12.66	29.24	18	11	24
5,280	1	12.02	27.76	17	10	22
6,600	$1\frac{1}{4}$	11.42	26.38	16	9	20
7,920	$1\frac{1}{2}$	10.88	25.13	15	8	19
10,560	2	9.88	22.82	14	7	18

Note: The possible suction lift will decrease about 2 ft for every 10°F increase in water temperature above 60°F; 1 lb/in.^{2} = 2.31 ft head of water.

the drawdown water level in the well; the motor is above ground. In the submersible pump, the pump and electric motor are suspended in the well attached to the discharge pipe, requiring a minimum 3-in.- (preferably 4-in.-) diameter casing. It is a multistage, centrifugal pump unit.

If the head against which a centrifugal pump operates is increased beyond that for which it is designed and the speed remains the same, then the quantity of water delivered will decrease. On the other hand, if the head against which a centrifugal pump operates is less than that for which it is designed, then the quantity of water delivered will be increased. This may cause the load on the motor to be increased, and hence overloading of the electric or other motor, unless the motor selected is large enough to compensate for this contingency.

Sometimes two centrifugal pumps are connected in series so that the discharge of the first pump is the suction for the second. Under such an arrangement, the capacity of the two pumps together is only equal to the capacity of the first pump, but the head will be the sum of the discharge heads of both pumps. At other times, two pumps may be arranged in parallel so that the suction of each is connected to the same pipe and the discharge of each pump is connected to the same discharge line. In this case, the static head will be the same as that of the individual pumps, but the dynamic head, when the two pumps are in operation, will increase because of the greater friction and may exceed the head for which the pumps are designed. It may be possible to force only slightly more water through the same line when using two pumps as when using one pump, depending on the pipe size. Doubling the speed of a centrifugal pump impeller doubles the quantity of water pumped, produces a head four times as great, and requires eight times as much power to drive the pump. In other words, the quantity of water pumped varies directly with the speed, the head varies as the square of the speed, and the horsepower varies as the cube of the speed. It is usual practice to plot the pump curves for the conditions studied on a graph to anticipate operating results.

The centrifugal pump has no valves or pistons; there is no internal lubrication; and it takes up less room and is relatively quiet. A single-stage centrifugal pump is generally used where the suction lift is less than 15 ft and the total head not over 125 to 200 ft. A single-stage centrifugal pump may be used for higher heads, but where this occurs, a pump having two or more stages, that is, two or more impellers or pumps in series, should be used. The efficiency of centrifugal pumps varies from about 20 to 85 percent; the higher efficiency can be realized in the pumps with a capacity of 500 gpm or more. The peculiarities of the water system and effect they might produce on pumping cost should be studied from the pump curve characteristics. A typical curve is shown in Figure 3-33. All head and friction losses must be accurately determined in arriving at the total pumping head.

Centrifugal pumps that are above the pumping water level should have a foot valve on the pump suction line to retain the pump prime. However, foot valves sometimes leak, thereby requiring a water connection or other priming

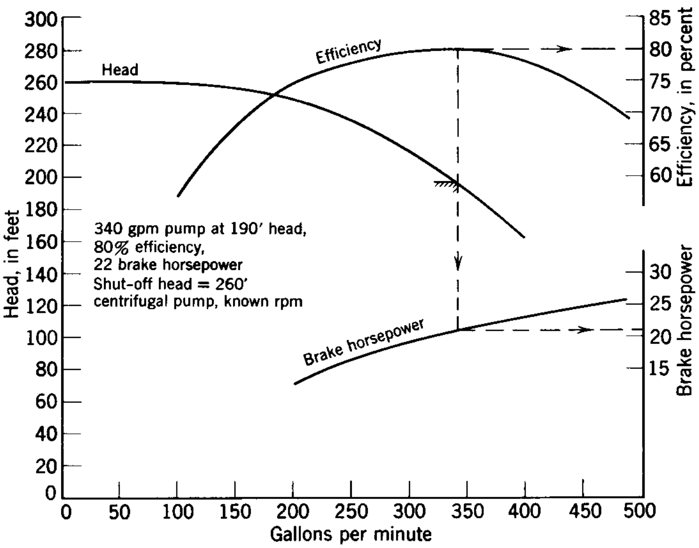


Figure 3-33 Typical centrifugal pump characteristic curves.

device or a new check valve on the suction side of the pump. The foot valve should have an area equal to at least twice the suction pipe. It may be omitted where an automatic priming device is provided. In the installation of a centrifugal pump, it is customary to install a gate valve on the suction line to the pump and a check valve followed by a gate valve on the pump discharge line near the pump. An air chamber, surge tank, or similar water-hammer suppression device should be installed just beyond the check valve, particularly on long pipelines or when pumping against a high head. Arrangements should be made for priming a centrifugal pump, unless the suction and pump are under a head of water, and the suction line should be kept as short as possible. The suction line should be sloped up toward the pump to prevent air pockets.

Pump maintenance items to check include cavitation, bearings, coupling alignments, packings, and mechanical seals. Pump manufacturers' catalog efficiencies do not include lift, friction losses in suction and discharge lines, elbow and increaser, or coupling, bearing frame, packing, or mechanical seal losses. Catalog efficiencies should be confirmed. Pump efficiency and capacity will vary with time—wear of bearings, disks or rings, stuffing box, impeller, and casing—as well as with pump and driver misalignment, change in pump speed, and increased pipe friction.

Jet Pump

The jet pump is actually a combination of a centrifugal pump and a water ejector down in a well below or near the water level. The pump and motor can be located some distance away from the well, but the pipelines should slope up to the pump about $1\frac{1}{2}$ in. in 20 ft. In this type of pump, part of the water raised is diverted back down into the well through a separate pipe. This pipe has attached to it at the bottom an upturned ejector connected to a discharge riser pipe that is open at the bottom. The water forced down the well passes up through the ejector at high velocity, causing a pressure reduction in the venturi throat, and with it draws up water from the well through the riser or return pipe. A jet pump may be used to raise small quantities of water 90 to 120 ft, but its efficiency is lowered when the lift exceeds 50 ft. Efficiency ranges from 20 to 25 percent. The maximum capacity is 50 gpm. There are no moving parts in the well. Jet pumps are shallow-well single-pipe-type (ejector at pump) and deep-well single- and multistage types (ejector in well). Multistage pumps may have impellers horizontal or vertical.

The air ejector pump is similar in operation to a water ejector pump except that air is used instead of water to create a reduced pressure in the venturi throat to raise the water.

Air-Lift Pump

In an air-lift pump, compressed air is forced through a small air pipe extending below the pumping water level in a well and discharged in a finely diffused state in a larger (education) pipe. The air–water mixture in the eduction pipe, being lighter than an equal volume of water, rises. The rise (weight of column of water) must at least equal the distance (weight of column of the same cross-sectional area) between the bottom of the eduction pipe and the water level in the well. A 60 percent submergence is best. For maximum efficiency, the distance from the bottom of the eduction pipe to the water level in the well should equal about twice the distance from the water surface to the point of discharge. The depth of submergence of the eduction pipe is therefore critical, as are the relative sizes of the air and eductor pipes. The area (in square inches) of the eduction pipe is

$$A = Q/20$$

where Q is the volume of water discharged (in gallons per minute) and

depends on V, the rate at which air is supplied (in cubic feet per minute):

$$V = Qh/125$$

where h is the distance between the water surface and the point of discharge (in feet).

Efficiencies vary from about 20 to 45 percent. The eduction pipe is about 1 in. smaller in diameter than the casing[316] (see also ref. 278, pp. 252–254).

The well casing itself can be used as the eductor pipe, provided it is not too much larger than the air pipe.

Hydraulic Ram

A hydraulic ram is a type of pump where the energy of water flowing in a pipe is used to elevate a smaller quantity of water to a higher elevation. An air chamber and weighted check valve are integral parts of a ram. Hydraulic rams are suitable where there is no electricity and the available water supply is adequate to furnish the energy necessary to raise the required quantity of water to the desired level. A battery of rams may be used to deliver larger quantities of water provided the supply of water is ample. Double-acting rams can make use of a nonpotable water to pump a potable water. The minimum flow of water required is 2 to 3 gpm with a fall of 3 ft or more. A ratio of lift to fall of 4 to 1 can give an efficiency of 72 percent, a ratio of 8 to 1 an efficiency of 52 percent, a ratio of 12 to 1 an efficiency of 37 percent, and a ratio of 24 to 1 an efficiency of 4 percent.[317,318] Rams are known to operate under supply heads up to 100 ft and a lift, or deliver heads, of 5 to 500 ft. In general, a ram will discharge from to of the water delivered to it. From a practical standpoint, it is found that the pipe conducting water from the source to the ram (known as the drive pipe) should be at least 30 to 40 ft long for the water in the pipe to have adequate momentum or energy to drive the ram. It should not, however, be on a slope greater than about 12° with the horizontal. If these conditions cannot be met naturally, it may be possible to do so by providing an open stand pipe on the drive pipeline, so that the pipe beyond it meets the conditions given. The diameter of the delivery pipe is usually about one-half the drive pipe diameter. The following formula may be used to determine the capacity of a ram:

$$Q = \frac{\text{supply to ram} \times \text{power head} \times 960}{\text{pumping head}}$$

where Q = gallons delivered per day
supply to ram = water delivered to and used by the ram, gpm
power head = available supply head of water, ft or fall
pumping head = head pumping against, ft, or delivery head

Note: This information plus the length of the delivery pipe and the horizontal distance in which the fall occurs are needed by manufacturers to meet specific requirements.

Pump and Well Protection

A power pump located directly over a deep well should have a watertight well seal at the casing as illustrated in Figures 3-11 and 3-12. An air vent is used on a well that has an appreciable drawdown to compensate for the reduction in air pressure inside the casing, which is caused by a lowering of the water level when the well is pumped. The vent should be carried 18 in. above the floor and flood level and the end should be looped downward and protected with screening. A downward-opening sampling tap located at least 12 in. above the floor should be provided on the discharge side of the pump. In all instances, the top of the casing, vent, and motor are located above possible flood level.

The top of the well casing or pump should not be in a pit that cannot be drained to the ground surface by gravity. In most parts of the country, it is best to locate pumps in some type of housing above ground level and above any high water. Protection from freezing can be provided by installing a thermostatically controlled electric heater in the pump house. Small, well-constructed, and insulated pump housings are sometimes not heated but depend on heat from the electric motor and a light bulb to maintain a proper temperature. Some type of ventilation should be provided, however, to prevent the condensation of moisture and the destruction of the electric motor and switches. See Figure 3-11.

Use of a submersible pump in a well would eliminate the need for a pump-house but would still require that the discharge line be installed below frost. See Figure 3-7.

Pump Power and Drive

The power available will usually determine the type of motor or engine used. Electric power, in general, receives first preference, with other sources used for standby or emergency equipment.

Steam power should be considered if pumps are located near existing boilers. The direct-acting steam pump and single, duplex, or triplex displacement pump can be used to advantage under such circumstances. When exhaust steam is available, a steam turbine to drive a centrifugal pump can also be used.

Diesel-oil engines are good, economical pump-driving units when electricity is not dependable or available. They are high in first cost. Diesel engines are constant low-speed units.

Gasoline engines are satisfactory portable or standby pump power units. The first cost is low, but the operating cost is high. Variable-speed control and direct connection to a centrifugal pump are common practice. Natural gas, methane, and butane can also be used where these fuels are available.

When possible, use of electric motor pump drive is the usual practice. Residences having low lighting loads are supplied with single-phase current, although this is becoming less common. When the power load may be 3 hp or more, three-phase current is needed. Alternating-current (AC) two- and three-phase motors are of three types: the squirrel-cage induction motor, the wound-rotor or slip-ring induction motor, and the synchronous motor. Single-phase motors are the repulsion–induction type having a commutator and brushes; the capacitator or condenser type, which does not have brushes and commutator; and the split-phase type. The repulsion–induction motor is, in general, best for centrifugal pumps requiring $\frac{3}{4}$ hp or larger. It has good starting torque. The all-purpose capacitor motor is suggested for sizes below $\frac{3}{4}$ hp. It is necessary to ensure the electric motor is grounded to the pump and to check the electrical code.

The *squirrel-cage motor* is a constant-speed motor with low starting torque but heavy current demand, low power factor, and high efficiency. Therefore, this type of motor is particularly suited where the starting load is large. Larger power lines and transformers are needed, however, with resultant greater power use and operating cost.

The *wound-rotor motor* is similar to the squirrel-cage motor. The starting torque can be varied from about one-third to three times that of normal, and the speed can be controlled. The cost of a wound-rotor motor is greater than a squirrel-cage motor, but where the pumping head varies, power saving over a long-range period will probably compensate for the greater first cost. Larger transformers and power lines are needed.

The *synchronous motor* runs at the same frequency as the generator furnishing the power. A synchronous motor is a constant-speed motor even under varying loads, but it needs an exciting generator to start the electric motor. Synchronous motors usually are greater in size than 75 to 100 hp.

An electric motor starting switch is either manually or magnetically operated. Manually operated starters for small motors (less than 1 hp) throw in the full voltage at one time. Overload protection is provided, but undervoltage protection is not. Full-voltage magnetic starters are used on most jobs. Overload and undervoltage control to stop the motor is generally included. Clean starter controls and proper switch heater strips are necessary. Sometimes a reduced voltage starter must be used when the power company cannot permit a full voltage starter or when the power line is too long. A voltage increase or decrease of more than 10 percent may cause heating of the equipment and winding and fire.

Lightning protection should be provided for all motors. Electric motors can be expected to have efficiencies of about 84 percent for motors under $7\frac{1}{2}$ hp to about 92 percent for motors of 60 hp or larger. Overall pump and motor efficiency of 65 percent can be achieved.[319] It is important to check with manufacturer and the National Electrical Manufacturers Association (NEMA).

Automatic Pump Control

One of the most common automatic methods of starting and stopping the operation of a pump on a hydropneumatic system is the use of a pressure switch. This switch is particularly adaptable for pumps driven by electric motors, although it can also be used to break the ignition circuit on a gasoline-engine-driven pump. The switch consists of a diaphragm connected on one side with the pump discharge line and on the other side with a spring-loaded switch. This spring switch makes and breaks the electric contact, thereby operating the motor when the water pressure varies between previously established limits.

Water-level control in a storage tank can be accomplished by means of a simple float switch. Other devices are the float with adjustable contacts and the electronic or resistance probes control and altitude valve. Each has advantages for specific installations.[320]

When the amount of water to be pumped is constant, a time cycle control can be used. The pumping is controlled by a time setting.

In some installations, the pumps are located at some distance from the treatment plant or central control building. Remote supervision can be obtained through controls to start or stop a pump and report pressure and flow data and faulty operation.

Another type of automatic pump switch is the pressure flow control. This equipment can be used on ground-level or elevated water storage tanks.

When pumps are located at a considerable distance from a storage tank and pressure controls are used to operate the pumps, heavy drawoffs may cause large fluctuations in pressure along the line. This will cause sporadic pump starting and stopping. In such cases and when there are two or more elevated tanks on a water system, altitude valves should be used at the storage tanks. An altitude valve on the supply line to an elevated tank or standpipe is set to close when the tank is full; it is set to open when the pressure on the entrance side is less than the pressure on the tank side of the valve. In this way, overflowing of the water tank is prevented, even if the float or pressure switch fails to function properly.

Water Hammer

Water hammer is the change in water pressure in a closed conduit (pipe) flowing full due to a very rapid acceleration or cessation of flow, resulting in very large momentary positive and negative pressure changes (surges) from normal. Causes are pump startup, pump power failure, valve operation, and failure of the surge protection device. Control devices used include vacuum breaker–air relief valves, controlled shutoff valves, flywheel on a pump motor, a surge tank, and a reservoir or standpipe floating on the distribution system. See Figure 3-32. Vacuum breaker–air relief valves are usually located at high points of distribution system pipelines. Pressure-relief valves are usually found in pump stations to control pressure surges and protect the pump station. Air chambers may have a diaphragm to separate the air–water interface to prevent absorption and loss of air in the chamber or an inert gas in place of air. They are used on short pipelines. Each pipeline system should be studied for possible water hammer problems and protected as indicated. Selection of the proper devices requires careful analysis and proper sizing.[321]

Rural Water Conditions in the United States[322]

A national assessment of rural water conditions made between May 1978 and January 1979 of a 2654-sample of 21,974,000 rural households (places with a population of less than 2500 and in open country) in the United States is shown in Table 3-29.

Ninety percent of the individual systems were well-water supplies, mostly drilled wells. The remainder relied on driven, bored, jetted, or dug wells as well as springs (275,000), cisterns (133,000), surface water (93,000), or hauled water (269,000). The median rural household system consisted of a 6-gpm pump and a 30-gal pressure tank with an effective volume of 0.3 gal. Systems in the west had a larger capacity. Ninety-one percent had piped water and an electric pump. Of the intermediate systems, 90 percent had two or three connections; 88 percent were drilled well supplies. Eighty-eight percent of the community systems had a median of 59 connections and 1.5 miles of distribution system. Ninety percent had groundwater sources and used an average of 36,000 gpd. Consolidated systems had a median of 153 connections. The median for average daily use was 43,000 gpd.

Nationally, 28.9 percent of all rural household water supplies had coliform concentrations exceeding the standard of 1/100 ml. Individual and intermediate systems were more often contaminated than community systems. Dug, driven, and jetted wells and springs were more likely to be contaminated. However, even the rural community systems showed significantly higher levels of coliform contamination than the larger public water systems. This points out sharply an unresolved problem and the need for greater attention to rural

TABLE 3-29 Rural Water Service and Water Quality

			Water	Quality
Water Service	Number of Systems	Number of Households[a]	% *E. coli*[b]	% Fecal *E. coli*
Individual systems	8,765,000	8,765,000	42.1	12.2
Intermediate systems[c]	845,000	2,228,000	43.3	12.2
Community systems[d]	34,000	10,981,000	15.5	4.5

Source: J. D. Francis et al., *National Assessment of Rural Water Conditions,* EPA 570/9-84-004, U.S. Environmental Protection Agency, Office of Drinking Water, Washington, DC, June 1984.

[a] Median of 2.65 persons per household.

[b] More than one per 100 ml.

[c] 2 to 14 connections.

[d] 15 or more connections.

water supplies, including the 34,000 rural community systems. The need for improved well and spring location, construction, and protection and competent intermediate and community system operation is apparent.

Design of a Household Water System

Major considerations in the design of a well-water system for a private dwelling are a dependable well yield and a well pump of adequate capacity and operating head. Figure 3-4 shows a well log and well yield testing. Figure 3-25 shows the probable range of the maximum momentary water demand for one or more dwelling units. See also Figure 3-26 for fixture unit basis for demand load in gallons per minute and Figure 3-29 for pressure tank and pump size. Figure 3-34 shows the components that make up the total well pump operating head. Table 3-27 gives recommended pump capacities and supplements text suggestions.

Residential Fire Sprinkler Design

Concern for fire protection using sprinklers extends to residential dwellings. Water requirement by hydraulic analysis is usually based on supplying 26 gpm to one or two sprinkler heads for not less than 10 to 20 min. Each sprinkler may cover an area 18 $\times$ 18 ft with a residual water pressure of 5 psi. A 1- to $1\frac{1}{2}$-in. water service is needed for the average dwelling, depending on the available pressure.

Where a dwelling has its own well-water system, a minimum 400-gal storage tank at a proper elevation is usually required, with consideration to the well and pump capacity. Consultation with the local building department, a fire protection engineer, and the state fire Insurance Services Office is advised even if not required.

EXAMPLES

Design of Small Water Systems

Small water systems, serving less than 10,000 households, supplied about 42 million people in the United States (1980 statistics). Many of these systems are marginally designed and poorly operated and maintained due to insufficient budgets, very low water rates, poorly paid and trained operators, and uninformed management. Such systems are frequently inadequately monitored and fail to meet drinking water standards. Some are too small to provide sufficient revenue to support proper operation, maintenance, and management. Very often, small water systems are the only alternative for small isolated communities and developments. A partial answer, where feasible, is the consolidation of small water systems or connection to a large municipal system.

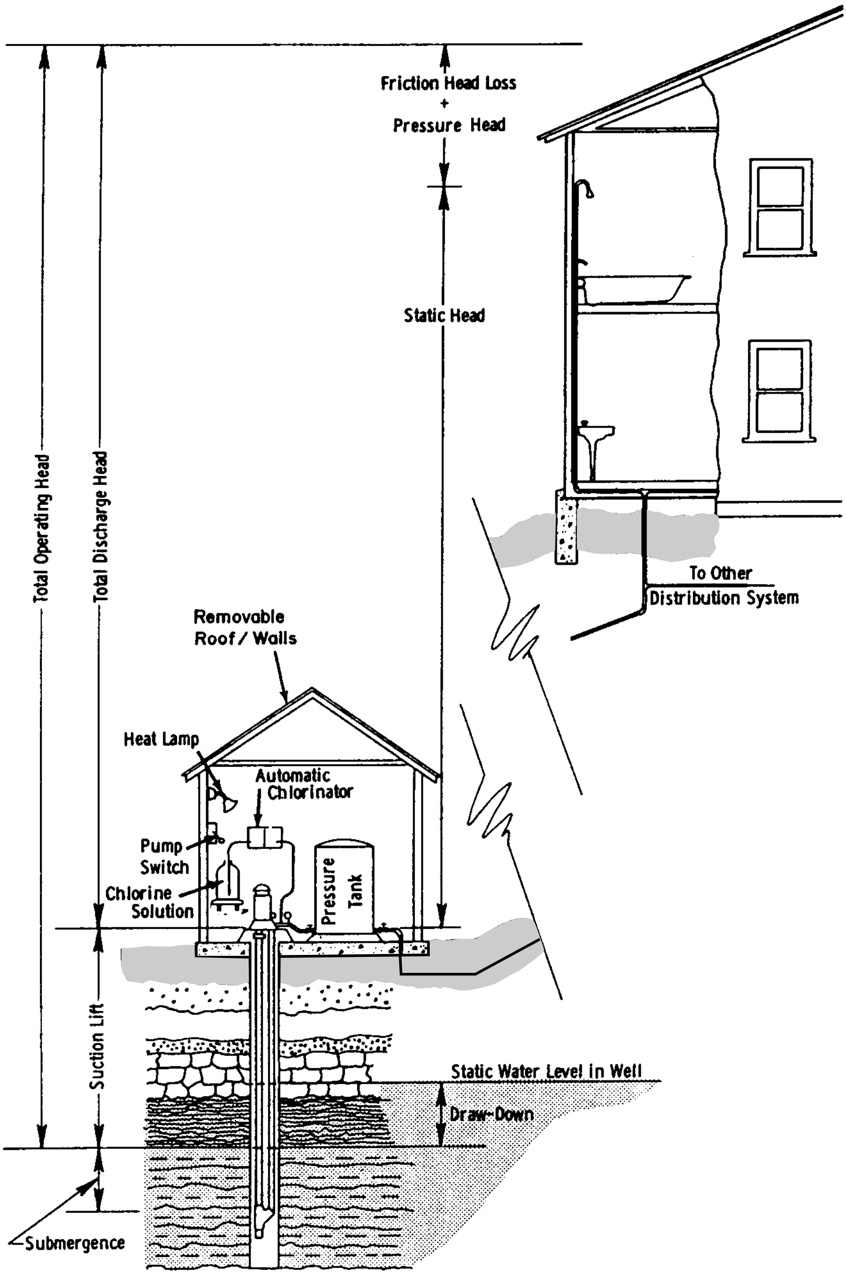


Figure 3-34 Components of total operating head in well pump installations. (*Source: Manual of Individual Water Systems,* EPA-570/9-82-004, U.S. EPA, Office of Drinking Water, Washington, DC, October 1982, p. 102.)

Other alternatives include regional management of several small systems, including professional supervision, administration, and technical and financial assistance. Rural water associations, local water works associations, and regulatory agencies can, and in many areas do, provide training programs, seminars, and speakers to meet some of the needs. Compliance with drinking water standards, operational problems, and maintenance can be discussed. The opportunity to share experiences is provided and made accessible to the small water system operator.

Experiences in new subdivisions show that peak water demands of 6 to 10 times the average daily consumption rate are not unusual. Lawn-sprinkling demand has made necessary sprinkling controls, metering, or the installation of larger distribution and storage facilities and, in some instances, ground storage and booster stations. As previously stated, every effort should be made to serve a subdivision from an existing public water supply. Such supplies can afford to employ competent personnel and are in the business of supplying water, whereas a subdivider is basically in the business of developing land and does not wish to become involved in operating a public utility.

In general, when it is necessary to develop a central water system to serve the average subdivision, consideration should first be given to a drilled well-water supply. Infiltration galleries or special shallow wells may also be practical sources of water if their supply is adequate and protected. Such water systems usually require a minimum of supervision and can be developed to produce a known quantity of water of a satisfactory sanitary quality. Simple chlorination treatment will normally provide the desired factor of safety. Test wells and sampling will indicate the most probable dependable yield and the chemical and bacterial quality of the water. Well logs should be kept in duplicate.

Where a clean, clear lake supply or stream is available, chlorination and slow sand filtration can provide reliable treatment with daily supervision for the small development. The turbidity of the water to be treated should not exceed 30 NTU. Preliminary settling may be indicated in some cases.

Other more elaborate types of treatment plants, such as rapid sand filters, are not recommended for small water systems unless specially trained operating personnel can be assured. Pressure filters have limitations, as explained earlier in this chapter.

The design of small slow sand filter and well-water systems is explained and illustrated earlier in Figures 3-17 and 3-18 and below in Figure 3-37.

An example (Figure 3-35) will serve to illustrate the design bases previously discussed. The design population at a development consisting of 100 two-bedroom dwellings, at two persons per bedroom, is 400. The average water use at 75 gal per person or 150 gal per bedroom is 30,000 gpd for the development. From Figure 3-25, the peak demand can vary from 100 to 320 gpm. An average conservative maximum or peak demand would be 210 gpm. Adjustment should be made for local conditions. This design provides no fire protection.

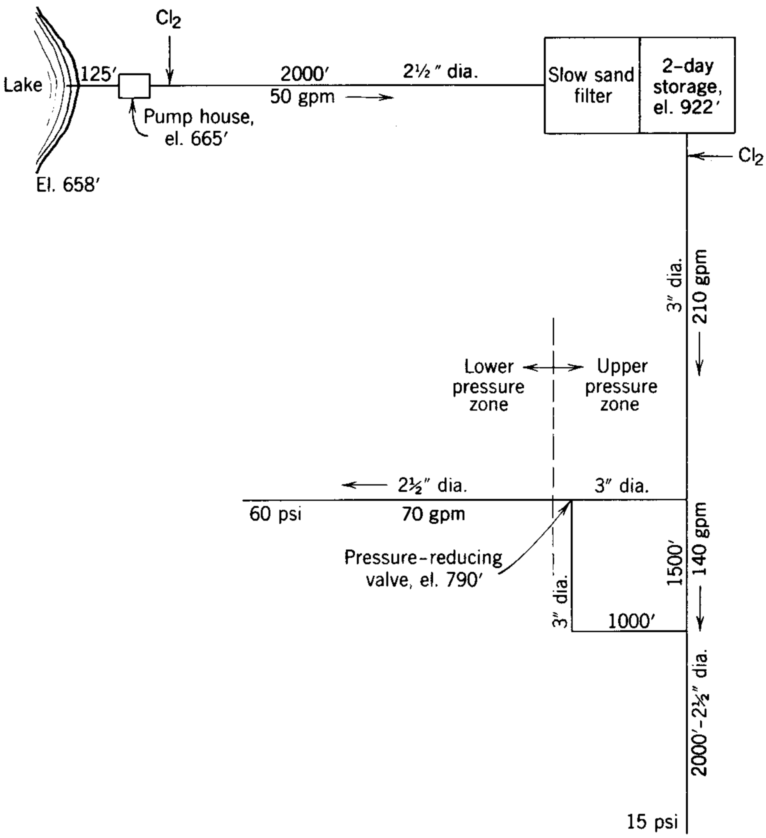


Figure 3-35 Water system flow diagram.

Examples showing calculations to determine pipe diameters, pumping head, pump capacity, and motor size follow.

In one instance, assume that water is pumped from a lake at an elevation of 658 ft to a slow sand filter and reservoir at an elevation of 922 ft. See Figure 3-35. The pump house is at an elevation of 665 ft and the intake is 125 ft long. The reservoir is 2000 ft from the pump. All water is automatically chlorinated as it is pumped. The average water consumption is 30,000 gpd. With the reservoir at an elevation of 922 ft, a pressure of at least 15 lb/in.^{2} is to be provided at the highest fixture. Find the size of the intake and discharge pipes, the total pumping head, the size pump, and motor. The longest known power failure is 14 hr and repairs can be made locally. Assume that the pump capacity is sufficient to pump 30,000 gal in 10 hr, or 50 gpm. Provide one 50-gpm pump and one 30-gpm standby, both multistage centrifugal pumps, one to operate at any one time and one generator.

From the above, with a flow of 50 gpm, a 2-in. pipeline to the storage tank is indicated.

The head losses, using Tables 3-30 and Table 3-31, are

$$\text{Intake, 125 ft of 2-in. pipe } (3.3 \times 1.25) = 4.1 \text{ ft}$$

For this calculation, assume the entrance loss and loss through pump are negligible. Say that there are four long elbows = 16.8 ft; two globe valves = 140 ft; one check valve = 16 ft; three standard elbows = 18.9 ft; and two 45° elbows = 6 ft. Total equivalent pipe = 198 ft of $2\frac{1}{2}$-in. pipe; head loss = 3.3 × 1.98:

discharge pipe, 2000 ft of $2\frac{1}{2}$-in. = 3.3 × 20	= 66.0 ft;
total friction head loss	= 76.6 ft;
suction lift = 7 ft to center of pump	= 7.0 ft;
static head, difference in elevation = 922 − 655	= 257.0 ft;
no pressure at point of discharge; and	
total head	= 340.6 ft.

Add for head loss through meters if used (Table 3-32).

If a 3-in. intake and discharge line is used instead of a $2\frac{1}{2}$-in. intake, the total head can be reduced to about 300 ft. The saving thus effected in power consumption would have to be compared with the increased cost of 3-in. pipe over $2\frac{1}{2}$-in. pipe. The additional cost of power would be approximately $76.65 per year, with the unit cost of power at $0.02/kW-hr. This calculation is shown below using approximate efficiencies.*

For a 340-ft head,

$$\text{Horsepower to motor} = \frac{\text{gpm} \times \text{total head in ft}}{3960 \times \text{pump efficiency} \times \text{motor efficiency}}$$

$$= \frac{50 \times 340}{3960 \times 0.45 \times 0.83} = 11.5$$

$$11.5 \text{ hp} = 11.5 \times 0.746 \text{ kW} = 8.6 \text{ kW}^{\dagger}$$

In 1 hr, at 50 gpm, 50 × 60, or 3000 gal, will be pumped and the power used will be 8.6 kW-hr. To pump 30,000 gal of water will require 8.6 × (30,000/3000) = 86 kW-hr.

If the cost of power is $0.02/kW-hr, the cost of pumping 30,000 gal of water per day will be 86 × 0.02 = 1.72, or $1.72.

* Adjust costs and interest rates to current conditions.

† Check pump and motor efficiencies with manufacturers.

TABLE 3-30 Friction Due to Water Flowing in Pipe

Capacity (gpm)	Friction Head Loss by Pipe Diameter[a]														
	1	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	6	8	10	12	14
1	2.1														
2	7.4	1.9													
3	15.8	4.1	1.3												
4	27.0	7.0	2.1	0.57											
5	41.0	10.5	3.2	0.84	0.40										
8	98.0	25.0	7.8	2.0	0.95										
10		38.0	11.7	3.0	1.4	0.50									
15		80.0	25.0	6.5	3.1	1.1									
20		136.0	42.0	11.1	5.2	1.8	0.61								
25			64.0	16.6	7.8	2.7	0.95	0.40							
30			89.0	23.5	11.0	3.8	1.3	0.54							
35			119.0	31.2	14.7	5.1	1.7	0.75							
40			152.0	40.0	18.8	6.6	2.2	0.91							
50				60.0	28.4	9.9	3.3	1.4							
60				85.0	39.6	13.9	4.6	1.9	0.47						
70				113.0	53.0	18.4	6.2	2.6	0.63						
80					68.0	23.7	7.9	3.3	0.81						
90					84.0	29.4	9.8	4.1	1.0						

TABLE 3-30 (*Continued*)

Capacity (gpm)	Friction Head Loss by Pipe Diameter[a]														
	1	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	6	8	10	12	14
100					102.0	35.8	12.0	5.0	1.2	0.41					
125						54.0	18.2	7.6	1.9	0.64					
150						76.0	26.0	10.5	2.6	0.87					
175						102.0	33.8	14.0	3.4	1.2					
200						129.0	43.1	17.8	4.4	1.5	0.62				
225							54.0	22.0	5.3	1.8	0.72				
250							65.0	27.1	6.7	2.2	0.92				
300							92.0	38.0	9.3	3.1	1.3				
400								65.0	16.0	5.4	2.2				
500								98.0	24.0	8.1	3.3	0.83			
600									33.8	11.7	4.7	1.2			
700									45.0	15.2	6.2	1.5	0.52		
800									57.6	19.4	8.0	2.0	0.67		
900									71.6	24.2	10.0	2.5	0.83		
1000									87.0	29.4	12.1	3.0	1.0	0.42	
1500										62.2	25.6	6.3	2.1	0.88	0.42
2000											43.6	10.8	3.6	1.5	0.71
3000												22.8	7.7	3.2	1.5
4000													13.1	5.4	2.6
5000													19.8	8.2	3.8

[a] In inches.

TABLE 3-31 Friction of Water in Fittings

	Friction Head Loss as Equivalent Number of Feet of Straight Pipe by Pipe Size (in.) (nominal diameter)											
Pipe Fitting	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	5	6
Open gate valve	0.4	0.5	0.6	0.8	0.9	1.2	1.4	1.7	2.0	2.3	2.8	3.5
Three-quarters closed gate valve	40.0	60.0	70.0	100.0	120.0	150.0	170.0	210.0	250.0	280.0	350.0	420.0
Open globe valve	19.0	23.0	29.0	38.0	45.0	58.0	70.0	85.0	112.0	120.0	140.0	170.0
Open angle valve	8.4	12.0	14.0	18.0	22.0	28.0	35.0	42.0	50.0	58.0	70.0	85.0
Standard elbow or through reducing tee	1.7	2.2	2.7	3.5	4.3	5.3	6.3	8.0	9.3	11.0	13.0	16.0
Standard tee	3.4	4.5	5.8	7.8	9.2	12.0	14.0	17.0	19.0	22.0	27.0	33.0
Open swing check	4.3	5.3	6.8	8.9	10.4	13.4	15.9	19.8	24.0	26.0	33.0	39.0
Long elbow or through tee	1.1	1.4	1.7	2.3	2.7	3.5	4.2	5.1	6.0	7.0	8.5	11.0
Elbow 45°	0.75	1.0	1.3	1.6	2.0	2.5	3.0	3.8	4.4	5.0	6.1	7.5
Ordinary entrance	0.9	1.2	1.5	2.0	2.4	3.0	3.7	4.5	5.3	6.0	7.5	9.0

Note: The frictional resistance to flow offered by a meter will vary between that offered by an open angle valve and globe valve of the same size. See manufacturers for meter and check valve friction losses; also Table 3-32. See manufacturer for head loss in butterfly, rotary, and special valves.

TABLE 3-32 Head Loss Through Meters

Flow (gpm)	Head Loss through Meter by Meter Size[a] (psi)								
	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	3	4	6
4	1								
6	2								
8	4	1							
10	6	2	1						
15	14	5	2	2					
20	25	9	4	3	1				
30		20	8	7	2	1			
40			15	12	4	2			
50			23	18	6	3			
75					14	5	1		
100					25	10	3	1	
200							10	4	1
300							24	9	2
400								16	4
500								25	6

Source: Adapted from G. Roden, "Sizing and Installation of Service Pipes," *J. Am. Water Works Assoc.* **38,** 5 (May 1946). Copyright 1946 by the American Water Works Association. Reprinted with permission.

Note: that flows of less than $\frac{1}{4}$ gpm are not usually registered by domestic meters.

[a] In inches.

For a 300-ft head,

$$\text{Horsepower} = \frac{50 \times 300}{3960 \times 0.45 \times 0.83} = 110.1 \text{ hp}$$

$$= 10.1 \times 0.746 \text{ kW} = 7.55 \text{ kW}$$

In 1 hr, 3000 gal will be pumped as before, but the power used will be 7.55 kW-hr. To pump 30,000 gal will require 7.55 × 10 = 75.5 kW-hr.

If the cost of power is $0.02 per kW-hr, the cost of pumping 30,000 gal will be 75.5 × 0.02 = 1.51, or $1.51.

The additional power cost due to using 2-in. pipe is 1.72 − 1.51 = $0.21 per day, or $76.65 per year.

At 4 percent interest (i), compounded annually for 25 years (n), $76.65 ($D$) set aside each year would equal about $3200 ($S$), as shown below:

$$D = \frac{i}{(1 + i)^n - 1} \times S \qquad 76.65 = \frac{0.04}{1 + 0.04)^{25} - 1}$$

$$S = \frac{76.65}{0.024} = \$3194, \quad \text{say } \$3200$$

This assumes that the life of the pipe used is 25 years and the value of money

4 percent. If the extra cost of 3-in. pipe over $2\frac{1}{2}$-in. pipe plus interest on the difference minus the saving due to purchasing a smaller motor and lower head pump is less than \$1200 (present worth of \$3200), then 3-in. pipe should be used.

The size of electric motor to provide for the 50-gpm pump against a total head of 340 ft is shown above to be 11.5 hp. Since this is a nonstandard size, the next larger size, a 15-hp motor, will be provided. If a smaller motor is used, it might be overloaded when pumping head is decreased.

The size of electric motor to provide for the 30-gpm pump is

$$\text{Horsepower to motor drive} = \frac{\text{gpm} \times \text{total head in ft}}{3960 \times \text{pump efficiency} \times \text{motor efficiency}}$$

But the total head loss through 2-in. pipe when pumping 30 gpm would be as follows:

Intake, 125 ft or $2\frac{1}{2}$-in. pipe	125	
Fittings, total equivalent pipe	198	
Discharge pipe, 2000 ft of $2\frac{1}{2}$-in.	2000	
Total friction head loss	$2323 \times \frac{1.3}{100}$	= 32 ft
Suction lift		= 9
Static head		= 255
Total head		= 296 ft

Horsepower to motor drive

$$\frac{30 \times 296}{3960 \times 0.35 \times 0.85} = 7.55 \text{ (use } 7\tfrac{1}{2}\text{-hp electric motor)}$$

Because of the great difference in elevation (658 to 922 ft), it is necessary to divide the distribution system into two zones so that the maximum pressure in pipes and at fixtures will not be excessive. In this problem, all water is supplied the distribution system at elevation 922 ft. A suitable dividing point would be at elevation 790 ft. All dwellings above this point would have water pressure directly from the reservoir, and all below would be served through a pressure-reducing valve to provide not less than 15 lb/in.^{2} at the highest fixture or more than 60 lb/in.^{2} at the lowest fixture. If two-thirds of the dwellings are in the upper zone and one-third is in the lower zone, it can be assumed that the peak or maximum hourly demand rate of flow will be similarly divided (Figure 3-35).

Assume the total maximum hourly or peak demand rate of flow for an average daily water consumption of 30,000 gpd to be 210 gpm. Therefore, 70 + 140 gpm can be taken to flow to the upper zone and 70 gpm to the lower zone. If a 3-in. pipe is used for the upper zone and water is uniformly drawn off, the head loss at a flow of 210 gpm would be about $\frac{1}{3} \times 20$ ft per 100 ft of pipe. And if $2\frac{1}{2}$-in. pipe is used for the lower zone and water is uniformly drawn off in its length, the head loss at a flow of 70 gpm would be about $\frac{1}{3} \times 6.2$ ft per 100 ft of pipe. If the pipe in either zone is connected to form a loop, thereby eliminating dead ends, the frictional head loss would be further reduced to one-fourth of that with a dead end for the portion forming a loop. Check all head losses.

In all of the above considerations, actual pump and motor efficiencies obtained from and guaranteed by the manufacturer should be used whenever possible. Their recommendations and installation detail drawings to meet definite requirements should be requested and followed if it is desired to fix performance responsibility.

In another instance, assume that all water is pumped from a deep well through a pressure tank to a distribution system. See Figure 3-36. The lowest pumping water level in the well is at elevation 160, the pump and tank are at elevation 200, and the highest dwelling is at elevation 350. Find the size pump, motor and pressure storage tank, operating pressures, required well yield, and size mains to supply a development consisting of 100 two-bedroom dwellings using an average of 30,000 gpd.

Use a deep-well turbine pump. The total pumping head will consist of the sum of the total lift plus the friction loss in the well drop pipe and connection to the pressure tank plus the friction loss through the pump and pipe fittings plus the maximum pressure maintained in the pressure tank. The maximum pressure in the tank is equal to the friction loss in the distribution system plus the static head caused by the difference in elevation between the pump and the highest plumbing fixture plus the friction loss in the house water system, including meter if provided, plus the residual head required at the highest fixture.

With the average water consumption at 30,000 gpd, the maximum hourly or peak demand was found to be 210 gpm. The recommended pump capacity is taken as 125 percent of the maximum hourly rate, which would be 262 gpm. This assumes that the well can yield 262 gpm, which frequently is not the case. Under such circumstances, the volume of the storage tank can be

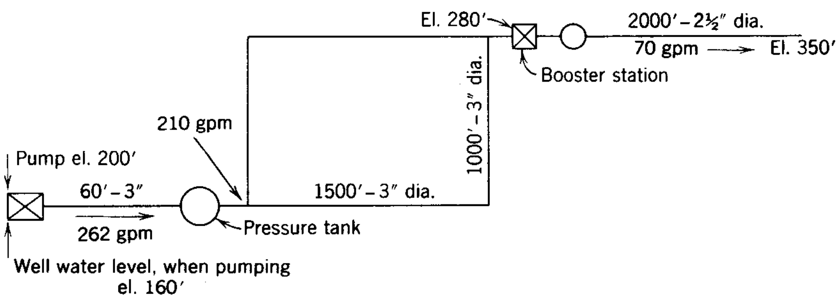


Figure 3-36 A water system flow diagram with booster station.

increased two or three times, and the size of the pump correspondingly decreased to one-half or one-third the original size to come within the well yield. Another alternative would be to pump water out of the well, at a rate equal to the safe average yield of the well, into a large ground-level storage tank from which water can be pumped through a pressure tank at a higher rate to meet maximum water demands. This would involve double pumping and hence increased cost. Another arrangement, where possible, would be to pump out of the well directly into the distribution system, which is connected to an elevated storage tank. Although it may not be economical to use a pressure-tank water system, it would be of interest to see just what this would mean.

The total pumping head would be

Lift from elevation 160–200 ft = 40 ft 40 ft

Figure 3-36 shows a distribution system that forms a rectangle 1000 × 1500 ft with a 2000-ft dead-end line serving one-third of the dwellings taking off at a point diagonally opposite the feed main. The head loss in a line connected at both ends is approximately one-fourth that in a dead-end line. The head loss in one-half the rectangular loop, from which water is uniformly drawn off, is one-third the loss in a line without drawoffs. Therefore, the total head loss in a 3-in. pipeline with a flow of about 210 gpm is equal to

$$\frac{1}{4} \times \frac{1}{3} \times \frac{20}{100} \times 2500 = 42 \text{ ft}$$

and the head loss through a 2000-ft dead-end line, with water being uniformly drawn off, assuming a flow of 70 gpm through $2\frac{1}{2}$-in. pipe is equal to

$$\frac{1}{3} \times \frac{6.2}{100} \times 2000 = 41 \text{ ft}$$

This would make a total of 42 + 41, or 83, ft. 83 ft

(For a more accurate computation of the head loss in a water distribution grid system by the equivalent pipe, Hardy Cross, or similar method, the reader is referred to standard hydraulic texts. However, the assumptions made here are believed sufficiently accurate for our purpose.)

The static head between pump and the curb of the highest dwelling plus the highest fixture is (350 − 200) + 12 = 162 ft. 162 ft

The friction head loss in the house plumbing system (without a meter) is equal to approximately 20 ft. 20 ft

The residual head at highest fixture is approximately 20 ft. 20 ft

The friction loss in the well drop pipe and connections to the pressure tank and distribution system with a flow of 262 gpm in a total equivalent length of 100 ft of 3-in. pipe is 30 ft. 30 ft

The head loss through the pump and fittings is assumed negligible.	355
Total pumping head	= 147 psi

Because of the high pumping head and so as not to have excessive pressures in dwellings at low elevations, it will be necessary to divide the distribution system into two parts, with a booster pump and pressure storage tank serving the upper half.

If the booster pump and storage tank are placed at the beginning of the 2000 ft of $2\frac{1}{2}$-in. line, at elevation 280 ft, only one-third of the dwellings need be served from this point. The total pumping head here would be as follows:

Friction loss in 2000 ft of $2\frac{1}{2}$-in. pipe with water withdrawn uniformly along its length and a flow of 70 gpm is	41 ft

$$\frac{1}{3} = 210 \times \frac{6.2}{100} = 41 \text{ ft}$$

The static head between the booster pump and the curb of the highest dwelling plus the highest fixture is

$(350 - 280) + 12 = 82$ ft	82 ft
The head loss in the house plumbing is 20 ft.	20 ft
The residual pressure at highest fixture is 20 ft.	20 ft
Booster pumping station total head	163 ft
	= 71 psi

The total pumping head at the main pumping station at the well would be as follows:

Lift in well is 40 ft.	40 ft
Friction loss in distribution system forming loop* is 42 ft.	42 ft
The static head between the pump and the booster station, which is also adequate to maintain a 20-ft head at the highest fixture, is $280 - 200 = 80$ ft.	80 ft
Friction loss in well-drop pipe and connections to the distribution system is 30 ft.	30 ft
Main pumping station, total head	192 ft
	= 84 psi

With an average daily water consumption of 30,000 gal, the average daily maximum demand, on a monthly basis, would be $30{,}000 \times 1.5 = 45{,}000$ gal. The ratio of the absolute maximum and minimum operating pressures at the main pumping station, using a 10-lb differential, would be

*At 210 gpm, peak flow $(\frac{1}{4} \times \frac{1}{3} \times \frac{20}{100} \times 2500) = 42$ ft.

$$\frac{84 + 14.7}{94 + 14.7} = \frac{98.7}{108.7} = 0.908, \quad \text{say } 0.90$$

From Figure 3-29 the pressure tank volume should be (28,500 gal) about 30,000 gal if 15 min of storage is to be provided at the maximum demand rate, 10,000 gal if 5 min storage is acceptable, or 2000 gal if 1 min storage is acceptable, with a standby pump and well of adequate capacity. When the average monthly maximum water consumption exceeds that in Figure 3-29, multiply the vertical *and* horizontal axis by 5 or 10 (or other suitable factor) to bring the reading within the desired range. The pump capacity, as previously determined, should be 262 gpm. Use a 260-gpm pump. If a 20-lb pressure differential is used, $P_1/P_2 = 0.83$, and Figure 3-29 indicates an 18,000-gal pressure tank could be used to provide 15 min storage at the probable maximum hourly demand rate of flow, or 6000 gal for 5 min storage.

The booster pumping station serve one-third of the population; hence, the average daily maximum demand on a monthly basis would be $\frac{1}{3}$(45,000), or 15,000, gal. The ratio of the absolute maximum and minimum operating pressures at the booster pumping station using a 10-lb differential would be

$$\frac{71 + 14.7}{81 + 14.7} = \frac{85.7}{95.7} = 0.90$$

From Figure 3-29, the pressure tank should have a volume of about 10,000 gal to provide 15 min storage at times of peak demand. The pump capacity should be 78 gpm. Use a 75-gpm pump. On the other hand, if the operating pressure differential is 20 lb and only 5 min storage at peak demand is desired, the required pressure tank volume would be 1600 gal.

To determine the required size of motor for the main pumping station and booster pumping stations, use the average of the maximum and minimum operating gauge pressures as the pumping head. The size motor for the main pumping station using manufacturer's pump and motor efficiencies is:

$$\frac{262 \text{ gpm} \times (192 + 11\frac{1}{2}) \text{ ft avg. had}}{3960 \times 0.57 \times 0.85} = 27.8$$

Use a 30-hp motor. The size motor for the booster station is

$$\frac{70 \text{ gpm} \times (163 + 11\frac{1}{2}) \text{ ft avg. head}}{3960 \times 0.50 \times 0.80} = 7.7$$

Use a $7\frac{1}{2}$- or 10-hp motor.

In the construction of a pumping hydropneumatic station, provision should be made for standby pump and motive power equipment.

The calculations are based on the use of a multistage centrifugal-type pump. Before a final decision is made, the comparison should include the relative merits and cost using a displacement-type pump. Remember that price and efficiency, although important when selecting a pump, are not the only factors to consider. The requirements of the water system and peculiarities should be anticipated and a pump with the desirable characteristics selected.

Design of a Camp Water System

A typical hydraulic analysis and design of a camp water system is shown in Figure 3-37.

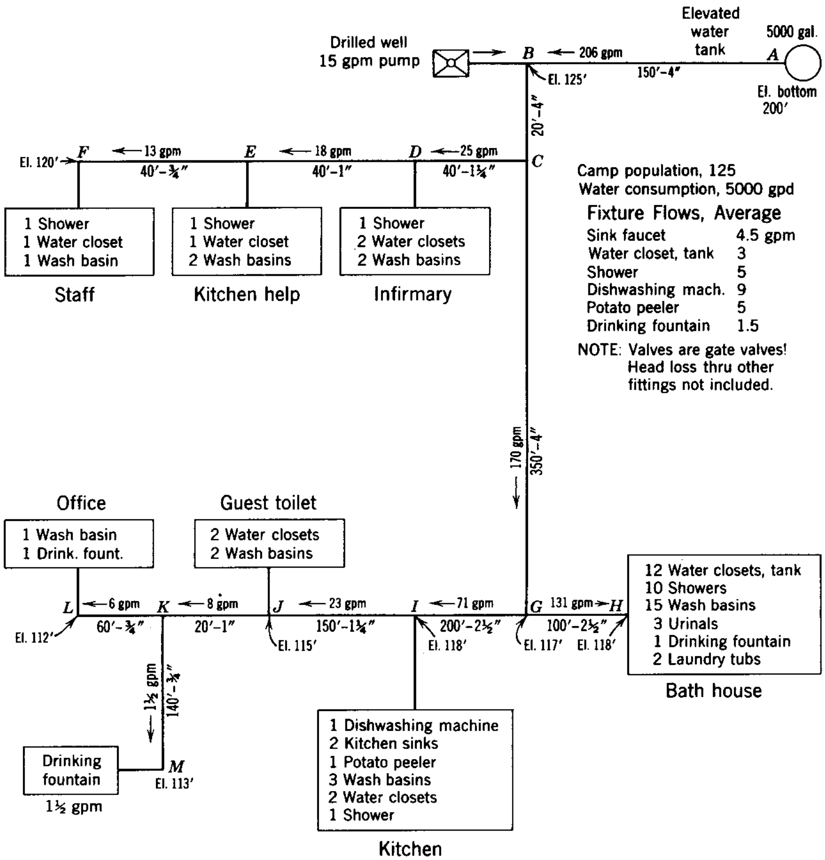
Water System Cost Estimates

Because of the wide variations in types of water systems and conditions under which they are constructed, it is impractical to give reliable cost estimates. Some approximations are listed to provide insight into the costs involved. Adjust costs using Engineering News Record (ENR) or other appropriate construction cost index. (See Table 4–30.)

1. The approximate costs (1990) of water pipes, valves, and hydrants, including labor and material but not including engineering, legal, land, and administrative costs are as follows*:

$\frac{3}{4}$-in. copper pipe, per ft	$ 10
1-in. copper pipe, per ft	12
$1\frac{1}{4}$-in. copper pipe, per ft	15
$1\frac{1}{2}$-in. copper pipe, per ft	19
$\frac{3}{4}$-in. service taps and curb boxes	150
6-in. ductile iron pipe, per ft	$15–20
8-in. ductile iron pipe, per ft	18–23
12-in. ductile iron pipe, per ft	25–30
16-in. ductile iron pipe, per ft	32–35
6-in. ABS or PVC pipe, per ft	$15–17
8-in. ABS or PVC pipe, per ft	18–20
10-in. ABS or PVC pipe, per ft	24–28
12-in. ABS or PVC pipe, per ft	32–40

*The assistance of Kestner Engineers, P. C., Troy, NY, is gratefully acknowledged in arriving at the cost estimates.



Distance			Gpm Flow			Head Available (Ft)				Pipe Size (in.)	Head Loss		Head (Ft Remaining)	Facility Served
From	To	Ft	Max.	%	Probable	Initial	+ Fall	− Rise	Total		Ft per 100 ft	Total		
A	C	170	295	70	206	0	75	0	75	4	4.5	7.6	67.4	
C	D	40	50	50	25	67.4	1.6	0	69	1¼	16.6	6.6	62.4	Inf., kitch., staff
D	E	40	30	60	18	62.4	1.0	0	63.4	1	36	14.4	49.0	Kitch., staff
E	F	40	13	90	12	49.0	1.6	0	50.6	¾	52	21	29.6	Staff cabin
C	G	350	245	70	170	67.4	8.0	0	75.4	4	3.4	11.9	63.5	
G	H	100	174	75	131	63.5	0	1	62.5	2½	20	20	42.5	Bath house
G	I	200	71	100	71	63.5	0	1	62.5	2½	6	12	50.5	Kitch. guest, off.
I	J	150	23	100	23	50.5	3.0	0	53.5	1¼	15	22	31.5	
J	K	20	8	100	8	31.5	0	0	31.5	1	7.8	1.6	29.9	
K	L	60	6	100	6	29.9	3.0	0	32.9	¾	12	7.2	25.7	Office
K	M	140	1½	100	1½	25.7	2.0	0	27.7	¾	1.0	1.4	26.3	Drink. fount.

Figure 3-37 Typical hydraulic analysis of camp water system. (See 4–36.)

6-in. double-gate valve and box	$300–400
8-in. double-gate valve and box	500–600
12-in. butterfly valve and box	600–800
6-in. hydrant assembly including valve, and tee on main	2300

2. Elevated storage, small capacity—20,000-gal capacity, \$50,000 to \$56,000; 50,000 gal, \$75,000 to \$134,000; 100,000 gal, \$124,000 to \$200,000. Ground-level storage—41,000 gal, \$45,000; 50,000 gal, \$54,000; 72,000 gal, \$57,000; 92,000 gal, \$63,000 (1990 cost).[323] For larger installations, standpipe costs may run \$90,000 for capacity of 0.15×10^6 gal; \$210,000 for 0.5×10^6 gal; \$350,000 for 1.0×10^6 gal; and \$750,000 for 3.0×10^6 gal. For elevated tanks, cost may run \$180,000 for 0.15×10^6 gal; \$460,000 for 0.5×10^6 gal; \$815,000 for 1.00×10^6 gal; and \$1,900,000 for 3.0×10^6 gal (1990 adjusted cost).
3. A complete conventional rapid sand filter plant including roads, landscaping, lagoons, laboratory, and low-lift pumps may cost \$450,000 for a 0.3-mgd plant; \$660,000 for a 0.5-mgd plant; \$1,120,000 for a 1.0-mgd plant; \$2,500,000 for a 3.0-mgd plant; \$3,700,000 for a 5.0-mgd plant; \$6,000,000 for a 10.0-mgd plant; and \$10,300,000 for a 20.0-mgd plant (1990 adjusted cost).
4. The annual cost of water treatment plants (at 7 percent, 20 years) has been estimated at \$63,000, \$126,000, and \$188,000 for 70-, 350-, and 700-gpm complete treatment package plants; \$600,000 for 5-mgd plant; \$240,000 and \$728,000 for 1- and 10-mgd direct filtration plants; and \$376,000 and \$1,600,000 for a 2- and 20-mgd GAC plants (1990 cost).[324]
5. Iron and manganese removal plant, well supply, 3 mgd \$1,700,000, including new well pumps and disinfection equipment, site work and treatment building (1990 adjusted cost).
6. Well construction costs including engineering, legal, and site development have been estimated[325] as follows:

Cost—Adjusted to 1990 ENR Construction Cost Index

Yield, gpm	70	350	500	600	700
Type	Drilled	Gravel Pack	Gravel Pack	Drilled	Gravel Pack
Diameter, in.	10	16–12	18–12	16	16–12
Depth, ft	40	50	80	68	50
Pump	Submersible	Turbine	Turbine	Turbine	Turbine 2 wells
Average Cost	\$186,000	\$285,600	\$276,000	\$300,000	\$560,000

7. The National Water Well Association reported it costs \$3000 to drill a private domestic well, \$12,000 to drill an irrigation well, and \$45,000 to drill a municipal or industrial well.[326] The average cost of a 6-in. drilled well is estimated at \$7 to \$15 per foot plus \$7 to \$10 per foot

for steel casing. A shallow well pump may cost $270 to $450 and a deep well pump $530 to $1900, plus installation (1990 adjusted cost).

CLEANING AND DISINFECTION

Special precautions must be taken before entering an open or covered well, spring basin, reservoir, storage tank, manhole, pump pit, or excavation to avoid accidents due to lack of oxygen (and excess carbon dioxide) or exposure to hazardous gases such as hydrogen sulfide or methane, which are found in groundwater and underground formations. Hydrogen sulfide, for example, is explosive and very toxic. Methane is flammable and in a confined space displaces oxygen. Open flames and sparks from equipment or electrical connections can cause explosion and hence must be prevented. Wells, tanks, and other confined spaces should be well ventilated before entering. Mechanical ventilation should be on and the atmosphere tested for oxygen and toxic gases *before* entering. In any case, the person entering should use a safety rope and full-body harness, and two strong persons above the ground or the tank should be ready to pull the worker out should dizziness or other weakness be experienced. Self-contained positive-pressure breathing apparatus should be available and used. It is essential to comply with state and federal occupational safety and health requirements. These include, in addition to confined space entry, such matters as hazardous operations and chemical handling, respiratory protection, electrical safety, excavations, and construction safety.

Wells and Springs

Wells or springs that have been altered, repaired, newly constructed, flooded, or accidentally polluted should be thoroughly cleaned and disinfected after all the work is completed. The sidewalls of the pipe or basin, the interior and exterior surfaces of the new or replaced pump cylinder and drop pipe, and the walls and roof above the water line, where a basin is provided, should be scrubbed clean with a stiff-bristled broom or brush and detergent, insofar as possible, and then washed down or thoroughly sprayed with water followed by washing or thorough spraying with a strong chlorine solution. A satisfactory solution for this purpose may be prepared by dissolving 1 oz of 70 percent high-test calcium hypochlorite made into a paste, 3 oz of 25 percent chlorinated lime made into a paste, or 1 pt of $5\frac{1}{4}$ percent sodium hypochlorite in 25 gal of water. The well or spring should be pumped until clear and then be disinfected as explained below.

To disinfect the average well or spring basin, mix 2 qt of $5\frac{1}{4}$ percent "bleach" in 10 gal of water. Pour the solution into the well; start the pump and open all faucets. When the chlorine odor is noticeable at the faucets, close each faucet and stop the pump. It will be necessary to open the valve or plug in the top of the pressure tank, where provided, just before pumping is stopped in order to permit the strong chlorine solution to come into contact with the entire inside of the tank. Air must be readmitted and the tank opening closed when pumping is again started. Mix one more quart of bleach in 10 gal of water and pour this chlorine solution into the well or spring. Allow the well to stand idle at least 12 to 24 hr; then pump it out to waste, away from grass and shrubbery, through the storage tank and distribution system, if possible, until the odor of chlorine disappears. Bypass or disconnect the carbon filter if it is part of the system; do not drain into the septic tank. *It is advisable to return the heavily chlorinated water back into the well, between the casing and drop pipe where applicable, during the first 30 min of pumping to wash down and disinfect the inside of the casing and the borehole, insofar as possible*. A day or two after the disinfection, *after the well has been pumped out and all the chlorine has dissipated,* a water sample may be collected for bacterial examination to determine whether all contamination has been removed. If the well is not pumped out, chlorine may persist for a week or longer and give a very misleading bacteriological result if a sample is collected and examined. It is not unusual to repeat well disinfection several times, particularly where contaminated water has been used during drilling and where the well has not been adequately surged, cleaned, and pumped out.

A more precise procedure for the disinfection of a well or spring basin is to base the quantity of disinfectant needed on the volume of water in the well or spring. This computation is simplified by making reference to Table 3-33.

Although a flowing well or spring tends to cleanse itself after a period of time, it is advisable nevertheless to clean and disinfect all wells and springs that have had any work done on them before they are used. Scrub and wash down the spring basin and equipment. Place twice the amount of calcium hypochlorite, swimming pool chlorine erosion tablets, or granular chlorine indicated in Table 3-33 in a weighted plastic container fitted with a cover. Punch holes in the container and fasten a strong line to the container and secure the cover. Suspend the can near the bottom of the well or spring, moving it up and down or around in order to distribute the strong chlorine solution formed throughout the water entering and rising up through the well or spring.

It should be remembered that disinfection is no assurance that the water entering a well or spring will be pollution free. The cause for the pollution, if present, should be ascertained and removed. Until this is done, all water used for drinking and culinary purposes should first be boiled.

Pipelines

The disinfection of new or repaired pipelines can be expedited and greatly simplified if special care is exercised in the handling and laying of the pipe during installation. Trenches should be kept dry and a tight fitting plug provided at the end of the line to keep out foreign matter. Lengths of pipe that

TABLE 3-33 Quantity of Disinfectant Required to Give a Dose of 50 mg/l Chlorine

Diameter of Well, Spring, or Pipe (in.)	Gallons of Water per feet of Water Depth	Ounces of Disinfectant/10-ft Depth of Water		
		70% Calcium Hypochlorite[a]	25% Calcium Hypochlorite[b]	$5\frac{1}{4}$% Sodium Hypochlorite[c]
2	0.163	0.02	0.04	0.20
4	0.65	0.06	0.17	0.80
6	1.47	0.14	0.39	1.87
8	2.61	0.25	0.70	3.33
10	4.08	0.39	1.09	5.20
12	5.88	0.56	1.57	7.46
24	23.50	2.24	6.27	30.00
36	52.88	5.02	14.10	66.80
48	94.00	9.00	25.20	120.00
60	149.00	14.00	39.20	187.00
72	211.00	20.20	56.50	269.00
96	376.00	35.70	100.00	476.00

[a] $Ca(OCl)_2$, also known as high-test calcium hypochlorite. A heaping teaspoonful of calcium hypochlorite holds approximately $\frac{1}{2}$ oz. One liquid ounce = 615 drops = 30 ml.
[b] $CaCl(OCl)$.
[c] $Na(OCl)$, also known as bleach, Clorox, Dazzle, Purex, Javel Water, and Regina, can be purchased at most supermarkets and drugstores.

have soiled interiors should be cleansed and disinfected before being connected. Each continuous length of main should be separately disinfected with a heavy chlorine dose or other effective disinfecting agent. This can be done by using a portable hypochlorinator, a hand-operated pump, or an inexpensive mechanical electric or gasoline-driven pump throttled down to inject the chlorine solution at the beginning of the section to be disinfected through a hydrant, corporation cock, or other temporary valved connection. Hypochlorite tablets can also be used to disinfect small systems, but water must be introduced very slowly to prevent the tablets being carried to the end of the line.

The first step in disinfecting a main is to shut off all service connections, then flush out the line thoroughly by opening a hydrant or drain valve below the section to be treated until the water runs clear. A velocity of at least 3 fps should be obtained. (Use a hydrant flow gauge.) After the flushing is completed, the valve is partly closed so as to waste water at some known rate. The rate of flow can be estimated with a flow gauge (the formula is in Appendix I) or by running the water into a can, barrel, or other container of known capacity and measuring the time to fill it. With the rate of flow known, determine from Table 3-34 the strength of chlorine solution to be injected into the main at the established rate of 1 pt in 3 min to give a dose of 50 mg/l. The rate of water flow can be adjusted and should be kept low for small-diameter pipe. It is a simple matter to approximate the time, in minutes,

TABLE 3-34 Hypochlorite Solution to Give a Dose of 50 mg/l Chlorine for Main Sterilization

Rate of Water Flow in Pipeline (gpm)	Quarts of $5\frac{1}{4}$% Sodium Hypochlorite Made Up to 10 gal with Water	Quarts of 14% Sodium Hypochlorite Made Up to 10 gal with Water	Pounds of 25% Chlorinated Lime to 10 gal Water	Pounds of 70% Calcium Hypochlorite to 10 gal Water
5	4.6	1.7	2.0	0.7
10	9.1	3.4	4.0	1.4
15	13.7	5.1	6.0	2.1
20	18.3	6.8	8.0	2.9
25	22.8	8.5	10.0	3.5
40	36.6	13.7	16.0	5.7

Notes: Add hypochlorite solution at rate of 1 pt in 3 min. The 10-gal solution will last 4 hr if fed at rate of 1 pt in 3 min. Mix about 50% more solution than is theoretically indicated to allow for waste. A 100-mg/l available chlorine solution is recommended by some agencies.

it would take for the chlorine to reach the open hydrant or valve at the end of the line being treated by dividing the capacity of the main in gallons by the rate of flow in gallons per minute. In any case, injection of the strong chlorine solution should be continued at the rate indicated until samples of the water at the end of the main show at least 50 mg/l residual chlorine. The hydrant should then be closed, chlorination treatment stopped, and the water system let stand at least 24 hr. At the end of this time the treated water should show the presence of 25 mg/l residual chlorine. If no residual chlorine is found, the operation should be repeated. Following disinfection, the water main should be thoroughly flushed out, to where it will do no harm, with the water to be used and samples collected for bacterial examination for a period of several days. If the laboratory reports the presence of coliform bacteria, the disinfection should be repeated until two consecutive satisfactory results are received. Where poor installation practices have been followed, it may be necessary to repeat the main flushing and disinfection several times. The water should not be used until all evidence of contamination has been removed as demonstrated by the test for coliform bacteria.

If the pipeline being disinfected is known to have been used to carry polluted water, flush the line thoroughly and double the strength of the chlorine solution injected into the mains. Let the heavily chlorinated water stand in the mains at least 48 hr before flushing it out to waste and proceed as explained in the preceding paragraph. Cleansing of heavily contaminated pipe by the use of a nontoxic, biodegradable, nonfoaming detergent and a "pig," followed by flushing and then disinfection, may prove to be the quickest method. Tubercles found in cast-iron pipe in water distribution systems protect microorganisms against the action of residual chlorine.

Where pipe breaks are repaired, flush out the isolated section of pipe thoroughly and dose the section with 200 mg/l chlorine solution and try to keep the line out of service at least 2 to 4 hr before flushing out the section and returning it to service.

Potassium permanganate can also be used as a main disinfectant. The presence and then the absence of the purple color can determine when the disinfectant is applied and then when it has been flushed out.[327] See also AWWA Standard for Disinfecting Water Mains, C651-86.

Storage Reservoirs and Tanks

Make sure the tank is adequately and continuously ventilated before entering. Check with an oxygen deficiency meter. Wear protective clothing during the work, including self-contained breathing apparatus with full-face piece. *Insist on all safety precautions*.

Before disinfecting a reservoir or storage tank, it is essential to first remove from the walls (also bottom and top) all dirt, scale, and other loose material. The interior should then be flushed out (a fire hose is useful) and disinfected by one of the methods explained below.

If it is possible to enter the reservoir or tank, prepare a disinfecting solution by dissolving 1 oz of 70 percent calcium hypochlorite (e.g., HTH, Perchloron, Pitt-Chlor) made into a paste, 3 oz of 25 percent calcium hypochlorite (chlorinated lime) made into a paste, or 1 pt of $5\frac{1}{4}$ percent sodium hypochlorite (e.g., Bleach, Clorox, Dazzle,) in 25 gal of water. Apply this strong 250-mg/l chlorine solution to the bottom, walls, and top of the storage reservoir or tank using pressure-spray equipment. Let stand for at least 2 hours. *Follow safety precautions given above*. See also AWWA Standard C652.

Another method is to compute the tank capacity. Add to the empty tank $1\frac{1}{4}$ lb of 70 percent calcium hypochlorite, 4 lb of 25 percent chlorinated lime completely dissolved, or 1 gal of $5\frac{1}{4}$ percent sodium hypochlorite for each 1000-gal capacity. Fill the tank with water and let it stand for 12 to 24 hr. This will give a 100+-mg/l solution. Then drain the water to waste where it will do no harm. Dechlorinate if necessary.

A third method involves the use of a chlorinator or hand-operated force pump. Admit water to the storage tank at some known rate and add at the same time twice the chlorine solution indicated in Table 3-34 at a rate of 1 pt in 3 min. Let the tank stand full for 24 hr and then drain the chlorinated water to waste. Rinse the force pump immediately after use.

It should be remembered, when disinfecting pressure tanks, that it is necessary to open the air-relief or other valve at the highest point so that the air can be released and the tank completely filled with the heavily chlorinated water. Air should be readmitted before pumping is commenced. In all cases, a residual chlorine test should show a distinct residual in the water drained out of the tanks. If no residual can be demonstrated, the disinfection should be repeated.

Coliform bacteria, klebsiella, and enterobacter have been a problem in redwood water tanks. Klebsiella have been isolated from water samples extracted from redwood, which are apparently leached from the wood (especially new tanks) when the tank is filled with water. Tanks are treated with soda ash to leach out wood tannins (7 days duration) and disinfected with 200 mg/l chlorine water prior to use. A free chlorine residual of 0.2 to 0.4 mg/l in the tank water when in use will keep bacterial counts under control.[328]

EMERGENCY WATER SUPPLY AND TREATMENT

Local or state health departments should be consulted when a water emergency arises. Their sanitary engineers and sanitarians are in a position to render valuable, expert advice based on their experience and specialized training. (See Chapter 10 for emergency situations.)

The treatment to be given a water used for drinking purposes depends primarily on the extent to which the water is polluted and the type of pollution present. This can be determined by making a sanitary survey of the water source to evaluate the significance of the pollution that is finding its way into the water supply. It must be borne in mind that all surface waters, such as from ponds, lakes, streams, and brooks, are almost invariably contaminated and hence must be treated. The degree of treatment required is based on the pollution present. However, under emergency conditions it is not practical to wait for the results of microbiological analyses. One should be guided by the results of sanitary surveys, diseases endemic and epidemic in the watershed area, and such reliable local data as may be available. Using the best information on hand, select the cleanest and most attractive water available and give it the treatment necessary to render it safe. Prior approval of the regulatory agency is usually required. Water passing through inhabited areas is presumed to be polluted with sewage and industrial wastes and must be boiled or given complete treatment, including filtration and disinfection, to be considered safe to drink; however, all chemical wastes may not be removed by conventional treatment.

Backpacker-type water filters with hand pump, manufactured by Katadyn[329] and First Need,[330] were found to be 100 percent effective in removing *Giardia* cysts when operated and maintained in accordance with the manufacturer's directions.[331] The Katadyn filter is also reported to remove bacteria and helminths from small quantities of water.

Boiling

In general, boiling clear water vigorously for 1 to 2 min will kill most disease-causing bacteria and viruses, including *E. histolytica* and *Giardia* cysts. Heating water to 158°F (70°C) will completely inactivate the *Giardia* cyst.[331] If sterile water is needed, water should be placed in a pressure cooker at 250°F

(121°C) for 15 min.[332] A pinch of salt or aerating the water from one container to another will improve the taste of the water, but be careful not to recontaminate the water in the process.

Chlorination

Chlorination treatment is a satisfactory method for disinfecting water that is not grossly polluted. It is particularly suitable for the treatment of a relatively clean lake, creek, or well water that is of unknown or questionable quality. Chlorine for use in hand chlorination is available in supermarkets, drugstores, grocery stores, and swimming pool supply stores and can be purchased as a powder, liquid, or tablet. Store solutions in the dark. Chlorine is more effective in water at 68°F (20°C) than at 36°F (2°C) as well as at low pH and turbidity.

The powder is a calcium hypochlorite and the liquid a sodium hypochlorite. Both these materials deteriorate with age. The strength of the chlorine powder or liquid is on the container label and is given as a certain percent available chlorine. The quantity of each compound to prepare a stock solution, or the quantity of stock solution to disinfect 1 gal or 1000 gal of water, is given in Table 3-35. When using the powder, make a paste with a little water, then dissolve the paste in a quart of water. Allow the solution to settle and then use the clear liquid, without shaking. The stock solution loses strength and hence should be made up fresh weekly. It is important to allow the treated water to stand for 30 min after the chlorine is added before it is used. Double the chlorine dosage if the water is turbid or colored.

Chlorine-containing tablets suitable for use on camping, hunting, hiking, and fishing trips are available at most drugstores. The tablets contain 4.6 grains of chlorine; they deteriorate with age. Since chloramines are slow-acting disinfectants, the treated water should be allowed to stand at least 60 min before being used. Iodine tablets (Globaline) and halazone tablets are also available at most sporting goods stores and drugstores. Check the expiration date.

Home-made chlorinators may be constructed for continuous emergency treatment of a water supply where a relatively large volume of water is needed. Such units require constant observation and supervision as they are not dependable. Figures 3-38 and 3-39 show several arrangements for adding hypochlorite solution. In some parts of the country, it may be possible to have a commercial hypochlorinator delivered and installed within a very short time. Some health departments have a hypochlorinator available for emergency use. Communicate with the local or state health department for assistance and advice relative to the manufacturers of approved hypochlorinators. Simple erosion-type chlorinators can also be purchased or improvised for very small places. A daily report should be kept showing the gallons of water treated, the amount of chlorine solution used, and the results of hourly residual chlorine tests.

TABLE 3-35 Emergency Disinfection of Small Volumes of Water

Product	Available Chlorine (%)	Stock Solution[a]	Quantity of Stock Solution to Treat 1 gal of Water[b]	Quantity of Stock Solution to Treat 1000 gal of Water[b]
Zonite	1	Use full strength	30 drops	2 qt
S.K., 101 solution	$2\frac{1}{2}$	Use full strength	12 drops	1 qt
Clorox, White Sail, Dazzle, Rainbow, Rose-X, bleach	$5\frac{1}{4}$	Use full strength	6 drops	1 pt
Sodium	10	Use full strength	3 drops	$\frac{1}{2}$ pt
Hypochlorite sodium	15	Use full strength	2 drops	$\frac{1}{4}$ pt
Hypochlorite calcium hypochlorite, "bleaching powder," or chlorinated lime	25	6 heaping table-spoonfuls (3 oz) to 1 qt of water	1 teaspoonful or 75 drops	1 qt
Calcium hypochlorite	33	4 heaping tablespoonfuls to 1 qt of water	1 teaspoonful	1 qt
HTH, Perchloron, Pittchlor, calcium	70	2 heaping tablespoonfuls (1 oz)	1 teaspoonful	1 qt

[a] One quart contains 135 ordinary teaspoonfuls of water.
[b] Let stand 30 min before using. To dechlorinate, use sodium thiosulfate in same proportion as chlorine. One jigger = $1\frac{1}{2}$ liquid oz. Chlorine dosage is approximately 5–6 mg/l. (1 liquid oz = 615 drops.) Make sure chlorine solution or powder is fresh; check by making residual chlorine test. Double amount for turbid or colored water.

Iodine

Eight drops of 2 percent tincture of iodine may be used to disinfect 1 qt of clear water (8 mg/l dose). Allow the water to stand at least 30 min before it is used. (Bromine can also be used to disinfect water, although its use has been restricted to the disinfection of swimming pool water.) Studies of the usefulness of elemental iodine show it to be a good disinfectant over a pH range of 3 to 8, even in the presence of contamination.[333] Combined amines

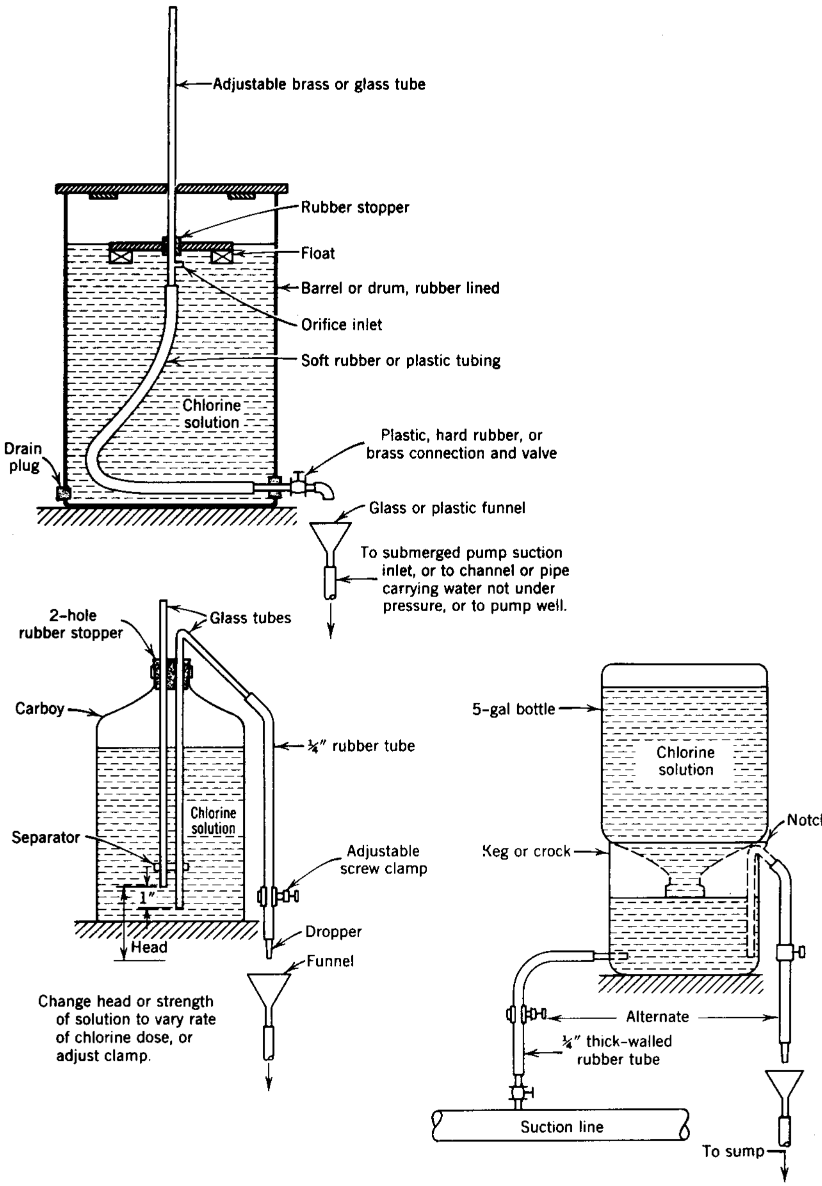
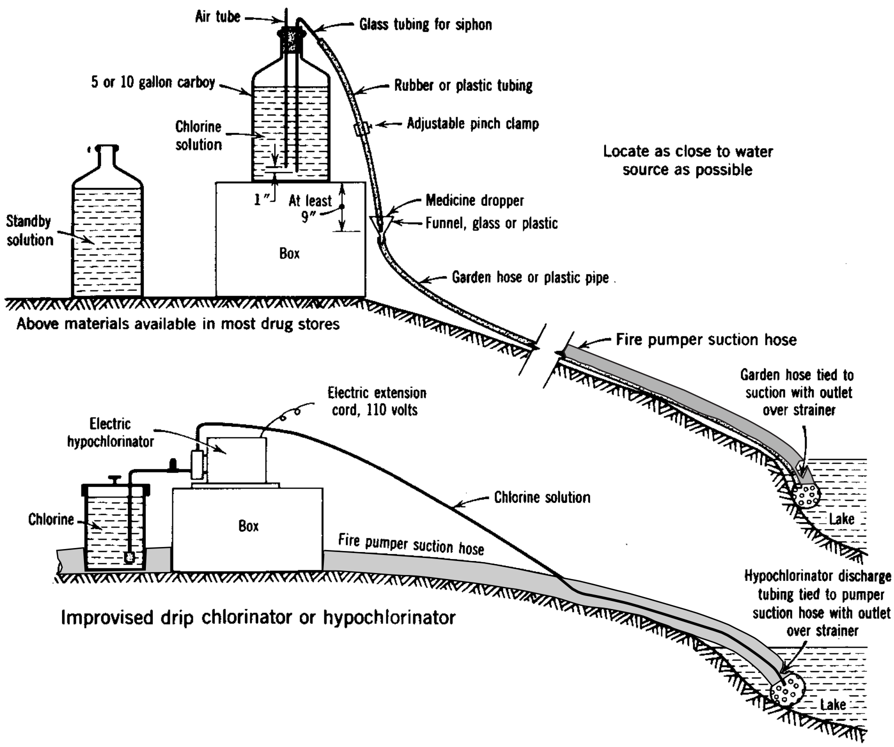


Figure 3-38 Homemade emergency hypochlorinators. To make chlorine solution, mix 4 pt of 5 percent hypochlorite to 5 gal of water.



Chlorine	Quantity to 5 gal Water	Rate of Feed 500 gpm Pumper
Perchloron or HTH, 70% available chlorine	4 lb*	4 oz or ¼ pt per min
Chlorinated lime, 24% available chlorine	12 lb*	4 oz or ¼ pt per min
Sodium hypochlorite, 14% available chlorine	20 pt	4 oz or ¼ pt per min

Figure 3-39 Emergency chlorination for fire supply, under health department supervision, for pumping into a hydrant on the distribution system, if necessary. Data for preparation and feed of chlorine solution: The asterisk denotes that the paste should be made in a jar; add water and mix; let settle for a few minutes then pour into carboy or other container and make up to 5 gal. Discard white deposit; it has no value. Dosage is 5 mg/l chlorine. Double solution strength if necessary to provide residual of 4 to 5 mg/l.

are not formed to use up the iodine. A dosage of 5 to 10 mg/l, with an average of 8 mg/l for most waters, is effective against enteric bacteria, *Giardia* and amoebic cysts, cercariae, leptospira, and viruses within 30 min. Tablets that can treat about 1 qt of water may be obtained from the National Supply Service, Boy Scouts of America, large camping supply centers, drugstores, and the Army, in emergency. These tablets dissolve in less than 1 min and are stable for extended periods of time. They are known as iodine water purification tablets, of which Globaline, or tetraglycine hydroperiodide, is preferred. They contain 8.0 mg of active iodine per tablet. The treated water is acceptable. Iodine is toxic. It should be reserved for emergency use only.[334]

Filtration in an Emergency

Portable pressure filters are available for the treatment of polluted water. These units can produce an acceptable water provided they are carefully operated by trained personnel. Preparation of the untreated water by settling, prechlorination, coagulation, and sedimentation may be necessary, depending on the type and degree of pollution in the raw water. Pressure filters contain special sand, crushed anthracite coal, or diatomaceous earth. Diatomite filtration, or slow sand filtration, should be used where diseases such as amebic dysentery, giardiasis, ascariasis, schistosomiasis, or paragonimiasis are prevalent, in addition, of course, to chlorination.

Slow sand filters (consisting of barrels or drums) may be improvised in an emergency. Their principles are given in Figure 3-17 and Table 3-18. It is most important to control the rate of filtration so as not to exceed 50 gpd/ft^2 of filter area and to chlorinate each batch of water filtered as shown in Table 3-35 in order to obtain reliable results.

Bottled, Packaged, and Bulk Water

The bottled water industry has shown a large growth in many parts of the world because of public demand for a more palatable and "pure" water. It is not uncommon to find a wide selection of waters from various sources in the United States and Europe and in supermarkets and small grocery stores in almost all parts of the world. A major bottler in France was reported to have a capacity of 800 million bottles per year. The 1989 production in the United States was estimated at 1384.4 million gallons per year.[335] There were an estimated 700 water-bottling plants in the United States in 1972.[336] In addition, self-service water vending machines that dispense water into an individual's container are available.* Per-capita consumption increased from 5.2 gal in 1985 to 6.2 gal in 1989, with a 1989 sales value of $2.375 billion, compared to $1.5 billion in 1985 and $275 million in 1975.[335,338] The demand for bottled water is of course minimized where a safe, attractive, and palatable public water supply is provided.

In an emergency, it is sometimes possible to obtain bottled, packaged, or tank-truck water from an approved source that is properly handled and distributed. Such water should meet the federal and state drinking water standards as to source, protection, and microbiological, chemical, radiological,

*Water vending maching sanitary design details are given in ref. 337.

and physical quality. Water that is transported in tank trucks from an approved source should be batch chlorinated at the filling point as an added precaution. The tank truck, hoses, fittings, and connections should, of course, be thoroughly cleaned and disinfected (not less than 100 mg/l chlorine solution) before being placed in service. Detergents and steam are sometimes needed, particularly to remove gross pollution, followed by thorough rinsing with potable water and disinfection. Only tank trucks with a dedicated use for hauling potable water should be used. Each tank of water should be dosed with chlorine at the rate of 1 to 2 mg/l and so as to yield a free chlorine residual of not less than 0.5 mg/l. See Table 3-35.

Milk pasteurization plants and beverage bottling plants have much of the basic equipment needed to package water in paper, plastic, or glass containers. Contamination that can be introduced in processing (filtration through sand and carbon filters) and in packaging (pipelines, storage tanks, fillers) should be counteracted by germicidal treatment of the water just prior to bottling. In any case, the source of water, equipment used, and operational practices must meet recognized standards.

Bottled water should meet EPA and state water quality standards for drinking water and comply with FDA regulations and industry standards for the processing and bottling of drinking water.[339,340] Many states also have detailed regulations or codes including water quality standards. The National Sanitation Foundation also has guidelines and makes plant inspections. The FDA microbiological quality standards are 9 of 10 samples less than 2.2 coliforms per 100 ml with no sample showing 9.2 or more by the multiple-tube fermentation method, and the arithmetic mean of all samples should be not greater than 1 per 100 ml with not more than one having 4.0 or more coliform organisms by the membrane filter method.[339] The standard plate count of the bottled water at the retail outlet should be less than 500 per 100 per milliliter. The FDA considers bottled water a "food" and regulates its purity.* Mineral water is exempt; its definition is vague. Mineral water has been defined as bottled water containing at least 500 ppm dissolved solids and originating entirely underground. Nevertheless, mineral waters should meet the physical, microbiological, and radiological standards for drinking water. Bottled water should also be free of *Pseudomonas aeruginosa*. Almost all bottled water in the United States is reported to be ozonized.

Bottled water may be labeled Natural Water (no change), Natural Sparkling Water (carbon dioxide added), Spring Water (groundwater), Purified Water (demineralized), Mineral Water (assumed 500 ppm or greater total dissolved solids), Seltzer Water (carbonated tap water), and Club Soda (carbonated with salt and minerals added). Up to 0.02 percent caffeine and 0.5 percent alcohol by weight may be added to Natural Sparkling Water, Club Soda, Seltzer, and soda water according to the FDA.[341]

* Other standards refer to turbidity, color, odor, chemical quality, fluoride, and radiological quality.

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4 Wastewater Treatment and Disposal

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DISEASE HAZARD

The improper disposal of human excreta and sewage is one of the major factors threatening the health and comfort of individuals in areas where satisfactory municipal, on-site, or individual facilities are not available. This is so because very large numbers of different disease-producing organisms can be found in the fecal discharges of ill and apparently healthy persons, as explained in Chapter 1.

Knowing that many pathogenic microorganisms and toxic chemicals are found in sewage, it becomes obvious that all sewage (wastewater) should be considered contaminated, beyond any reasonable doubt, with disease-producing organisms and toxic chemicals. In addition, it is known that some pathogenic organisms will survive from less than one day in peat to more than two years in freezing moist soil.[1] Moist soil is favorable and dry soil is unfavorable for survival of many pathogens.

Numerous writers[1–8]* have summarized the work of investigators who studied the survival of enteric pathogens in soil, water, and wastewater. In general, available data show that primary sedimentation can be expected to remove zero to 30 percent of the viruses; 50 to 90 percent of the bacteria, taenia ova, and cholera vibrio; zero percent of the leptospires; 10 to 50 percent of *Entamoeba histolytica;* 30 to 50 percent of the ascaris; and 80 percent of the schistosomes. Trickling filters can remove 90 to 95 percent of the viruses,

*Reference 2 is a historical review of medical and engineering literature covering 180 selected references.

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0–471-41813-7

bacteria, and cholera vibrio; zero percent of the leptospires; 50 percent of *E. histolytica;* 70 to 100 percent of the ascaris; 50 to 99 percent of the schistosome ova; and 50 to 95 percent of the taenia ova. Activated sludge treatment can remove 90 to 99 percent of the viruses, bacteria, and cholera vibrio; zero percent of the leptospires; 50 percent of *E. histolytica;* 70 to 100 percent of the ascaris; and 50 to 99 percent of taenia ova. Stabilization pond (not less than 25-day retention) can be expected to remove all viruses, bacteria, vibrio, leptospires, *E. histolytica* ascaris, schistosome ova, and taenia ova. Septic tanks can be expected to remove 50 to 90 percent of the cholera vibrio, ascaris, schistosoma, and taenia present; 100 percent of the leptospires; and zero percent of *E. histolytica.*[8] Waste stabilization ponds in series (three with 25-day retention) remove practically all enteric viruses, bacteria, protozoan cysts, and helminth eggs.[7] Chemical coagulation, flocculation, sedimentation, and filtration will remove nearly all viruses, bacteria, protozoa, and helminths, particularly if supplemented by chlorination or other effective disinfection treatment. However, in practice, failure of sewage treatment equipment, bypassing of raw or partially treated sewage, and variations in treatment efficiency cannot ensure continuous removal of all pathogens. It should be remembered that sewage treatment does not prevent waterborne diseases such as those mentioned; treatment of drinking water does that. Sewage treatment is still essential to minimize the pollution load on water treatment plants and the health risks associated with drinking water and recreational water sources. It is a *partial* barrier to the spread of waterborne diseases. Complete water treatment tailored to the water source is the final barrier. See Tables 1-7 and 18 for survival of certain pathogens.

The waterborne microbiological agents of concern are the pathogenic bacteria, viruses, helminths, protozoa, and spirochetes. The more important infectious bacterial agents are associated with shigellosis and salmonella infections. The viral agents are associated more commonly with infectious hepatitis A, viral gastroenteritis, and other enteric viral diseases. The helminths are associated with ascariasis, taeniasis, dracunculiasis, trichuriasis, toxocariasis, enterobiasis, and other illnesses. The protozoa are generally associated with amebiasis and giardiasis. The spirochetes are associated with leptospirosis. To these should be added nonspecific diarrheas, secondary skin infections through scratches and open wounds, and infections of the eyes, ears, nose, and throat.

The transmission of microbiological agents of disease is dependent upon many factors, dose and virulence being most important. A sufficient number of organisms must be ingested to cause illness; data for some microbiological agents are available[9–11]; see Table 1-9.

It has also been brought out that *E. histolytica* and giardia cysts, hepatitis viruses, and tapeworm eggs withstand the normal chlorination treatment given sewage. Since chlorination of wastewater treatment plant effluent may not protect against these diseases but only minimize the probability, more advanced treatment may be needed in some circumstances, such as where human contact or ingestion is probable. Other practical and more effective means of disinfection need to be investigated, in addition to better mixing and increased contact time, which will not result in the formation of chloro-organics or other substances potentially harmful to humans and aquatic life. In the meantime, chlorination is acknowledged to far outweigh any risks it may have to human health. See also Chlorine Treatment for Operation and Microbiological Control, Chapter 3, and Disinfection—Chlorination, this chapter.

Aside from the known disease outbreaks caused by drinking contaminated water and consuming contaminated shellfish, there have been incidents of disease transmission by swimming in contaminated waters, although not well documented. For example, shigellosis was associated with swimming in the Mississippi River about 5 miles south of the Dubuque, Iowa, sewage treatment plant.[12] In another example, a coxsackievirus B epidemic attributed to sewage contamination occurred at a boys' summer camp on Lake Champlain, New York.[13] See also Health Considerations, Chapter 9.

Infectious diseases vary in their clinical manifestations from severe to mild. Many do not come to the attention of practicing physicians or epidemiologists or are not reported. Because of this, it cannot be assumed that relationships between sewage discharges and diseases do not exist. On the contrary, knowing that they do exist, it is essential that unnecessary human suffering and illness be prevented by the application of existing knowledge.

Therefore, the mere exposure of excreta, sewage, or other wastewater (including gray water) on the surface of the ground or its improper treatment and disposal immediately sets the stage for possible disease transmission by direct contact, a vehicle or vector such as an individual or the housefly, an inanimate object such as a child's toy, or ingestion of excreta or sewage directly from soiled fingers or via contaminated water or food. This is especially true in developing countries where enteric diseases are prevalent and clean water, sanitation, and personal hygiene are wanting. Diarrheal illnesses, especially in young children, were reduced 16 percent where water quality was improved, 25 percent where water, not necessarily potable, was made available, 37 percent where both water availability and quality were improved, and 22 percent where excreta disposal facilities were improved.[14]

Sewage sludge (commonly referred to as biosolids) accumulates the heavy metals in municipal wastewater that do not pass through with the effluent. Many of the metals are very toxic; hence, the use of such biosolids as a soil builder may result in higher levels of toxic metals in treated vegetation and in animals feeding on the vegetation. The use of pesticides containing lead, mercury, barium, and cadmium as well as fallout from air pollution may contribute additional toxic contaminants. Therefore, biosolids should not be used as a soil builder or fertilizer supplement for crops for forage unless it is found to be free of significant amounts of toxic metals and parasite ova or other pathogens. See Biosolids Treatment and Disposal, this chapter.

Awareness of these dangers, coupled with adequate treatment of sewage, provision of potable water, sanitation, and personal hygiene, is recognized as being primarily responsible for reducing intestinal and waterborne diseases to their present low level in many parts of the world. Maintenance of the disease barriers and vigorous application of basic sanitary engineering and sanitation principles in less developed areas of the world are necessary for the enjoyment of a healthy environment and better quality of life. It may appear inconceivable, but there are still suburban and rural areas in the United States and abroad where the discharge of raw or inadequately treated sewage to roadside ditches and streams is commonplace. See Chapter 1 and Figure 1-2 for additional details on disease control.

Municipal and industrial wastewater pollution has been brought under reasonable control in the United States and now requires maintenance. But nonpoint land pollution, combined and storm sewer overflows toxic chemicals in harbor, lake, stream sediments, and sludges, and fallout of toxic chemicals from air emissions on the land, on surface water, and into groundwater present unresolved problems.

Criteria for Proper Wastewater Disposal Proper disposal of sewage and other wastewater is necessary not only to protect the public's health and prevent contamination of groundwater and surface water resources but also to preserve fish and wildlife populations and avoid the creation of conditions that could detract from the attractiveness of a community, tourist establishment, resort, and recreational areas. The following basic criteria should be satisfied in the design and operation of an excreta, sewage, or other wastewater disposal system[15]:

1. prevention of microbiological, chemical, and physical pollution of water supplies and contamination of fish and shellfish intended for human consumption;
2. prevention of pollution of bathing and recreational areas;
3. prevention of nuisance, unsightliness, and unpleasant odors;
4. prevention of human wastes and toxic chemicals from coming into contact with humans, grazing animals, wildlife, and food chain crops or being exposed on the ground surface accessible to children and pets;
5. prevention of fly and mosquito breeding and exclusion of rodents and other animals; and
6. strict adherence to standards for groundwater and surface-water protection and compliance with federal, state, and local regulations governing wastewater disposal and water pollution control.

Failure to observe these basic principles can result in the development of health hazards and the degradation of living conditions, recreational areas, and natural resources that are essential for the well-being of the general public. Protection of land and water resources should be national policy, and every efforts should be made to prevent their pollution by improper treatment and disposal of sewage and other wastewaters.

DEFINITIONS

Before proceeding further, it is desirable to define some commonly used terms.

Aerobic Bacteria Bacteria that require free dissolved oxygen for their growth. Carbon, nitrogen, and phosphorus are required nutrients for growth.

Anaerobic Bacteria Bacteria that grow only in the absence of free dissolved oxygen. They obtain oxygen from breaking down complex organic substances. The products formed first are organic acids, carbon dioxide, acid carbonate, and hydrogen sulfide; then ammonia, acid carbohydrates, carbon dioxide, and sulfides; and finally ammonia, methane, carbon dioxide, sulfides, and humus.

Biochemical Oxygen Demand (*BOD*) The difference between the initial dissolved oxygen in a sample and the dissolved oxygen in a duplicate sample after a stated period of time, when examined in accordance with *Standard Methods for the Examination of Water and Wastewater* (see Bibliography). This characteristic of surface water, sewage, sewage effluent, polluted water, industrial waste, or other wastewater is the amount of dissolved oxygen in milligrams per liter required during stabilization of the decomposable organic matter by aerobic bacterial action. Complete stabilization may require 100 days at 68°F (20°C). Incubation for 5 days (carbonaceous demand satisfied) or 20 days (total carbonaceous plus nitrification demand satisfied) is not unusual, but as used in this chapter and text, BOD usually refers to the 5-day carbonaceous demand test unless otherwise specified. The 20-day demand approaches the ultimate demand. It also measures the oxygen used to oxidize inorganic material such as sulfides and ferrous iron as well as the oxygen used to oxidize reduced nitrogen forms if the organisms that bring about nitrification are present. Inorganic nitrogen may be in the form of ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, or gaseous nitrogen. The nitrogen oxygen demand due to organic and ammonia nitrogen forms, the total Kjeldahl nitrogen, may represent 60 percent or more of the total oxygen demand potential of sewage transferred downstream if not reduced or removed to an acceptable level. If a stream flow exceeds 5 days, the nitrogenous demand in sewage effluent becomes significant. Generally for *domestic* sewage, 1 lb of 5-day BOD is roughly equivalent to 1.5 lb of ultimate BOD. If 1 lb of BOD is completely aerated, requiring 1.3 lb of oxygen, 0.14 lb of inert residue will remain.

Biosolids The solid, semisolid, or liquid residue that is generated during the treatment of domestic waste. Examples of biosolids include sewage sludge and septage. Sewage sludge is the material that settles out of wastewater during its treatment in a treatment plant. Septage is the material that is pumped out of septic tanks.

Chemical Oxygen Demand (*COD*) A measure of the amount of oxygen, in parts per million or milligrams per liter, chemically (rather than biologically) consumed under specific conditions in the oxidation of organic and oxidizable inorganic materials in water. It is usually higher than the BOD of the water. The COD is usually measured in relation to certain industrial wastes. The test is relatively rapid. It does not oxidize some organic pollutants (pyridine, benzene, toluene) but oxidizes some inorganic compounds that are not measured, that is, affected by the BOD analysis.

Coliform Organisms See Bacterial Examinations, Chapter 3.

Contamination See Definitions, Chapter 1.

Dissolved Oxygen (*DO*) The oxygen in water that is available to support aquatic life and that is used by wastewater discharged to a water body. Cold water holds more oxygen in solution than warm water. Game fish require at least 4 to 5 mg/l DO. Absence of DO results in anaerobic conditions and foul odors.

Domestic Sewage The used water from a home or community. Includes toilet, bath, laundry, lavatory, and kitchen-sink wastes. See Table 4-1. Sewage from a community may include animal, industrial, and commercial wastes and groundwater and surface water infiltration. Hence, the more inclusive term *wastewater* is also in general usage. The terms are used interchangeably. Normal domestic sewage will average less than 0.1 percent total solids in soft-water regions. The strength of wastewater, including sewage, is commonly expressed in terms of five-day BOD, suspended solids, and COD.

Excreta The waste matter eliminated from the body; about 27 grams per capita per day dry basis (100–200 grams wet) with about 400 billion *Escherichia coli*.[16] Mara[17] reports an average weight of 150 grams feces wet basis, 2000 million fecal coliform, and 450 million fecal streptococci per capita per day.

Facultative Bacteria These have the ability to live under both aerobic and anaerobic conditions. Obligate aerobes can grow only in the presence of oxygen.

Industrial Waste Any liquid, gaseous, solid, or waste substance or a combination thereof resulting from any process of industry, manufacturing, trade, or business or from the development or recovery of any natural resources, which may cause or might reasonably be expected to cause pollution of water in contravention of the adopted state standards.

MA7CD10 The critical stream flow of the minimum average 7-consecutive-day flow at a recurrence interval of 10 years. Critical temperatures: 75°F (24°C) trout waters; 77°F (25°C) nontrout. A MA7CD10 stream with a flow of less than 0.1 cfs, or which periodically runs dry, is an intermittent stream. Effluent discharged to an intermittent stream should have a BOD of 5 mg/l or less, suspended solids of 10 mg/l or less, and dissolved oxygen of 7 mg/l.

MA30CD10 The minimum average 30-consecutive-day flow at a recurrence interval of 10 years.

National Pollutant Discharge Elimination System (*NPDES*) The national system for the issuance of permits for the discharge of treated sanitary, industrial, and commercial wastes under the 1972 Federal Water Pollution Control Act. The permit specifies the treatment to be used to protect water quality.

Nonpoint Pollution Any source other than a point source that is man made or man induced and results in the alteration of the chemical, physical, biological, or radiological integrity of water.[18] It may be a combination of many areawide sources or widely separated sources.

Pollution Pollution in its broad sense has been defined in Chapter 1. Water pollution, more specifically, is the addition of agricultural, domestic, industrial, and commercial wastes in concentrations or quantities that result in the measurable degradation of water quality. Contaminants are present in concentrations that may restrict water use. Included are thermal and radiological wastes. A *point source* of pollution is ''any discernible, confined, or discrete conveyance from which pollutants are or may be discharged,''[18] such as a pipe, ditch, well, vessel, vehicle, and feed lot.

Privy (*or One of Its Modifications*) The common device used when excreta is disposed of without the aid of water. When excreta is disposed of with water, a *water carriage* sewage disposal system is used; generally, all other domestic liquid wastes are included.

Refractory Organics Man-made organic compounds that degrade very slowly. Examples are chlordane, endrin, DDT, and lindane. Also, a material having the ability to retain its physical shape and chemical identity when subjected to high temperatures.[18]

Sewer, Sewerage, Sewage or Wastewater Treatment Plant, or Sewage Works When storm water and domestic sewage enter a sewer, it is called a *combined sewer*. If domestic sewage and stormwater are collected separately, in a *sanitary sewer* and a *storm sewer* the result is a *separate sewer system*. A *sewer system* is a combination of sewers and appurtenances for the collection, pumping, and transportation of sewage,

TABLE 4-1 Characteristics of Wastewater[a]

Constituents	Domestic Wastewater (Community)[b]	Household Wastewater[c]	Septic Tank Household Effluent[d]	Gray Water[e,f]	Black Water[e,f]	Septic Effluent Rest Area[g]
Color						
Nonseptic	Gray					
Septic	Blackish	—	3.5			
Odor						
Nonseptic	Musty					
Septic	H_2S	—	4.5			
Temperature, °F	55–90[h]	63				
Total solids	800	968	820	528	621	
Total volatile solids	425	514				
Suspended solids	200	376	101	162	77	165
Volatile Suspended Solids	130					
Settleable solids	5					
pH	7.5	8.1	7.4	6.8	7.8	8.2
Total nitrogen	40	84	36	11.3	153	140
Organic nitrogen	25					
Ammonia nitrogen	0.5	64	12	1.7	138	
Nitrate nitrogen	0.5	—	0.12	0.12	0.22	0.6
Total phosphate	15	61	15	1.4	18.6	29
Total bacteria, per 100 ml	30×10^8	—	76×10^6			
Total coliform, MPN[i]/100 ml	30×10^6	—	110×10^6	24×10^6[g]	0.25×10^6	
Fecal coliform, per 100 ml	—	—	—	1.4×10^6		
		435	140	149	90	165
COD	—	709	675	366	258	405
Total organic carbon	—	—	—	125	97	
Grease	—	65				

[a] Average, in mg/l unless otherwise noted.

[b] P. F. Atkins, "Water Pollution by Domestic Waves," in *Selection and Operation of Small Wastewater Treatment Facilities—Training Manual,* by C. E. Sponagle, U.S. Environmental Protection Agency, Cincinnati, OH, April 1973, p. 3-3.

[c] K. S. Watson, R. P. Farrell, and J. S. Anderson, "The Contribution from the Individual Home to the Sewer System," *J. Water Pollut. Control Fed.,* December 1967, pp. 2039–2054.

[d] J. A. Salvato, Jr., "Experience with Subsurface Sand Filters," *Sewage Ind. Wastes,* **27**(8) 909–916 (August 1955).

[e] Septic tank effluent. The higher concentration of coliform bacteria in the gray-water effluent are attributed to the large amounts of undigested organic matter in kitchen wastewater.

[f] M. Brandes, *Characteristics of Effluents from Separate Septic Tanks Treating Grey Water and Black Water from the Same House*, Ministry of the Environment, Toronto, Canada, October 1977, pp. 9, 27.

[g] R. O. Sylvester and R. W. Seabloom, *Rest Area Wastewater Disposal*, University of Washington, Seattle, WA, January 1972, p. 30.

[h] For the central states zone in the United States.

[i] MPN = most probable number.

and is sometimes called *sewerage;* when facilities for treatment and disposal of sewage, known as the *sewage* or *wastewater treatment plant,* are included, the reference would be to a *sewage works*.

Suspended Solids Those solids that are visible and in suspension in water. They are the solids that are retained on the asbestos mat in a Gooch crucible.

Total Organic Carbon (TOC) This test is a measure of the carbon as carbon dioxide; the inorganic carbon compounds present interfere with the test; hence, they must be removed before the analysis is made or a correction is applied.

Wastewater See *Domestic Sewage.*

STREAM POLLUTION AND RECOVERY

Nonpoint Pollution

It is estimated that one-half or more of the pollutant load on surface water and groundwater is caused by nonpoint sources, including atmospheric deposition and acid rain, urban and rural land runoff, infiltration, and percolation through the soil to the groundwater. The pollutants may contain organic and inorganic chemicals and pathogens. Specific potential sources are pesticides, fertilizers, and sediments from agricultural activities; manure spreading, barnyards, loafing barns, and pen stables; logging, skidding, and logging roads; highway and other construction, land clearing, and land development; surface mining, dredging, oil and gas drilling, and mine tailings; land disposal of sludge, wastewater, and industrial wastes; landfill leachate; concentration of failing septic tank systems on small lots; runoff from streets and parking lots; pesticides and fertilizers from lawns and golf courses; stream channelization, dredging, stream bank modification, and flow regulation modification; spills, contaminated sediments, uncovered stored and applied deicing agents; saltwater intrusion, leaking underground petroleum and chemical storage tanks; and industry stack and motor vehicle emission deposition.[19]

Control of nonpoint pollution, including atmospheric deposition, remains a challenge and must start with source prevention and control. Major preventive measures are land-use controls and land management (erosion control, conservation tillage, animal waste storage, integrated pest management, and retention basins). Farm operators, for example, can implement a plan developed in cooperation with their Soil Conservation Service and the Conservation District. Technical and financial assistance is also available from the U.S. Department of Agriculture (USDA) Soil Conservation Service and others. The Soil Conservation Service has a computerized geographic information system (GIS) to make soil, topographic, land-use, and other pertinent data available. Less toxic chemicals must be formulated and used in lesser amounts in conjunction with integrated pest management.

Stormwater runoff and combined sewer overflows containing sediment, oil, grease, and other toxic materials can be passed through retention basins to minimize the pollution load on receiving streams. The U.S. Environmental Protection Agency (EPA) requires cities with a population greater than 100,000 to prepare a management program to control storm sewer and combined sewer overflows and obtain a NPDES permit. See (a) Combined Sewer Overflow and (b) Separate Storm Sewers, this chapter.

Pollution Measurement

The five-day BOD is the best single-strength measure of wastewater or polluted water containing degradable wastes. However, organic and inorganic loading, aquatic organisms including animal life (benthos) in the bottom sediments, the COD where indicated, the dissolved oxygen, and the sanitary survey taken all together with the BOD (carbonaceous and nitrogenous) are the best indicators of organic water pollution. Dissolved oxygen is the best indicator of a water body's ability to support desirable aquatic life and its waste assimilation capacity. Other chemical, physical, and biological parameters, such as bioassay and diversity of species, provide additional information, particularly in relation to chemical pollution. Total and fecal coliform density, pH, nitrates, nitrites, Kjeldahl nitrogen, phosphates, chlorides, turbidity, suspended solids, total solids, specific conductivity, temperature, toxics, grease, fats, and oils are also significant in determining water quality for specific situations. Major water pollutant categories include oxygen-demanding materials, infectious agents (protozoa, bacteria, viruses, and helminths), nutrients, toxic substances, thermal pollutants, sediments, oil, and hazardous substances.

In freshly polluted water, the first stage consists mostly of oxidizing carbonaceous matter. This is demonstrated by an immediate increase in oxygen utilization and stream BOD in the area of pollution discharge, followed by the second, or nitrification, stage, in which a lesser but uniform rate of oxygen utilization takes place for an extended period of time. This is accompanied by a related characteristic change in the stream biota, as illustrated in Figure 4-1 and as discussed below.

Stream Degradation and Recovery

Stream pollution (organic) is apparent along its length by a zone of degradation just below the source, a zone of active decomposition, and, if additional pollution is not added, a zone of recovery or self-purification. In the zone of degradation, the oxygen in the water is decreased, suspended solids may be increased, and the stream bottom accumulates sludge. The fish life changes from game and food species to coarse fish. Worms, snails, and other biota associated with pollution such as rat-tailed maggots, tubifex worms, and sewage fungi increase. In the zone of active decomposition, the dissolved oxygen

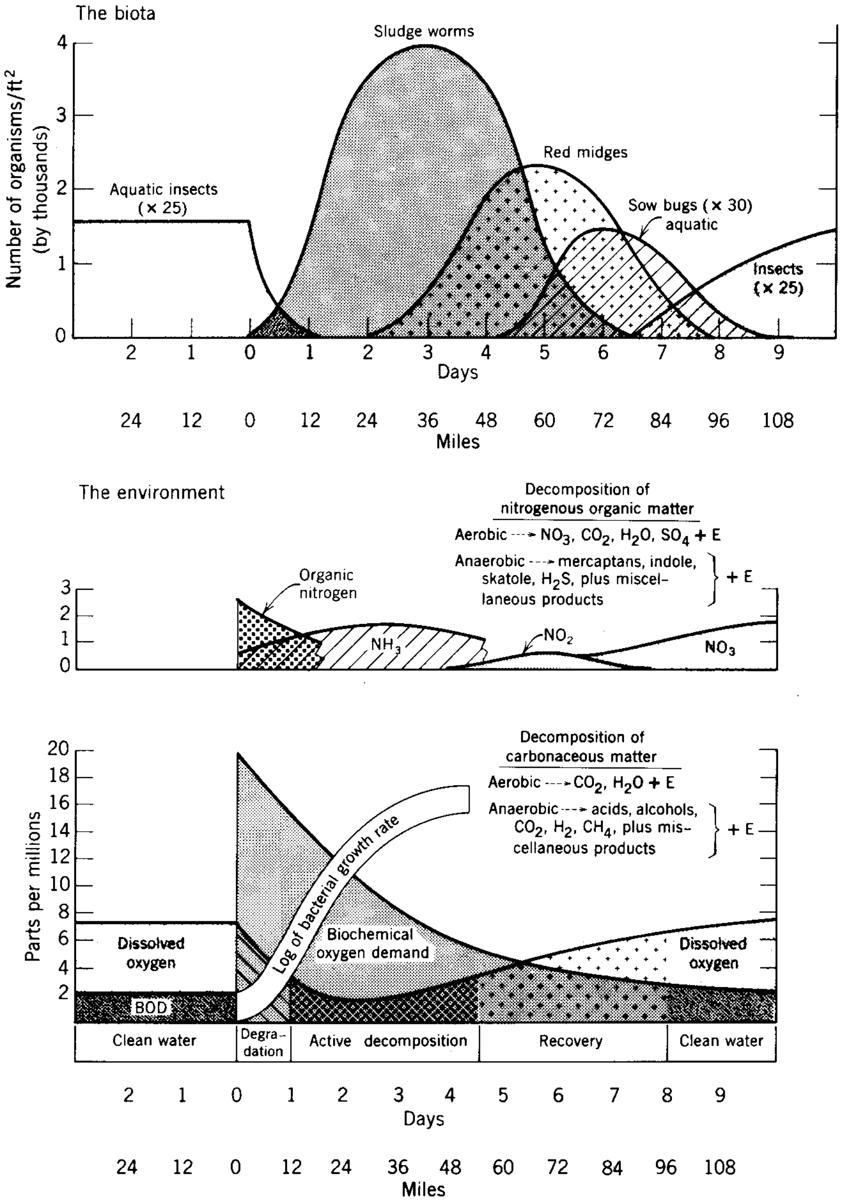


Figure 4-1 Stream degradation and recovery. The assumptions in the hypothetical pollution case under discussion are a stream flow of 100 cfs, a discharge of raw sewage from a community of 40,000, and a water temperature of 77°F (25°C), with typical variation of dissolved oxygen and BOD. The biota population curve is composed of a series of maxima for individual species, each multiplying and dying off as stream conditions vary. The equivalent curve shows that with a heavy influx of nitrogen and carbon compounds from sewage, the bacterial growth rate is accelerated and dissolved oxygen is utilized for oxidation of these compounds. As this proceeds, food is "used up" and the BOD declines. (*Source:* A. F. Bartsch and W. M. Ingram, "Stream Life and the Pollution Environment," *Public Works,* July 1959. This illustration originally appeared in the July 1959 issue of *Public Works*®, published by Public Works Journal Corporation, 200 South Broad Street, Ridgewood, NJ 07450. © 2002 Public Works Journal Corporation. All rights reserved.)

is further reduced and may approach zero. The water becomes turbid and gives off foul odors. Fish disappear, anaerobes predominate in the bottom mud, and midges, larvae, and sludge worms become very numerous. In the zone of recovery, the process is gradually reversed and the stream returns to normal, as indicated by the presence first of clams, snails, crayfish, and sow bugs, then of sunfish, stonefly nymph, caddis fly, mayfly nymph, bass, and riffle beetle. The zones mentioned should not be discernible or experienced where sewage has been given adequate treatment before discharge. With an increase in stream water temperature, there is an increase in biological activity and biological oxidation of the polluting materials. Algae concentrations tend to follow bacterial concentrations. A ratio of fecal coliform (FC) to fecal streptococci (FS) about 4.4 indicates human source pollution. A FC–FS ratio of less than 1 indicates domestic animal pollution.

Measurement of Water Quality

It is often difficult to show in true life and in easily understandable terms the improvement in a stream or lake water quality attributable to wastewater treatment. A method originally proposed by Brown et al.[20,21] uses nine parameters to establish the "arithmetic water quality index" (WQI). The parameters are fecal coliform count, pH, biochemical oxygen demand, nitrate, phosphate, temperature (deviation from equilibrium), turbidity, total solids, and percent saturation of dissolved oxygen. The judgment of some 100 water experts was used in ranking the water quality parameters from 0 (worst) to 100 (best), which were then used to validate the WQI. The system can be applied to compare before and after treatment effects on a stream. Similar systems have been proposed by others.[22–26] A WQI of 71 to 100 is good, 51 to 70 is medium, 0 to 50 is poor. Federal and state water pollution control agencies have their own system to evaluate progress. The U.S. Geological Survey (USGS) and regional and state water pollution control agencies maintain stream-monitoring stations for the measurement of flow and selected pollutant concentrations. The USGS water quality parameters measured include dissolved oxygen, fecal coliform and streptococcus, suspended solids, total dissolved solids, phosphorus, nitrates, chlorides, lead, arsenic, mercury, cadmium, and pesticides.[27] The WQI parameters selected should be supplemented by indices of inorganic and organic chemicals such as cadmium, lead, mercury, polychlorinated biphenyl (PCB), mirex, trichloroethylene, vinyl chloride, and the like as well as by the effects on benthic and aquatic organisms.

WATER QUALITY CLASSIFICATION

The Clean Water Act of 1972 as amended, administered by the EPA and participating states, set as a goal the restoration and maintenance of the chemical, physical, and biological integrity of the nation's waters and to make surface waters of fishable and swimmable quality. To help accomplish these goals, the EPA established the National Pollutant Discharge Elimination System (NPDES), which prohibits the discharge of pollutants into U.S. waters unless a permit is issued by the EPA or the state. The NPDES permit contains effluent pollutant limitations designed to maintain the established best-use water quality. Included are monitoring, housekeeping, and reporting requirements and possibly effluent biological tests for overall aquatic toxicity (whole effluent toxicity). Toxicity identification and reduction may also be required. The permit must be renewed at least once every five years.

It should be kept in mind that the remaining major causes of stream pollution are nonpoint sources, which are not regulated, accounting for approximately 50 percent of the total pollution, plus storm sewer and combined sewer overflows.

States classify surface and underground waters and adopt water quality criteria and standards after public hearings. Water quality classifications are based on their best usage. The best-use designation takes into account such factors as stream flow; water quality; past, present, and desired uses of the water; and bordering lands.

For example, surface waters may be classified for best usage as Class AA and A Drinking Water (and all other uses); Class B, Bathing and Swimming (but not drinking); Class C, Fish Propagation and Fishing; and Class D, Fish Survival. A higher class water such as A must also be suitable for a lower class such as bathing. Special classifications might be trout spawning and trout protection.

Groundwaters may be classified as Class I, Drinking Water; Class II, Irrigation; Class III, Fish, Aquatic Life, and Livestock; Class IV A and B, Industrial; Class V, Geothermal or Associated with Hydrocarbons or Minerals; and Class VI, Unsuitable or Unusable. Emphasis is placed on the prevention of groundwater pollution through the designation of drinking water aquifers; discharge permit requirements; regulation of underground fuel storage and hazardous chemicals; regulation of septic tank additives and septic tank system design, septic tank management, and agricultural management; groundwater withdrawal; public education; and a groundwater protection program including regulation of well drilling, landfills, hazardous waste facilities, and gas drilling.

Salt waters in coastal zones may be similarly classified using the designations SA, SB, SC, and SD. SA is like Class A but protects the quality of shellfish for human consumption instead of drinking water. In some states, all nonsaline groundwaters are classified for use as drinking water Class GA.

Wastewater discharged into Class A or Class I waters must be treated and limited in amount and concentration so that the receiving surface water and groundwater are safe as drinking water supply sources. All surface water must be safe for aquatic organisms and primary contact recreation. Wastewater treatment plant effluents must not contravene NPDES permit limitations and water classification.

Biological, physical, and chemical standards are established for each water quality class. These include such factors as coliform bacteria, pH, turbidity, color, temperature, taste- and odor-producing substances, dissolved oxygen, and 95 or more toxic substances, including metals, organic compounds, and radioactive materials. Analyses to determine compliance with the NPDES permit requirements depend on the characteristics of the wastewater, including industrial wastes, and the requirements of the regulatory agency. Samples collected for plant effluent compliance with receiving water standards should be collected from a zone in the receiving water after mixing, where there is a 10:1 dilution ratio unless otherwise specified.

An example of a water classification based on its best usage, the conditions related to best usage, and the water quality standards to be met are provided in Table 4-2.

Biomonitoring

The examination of samples for required physical and chemical analyses, including, where indicated, the 129 federally established priority toxic pollutants, is very time consuming and may not be adequate to accomplish the objectives of the Clean Water Act. Other chemicals and combinations of chemicals may also cause toxicity. To overcome this weakness and assess the cumulative effects of multiple sources of pollution on aquatic life, the EPA recommends that NPDES permits also require whole-effluent toxicity tests, including biomonitoring, to identify toxicity in the wastewater effluent followed by toxicity reduction where indicated. Biomonitoring may consist of controlled laboratory experiments and field monitoring of abnormalities in fish and aquatic insects. The toxicity of a chemical is affected by water hardness, temperature, pH, total organic carbon, suspended solids, and other factors; hence, results are specific only for a particular water and time. Also, aquatic species bioconcentrate chemicals at different levels. Sediment testing provides additional information on toxicant bioaccumulation.

Organisms commonly used in biomonitoring wastewater effluents and streams also receiving nonpoint discharges include the following: fish—fathead minnow, rainbow trout, bluegill sunfish, channel catfish; invertebrates—water fleas (*Ceriodaphnia*), crayfish, snails, shrimp; bacteria—bioluminescent bacteria; algae—green algae and blue-green algae. The EPA has prepared procedure manuals for aquatic toxicity evaluation.[28]

EUTROPHICATION

Lakes, reservoirs, and estuaries go through a natural aging or maturing process. The rate of aging, or eutrophication, is dependent on the amount and type of natural and synthetic nutrients received as well as light, temperature, water body size, and depth. The degree of eutrophication is indicated by the

TABLE 4-2 Surface Water Classification and Standards: International Boundary Waters

Section 702.1 Class A—Special Waters

GREAT LAKES WATER QUALITY AGREEMENT OF 1972

Best usage of waters: Source of water supply for drinking, culinary or food-processing purposes, primary contact recreation, and any other usages.

Conditions related to best usage: The waters, if subjected to approved treatment, equal to coagulation, sedimentation, filtration, and disinfection with additional treatment, if necessary, to reduce naturally present impurities, meet or will meet New York State Department of Health drinking water standards, and are or will be considered safe and satisfactory for drinking water purposes.

Items	Specifications
Quality Standards for Class A—Special Waters	
1. Coliform	The geometric mean of not less than five samples taken over not more than a 30-day period should not exceed 1000/100 ml total coliform or 200/100 ml fecal coliform.
2. Dissolved oxygen	In the rivers and upper waters of the lakes not less than 6.0 mg/l at any time. In hypolimnetic waters, if should be not less than necessary for the support of fish life, particularly cold-water species.
3. Total dissolved solids	Should not exceed 200 mg/l
4. pH	Should not be outside the range of 6.7–8.5
5. Iron	Should not exceed 0.3 mg/l as Fe
6. Phosphorus	Concentrations should be limited to the extent necessary to prevent nuisance growths of algae, weeds, and slimes that are or may become injurious to any beneficial water use.
7. Radioactivity	Should be kept at the lowest practicable levels and in any event should be controlled to the extent necessary to prevent harmful effects on health
8. Taste- and odor-producing substances, toxic wastes, and deleterious substances	None in amounts that will interfere with use for primary contact recreation or that will be injurious to the growth and propagation of fish or that in any manner shall adversely affect the flavor, color, or odor thereof or impair the waters for any other best usage as determined for the specific waters assigned to this class
9. Suspended, colloidal, or settleable solids	None from sewage, industrial wastes, or other wastes that will cause deposition or be deleterious for any best usage determined for the specific waters assigned to this class

TABLE 4-2 (*Continued*)

Items	Specifications
	Quality Standards for Class A—Special Waters
10. Oil and floating substances	No residue attributable too sewage, industrial wastes, or other wastes or visible oil film or globules of grease
11. Thermal discharges	Shall assure protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water

quantity of planktonic algae (phytoplankton), zooplankton, bacteria, fungi, and detritus; reduced water transparency or clarity (Secchi disc depth); dissolved oxygen in the water near the surface; and pH. Reduced dissolved oxygen may cause the release of hydrogen sulfide, ammonia, methane, iron, and manganese. Sunlight stimulates the growth of algae.

A young lake is said to be *oligotrophic*. It is usually relatively clear, high in dissolved oxygen, and deep and receives few nutrients, thereby supporting little plant and animal life. As nutrients increase, together with siltation due to the acts of humans and nature, plant and animal life increases. The lake then begins to mature and is referred to as a balanced *mesotrophic* lake. The continued siltation and accumulation of organic matter begin to fill up the lake, making it shallower. This, together with proper nutrients, increases the growth of aquatic plants, particularly algae, and the lake becomes mature, or *eutrophic,* with low water transparency, large organic deposits colored brown or black, and often hydrogen sulfide odors. If there is an excess of nutrients, the algal growths greatly increase (“bloom”), die, and decay. The decay process uses up more oxygen to the point of there not being enough for other forms of aquatic life. As the growth and decay progress, the lake fills with organic matter and silt to become a marsh and, eventually, dry land.

The aging process, or eutrophication, of a lake normally takes place over hundreds of years. With the addition of the proper combination of nutrients, the aging process can be greatly accelerated.

The nutrients associated with eutrophication include phosphorus, nitrogen, and organic carbon, any one of which may be a limiting factor in algal growth. Phosphorus appears to be the most practical nutrient to control.[29] The source may be compounds discharged to the atmosphere and their precipitation, groundwater, lake sediment (internal regeneration of phosphorus), tributary and stream drainage, agricultural runoff, animal pastures and fertilizer, forest runoff, urban and suburban drainage, and domestic wastewater. Nitrate nitrogen is more likely to infiltrate during heavy rains, whereas phosphate phosphorus is more readily adsorbed on soil and transported with sediment.[30] The nitrogen, phosphorus, and carbon from land drainage alone have been found to be adequate to support algal growths at the nuisance level. The upgrading of wastewater treatment or a detergent phosphate ban *alone* will not, as a rule, reverse the aging process in a lake or pond water.[31] Other nonpoint sources of nutrients, including stormwater drainage from urban, suburban, and rural areas, must also be removed. If wastewater contributes more than 20 percent of the total phosphorous load to a water body, a detergent phosphorous ban is believed likely to produce only a marginally detectable improvement in eutrophication-related water quality.[32,33]

Lee et al.[34] concluded that phosphorous is a key element in controlling the growth of planktonic algae in fresh water and that nitrogen is generally the controlling element in marine waters. From 1970 to 1980, decreased phosphorous loadings in the Great Lakes have improved water quality. Stumm[35] states that ‘‘the entire limnological community is united in the opinion that reduction of the supply of phosphate to receiving waters is the only cure against manmade eutrophication.’’[35] But for many bodies of water phosphorus from nonpoint sources will also have to be controlled if the water quality is to be restored to desirable levels. Randall et al.[36] found that eutrophication in a reservoir could not be controlled by reduction of point sources of phosphorus and biochemical oxygen demand alone. Over 85 percent of the nitrogen and phosphorus entering the reservoir came from stormwater runoff, mostly from urbanized areas. Sawyer[37] indicates that any lake having 0.01 mg/l inorganic phosphorus and 0.3 mg/l nitrogen can expect to have major algal blooms. Ahern and Weand[38] found that, in general, higher phosphorous concentrations are associated with lower transparencies as measured with a Secchi disc. The desirable total phosphorous level in reservoir waters was 0.03 mg/l *total* phosphorus or less and, based on transparency, there does not seem to be any reason to require phosphorous controls unless they can reduce phosphorous concentrations to 0.08 to 0.03 mg/l and in some instances to 0.01 mg/l or less. Municipal wastewater treatment plant effluent should not exceed 1.0 mg/l on an average monthly basis (U.S. Great Lakes basin). Watershed land-use control is a major factor in the prevention of pollution, sediment transport, and eutrophication. See (a) Control of Microorganisms and (b) Chemical Examinations (Phosphorus, and Nitrates), Chapter 3.

SMALL WATERBORNE WASTEWATER DISPOSAL SYSTEMS

The number of households in the United States served by public sewers, septic tank or cesspool systems, or other means is shown in Table 4-3. With an estimated average occupancy of 3.0 persons per household in 1970, 2.7 in 1980, and 2.4 in 1990, a total of 58.5 million people were dependent on individual on-site facilities in 1970, 59.9 million in 1980, and 62.7 million in 1990. This represents 28.8 percent of the population in 1970, 26.4 percent in 1980, and 25.2 percent in 1990. At an estimated water usage of 50 gallons per capita per day, about 3 billion gallons of sewage is discharged each day to on-site sewage disposal systems and thence to the groundwater. It is ap-

TABLE 4-3 Housing Units Served by Public Sewers and Individual Facilities

	Number of Housing Units Served[a]		
Sewage Disposal Facility	1970	1980	1990
Public sewer	48,187,675	64,569,886	76,455,211
Septic tank or cesspool	16,601,792	20,597,165	24,670,877
Other means	2,904,375	1,602,338	1,137,590
Total housing units	67,693,842	86,769,389	102,263,678
Total population	203,302,031	226,542,203	248,709,873

Source: American Housing Survey, U.S. Census Bureau, Washington, DC, 1970, 1980, 1990.

[a] All units were not occupied.

parent that there is a need for continued support and research for on-site sewage treatment and disposal facilities, in addition to municipal facilities.

The provision of running water in a dwelling or structure immediately introduces the requirement for sanitary removal of the used water. Where sewers are available, connection to the sewer will solve a major sanitation problem. Where sewers are not provided or anticipated, as in predominantly rural areas and many suburban areas, consideration must be given to the proposed method of collection, removal, treatment, and disposal of wastewater. With a suitable soil, the disposal of wastewater can be simple, economical, and inoffensive, but careful maintenance, in addition to proper design and construction, is essential for continued satisfactory operation. Where rock or groundwater is close to the surface or the soil is a tight clay, it would be well to investigate some other property. Sometimes the groundwater level can be lowered by the proper design and construction of curtain drains.

The common system for wastewater treatment and disposal at a private home in a rural area consists of a proper septic tank for the settling and treatment of the wastewater and a subsurface absorption system for the disposal of the septic tank overflow, provided the soil is satisfactory. The soil percolation test and soil characteristics are commonly used as a means for determining soil permeability or the capacity of a soil to absorb settled wastewater. This and the quantity of wastewater from a dwelling are the bases upon which a subsurface sewage disposal system is designed. Sand filters, elevated systems in suitable fill, evapotranspiration–absorption systems, evapotranspiration beds, aeration systems, stabilization ponds or lagoons, recirculating toilets, and various types of toilets and privies are used under certain conditions and where the soil is unsuitable. These are discussed later in this chapter.

Wastewater Characteristics

The composition of wastewater can be expected to vary considerably depending on the community and water use, industries served, infiltration, and whether the sewers are combined sewers or sanitary sewers. However, the wastewater from a residential community is fairly uniform. The characteristics of average domestic wastewater, septic tank effluent, septic tank gray-water effluent, and septic tank black-water effluent are given in Table 4-1.

The wastewater from water closet and latrine or aqua privy flushing is referred to as *black water*. All other domestic wastewater is referred to as *gray water*.

For all practical purposes and from a public health standpoint, gray water should be considered sewage or wastewater and should be treated as such. Gray water can be expected to contain pathogens from the bathroom shower and wash basin and from clothes washing, including baby diapers and clothing. Gray water is amenable for treatment in a septic tank and subsurface absorption system.

General Soil Characteristics

In its broadest sense, soil is made up of glacial deposits and weathered, decayed, or broken-down rock containing varying amounts of organic material such as animal and plant wastes. Destruction of rock is accomplished by water and rainfall, wind, glacial ice, chemical or biochemical action, plant life, freezing and thawing, heat, and other forces to form soil. The soil may accumulate in place or may be transported by wind, water, or glacial ice. Soil that accumulates in place is representative of the rock from which it has been derived and the local flora and fauna. Soils may be divided, for reference purposes, into gravel, sand, silt, and clay and, depending on which is predominant, into sandy loam, gravely loam, silty loam, loam, clay loam, and clay, with and without large cobbles and stones. See Table 4-4. Silt feels smooth; clay is plastic when wet; cobbles are 75 to 250 mm in size; and stones are larger than 250 mm. Loam, for example, is soil that is 7 to 27 percent clay by weight, 28 to 50 percent silt, and less than 52 percent sand.

TABLE 4-4 U.S. Department of Agriculture Size Limits for Soil Separates

Soil Separate	Size Range (mm)	Tyler Standard Sieve No.
Sand	2–0.05	10–270 mesh
Very coarse	2–1	10–16
Coarse	1–0.5	16–35
Medium	0.5–0.25	35–60
Fine	0.25–0.1	60–140
Very fine	0.1–0.05	140–270
Silt	0.25–0.002	—
Clay	<0.002	—

Source: Design Manual, Onsite Wastewater and Disposal System, U.S. Environmental Protection Agency, Office of Water Program Operations, Washington, DC, October 1980, pp. 367–374.

If the content of particles coarser than sand is as much as 15 percent, an appropriate modifier is added, for example, "gravely" (USDA).

Figure 4-2 illustrates a typical earth formation with the top layer, or topsoil, as much as 2 or 3 ft deep, although on the average it will be about 6 to 8 in. or less. The topsoil is usually richer in humus (the organic portion of soil, decomposing plant or animal matter and their products). Clay loam and clay do not drain well and are usually considered unsuitable for the disposal of sewage and other wastewater by subsurface means. Some of the chemicals in clay soil can be displaced by salts, acids, and bases. This ion exchange process, for example, accounts for soil acidity and alkalinity, the friability of some clays, the binding of potassium and ammonium in soil, and the travel of nitrogen through soils.[39]

Soil Characteristics and Clues The permeability of a soil, or the ability of the soil to absorb and allow water and air to pass through, is related to the chemical composition, color, texture, and granular structure of the soil. The soil texture refers to the proportion of clay, silt, and sand less than 2 mm in diameter, to its filtration capacity and permeability. The soil structure refers to the agglomeration or clumping of particles of clay, silt, and sand and the intervening cleavage planes indicating hydraulic conductivity and shrink/swell potential. The microbial population and root penetration modifies the properties of the soil as noted below. A lump of soil with good structure will break apart, with little pressure, along definite cleavage planes. Horizontal cleavage restricts vertical percolation and permits a perched water table to exist. Prismatic and columnar structures enhance vertical percolation, and blocky and granular structures enhance both horizontal and vertical water

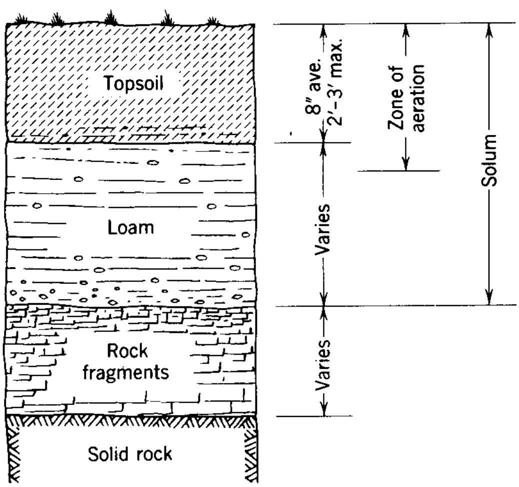


Figure 4-2 Typical earth formation.

flow.[40] If the color of the soil is yellow, brown, or red, it would indicate that air, and therefore water, passes through. However, if the soil is blue or grayish, it would indicate a soil saturated for extended periods; if mottled brown and red, it would indicate a fluctuating seasonal high water table or poor aeration and therefore an intermittently saturated or tight soil that is probably unsuitable for subsurface absorption of wastewater. The absorption field and dwelling basement would probably be flooded at times if not drained. A grayish soil, however, may be suitable if drained but is generally unsuitable. Magnesium and calcium tend to keep the soil loose, whereas sodium and potassium have the opposite effect. Sodium hydroxide, a common constituent of so-called septic tank cleaners, would cause a breakdown of soil structure with resultant smaller pore space and reduced soil permeability.

Role of Microorganisms and Macroorganisms Aerobic oxidizing bacteria, that is, oxygen-loving bacteria, are found in the zone of aeration. This zone extends through the topsoil and into the upper zone of the subsoil, depending on the soil structure and texture. Earthworm, insect, and small-animal populations, root penetrations, soil moisture, and other factors also influence the extent of the zone of aeration. The topsoil may contain organic matter, minerals, air, water, supportive vegetative organisms such as bacteria, fungi including yeasts and molds, and protozoa, nematodes, actinomycetes, algae, rotifers, earthworms, insects, and larger animals. A gram of topsoil can be expected to contain millions of bacteria and other organisms. These organisms have the faculty of reducing complex organic matter to simpler forms through their life processes. Earthworms, fungal activity, and small animals play an important role together with other soil flora and fauna in keeping soil fertile and aerated.

Septic tank effluent, for example, which contains material in solution, colloidal state, and suspension, when discharged into or close to the topsoil, will be acted upon by these organisms and reduced to "soil" as well as liquids and gases. This is accomplished provided the sewage is not discharged at too great a volume and concentration into the earth in the zone of aeration. A waterlogged soil impedes oxygen transfer and destroys the aerobic organisms, producing anaerobic conditions that tend to preserve the organic matter in septic tank effluent, thereby delaying its decomposition and increasing mechanical clogging of the liquid–soil interface with organic matter, including slimes and sulfides. In addition, the nitrites in septic sewage are toxic to plants. Complete soil treatment of septic tank effluent requires that it be discharged into the unsaturated soil zone at an acceptable rate to fully utilize the treatment available through physical filtration and chemical and biological degradation processes. Travel through 1 to 2 ft of unsaturated silty, sandy, or clay loam soil can be expected to remove practically all sewage microorganisms and protect the groundwater. However, soil conditions vary. Greater unsaturated soil depth is required in coarse granular soils.

Maintenance of Soil Infiltrative Capacity

To assist in the maintenance of aerobic conditions, subsurface absorption fields are usually laid at depths of 24 to 30 in., although depths as great as 36 in. or more are sometimes used. The gravel around the open-joint tile or perforated pipe should extend up into the zone of aeration, usually within 8 to 12 in. of the ground surface.

McGauhey and Winneberger[41] call attention to the recovery infiltrative capacity of trench sidewalls after resting a few hours; the need to have a permeable soil in the first instance; the insulating effect of impermeable lenses or strata to the downward percolation of water; the reduction of percolative capacity of soils containing colloids that swell; and the necessity for the groundwater table to be at a sufficient depth to permit the soil to drain during rest periods rather than water remaining suspended by surface tension and capillary phenomena. They state that "loss of infiltrative capacity is directly traceable to the organic fraction of sewage, which leads to clogging of the soil surface by suspended solids, bacterial growth, and ferrous sulfide precipitation."[41]

They report "conclusively that intermittent dosing and draining of the soil system is necessary to the maintenance of optimum infiltration rates."[41] In a subsequent report, narrow trenches 8 to 12 in. wide and placement of the distributing line as high as possible are advised to provide a maximum effective sidewall surface area.[42] It has also been found that "soil clogging can be delayed or altogether mitigated by reducing the applied mass loading rate of the total biochemical oxygen demand (carbonaceous plus nitrogenous) and total suspended solids either through lower hydraulic loading rates or reduced effluent concentrations."[43] Full loading (siphon chamber or pump) on an intermittent basis will promote even distribution of wastewater, resting, and maintenance of aerobic conditions in the trench and soil. Prolonged resting periods (several months to a year) will permit restoration of infiltrative capacity, but two absorption systems and a diversion gate or valve are needed to permit alternate use of each system. Laak[44] believes that soil seepage beds will function forever if the system is properly designed, constructed, and maintained. There is no evidence to suggest that soil clogging is irreversible.

Soil adsorptive capacity is an important consideration in the design of a septic tank system for the protection of the groundwater. Robeck et al.[45] advise that a soil must have a low permeability (effective size 0.1 to 0.3 mm) and some adsorptive capacity to allow organic material to be retained. A minimum soil organic content of 0.5 to 1 percent is suggested (found in practically all agricultural soil, together with some clay and silt, which add to the adsorptive capacity). Under such circumstances pathogenic and essential aerobic organisms, which are capable of degrading such food sources as detergents and other organic matter, are retained. A soil with low adsorption (coarse gravel) or a formation with solution channels, fractures, or fissures will permit pollution to travel long distances without purification. Careful consideration to these factors in the design of subsurface sewage disposal systems is necessary.

Hydrogen peroxide has been used on an experimental basis to restore and maintain the infiltrative capacity of clogged absorption systems, but its effectiveness is short-lived. The soil percolation capacity is greatly reduced. Use of hydrogen peroxide is not recommended.[46]

Site Investigation, Soil Profile, and Suitability

Prior to the construction of a sewage disposal system, subsurface explorations are necessary to determine the subsoil formation in a given area. An auger with an extension handle is often used in the investigation, but a backhoe should also be employed for deep test holes in large systems. The examination of road cuts, stream embankments, or building excavations provides useful information. Wells and well drillers' logs can also be used to obtain information on groundwater and subsurface conditions. In some areas subsoil strata vary widely within short distances and numerous borings are required in the selected site. Agricultural* and highway soil maps, if available, can give an indication of soil characteristics, provided the number and depth of the soil cores or test holes used to prepare the soil maps are representative of the soil strata and area to be used for the subsurface disposal of wastewater. Aerial photograph maps† are also very useful to experienced individuals. If the subsoil appears suitable (as judged by a study of soil maps and soil texture and an investigation of the structure, color, and depth or thickness of permeable strata and their swelling characteristics), percolation tests should be made at points and elevations selected as typical of the area in which the disposal system is to be located to establish a settled sewage application rate for design purposes.

Like the soil percolation test (discussed later), soil maps and reports have limitations. The variability in soils and the map scale make impractical a prediction of soil characteristics and behavior on an individual plot for a subsurface soil absorption system. However, the soil survey map and report are extremely useful when supplemented by a field investigation of a specific site (including soil percolation tests) made by a qualified person.[47]

It is necessary to have at least 2 ft of suitable soil between the bottom of absorption trenches and leaching pits and the highest groundwater level, clay, rock, or other relatively impermeable layer. This helps ensure removal of most of the pathogenic viruses, bacteria, protozoa, and helminths in septic tank effluent before they reach the groundwater. Some agencies require a minimum of 3 or 4 ft. Seasonal groundwater levels can be determined by means of test

* See local Soil Conservation Service, USDA.

† Farm Service Agency (FSA) Aerial Photography Field Office, Salt Lake City, UT.

holes, soil clues, piezometers, and rust accumulation on steel rods driven in the ground.

The design of leaching pits and cesspools is based on the ability of the soil found at the depth between 3 and 8 or 10 ft to absorb water. Sometimes pits are made 20 to 25 ft or more in depth, using prefabricated sections, in order to reach permeable soil. It is not known to what extent viruses, bacteria, protozoa, and metazoa are active in leaching pits and cesspools. Since relatively large quantities of sewage would be discharged in a small area, designs incorporating cesspools or leaching pits must take into consideration the soil texture and structure, direction and depth of groundwater flow, and relative location of wells or springs with respect to their possible pollution. Cesspools and leaching pits should be prohibited in shale, coarse sand, gravel, and limestone areas or where groundwater is within 3 to 4 ft of the bottom and avoided when shallow wells or springs are in the vicinity, unless adequate protecting distances and soils can be ensured.

Where the soil is relatively nonpermeable at shallow and deep depths, an alternate treatment and disposal system (discussed later) is needed in place of a conventional leaching system. Preferably, construction should be postponed in such situations until sewers are available.

It is extremely important while in the planning stage, before building construction is started, to consider the following:

1. The suitability of the soil to absorb settled sewage as determined by soil percolation tests, soil characteristics, and the type and size of the disposal system required. At least 4 to 5 ft of suitable soil should be available over clay, hardpan, rock, or groundwater for absorption trenches and 8 to 10 ft for leaching pits. The hydraulic conductivity of the soil below, around, and downgrade from the absorption system should permit adequate dispersal of the sewage effluent.
2. The area of land available for the sewage disposal system and its adequacy for sewage disposal and water supply protection. This should include the location of existing and proposed on-site and off-site sewage disposal systems and underground sources of drinking water; type of well construction, underground strata, and depth of water-bearing source; slope of the groundwater table; and protecting distances between wells and sewage disposal systems.
3. The elevation of the sewage disposal units, the house sewer, the house drain, the first-floor level, and location of the lowest plumbing fixture. Sometimes the installation of a sewage pump, excavation at a greater depth, or the carting in of earth fill is made necessary because the slope of the ground surface, clay or rock level, and depth of the underground water are not considered in the planning stage. Earth fill will require careful selection and placement to achieve uniform density without

compaction, stabilization for about one year, and testing for percolation since the original soil structure will have been changed.

4. The location of rock outcrops, hills, large trees, stormwater drains, watercourses, adjoining structures; also bathing beaches, shellfish-growing areas, and water supply intakes.
5. Surface and underground water drainage, including roof, cellar, and foundation drainage (this drainage must be excluded from the sewage disposal system to prevent the system becoming overloaded and waterlogged).
6. The average rainfall and temperature during the period of use.

Information on aquifer geology, well yields, well pump capacities, and static and pumping water levels will help determine the circle of influence and travel of underground pollution. All these factors should be carefully evaluated by a trained person before a decision is made and construction is started. The state and county sanitary or public health engineers and sanitarians are trained to give sound advice.

Travel of Pollution from Septic Tank Absorption Systems

Groundwater contamination potential from a septic tank leaching system is determined by the physical, chemical, and microbiological characteristics of the soil; the unsaturated soil depth to groundwater; the volume and strength of the septic tank effluent; and the biological slime or mat on the trench gravel, bottom, and sidewalls. The ability of the soil to remove or reduce the organic and inorganic contaminants is variable and determined by many factors. These include activity in the vegetation root zone to take up or break down chemical and organic substances. As the contaminants percolate downward and laterally, they may be volatilized, filtered, absorbed, attenuated, adsorbed, neutralized, hydrolized, changed, and broken down by aerobic and anaerobic microorganisms. There is some dilution of contamination, and the contamination that does reach the groundwater will usually travel very slowly as compared to surface water. It should be noted that the extent and health significance of groundwater contamination by a properly sited, designed, and constructed septic tank system is minimal. Concerns to be addressed include the persistence and potential transport of pathogenic viruses, bacteria, protozoa, and helminths, in addition to nitrates, phosphates, and household toxic cleaning compounds, particularly in granular coarse-textured soils such as coarse sand and gravel.[48] The biological mat that forms in absorption field trenches further minimizes the travel of microorganisms. Because of their larger size, protozoa and helminths are not likely to travel significant distances compared to bacteria and viruses.

There are indications that 4 ft (122 cm) of unsaturated coarse-grained sandy soil is not adequate to prevent bacteria from reaching saturated soils beneath on-site septic tank absorption trenches. However, no bacteria traveled beyond 3.6 ft (110 cm) in loamy sandy soil. The percentage of clay and silt particles passing the U.S. Standard Sieve No. 200 with openings of 0.075 mm and organic matter appear to be the major factors in bacteria retention by straining and adsorption and in bacteria die-off.[49]

Studies show that unsaturated soil beneath absorption trenches will remove a high percentage of total dissolved solids, five-day BOD, soluble organic carbon, ammonia nitrogen, iron, viruses, coliforms, fecal coliforms, and fecal streptococci from septic tank effluent. Phosphate (total PO_4-P) removal may or may not be high (removal or retention is dependent upon the type of soil). Nitrates will increase in the vicinity of the leaching system as ammonia, organic nitrogen, and nitrites convert to nitrates but decrease downstream with microbial denitrification, distance, and dilution.[50]

Soils containing loam (clay, silt, and sand) will remove most of the phosphorus, soluble orthophosphates, and microorganisms in sewage effluent. If the absorption trenches are kept shallow (top of gravel about 8 to 12 in. from the ground surface) as recommended, the vegetative cover root system over the absorption field penetrates and takes up much of the nitrogen during the growing season, which coincides with maximum system use at summer vacation homes, resorts, and recreational areas. Moisture is also removed by capillarity and evapotranspiration. Hence, the danger of phosphates and nitrates traveling any significant distance through the soil (other than coarse-textured granular soils) to the groundwater table and contributing significant amounts of nutrients that might reach a lake or other impoundment and accelerate its eutrophication can be greatly minimized. This is particularly so when considered in relation to the phosphorous and nitrogen contribution from surface runoff, stormwater, and wastewater discharges to lakes and streams. There are, however, some ecologically critical waters where even minimal amounts of phosphorus and/or nitrogen, regardless of source, should be avoided. But this may be impossible, as natural sources of nitrogen from precipitation and/or phosphorus from automobile exhaust, phosphorus and nitrogen from agricultural, uncultivated, and forest area, and stormwater overflows cannot in practice be eliminated. Even if minimized, there may still be sufficient amounts of nutrients reaching sensitive waters to cause algal growths and natural eutrophication, although it is hoped at a slower rate.

Laboratory studies using nine types of soil indicate that passage through 40 to 50 cm of an agricultural-type soil is very effective in removing viruses from water, with soils at pH below 7.0 to 7.5 best.[51] Culp[52] concluded that, although not well established, soil with reasonable amounts of silt and clay removes viruses within the first 2 ft. Wellings et al.[53] reported virus travel of 5 ft in sandy soil spray irrigated with chlorinated activated sludge effluent and also travel to 6- and 20-ft-deep wells. Slow sand filters dosed uniformly at standard loading rates removed 99 percent or more viruses from septic tank effluent over a two-year period under controlled experimental conditions.[54] Sorber and his co-workers[55] found that enteric viruses can be recovered in soils at considerable distances from their point of application. It is apparent that the travel of pollution is not reduced to an exact science.

Travel of chemical pollution from other than septic tank absorption systems often presents a more serious problem in that the pollution may travel long distances, not be filtered in passage through the soil, and persist for long periods of time. Spills, leaking petroleum and other hazardous chemical storage tanks, lagoons, and old landfills are other examples. Millions of underground tanks are leaking. See Chapter 3: (a) Travel of Pollution through the Ground, (b) Well Contamination—Cause and Removal, and (c) Prevention and Removal of Organic Chemicals.

Soil Percolation Test

Background of the Soil Percolation Test The suitability of soil for the subsurface disposal of sewage and other wastewater can be determined by a study of soil characteristics and the soil percolation test. The test is a measure of the relatively constant rate at which clear water maintained at a relatively constant depth (6 in.) will seep out of a standard-size test hole (Ryon[56] used a 12-in. square hole) that has been previously saturated; the bottom of the test hole is at the approximate depth of the proposed absorption system and greater than 2 ft above the seasonal high groundwater, rock, or tight soil. Ryon[56] first introduced this test in 1924 based on his investigation of subsurface disposal systems that had failed or were about to fail after 20 years of use in New York State. He plotted the results of his tests, covering a wide range of soils, and developed ‘‘safe gallons per square foot per day subsurface irrigation rates.’’ The soil percolation test developed by Ryon has been used throughout the world and, except for some refinements,* remains the only rational basis for the design of subsurface disposal systems. Ryon emphasized the importance of ‘‘taking care to wet the soil before pouring water in for the test if it appears dry’’ and that ‘‘the ground must be thoroughly wet before the test is made’’ (ref. 56, pp. 11–14). *Saturation of the soil is essential* to compensate for soil swell, simulate wet conditions, and obtain reproducible results, that is, a relatively constant rate of water drop in the test hole. The work done by Ryon was confirmed by the Public Health Service (PHS) in independent field tests and, in spite of its limitations, serves as the major basis for present-day design of subsurface absorption systems, adjusted for the automatic home clothes washer and garbage grinder disposal unit.[57]

The reliability of the soil percolation test is increased by scientific evaluation of soils maps by a qualified person (as noted in this chapter under (a)

*Two inches of gravel in the bottom of the test pit and reemphasis on prior soaking of the hole.

General Soil Characteristics and (b) Site Investigation, Soil Profile, and Suitability). Special training and experience in soils is very helpful in properly interpreting the soils data.

Other investigators have studied the test to determine the effect of the shape of the test hole and the saturation of the soil on the percolation test. It has been found that the shape of the hole has no effect; size or diameter does affect results. However, it is again emphasized that *saturation of the soil is essential* to obtain reproducible results, that is, a constant rate of water drop in the test hole. This was recognized by Ryon[56] and needs to be continually emphasized.

One of the main significant differences of opinion in connection with the soil percolation test is its interpolation to determine the allowable rate of septic-settled sewage application per square foot of leaching area. This rate is taken as a percentage of the actual amount volume of water a test hole accepts in 24 hr. Various investigators have stated that this rate should be 0.4 to 3.5 (Ryon[56]) to 5.0 or 7.0 percent of the actual amount of water absorbed or accepted by the test hole. The rate is recorded in the minutes it takes the water level to drop 1 in.

Percolation Test Percolation tests and soils studies help to determine the acceptability of the site and establish the design size of the subsurface disposal system. The length of time required to carry out percolation tests will vary with different types of soil. The safest method is to make tests in holes that have been kept filled with water at least 4 hr, preferably overnight, except where the soil is clean sand or gravel. This is particularly desirable if the tests are to be made by an inexperienced person, and for some soils, such as those that swell on wetting, this precaution is necessary even if the person carrying out the test has had considerable experience. Percolation rates in such cases should preferably be calculated from test data obtained after the soil has had an opportunity to swell overnight. An adequate number of tests should be made to ensure a valid result (ref. 15, p. 128). Some agencies require that soil tests be made during the wet period of the year to minimize error.

The soil percolation test is performed as follows:

1. Dig a hole about 1 ft^2 (the EPA suggests a 6-in.-diameter hole) and to the depth at which it is proposed to lay the drain tile or perforated pipe. Scrape the inside of the hole to remove all smooth or cemented patches. A good average depth is 24 to 30 in. About 2 in. of washed pea gravel should be placed in the bottom of the hole. See Figure 4-3.

2. Slowly pour about 12 in. of water on the gravel in the hole to prevent scour. If the soil is relatively tight, let the water soak for about 4 hr, adding more water as necessary, and proceed as explained in step 3. If the soil is very absorbent, allow the water to seep away; if the soil contains clay or fine

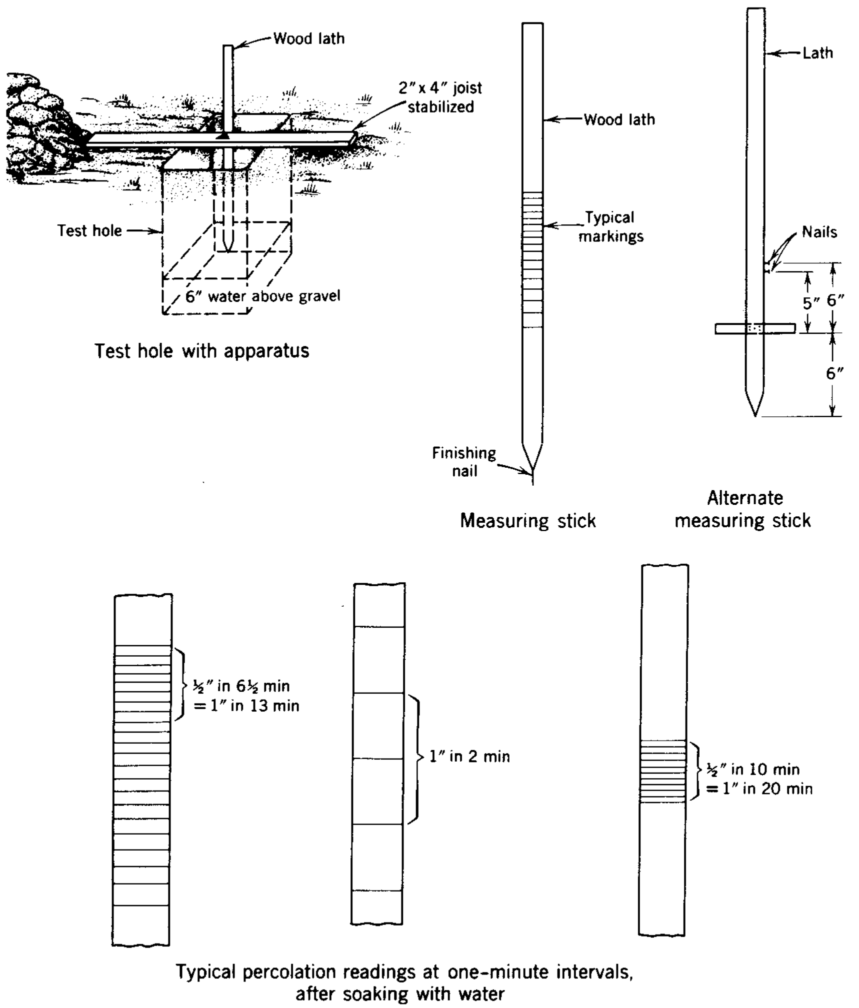


Figure 4-3 Soil percolation test. (Place 2 in. of gravel in bottom of test hole.)

silt, soak overnight. Add another 8 in. of water in the hole and proceed as in step 3. The test can be expedited by routinely having all test holes filled with water the night before the tests are made to allow ample time for soil swelling and saturation. Arrangement should be made to refill the holes. A 5-gal carboy, with a stopper and plastic tubing, filled with water could be inverted over the hole.

3. Measure the rate at which the water surface drops. This can be done by placing a piece of 2 × 4 across the hole, *being careful to anchor it in a*

firm position. Then, using a point or line on the 2 × 4 as a reference (see Figure 4-3) for the remainder of the test, slide a pointed slat or similar measuring stick straight down until it just touches the water surface. Immediately read the exact time on your watch and draw a horizontal pencil line on the measuring stick using the point or line on the 2 × 4 as a guide. Repeat the test at 1-min intervals, if the water level drops rapidly, or at 5- or 10-min intervals if the water level drops slowly. Observe the space between the pencil markings. Keep the depth of water in the hole at about 6 in. above the gravel. When at least three spaces become relatively equal between the 6- and 5-in. water depth in the test pit, the test is completed, since equilibrium conditions have been reached for all practical purposes. The percolation test result is recorded as the minutes it takes for the water level to drop 1 in.

4. With the aid of a ruler, measure the space between the *equal* pencil markings and reduce this to the number of minutes it takes for the water level to drop 1 in. This can be approximated closely with a ruler or can be computed. For example, if the interval between 5-min readings is $\frac{3}{8}$ in., the time for the water level to drop 1 in. is calculated as

$$\frac{\frac{3}{8}\text{ in.}}{5\text{ min}} = \frac{1\text{ in.}}{x\text{ min}}, \quad \text{or } \tfrac{3}{8}x = 5, \quad \text{or } x = 13\tfrac{1}{3}, \quad \text{say } x = 15\text{ min}$$

Tests must be carefully made to minimize errors due to soil swelling, smearing, variations in soils characteristics, inaccurate readings, and water scour.

Make at least three tests for the average lot; six tests are preferable where soil is not relatively uniform. Consider the soil characteristics and excavate the test holes to a depth of 4 to 6 ft to ensure groundwater, rock, or tighter soil is not encountered. *Interpret the percolation test results in the light of soil characteristics and soil clues as previously described.* Deeper borings may be indicated if clay or hardpan is encountered to determine the thickness of the soil horizons. Adjustments must be made if a lense of dense or impermeable material, which could cause a perched water table, or if a less permeable soil, which could cause a mounded water table, is encountered.

5. Use Table 4-5 to determine the allowable rate of settled sewage application in gallons per day per square foot of bottom trench area (gpd/ft^2) in an absorption trench system. Table 4-5 is applicable only for typical residential sewage. For other applications adjust for organic loading, BOD, suspended solids (SS), COD, total Kjeldahl nitrogen (TKN), and grease in septic tank effluent.

An example will serve to illustrate how the soil test results are used.

TABLE 4-5 Interpretation of Soil Percolation Test

Time for Water to Fall 1 in. (min)	Allowable Rate of Settled Sewage Application (gpd/ft^2)			
	U.S. PHS[a]	U.S. EPA[b]	GLUMR[c]	Ryon[d]
<1	5.0[e]	—	1.2	4.0–3.4
1	5.0[e]	1.2	1.2	3.3
2	3.5[e]	1.2	1.2	2.9
3	2.9[e]	1.2	1.2	2.7
4	2.5[e]	1.2	1.2	2.4
5	2.2[e]	1.2	1.2	2.2
6	2.0	0.8	0.9	
7	1.9	0.8	0.9	2.0
8	1.8	0.8	0.9	
9	1.7	0.8	0.9	
10	1.6	0.8	0.9	1.7
11	1.5	0.8	0.6	
12	1.4	0.8	0.6	
15	1.3	0.8	0.6	1.4
16	1.2	0.6	0.6	
20	1.1	0.6	0.6	1.1
25	1.0	0.6	0.6	
30	0.9	0.6	0.6	0.9
31	0.8	0.45	0.5	
35	0.8	0.45	0.5	
40	0.8	0.45	0.5	
45	0.7	0.45	0.5	0.7
46	0.7	0.45	0.45	
50	0.7	0.45	0.45	
60	0.6	0.45	0.45	0.4
61–120	[f]	0.2	[f]	0.2
>120	[g]	[f]	[f]	[g]

Note: Be guided by state and local regulations.

[a]U.S. Public Health Service, *Manual of Septic-Tank Practice*, PHS Pub. No. 526, Department of Health and Human Services, Washington DC, 1967. Increase leaching area by 20% where a garbage grinder is installed and by additional 40% where a home laundry machine is installed. The required length of the absorption field may be reduced by 20% distribution lateral or by 40% if 24 in. of gravel is used, provided the bottom of the trench is at least 24 in. above the highest groundwater level. Superceded by the U.S. EPA *Manual.*

[b]*Design Manual*, *Onsite Wastewater Treatment and Disposal Systems*, U.S. Environmental Protection Agency, Cincinnati, OH, October 1980. Soils with percolation rates <1 min/in. can be used if the soil is replaced with a suitably thick (>2-ft) layer of loamy sand or sand. Use 6–15 min/in. percolation rate. Rates based on septic tank effluent from a *domestic* wastewater source are used to determine the required *trench* bottom area. Reduce application rate where applied BOD and total suspended solids (TSS) is higher than domestic sewage. Additional area credit may be given for sidewall trench area if more than 6 in. of gravel is placed below the distributor. The trench or bed bottom must be at least 2–4 ft above the seasonally high water table, bedrock, or clay soil. The EPA and GLUMR application rates are lower than the U.S. PHS rates. The former recognize the importance of settled sewage retention in the unsaturated zone to obtain maximum purification before it reaches the groundwater and results in a larger disposal system.

TABLE 4-5 (*Continued*)

[c]GLUMR, *Recommended Standards for Individual Sewage Disposal Systems*, Great Lakes–Upper Mississippi River Board of State Sanitary Engineers, Albany, NY, 1980. Absorption trench or bed shall not be constructed in soils having a percolation rate slower than 60 min/in. of where rapid percolation may result in contamination of water-bearing formation or surface water. The percolation rate is for *trench* bottom area. For absorption *bed*, use application rate of 0.6 gpd/ft^2 for percolation rate up to 6 min/in., then use 0.45 gpd/ft^2. Trench or bed bottom, or seepage pit bottom, should not be less than 3 ft above highest groundwater level. Maximum trench width credit shall be 24 in. for design purposes, even if trench is wider.
[d]H. Ryon, *Notes on Sanitary Engineering*, New York State, Albany, NY, 1924, p. 33. This is given for historical perspective, as are U.S. PHS rates.
[e]Reduce rate to 2.0 gpd/ft^2 where a well or spring water supply is downgrade; increase protective distance and place 6–8 in. sandy soil on trench bottom below gravel and between gravel and sidewalls.
[f]Soil not suitable.
[g]See the section on small wastewater disposal systems for unsuitable soils or sites in this chapter.

Example

Number of bedrooms: 3.

Required septic tank: 1000 gal liquid volume.*

Average of soil tests for absorption field, from table: 0.9 gpd/ft^2 (1 in. in 30 min).

Estimated sewage flow at 150 gal per bedroom: 450 gpd.

Required leaching area: 450/0.9; plus 60% for garbage grinder and clothes washer: 800 ft^2 (using the U.S. PHS rate).

The required area can be obtained by providing the following:

800/1.0 or 800 linear feet of tile in trenches 12 in. wide, or recommended widths

800/1.5 or 533 linear feet of tile in trenches 18 in. wide, or recommended widths

800/2.0 or 400 linear feet of tile in trenches 24 in. wide, or recommended widths

Note: No additional credit is given for bottom area for trenches wider than 2 ft; the trench may be wider. The required leaching area using the Great Lakes–Upper Mississippi River Board or EPA recommendation would be 450/0.6 = 750 ft^2.

A variation of the soil percolation test is to observe the time for the water level to drop from a depth of 6 to 5 in. after saturation, as shown in Figure

*Assumes a home laundry machine and a garbage grinder are to be installed.

4-3. Repeat the test, adding water as necessary, and if the times recorded in subsequent tests are within 10 percent or $\frac{1}{16}$ in., use this time to determine the allowable rate of settled sewage application per square foot per day using Table 4-5. If the ‘‘times’’ vary by more than 10 percent, repeat the test until the times for two successive tests do not vary by more than 10 percent. With a tight soil, this method will take somewhat longer to perform than the first method. Some sanitary engineers and sanitarians prefer to continue the test until the times for the water to fall 1 in. are within 3 to 5 percent.

Many variations and refinements of the soil percolation test, including the use of a float gauge, inverted carboy as in a water cooler, and permeability test, have been proposed.[58–60] In any case, a sufficient number of soil tests should be made that will give information representative of the soil, as indicated by a relatively constant rate of water drop in the test hole. This will also make possible determination of an average percolation rate that can be used in design. A typical layout is shown in Figure 4-4.

Where a small rural real estate subdivision is under consideration, at least three holes per acre should be tested and soil borings made. More holes should be tested if the percolation results vary widely, say by more than 20 percent. If rock, clay, hardpan, or groundwater is encountered within 4 ft of the ground surface, the property should be considered unsuitable for the disposal of sewage by means of conventional subsurface absorption fields. An alternative system may be considered. This calls for the exercise of trained professional judgment.

In special cases, where tighter soil is encountered just below the bottom of the test hole, interpretation of the results might require adjustment of the allowable sewage application to that based on the tighter soil.

It should be pointed out that the ill repute of septic tank absorption systems in some areas is due to improperly performed and interpreted soil percolation tests, high groundwater, poor construction, lack of maintenance, or abuse of the system and to the use of septic tanks where they were never intended. Inadequate design, lack of inspection by regulatory agencies, and failure to consider soil color, texture, and structure may contribute to the problem.

Absorption systems should not be constructed on filled-in ground until it has been thoroughly settled or otherwise stabilized. Percolation tests should be made in fill after at least a 6-month, preferably 12-month, settling period and after complete stabilization of the soil. Percolation tests cannot be made in frozen ground. Soil tests in fill are not reliable as the soil structure, texture, moisture, and density will be quite variable. See Small Wastewater Disposal Systems for Unsuitable Soils or Sites, this chapter.

Where the ground is flat, provision should be made to drain surface water from off and around the absorption field to prevent the soil from becoming waterlogged. On steeply sloping ground, a surface-water diversion ditch or berm should be provided above and around the absorption field to minimize water infiltration and prevent the absorption field from being washed out. This

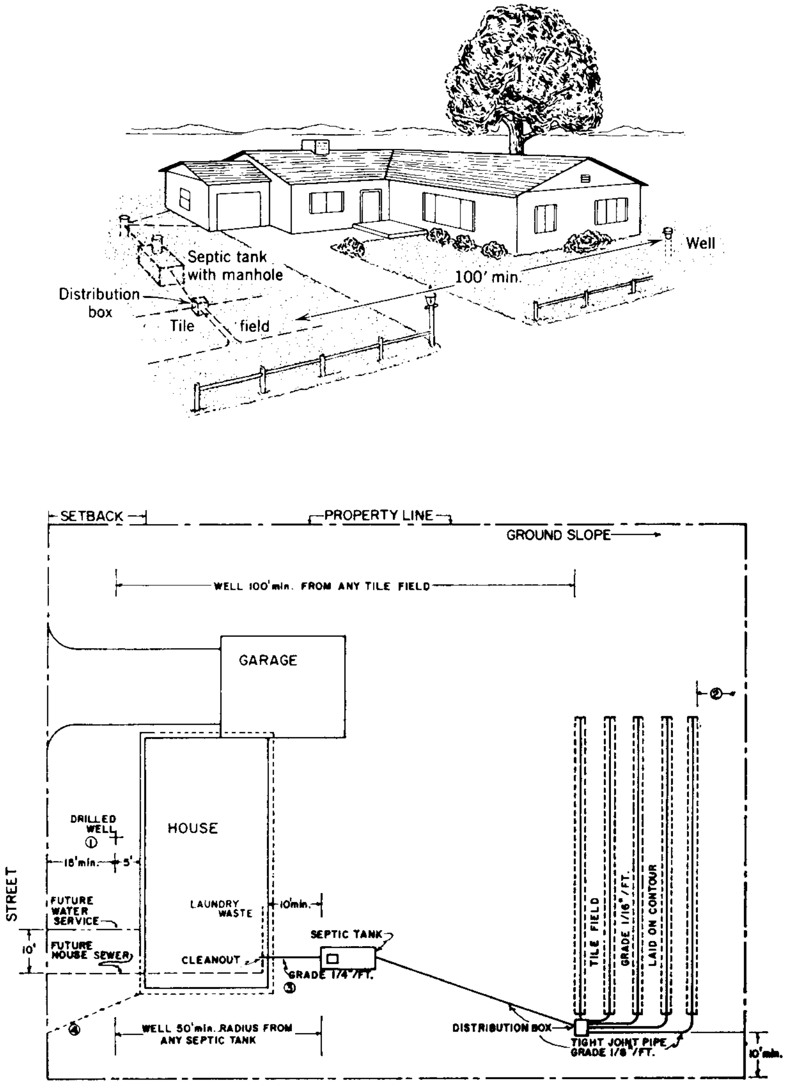


Figure 4-4 Typical private water supply and sewage disposal layouts. *Notes:* (1) Watertight footing drain within 25 ft of well. (2) Tile field to be 50 ft or more from any lake, swamp, ditch, or watercourse and 10 ft or more from any waterline under pressure. (3) Cast-iron pipe, lead-caulked joints within 50 ft of any well. (4) Discharge footing, roof, and cellar drainage away from sewerage system and well. (5) Grade lot to drain surface runoff away from the subsurface absorption system.

will also prevent silt and mud from washing into the trench during construction and coating the bottom with a relatively impervious film. It is also important to point out that the undesirable practice of walking in the bottom of trenches causes a compaction of the earth and a reduced percolation capacity. If this happens, rake the bottom to restore the original surface. Ensure that the trench bottom is on a slope of $\frac{1}{16}$ in./ft or less.

Where leaching pits are permitted, the soil test is made in a test hole about 1 ft^2, where the soil profile changes, at a depth about one-half the proposed *effective depth* of the leaching pit, and at the bottom. Upon completion of the test, the hole should be extended an additional 2 to 3 ft to ensure that the soil at a greater depth is similar to that tested and that groundwater is not encountered. The test is made in the same manner as explained for an absorption system but at the greater depth. The results are interpreted in Table 4-5.

The design of septic tanks, subsurface absorption fields, and seepage pits is explained and illustrated in the discussion of these systems that follows.

Estimate of Sewage Flow

The sewage flow to be expected from a dwelling or other type of establishment is not constant each day. The day of the week, season of the year, habits of the people, water pressure, type and number of plumbing fixtures, and type of place or business maintained are some of the factors affecting the probable sewage flow. The design cannot be based on the minimum flow but must be based at least on the average maximum. Daily water-meter consumption figures from a similar type of establishment taken over an extended period of time, including weekends and maximum days, would be of value in arriving at a good average maximum daily flow estimate to be used in design. Caution must be used when interpreting quarterly, semiannual, or annual meter readings, as averages derived from these figures will be low unless corrected for vacation periods, weekends and holidays, seasons of the year, and so on. In the absence of actual figures, the per-capita or unit estimated water flow given in Table 3-14 may be used as a guide.

Fixture bases of estimating sewage flow assume that all water used finds its way to the sewage disposal or treatment system. Adjustment should be made for lawn watering, car washing, and so on. In one method, the total number of different types of fixtures is summarized. The sum of each type is multiplied by the usual flow from such a fixture per use or operation. The frequency of use per hour can be estimated for the type of establishment under study. Knowing the number of hours of daily operation, a rough estimate of the probable flow in gallons per day can be arrived at.

Another fixture basis of estimating sewage flow is given in Table 4-6. Although the fixtures refer to country clubs, public parks, and restaurants, they can be applied with modifications to similar types of establishments. The fixture bases of estimating sewage flow are useful in determining the required size drain or sewer line and also as a check on other methods. Fixture unit values in Table 4-7 can also be used with Figure 3-26 for the same purpose.

A third fixture unit basis of estimating sewage flow is that described in Chapter 3 using the probability curves developed by Roy Hunter (*Methods of*

TABLE 4-6 A Fixture Basis of Estimating Sewage Flow

Type of Fixture	Gallons per Day per Fixture, Country Clubs[a]	Gallons per Hour per Fixture, Public Parks[b]	Gallons per Hour per Fixture (Average), Restaurants[c]
Shower	500	150	17
Bathtub	300	—	17
Washbasin	100	—	$8\frac{1}{2}$
Water closet	150	36	42 (flush valve) 21 (flush tank)
Urinal	100	10	21
Faucet	—	15	$8\frac{1}{2}$, 21 (hose bib)
Sink	50	—	17 (kitchen)

[a] J. E. Kiker, Jr., "Subsurface Sewage Disposal," *Fla. Eng. Exp. Sta.,* Bull. No. 23 (December 1948).
[b] National Park Service.
[c] After M. C. Nottingham Companies, CA.

Estimating Loads in Plumbing Systems [*BMS65*], National Bureau of Standards, 1940). These flows are somewhat high, being based on estimated peak discharge. An analysis made by Wyly[61] is based on the estimated average discharge. For two-bath houses with automatic dishwasher, clothes washer, and garbage grinder, for a total of 19 fixture units per home, the discharge may be 1.6 gpm for 1 home, 7.6 gpm for 5 homes, 15.2 gpm for 10 homes, 30.4 gpm for 20 homes, 76 gpm for 50 homes, and 152 gpm for 100 homes. See Peak-Demand Estimates, Chapter 3.

The design flow and sewage application rate for subsurface absorption systems should take into consideration the strength of the septic tank effluent (BOD and TSS), in addition to the hydraulic loading.

House Sewer and Plumbing

The house or building sewer is that part of the building drainage system carrying sewage that extends from the septic tank or public sewer to a point 3 ft out from the foundation wall. That portion of the drainage system extending from the house sewer horizontally into the structure is the house or building drain. The recommended size of the sanitary drainage piping is given in Table 4-8, although the local plumbing or building code will govern, where one has been adopted. In general, the house drain and building sewer should be not less than 4-in. bell-and-spigot cast-iron pipe with lead-caulked or equal joints. Other plastic or composition pipe constructed of durable material and laid with tight joints is also used.

Increasing fittings with smooth joints should be used where the pipe size increases in diameter. Sewer lines should be laid in a straight line to the septic tank where possible. If bends are necessary, use one or two 45 ells, as may

TABLE 4-7 Sanitary Drainage Fixture Unit Values

Fixture or Group	Fixture Unit Value
Bathroom group consisting of a lavatory, bathtub or shower stall, and a water closet (direct flush, valve)	8
Bathroom group consisting of a lavatory, bathtub or shower stall, and a water closet (flush tank)	6
Bathtub with $1\frac{1}{2}$ trap	2
Bathtub with 2″ trap	3
Bidet with $1\frac{1}{2}$ trap	3
Combination sink and wash tray with $1\frac{1}{2}$ trap	3
Combination sink and wash tray with food waste grinder unit (separate $1\frac{1}{2}$ trap for each unit)	4
Dental unit or cuspidor	1
Dental lavatory	1
Drinking fountain	$\frac{1}{2}$
Dishwasher, domestic type	2
Floor drain	1
Kitchen sink, domestic type	2
Kitchen sink, domestic type with food waste grinder unit	3
Lavatory with $1\frac{1}{2}$ waste plug outlet	2
Lavatory with $1\frac{1}{4}$ or $1\frac{3}{8}$ waste plug outlet	1
Lavatory (barber shop, beauty parlor, or surgeon's)	2
Lavatory, multiple type (wash fountain or wash sink), per each equivalent lavatory unit	2
Laundry tray (1 or 2 compartments)	2
Shower stall	2
Showers (group) per head	3
Sink (surgeon's)	3
Sink (flushing rim type, direct flush valve)	8
Sink (service type with floor outlet trap standard)	3
Sink (service type with P trap)	2
Sink (pot, scullery, or similar type)	4
Urinal (1 flush valve)	8
Urinal ($\frac{3}{4}$ flush valve)	4
Urinal (flush tank)	4
Water closet (direct flush valve)	8
Water closet (flush tank)	4
Swimming pools, per each 1000-gal capacity	1
Unlisted fixture, $1\frac{1}{4}$ or less fixture drain or trap size	1
Unlisted fixture, $1\frac{1}{2}$ fixture drain or trap size	2
Unlisted fixture, 2 fixture drain or trap size	3
Unlisted fixture, $2\frac{1}{2}$ fixture drain or trap size	4
Unlisted fixture, 3 fixture drain or trap size	5
Unlisted fixture, 4 fixture drain or trap size	6

Source: New York State Uniform Fire Prevention and Building Code,, Division of Housing and Community Renewal, New York, January 1984, Table I-903, pp. 276, 277.

TABLE 4-8 Maximum Permissible Loads for Sanitary Drainage Piping[a]

Pipe Diameter (in.)	Any Horizontal Fixture Branch	One Stack of Three Stories or Less in Height	Stacks More Than Three Stories in Height		Building Drain and Building Drain Branches from Stacks by Slope			
			Total for Stack	Total at One Story	$\frac{1}{16}$ (in./ft)	$\frac{1}{8}$ (in./ft)	$\frac{1}{4}$ (in./ft)	$\frac{1}{2}$ (in./ft)
$1\frac{1}{4}$[b]	1	2	2		np	np	np	
$1\frac{1}{2}$[b]	3	4	8	2	np	np	np	np
2a	6	10	24	6	np	np	21	26
$2\frac{1}{2}$[b]	12	20	42	9	np	np	24	31
3	20[c]	30[d]	60[d]	16[c]	np	np	27[a]	36[c]
4	160	240	500	90	np	180	216	250
5	360	540	1100	200	np	390	480	575
6	—	960	1900	350	np	700	840	1000
8	—	—	3600	600	1400	1600	1920	2300
10	—	—	5600	1000	2500	2900	3500	4200
12	—	—	—	—	3900	4600	5600	6700

Source: New York State Uniform Fire Prevention and Building Code, Division of Housing and Community Renewal, New York, January 1984, p. 279.

[a] In terms of fixture units.
[b] No water closets permitted.
[c] Not over two water closets permitted.
[d] Not over six water closets permitted.
np: not permitted.

be needed, and provide a cleanout. A manhole is sometimes preferable. A cleanout should also be provided at the end of the building drain in the basement and ahead of the septic tank when the tank is located 30 or more feet from the cleanout on the building drain. A cleanout may be provided on a buried sewer line by installing a tee fitting in the line with the vertical leg up and connecting to it a section of pipe extending to the ground surface. The fitting, sewer joints, and pipe extension should be encased in 6 in. of concrete. All cleanouts should have tight-fitting brass caps. See Figures 4-5 and 4-6.

Grease Trap

A grease trap, interceptor, or separator is a unit designed to remove grease and fat from kitchen wastes. Liquid wastes leaving properly designed and maintained units should not cause clogging of pipes or have a harmful effect on the bacterial and settling action in a septic tank.

Grease traps are of the septic tank and commercial types. The commercial types are of questionable value, unless the unit and storage chamber are regularly cleaned, a repulsive chore in restaurants. In the septic tank type, use is made of the cooling, separating, and congealing effect obtained when the warm or hot, greasy liquid wastes from the kitchen mix with the cooler liquid standing in the tank. There is also a natural tendency, if mixing is not too rapid, for the warmer liquid to rise and the cooler liquid, from which grease has been separated, to settle and be carried out with the food particles. *A grease trap is unnecessary in the average private home.* The small quantity

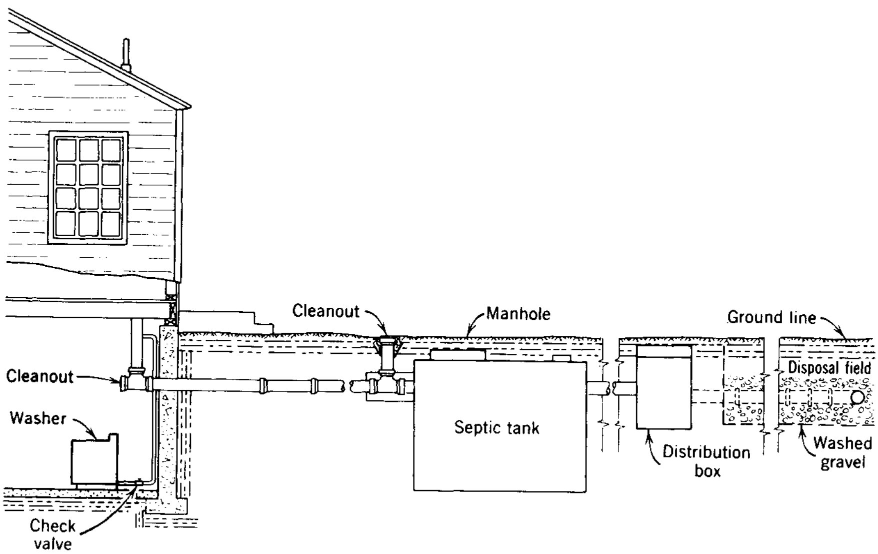


Figure 4-5 Section showing sewage disposal system.

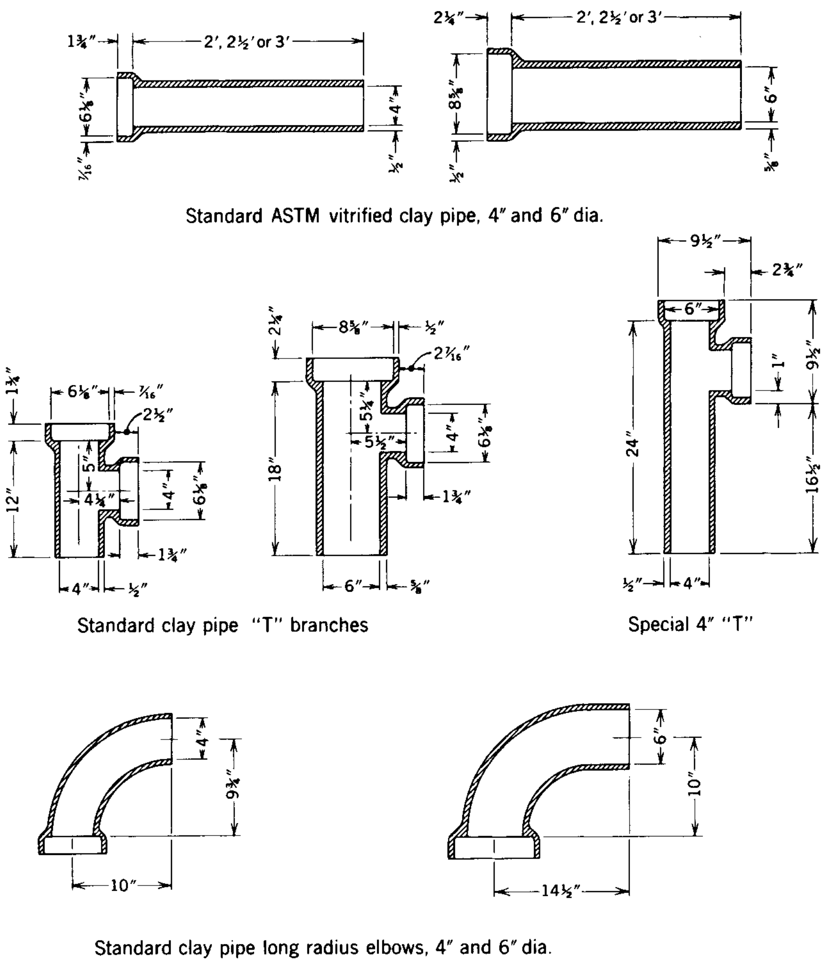


Figure 4-6 Details of some clay pipe fittings. (Cement mortar joints are unsatisfactory where sulfides are expected.)

of fat and grease that does find its way into the kitchen drain is mixed with soaps and detergents and is difficult to separate. In any case, such small quantities would not be harmful when allowed to enter a proper-size septic tank. Grease traps of the septic tank type should be provided, however, in restaurants and similar establishments where the quantity of grease and fats in liquid wastes is likely to be large. All grease traps should discharge into the building sewer ahead of the septic tank. Grease traps should be located within 20 or 30 ft from the plumbing fixtures served to prevent congealing and clogging of waste lines.

The capacity of the septic tank type of grease trap is made equal to the maximum volume of water used in a kitchen during a mealtime period. Garbage is not discharged to the sewer. The type of meals served and kitchen equipment used should be taken into consideration. A capacity of $2\frac{1}{2}$ or 3 gal per meal served during a mealtime is frequently used, up to 5 gal where full meals are served. The tank should be located in a protected, accessible place outside the building, using the same precautions as for the septic tank. It should have a tight-fitting removable cover. Heavy cast iron and steel make satisfactory covers. When covers do not fit tightly, a silicon or rubber seal around the cover or a layer of clay soil over the cover may be necessary to eliminate odors. In another design basis (ref. 40, pp. 321–327),

$$
\begin{aligned}
\text{Tank capacity (gal)} = \tfrac{1}{2}\,[&\text{number of seats in dining room}\\
&\times \text{wastewater per meal (5 gal)}\\
&\times \text{storage factor (2 avg.)}\\
&\times \text{hours open}]\\
&\times \text{loading factor (1.0 avg.)}
\end{aligned}
$$

The construction of several septic-tank-type grease traps is shown in Figure 4-7. Large tanks should have two compartments. Grease traps can be built on the job out of concrete or brick masonry or can be prefabricated out of metal, concrete, or terra cotta, with inlet and outlet arrangements as shown in the sketches. Because of the greater capacity of septic-tank-type grease traps, they do not require cleaning as frequently as the commercial type. Nevertheless, they must be cleaned so as not to greatly reduce the liquid volume available for cooling of the greasy wastes entering and, of course, to prevent large quantities of grease being carried over to the septic tank. The frequency of cleaning should be determined at each establishment during operation, when the grease occupies one-half the liquid depth of the tank. Cleaning at monthly intervals may be sufficient, but experience should dictate the frequency. One person should be given this responsibility, and a supervisor should check to see that the job is done. Grease removed from a grease trap may be disposed of with the garbage, rendered and sold, or thoroughly buried as explained under Privies, Latrines, and Waterless Toilets in this chapter, depending on local conditions and requirements. A minimum size for a grease trap is 750 gal.

Septic Tank

A septic tank is a watertight tank designed to slow down the movement of raw sewage and wastes passing through so that solids can separate or settle out and be broken down by liquefaction and anaerobic bacterial action. It does not purify the sewage, eliminate odors, or destroy all solid matter. The septic tank simply conditions the sewage so that it can be disposed of normally to a subsurface absorption system without prematurely clogging the

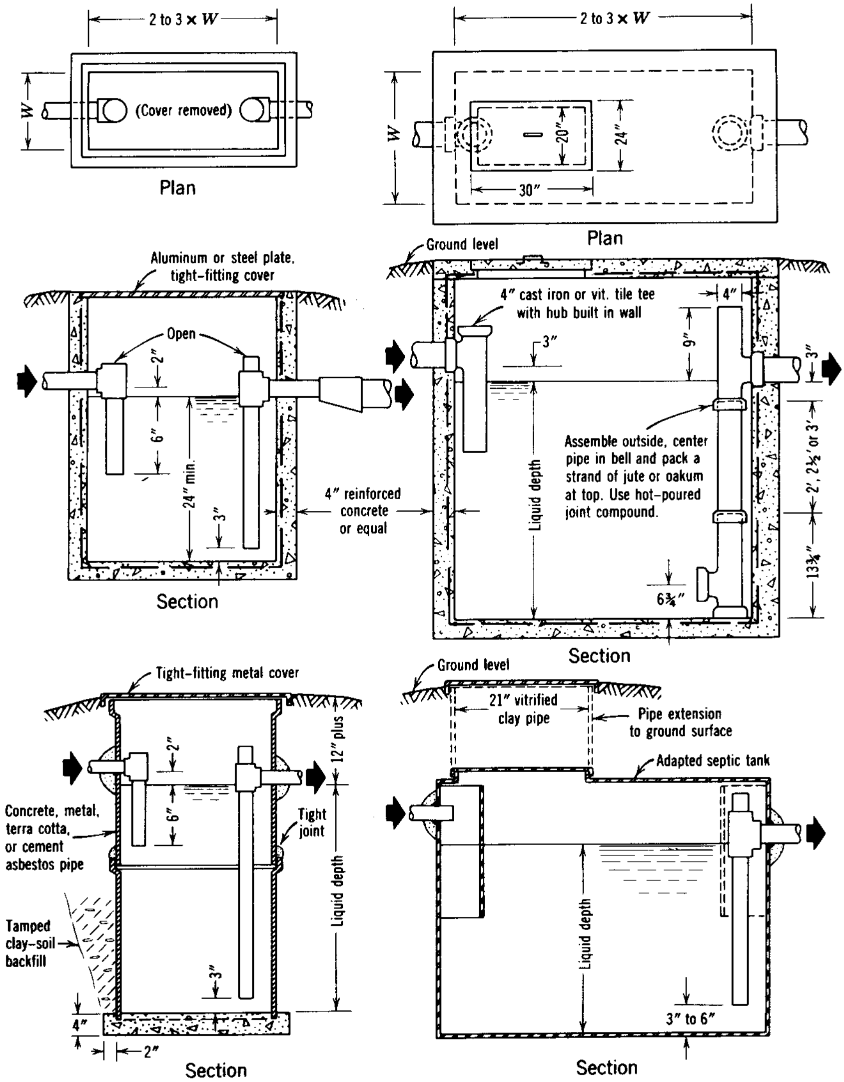


Figure 4-7 Grease trap details. Manhole over the outlet is also recommended for large tank.

system. Suspended solids removal is 50 to 70 percent; five-day BOD removal is about 60 percent.

Recommended septic tank sizes based on estimated daily flows are given in Tables 4-9 and 4-10. The septic tank should have a liquid volume of not less than 750 gal. When a tank is constructed on the job, its liquid volume can be increased at a nominal extra cost, thereby providing capacity for possible future additional flow, garbage grinder, and sludge storage. A plastic

TABLE 4-9 Water Supply and Sewerage Schedule (Use Combination of Headings that Fit Local Conditions)

Population			Septic Tank Minimum[b,c]				Tile Field Laterals[c,d]	
Bedrooms	Persons	Sewage Flow (gpd)[a]	Length (ft)	Width (ft)	Depth (ft)	Volume (gal)	Nominal Length (ft)[e]	Trench Width (in.)[e]
2 or less	4	300	$7\frac{1}{2}$	$3\frac{1}{2}$	4	750		
3	6	450	9	4	4	1000		
4	8	600	11	4	4	1250		
5	10	750	$10\frac{1}{2}$	5	4	1500		

Population			Leaching Pit System[c,d]			Water Supply—Well, Drilled[g]	
Bedrooms	Persons	Number of Pits[e]	Size[e]	Depth[e]	Service[f]	Pump Size (gal/hr)	Pressure Tank (gal)
2 or less	4				$\frac{3}{4}$ in.	250	42
3	6				$\frac{3}{4}$	300	82
4	8				1	360	82
5	10				$1\frac{1}{4}$	450	120

Population		Sand Filter System[c,h]			Chlorine Contact Tank[c]			Sump Pump Float Setting (gal)[c]
Bedrooms	Persons	Length (ft)	Width (ft)	20	Length (ft)	Width (ft)	Depth (in.)	
2 or less	4	21½	12	260	3	2	8	—
3	6	21	18	390	3	2	12	30
3	6	32½	12	390	3	2	12	30
4	8	30	18	520	3	2	16	40
4	8	43	12	520	3	2	16	40
5	10	36	18	650	3	2	20	50
5	10	54	12	650	3	2	20	50

[a] The design basis is 75 gal/person and 150 gal/bedroom.

[b] Includes provision for home garbage grinder and laundry machine. Larger than minimum size septic tank is strongly recommended.

[c] See detail drawings for construction specifications.

[d] Based on the results of soil percolation tests. Discharge all kitchen, bath, and laundry wastes through the septic tank but *exclude* roof and footing drainage, surface and groundwater, and softener wastes.

[e] Determined by site and soil percolation test.

[f] Use next larger diameter house service line if water is corrosive or hard, service line is 50–100 ft long, two bathrooms are provided, or flush valve is used for water closet. These pipe sizes are based on the use of brass or copper pipe; use next larger size if iron pipe is proposed.

[g] The minimum dependable well yield should be 3–7 gpm.

[h] Sand filter normally should not be used. Reserve for compelling circumstances to relieve an impending or existing public health hazard.

TABLE 4-10 Suggested Large-Tank Dimensions

Gallons	Width (ft)	Length (ft)	Depth (ft)
1,000	4	9	4
1,250	4	11	4
1,500	5	$10\frac{1}{2}$	4
1,750	5	12	4
2,000	5	14	4
2,250	6	13	4
2,500	6	$14\frac{1}{2}$	4
2,750	6	16	4
3,000	6	17	4
3,250	6	15	5
3,500	6	16	5
3,750	6	17	5
4,000	7	16	5
5,000	7	$19\frac{1}{2}$	5
6,000	8	$20\frac{1}{2}$	5
7,000	8	24	5
8,000	8	23	6
10,000	8	28	6

Concrete details:

1. Concrete for top and bottom 4 in. thick for 2000-gal tank or smaller and 6 in. for 2000- to 10,000-gal tank.
2. Concrete for sides and ends 6 in. thick for 6000-gal tank or smaller and 8 in. for 6000- to 10,000-gal tank.
3. Reinforce with $\frac{3}{8}$-in. deformed rods 4 in. on center both ways for ordinary loading. Place rods 1 in. above bottom of top slab and 1 in. in from inside of tank for sides, ends, and bottom. Overlap $\frac{3}{8}$-in. rods 15 in. where needed. Adjust steel for local conditions.
4. Concrete mix: 1 bag cement to $2\frac{1}{4}$ ft^3 sand to 3 ft^3 gravel with 5 gal water for moist sand.

sludge and gas deflector on the outlet as shown in Figure 4-8 is highly recommended.* Regulatory agencies are requiring a minimum 1000-gal septic tank in some instances.

The detention time for large septic tanks† should not be less than 24 to 72 hr. Schools, camps, theaters, factories, and fairgrounds are examples of places where the total or a very large proportion of the daily flow takes place within a few hours. For example, if the total daily flow takes place over a period of 6 hr (one-fourth of 24 hr), the septic tank should have a liquid volume equal to four times the 6-hr flow to provide a detention equivalent to 24 hr over the period of actual use. The larger tank would minimize scouring of septic tank sludge and scum and carryover of solids into the absorption system.

*First suggested by J. A. Salvato, *Environmental Sanitation,* Wiley, New York, 1958, p. 208.

†Inspect every 3 months and clean, if necessary. Measure inlet flows monthly and compare with design flow. Check annually BOD, SS, and pH for major changes.

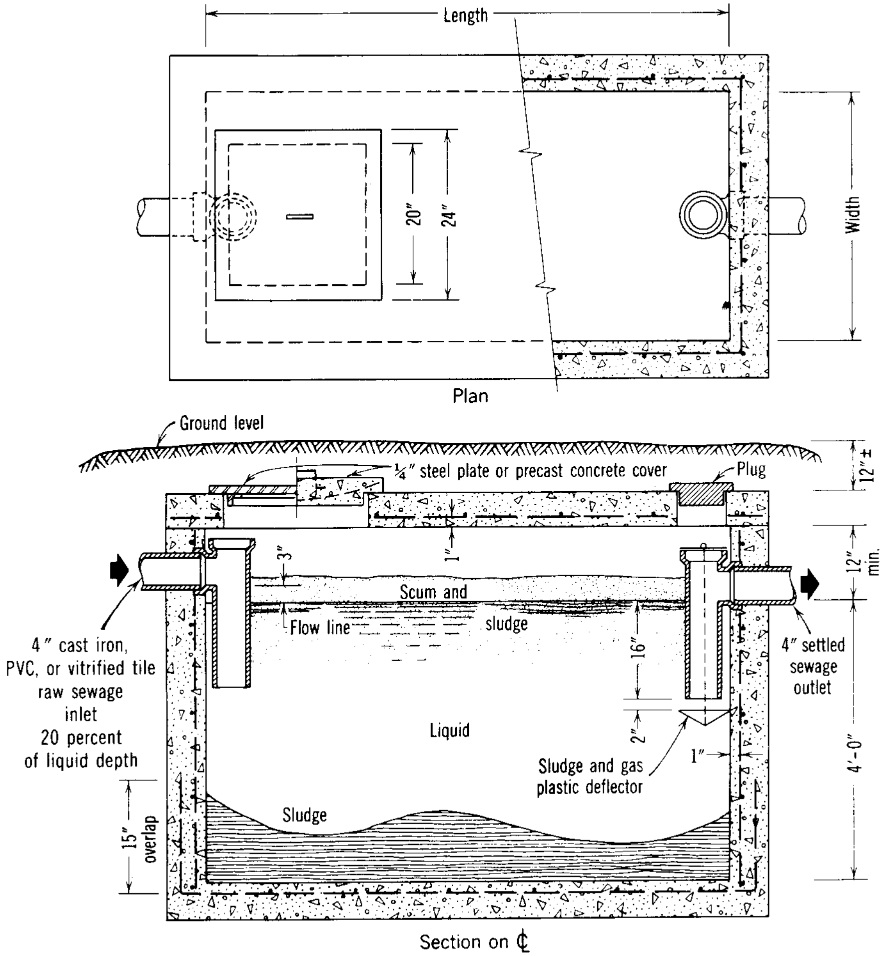


Figure 4-8 Details for small septic tanks. Recommended construction for small septic tanks:

Top—Reinforced concrete poured 3 to 4 in. thick with two $\frac{3}{8}$-in. steel rods/ft or equivalent and a 20 × 20-in. manhole over inlet or precast reinforced concrete 1-ft slabs with sealed joints.

Bottom—Reinforced concrete 4 in. thick with reinforcing as in "top" or plain poured concrete 6 in. thick.

Walls—Reinforced concrete poured 4 in. thick with $\frac{3}{8}$-in. steel rods on 6-in. centers both ways or equivalent; plain poured concrete 6 in. thick; 8-in. brick masonry with 1-in. cement plaster inside finish and block cells filled with mortar.

Concrete mix—One bag of cement to $2\frac{1}{4}$ of sand to 3 ft^3 of gravel with 5 gal of water for moist sand. Use 1:3 cement mortar for masonry and 1:2 mortar for plaster finish. Gravel or crushed stone and sand shall be clean, hard material. Gravel shall be $\frac{1}{4}$ to $1\frac{1}{2}$ in. in size; sand from fine to $\frac{1}{4}$ in.

Bedding—At least 3 in. of sand or pea gravel, leveled.

Cover—Raised cover by means of collar if tank greater than 12 in. below ground.

Pumping of raw sewage, if required, directly into a septic tank will cause scour and carryover of solids and should be avoided. Pumping into an equalizing tank ahead of the septic tank is a possible solution, but it will require frequent maintenance. The problem can be avoided by pumping septic tank effluent from a sump to the soil absorption system.

If the septic tank is to receive ground garbage, its capacity should be increased by at least 50 percent. Some authorities recommend a 30 percent increase. Others recommend against garbage disposal to a septic tank.

Septic tanks can be constructed of good-quality reinforced concrete on the job as explained in Figures 4-8 and 4-9 and Tables 4-9 and 4-10. Standard concrete block tanks, with cells filled with concrete, require two $\frac{1}{2}$-in. cement plaster coats on the inside to provide a smooth watertight finish. Precast-reinforced concrete and commercial tanks of metal, fiberglass, polyethylene, and other composition materials are also available. Since some metal tanks have a limited life, it is advisable that their purchase be predicated on their

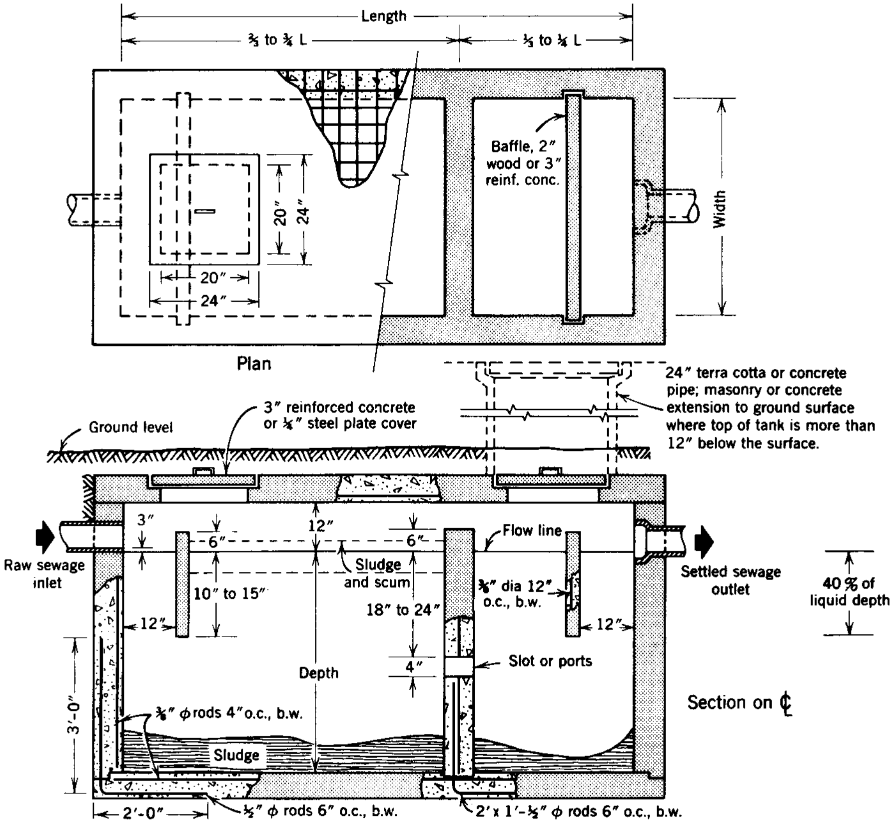


Figure 4-9 Details for large septic tanks. (See Table 4-10.)

meeting certain minimum specifications. These should include a guaranteed 20-year minimum life expectancy, not less than 12- or 14-gauge metal thickness, thorough covering both inside and outside with a heavy, continuous, protective, acid-resistant coating, and a minimum liquid capacity of 750 gal. Metal septic tanks manufactured in accordance with the Department of Commerce Commercial Standard, provided with a minimum 16- to 18-in. manhole, represent a great improvement over the ordinary metal tank. Large metal tanks, with a capacity greater than 1000 gal, should be 8- to 10-gauge metal. In any case, it should be kept in mind that metal tanks, especially the baffles and area above the waterline, have a limited life. Precast concrete baffles also have a limited life. Use rigid plastic tees. The bottom of the excavation for the septic tank should be carefully leveled at the proper elevation and well bedded on a layer of sand or pea gravel to prevent uneven settlement of the septic tank and breaks at the inlet and outlet lines.

The depth of septic tanks and the ratio of width to length recommended by most health departments are very similar. A liquid depth of 4 ft and a ratio of width to length of 1:2 or 1:3 is common. Depths as shallow as 30 in. and as deep as 6 ft have been found satisfactory. Compartmented tanks are somewhat more efficient. The first compartment should have 60 to 75 percent of the total volume. Open-tee inlets and outlets as shown in Figure 4-8 are generally used in small tanks, and high-quality reinforced concrete baffled inlets and outlets as shown in Figure 4-9 are recommended for the larger tanks.* Precast open concrete tees or baffles have in some instances disintegrated or fallen off; vitrified clay, cast-iron, polyvinyl chloride (PVC), alkyl benzene sulfonate (ABS), or polyethylene (PE) tees should be used. Cement mortar joints are unsatisfactory. A better distribution of flow and detention is obtained in the larger tank with a baffle arrangement of preferably rigid acid-resistant plastic. A minimum 16-in. manhole over the inlet of a small tank and a 20- to 24-in. manhole over both the inlet and outlet of a larger tank, constructed with a top slab poured monolithically with the sides, are preferred to a sectional slab top. The sectional slab top can, however, be more easily purchased or constructed on a flat surface over a plastic sheet with a minimum of form lumber. Joints will require a seal to prevent the entrance of surface water into the tank.

An efficient septic tank design should provide for a detention period longer than 24 hr; an outlet configuration with a gas baffle to minimize suspended

*The *Manual of Septic-Tank Practice*[62] states that "the outlet device should generally extend to a distance below the surface equal to 40 percent of the liquid depth. For horizontal, cylindrical tanks, this should be reduced to 35 percent." The inlet should penetrate at least 6 in. below the liquid level but not greater than the outlet. The distance between the liquid line and underside of the tank (air space) should be approximately 20 percent of the liquid depth. In horizontal, cylindrical tanks, the area should be 15 percent of the total circle. Sludge accumulation $S = 17 + 7.5t$, in which S = sludge in gallons per capita and t = years after cleaning.

solids carryover (see Figure 4-8); maximized surface-area-to-depth ratio for all chambers (ratio more than 2); and a multichamber tank with interconnections similar to the outlet design (open-tee inlet and outlet).[63]

The elevation of the septic tank and the inlet should be selected and established with regard to the landscaping, elevations of sewers that discharge to the septic tank, elevation of dosing tank outlet pipe inverts where used, location available and elevation of the area selected for the disposal or treatment system, and the high-water level of groundwater and nearby watercourses to ensure gravity flow, provided the topography makes this possible. On the other hand, if pumping is required, it should be taken into consideration in the initial design and every advantage taken of this necessity to reduce excavations and shorten and straighten lines. If pumping is required, an equalization tank ahead of the septic tank is necessary to prevent scour and carryover of solids.

Septic tank soil absorption systems in *continuous* operation are not likely to freeze. Studies near Ottawa, Canada, showed that winter operation did not pose any special problems,[64] and observations by the author in the Yukon Territory, Canada (1944), confirm this.[65]

Care of Septic Tank and Subsurface Absorption Systems

Proper maintenance of a properly designed and constructed septic tank system is the best assurance of satisfactory operation of a subsurface sewage disposal or treatment system and prevention of sudden replacement expenses.

A septic tank for a private home will generally require cleaning every three to five years depending on occupancy, but in any case it should be inspected once a year. If a garbage disposal unit is used, more frequent cleaning is needed. Septic tanks serving commercial operations should be inspected at least every six months. When the depth of settled sludge or floating scum approaches the depth given in Table 4-11, the tank needs cleaning.[63,66] Sludge accumulation in a normal home septic tank has been estimated at 69 to 80 liters (18–21 gal) per person per year.[66,67] Reports of septage generated vary widely. The U.S. average has been estimated at 55 gal per capita per year.[68] The Ontario Ministry of the Environment set the permissible highest level of sludge at 0.45 m below the bottom of the outlet fitting. Gray-water septic tank sludge was found to accumulate at the rate of 8.3 liters (2.2 gal) per person per year and black wastewater sludge at the rate of 65.7 liters (17.4 gal) per person per year.[69] A long pole having a small board about 6 $in.^2$ nailed to the bottom to make a plunger, with Turkish toweling wrapped around the lower 18 in. of the pole, can be used to measure the sludge depth and floating-scum thickness. The appearance of particles or scum in the effluent from a septic tank going through a distribution box is also an indication of the need for cleaning. Routine inspection and cleaning will prevent solids from being carried over and clogging the treatment or leaching systems. The larger the septic tank above the minimum, the less frequent the need for

TABLE 4-11 Allowable Sludge Accumulation

	Sludge Accumulation by Tank Liquid Depth (in.)			
Tank Capacity (gal)	30 in.	36 in.	48 in.	60 in.
250	4			
300	5	6		
400	7	9	10	
500	8	11	13	15
600	10	14	16	18
750	13	16	19	23
900	14	18	22	26
1000	14	18	23	28
1250	—	18	24	30

Source: Manual of Septic-Tank Practice, PHS Pub. No. 526, Department of Health, Education, and Welfare, Cincinnati, OH, 1967.

Note: Table assumes the outlet baffle or tee depth below the flow line is 40% of the tank liquid depth. Clean the tank when the bottom of the scum layer builds up to within 3 in. of the bottom of the baffle or tee outlet or when the sludge depth approaches the depth given in this table. For example, a tank 48 in. deep with a capacity of 750 gal will require cleaning when the sludge accumulation reaches 19 in.

cleaning. A contractual arrangement for annual inspection and cleaning as needed and noted above is a good investment. Community cooperation in this regard should be encouraged. A maintenance district might be formed.

It is best to clean a septic tank during the dry months of the year. The groundwater level should be low (to prevent possible flotation of the tank) and bacterial adjustment will proceed faster in warm weather.

Septic tanks are generally cleaned by septic tank cleaning firms. They mix and pump the entire contents, referred to as septage, out into a tank truck with special equipment. Care must be taken to prevent spillage and consequent pollution of the surrounding ground. Sludge sticking to the inside of a tank that has just been cleaned would have a seeding effect and assist in renewing the bacterial activity in the septic tank. The septic tank should not be scrubbed clean. This is a good time to inspect the inlet and outlet baffles for damage and possible replacement with PVC tees.

The use of septic tank cleaning solvents or additives containing halogenated hydrocarbon, aromatic hydrocarbon, toxic, or hazardous chemicals can cause carryover of solids and clogging of the absorption field. The chemicals can also contaminate the groundwater. Such chemicals should not be permitted. The same precaution would apply to commercial and industrial sewage septic systems. Public education is also necessary.

The contents of the septic tank, called septage, should preferably be emptied into a sanitary sewer or wastewater treatment plant if prior approval is obtained. Disposal at a plant dumping station provided with bar racks, holding tank, pump, and aeration tank may be required prior to discharge to the wastewater treatment plant. Alternative methods[70] for the disposal of septage consists of ridge-and-furrow, spray irrigation, plow-furrow-cover, subsurface injection, and sanitary landfill under controlled conditions, with storage when necessary in colder climates when the ground is frozen to prevent runoff. Also possible are leaching lagoons in which the sludge is periodically removed and disposal lagoons in which the sludge can be removed or allowed to dry for disposal in a sanitary landfill or covered over with 2 ft of earth. Septage treatment facilities include aerated lagoons; facultative lagoons; composting with dry organic matter for moisture control; chemical treatment using lime, chlorine,[71] alum, polyelectrolytes, and ferric chloride; and other proprietary processes. A permit is usually required for septage treatment and disposal.

Safety and Other Precautions Excavations such as for septic tanks, trenches, privies, leaching pits, dry wells, pump wells, storage tanks, and cesspools can create a safety hazard to workers and passersby, especially children. No person should be permitted to work in a trench or pit 5 ft or more in depth that has sides or banks with slopes steeper than 45° unless the sides or banks are supported with sheeting or shoring. Any excavation in sand, silt, loam, or clay 3 ft or more in depth needs sidewall protection to prevent cave-in; excavated material should be placed at least 24 in. back from the edges. Where the excavation is left unattended, a fence or a barricade should be placed around the opening or the opening should be covered with properly supported 2-in. planking or $\frac{3}{4}$-in. exterior-grade plywood. If sheeting is used and extended 42 in. above the adjacent ground, other barricades are not usually necessary.[72]*

Do not enter the tank!

An individual should not enter a septic tank, septic privy pit, pump well, manhole, storage tank, sludge digestion tank, or aqua privy tank that has been emptied, regardless of whether it is open or covered. Cases of asphyxiation and death have been reported due to the lack of adequate oxygen or presence of toxic gases in the emptied tank. If it should become necessary to inspect or make repairs, at least three strong individuals should be present. The tank should first be checked with a gas detector[73]† for oxygen and toxic gases and thoroughly ventilated using a blower, which is kept operating. Then two persons should remain on top and the third make the inspection or repairs wearing a full-body safety harness connected to a pulley supported by a tripod or other support so that he or she can be hauled out in case of trouble. The tank

* See also state and local regulations.

† Hazardous gas monitoring equipment is available to detect the presence of and measure the concentration of methane, hydrogen sulfide, and lack of oxygen. Check also liquid manure tanks. *Do not enter.*

should not be left uncovered or unguarded as small children or pets could possibly fall in. See Safety, later in this chapter.

Certain chemicals should not be added to septic tank systems. The use of 1 gal of sulfuric acid to "unclog" a home septic tank system resulted in reaction with sulfides present and the release of toxic fumes (H_2S), which overcame three and killed two persons.[74] The mixing of household cleaning compounds such as chlorine bleach and ammonia, caustic soda (lye), or similar cleaners is dangerous as toxic gases such as chlorine are released. This can cause injury to the throat and lungs and possibly permanent damage and death. Soap, drain solvents, disinfectants, and similar materials used individually for household purposes are not harmful to septic tank operation unless used in large quantities. Organic solvents and cleaners, pesticides, and compounds containing heavy metals could contaminate the groundwater and well-water supplies. They should not be disposed of in a septic tank system. Exclude sanitary napkins, absorbent pads, and tampons.

There may be occasions when the level of the contents in a septic privy drops below the overflow level or the water level in an aqua privy drops below the bottom of the squat plate funnel and pipe. In such circumstances, the use of special chemical compounds to promote liquification and/or control odors may be hazardous. The gases emitted may be explosive and may be ignited by a discarded match or lighted cigarette. It is safer to add water and mix the contents with a long pole.

Salt or brine from a household zeolite softening unit backwash wastewater, in amounts as little as 1.2 percent, temporarily retards the bacterial action in the septic tank and tends to build up in the sludge, but the salt is gradually flushed out as the sludge digests, rises, and falls. However, the salt (sodium) tends to cause swelling and clogging of clay loam soils due to soil structure breakdown. Therefore, it is not prudent to discharge brine waste to the septic tank. The calcium and magnesium in water to be softened replace the sodium in the zeolite filter media, and the sodium passes through with the treated water. The unit is regenerated by flushing a solution of common salt through the zeolite filter media and filtering to waste until there is no longer any salt in the filtered water, during which time the calcium and magnesium attached to the zeolite are replaced by the sodium in the salt, causing calcium and magnesium to also be flushed out with the chloride. The calcium and magnesium salts, released during regeneration and added to the wastewater entering the septic tank and then the absorption system, tend to keep the soils open, counteracting to some extent the action of the sodium in the regenerated water and the wastewater during regeneration. It appears that the detrimental effect of all the sodium would supersede the beneficial effect of the calcium and magnesium salts. If water softener wastewater is discharged to the septic tank, the area of the absorption system should be increased to handle an additional hydraulic load of about 75 gal per day.

High weeds, brush, shrubbery, and trees, although consumers of groundwater, should not be permitted to grow over an absorption system or sand filter system. It is better to crown the bed, seed the area to grass, and build up a lawn. Sunlight and exposure to wind are beneficial as they encourage evapotranspiration.

If trees are near the sewage disposal system, difficulty with roots entering poorly joined sewer lines can be anticipated. Lead-caulked cast-iron pipe, a sulfur-base or bituminous pipe joint compound, mechanical clay pipe joints, copper rings over joints, and lump copper sulfate in pipe trenches have been found effective in resisting the entrance of roots into pipe joints. Roots will penetrate first into the gravel in absorption field trenches rather than into the pipe. About 2 to 3 lb of copper sulfate crystals flushed down the toilet bowl once a year will destroy roots the solution comes into contact with but will not prevent new roots from entering. The application of the chemical should be done at a time, such as late in the evening, when the maximum contact time can be obtained before dilution. Copper sulfate will corrode chrome, iron, and brass; hence, it should not be allowed to come into contact with these metals. Cast iron is not affected to any appreciable extent. Some time must elapse before the roots are killed and broken off. Copper sulfate in the recommended dosage will not interfere with operation of the septic tank.[75] The cutting or mechanical removal of roots in sewers tends to increase root growth and size, leading to more problems and sewer repair. The flooding of sewers with a copper sulfate solution or a foam containing copper sulfate can provide longer contact time with roots and should be more effective in their removal. Television scanning in two to three years may show the need for retreatment. An EPA registered herbicide or a chemical foam is also reported to be effective.[76]

Flooding of sewer lines with scalding water [(180–210°F) (82–99°C)] will kill roots subjected to a 30-min soak at 170°F (76°C). A portable steam generator is needed to reheat recirculated water to maintain the water temperature and compensate for heat loss. A temperature of 122°F (50°C) will kill most plant tissue.[77]

Hydrogen peroxide has been used to oxidize the sludge and organic growths in clogged distribution lines and trenches. If used, it should be handled with extreme care. Hydrogen peroxide is a strong oxidizing agent and potentially explosive. Its effectiveness is temporary and the soil percolation capacity is greatly reduced.[46]

Causes of Failure of Septic Tank System and Corrective Measures Common causes of septic tank system failures are seasonal high groundwater; carryover of solids into the absorption field due to use of septic tank cleaning compounds, lack of routine cleaning of the septic tank, or outlet baffle disintegration or loss; leaking plumbing fixtures, especially water closets; excessive water use, connected roof and footing drains, and hydraulic overloading; uneven settlement of the septic tank, connecting pipe, or distribution box; and improper design and construction of the absorption system, including compaction and smearing of absorption trench bottom and sidewalls. One must avoid soil compaction, construction during wet weather, leaving trenches open during a rainstorm or snowstorm, surface-water drainage into open absorption trenches, and walking in trenches when leveling and cleaning; raking should be done prior to placement of gravel.

Corrective measures, once the cause is identified, might include water conservation measures such as reduced water usage, low-flush toilets, low-flow shower heads, reduced water pressure, faucet aerators, spray taps, and use of a commercial laundromat. In an emergency, consideration might be given to installation of a recirculating toilet, air-assist toilet, composting toilet, separation and reuse of gray water, and a holding tank. Other measures to consider are cleaning the septic tank and flushing out distribution lines (*do not empty tank if groundwater level is high—tank will float to surface*); installation of additional leaching lines; installation of a separate absorption system and division box or gate for alternate use with the annual resting of existing system; lowering the water table with curtain drains; discontinuation of use of septic tank cleaning compounds; replacing corroded or disintegrated baffles with terra cotta, cast-iron, ABS, or PVC tees; replacing or releveling distribution box on a gravel footing extended below frost; cleaning the septic tank every three years; disconnecting roof, footing, and area drains; or some combination of measures as applicable.

Use of Additives Compounds that are supposed to make tank cleaning unnecessary may actually cause solids to be carried over into the absorption or treatment system and the penetration of fine solids into the soil infiltrative surface with resultant clogging. A grab sample collected from a septic tank serving a 60-unit trailer park showed a total solids concentration of 15,058 mg/l one day after a septic tank cleaner had been added. In this author's experience, the effluent from the sand filter following the septic tank showed a total solids content of 1038 mg/l at the same time.

Some septic tank cleaners (degreasing compounds) contain sodium or potassium hydroxide or sulfuric acid. Acids and bases are only temporarily effective in unclogging absorption trenches. Sodium hydroxide causes solids deflocculation and dispersion on and in the soil, with resultant sealing of the infiltrative surface. Others contain methylene chloride, trichloroethylene, methyl chloroform, trichloroethane, or orthodichloro-benzene, which are suspected of being carcinogenic. These and other toxic compounds may eventually reach the groundwater and endanger well-water supplies in the area. Their use is not advised and should be prohibited where the groundwater is a source of water supply.

Commercial compounds alleged to prevent septic tank system clogging and backup usually require regular application; weekly or monthly is not unusual. Temporary relief may be obtained, but the cost of the chemical on an annual basis could equal twice the cost of having a septic tank cleaned *annually*. Hydrogen peroxide applied to clogged distribution lines has been only temporarily effective; it destroys soil structure. Special bacteria and enzymes added to septic tanks to prevent or ameliorate failure of septic tank absorption systems have been of debatable effectiveness. They are not likely to contaminate nearby wells; organic solvent-type products can contaminate drinking water sources.[78]

A starter, such as yeast, added to a septic tank does not accelerate the digestion. The addition of 6 gal of digested sludge per capita to a new septic tank appears to have a beneficial seeding effect. A new septic tank does not need a starter or other additive to function. The sewage it receives contains the organisms necessary to initiate and promote anaerobic digestion. Slug doses of household chemicals, 4.8 liters of liquid bleach, 9.5 liters of liquid lysol, or 18.9 g of Drano crystals to a 3780-liter septic tank, was reported to not harm bacterial action.[79]

Division of Flow to Soil Absorption System

The overflow from a septic tank should be run to a distribution box to ensure equal division of the settled sewage flow to all the leaching pits or laterals comprising the disposal or treatment system. The distribution box should have a removable cover extended to the surface to simplify inspection of the septic tank effluent and flow distribution to the disposal or treatment system. *Outlets must leave the distribution box at exactly the same level.* Eccentric inserts for distribution box outlets are also available to balance the flow to each lateral. A gravel fill or footing under the box, extending below frost, will help keep the box level. A baffle is usually necessary in front of the inlet to break the velocity of the incoming sewage and permit equal distribution to the outlets. Bricks or blocks are very useful for this purpose. Details of distribution boxes are given in Figure 4-10 (and 4-12 below). If the outlets are constructed about 6 in. above the bottom of the distribution box, the liquid collected will have the effect of breaking the incoming velocity of the settled sewage. In any case, it is important to place all outlets at the same level and obtain equal distribution of flow to each of the laterals. A $\frac{1}{8}$-in. mesh plastic basket screen over each outlet would prevent large particles of septic tank sludge from being carried into the absorption field. Backup would occur at the box without ruining the absorption field, signaling the need to replace the septic tank outlet baffle or clean the septic tank.

Serial distribution of sewage (Figure 4-11) by the use of tees and elbows is reported to have certain advantages over the use of distribution boxes.[62] It compensates for varying soils and absorptive capacity; it forces full use of a trench before overflow to the next and overcomes the hazard of overflow associated with the parallel system if one trench is overloaded due to uneven flow distribution from an improperly installed distribution box. However, greater expertise is needed in construction. This method of sewage distribution promotes creeping failure of the absorption system due to overloading of the beginning laterals and trenches, thereby promoting anaerobic conditions rather than aerobic. Drop manholes (Figure 4-12) or a dosing system (see Figure 4-30 later) provides more reliable and balanced wastewater distribution on sloping ground.

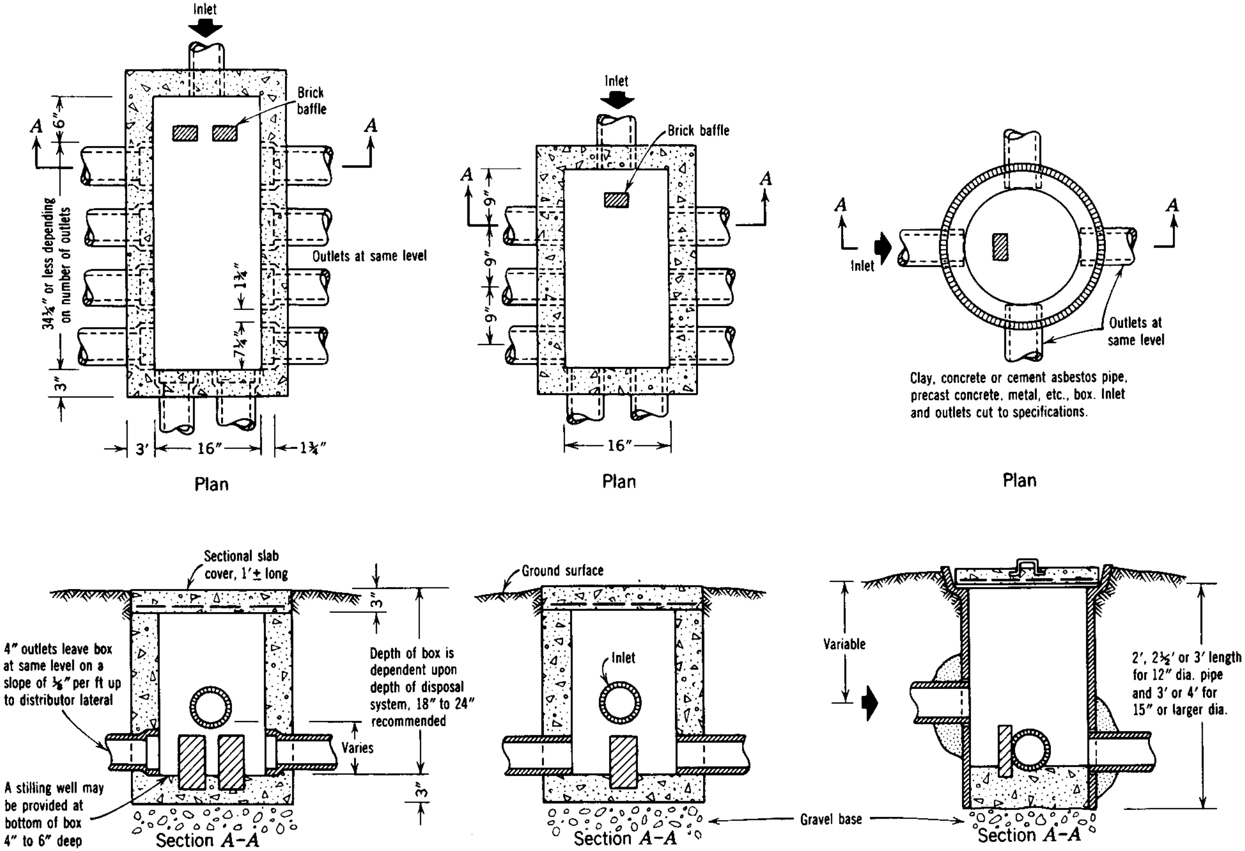


Figure 4-10 Distribution box details (bottom of gravel below frost; level box on 12 in. of well-stabilized gravel). Vitrified clay tile and plastic distribution boxes better resist deterioration.

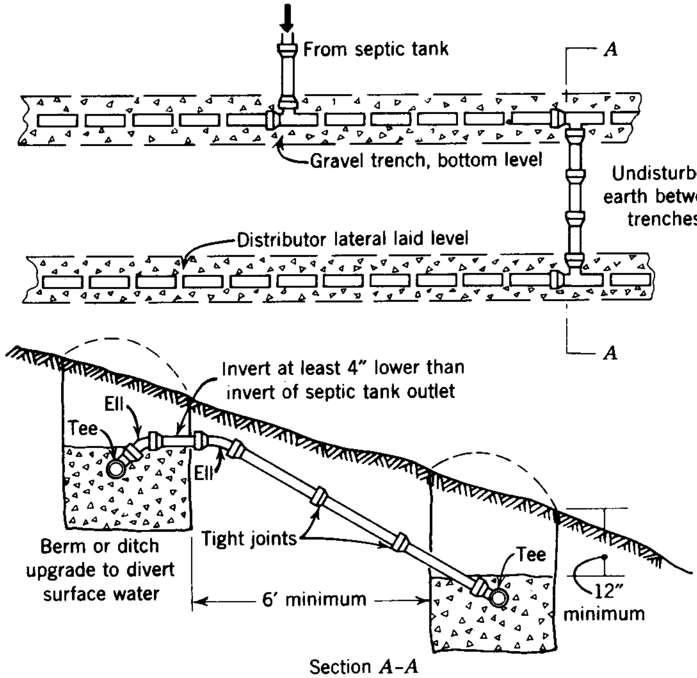


Figure 4-11 Serial distribution for sloping ground. (Adapted from Manual of Septic-Tank Practice, U.S. PHS Pub. 526, Department of Health, Education, and Welfare, Washington, DC, 1967.)

On steep grades, special provision must be made for reducing the velocity of the sewage leaving the septic tank in order to get good distribution to the subsurface tile field or absorption system. Drop manholes are used for this purpose. The flow can be divided approximately in proportion to the length of the absorption system at each manhole. Drop-manhole details are shown in Figure 4-12.

A flow diversion box or two-port valve on the line leaving the septic tank to permit use of alternate absorption systems, say on a six-month cycle, will promote maintenance of trench infiltrative capacity, aerobic conditions, and prolonged life if the septic tank is cleaned regularly (every three years). See Table 4-11.

Subsurface Soil Absorption Systems

The conventional subsurface absorption system following the septic tank is the absorption field or leaching pit. The cesspool is still used for raw sewage, although generally prohibited, and the dry well is used for the disposal of rainwater, footing, roof, and basement floor drainage. Where the soil is not suitable for subsurface disposal, a sand filter, evapotranspiration system, mod-

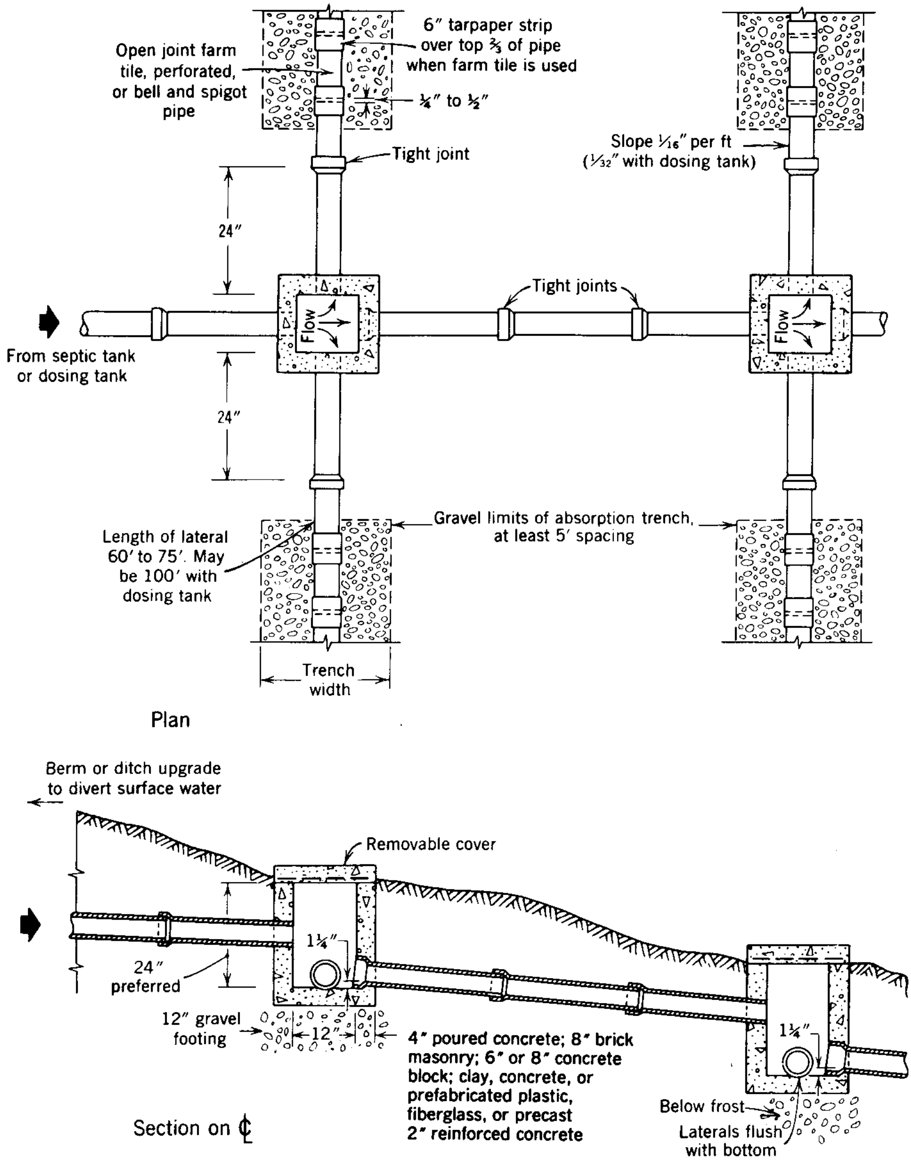


Figure 4-12 Drop-manhole details for absorption field on sloping ground.

ified tile field system, aeration system, system in fill, mound system, stabilization pond, or some combination may be used. These systems are discussed later.

In all cases, it is again emphasized to avoid compaction of trench bottoms and soil where the absorption system is to be built. Smearing of trench bottoms and sidewalls must be removed. Construction must not take place during wet weather or on wet soil, trenches must not be left open during a rainstorm or snowstorm, and surface-water drainage must not be permitted to enter the trenches.

Absorption Field System

The soil percolation test and soil clues basis for the design of absorption systems were given earlier in this chapter. Design standards and details for absorption systems are shown in Figures 4-5, 4-11 to 4-13 and Table 4-12.

The absorption field laterals should be laid in narrow trenches (18–24 in.), parallel to the contour and perpendicular to the groundwater flow, preferably not more than 24 in. below the ground surface, and spaced as shown in the illustrations, to provide dispersion of the septic tank effluent over a larger area, utilize the more absorbent topsoil, and promote the maintenance of aerobic conditions in the absorption trenches. The highest seasonal groundwater level should be at least 2 ft, and preferably 4 ft, below the bottom of trenches, depending on the capillarity and coarseness of the unsaturated soil beneath the trench, to maintain it unsaturated. Where laterals must be laid at a greater depth, the gravel fill around the open joint or perforated lateral should extend at least to the topsoil and as shown in Figures 4-13 and 4-14 to promote aerobic conditions, evapotranspiration, and nitrogen and phosphorous removal. The sunny and open side of a slope is the preferred location for an absorption field to promote evapotranspiration, if there is a choice. After settlement and grading, the absorption field area should be seeded to grass. Permeable geotextile fabric may be used in place of pea gravel, straw, or untreated paper to prevent the infiltration of soil fill into the trench gravel.

Possible elevations of absorption field distribution laterals to stay 24 in. or more above seasonal high groundwater, bedrock, tight clay soil, or other natural barrier condition are shown in Figure 4-14.

When the total length of the laterals to provide the required leaching area is 500 to 1000 linear feet, a siphon or pump should be installed between the septic tank and absorption system to distribute the sewage to all the laterals. If the total required length of the laterals is 1000 to 3000 linear feet, the system should be divided into two or four sections with alternating feed to each section or each two sections when four are provided. Where the total length of laterals required is greater than 3000 linear feet, it is advisable to investigate a secondary treatment process, although larger absorption systems can operate satisfactorily if the site and soil permeability are suitable to disperse the effluent and prevent groundwater mounding. Annual resting of sections is strongly recommended. In some instances, flat topography makes it impossible to install siphons and still obtain distribution of settled sewage by gravity to all the laterals. In such cases, it would be necessary to install a sump and pump(s) or ejector(s); however, the design should permit gravity flow to the absorption system in case of pump failure, if possible. Dosing arrangements are discussed later.

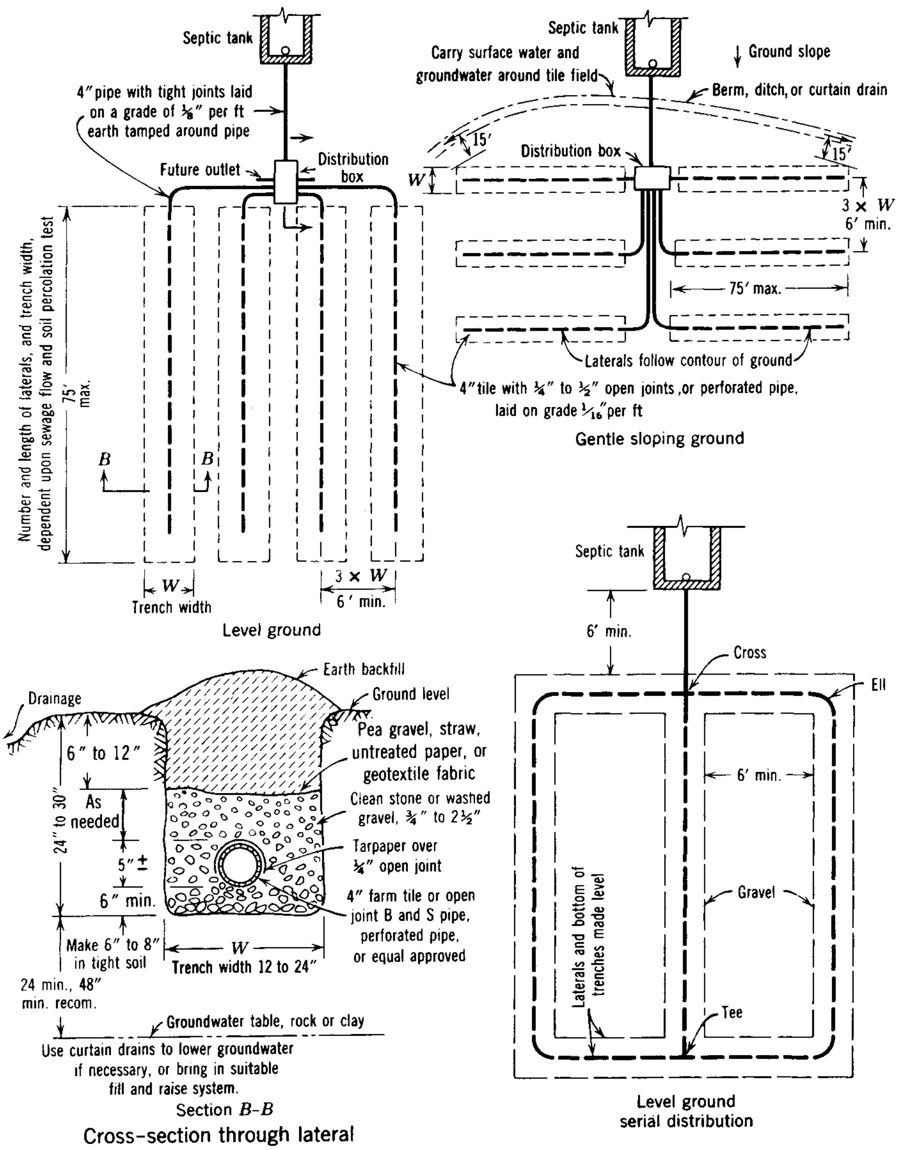


Figure 4-13 Arrangements and details for absorption field disposal systems. See local regulations.

Absorption field laterals must be laid on careful grades. *The bottom of trenches should be dug practically level, on the same grades as the laterals,* to prevent the sewage running out at one end of a trench or onto the ground surface. Laterals for fields of less than 500 ft in total length, without siphon or pump dosing, should be laid on a slope of $\frac{1}{16}$ in./ft or 3 in./50 ft. When

TABLE 4-12 Suggested Minimum Standards—Subsurface Sewage Disposal Systems

Item	Material	Size	Grade	Minimum Governing Distances: To Building or Property Line	Minimum Governing Distances: To Well or Suction Line	Minimum Governing Distances: To Water Service Line
Sewer to septic tank	Cast iron for 10 ft from building recommended	4 in. min. diameter recommended	$\frac{1}{4}$ in./ft max., $\frac{1}{8}$ in./ft min.	5 ft or more recommended	25 ft if cast-iron pipe, otherwise 50 ft	10 ft horizontal[a]
Septic tank	Concrete or other applied material. Use a 1 : $2\frac{1}{4}$: 3 mix	Minimum 750 gal, 4 ft liquid depth, with min. 16 in. mean height over inlet	Outlet 2 in. below inlet	10 ft	50 ft	10 ft
Lines to distribution box and disposal system	Cast iron, vitreous clay, concrete, or composition pipe	Usually 4 in. diameter on small jobs	$\frac{1}{8}$ in./ft; but $\frac{1}{16}$ in./ft with pump or siphon	10 ft	50 ft	10 ft
Distribution box	Concrete, clay tile, masonry, coated metal, etc.	Minimum 12 × 12 in. inside carried to surface; baffled.	Outlets at same level	10 ft	100 ft	10 ft
Absorption field[b]	Clay tile, vitreous tile, concrete, composition pipe, laid in washed gravel or crushed stone, $\frac{3}{4}$–$2\frac{1}{2}$ in. size, min. 12 in. deep	4 in. diameter, laid with open joint or perforated pipe; depth of trench 24–30 in.	$\frac{1}{16}$ in./ft, but $\frac{1}{32}$ in./ft with pump or siphon	10 ft except when fill used, in which case 20 ft required	100 ft	10 ft (25 ft from any stream; 50 ft recommended)

Sand filter[b]	Clean sand, all passing $\frac{1}{4}$ in. sieve with effective size of 0.30–0.60 mm and uniformity coefficient less than 3.5. Flood bed to settle sand.	Send 2-1b sample to health department for analysis 15 days before construction.	Laterals laid on slope $\frac{1}{16}$ in./ft; but $\frac{1}{32}$ in./ft with pump or siphon	10 ft	50 ft	10 ft (25 ft from any stream; 50 ft recommended)
Leaching or seepage pit[b]	Concrete block, clay tile, brick, fieldstone, precast	Round, square, or rectangle	Line to pit $\frac{1}{8}$ in./ft	20 ft	150 ft plus in coarse gravel	20 ft (50 ft from any stream)
Chlorine contact-inspection tank	Concrete, concrete block, brick, precast	2 ft $\times$ 4 ft and 2 ft liquid depth recommended	Outlet 2 in. below inlet	10 ft	50 ft	10 ft

Note: A slope of $\frac{1}{16}$ in./ft = 6.25 ft/100 ft = 0.0052 ft/ft = 0.52%. All parts of disposal and treatment system shall be located above groundwater and *downgrade* from sources of water supply. The architect, builder, contractor, and subcontractor should establish and verify all grades and check construction. Laundry and kitchen wastes should discharge to the septic tank with other sewage. The volume of the septic tank should be increased by 50% if it is proposed to also install a garbage grinder. No softening unit wastes, roof or footing drainage, surface water or groundwater should enter the sewerage system. Where local regulations are more restrictive, they govern, if consistent with county and state regulations.

[a] Water service and sewer lines may be in same trench if cast-iron sewer with lead-caulked joints is laid at all points 12 in. below water service pipe or sewer may be on dropped shelf at one side at least 12 in. below water service pipe, provided sound sewer pipe is laid below frost with tight and root-proof joints, which is not subject to settlement, superimposed loads, or vibration. Separate trenches are strongly recommended.

[b] *Manual of Septic-Tank Practice,* PHS Pub. No. 526 (1967), states that the leaching area should be increased by 20% where a garbage grinder is installed and by 40% where a home laundry machine is also installed. It recommends that the gravel in the tile field extend at least 2 in. above pipe and 6 in. below the bottom of the pipe.

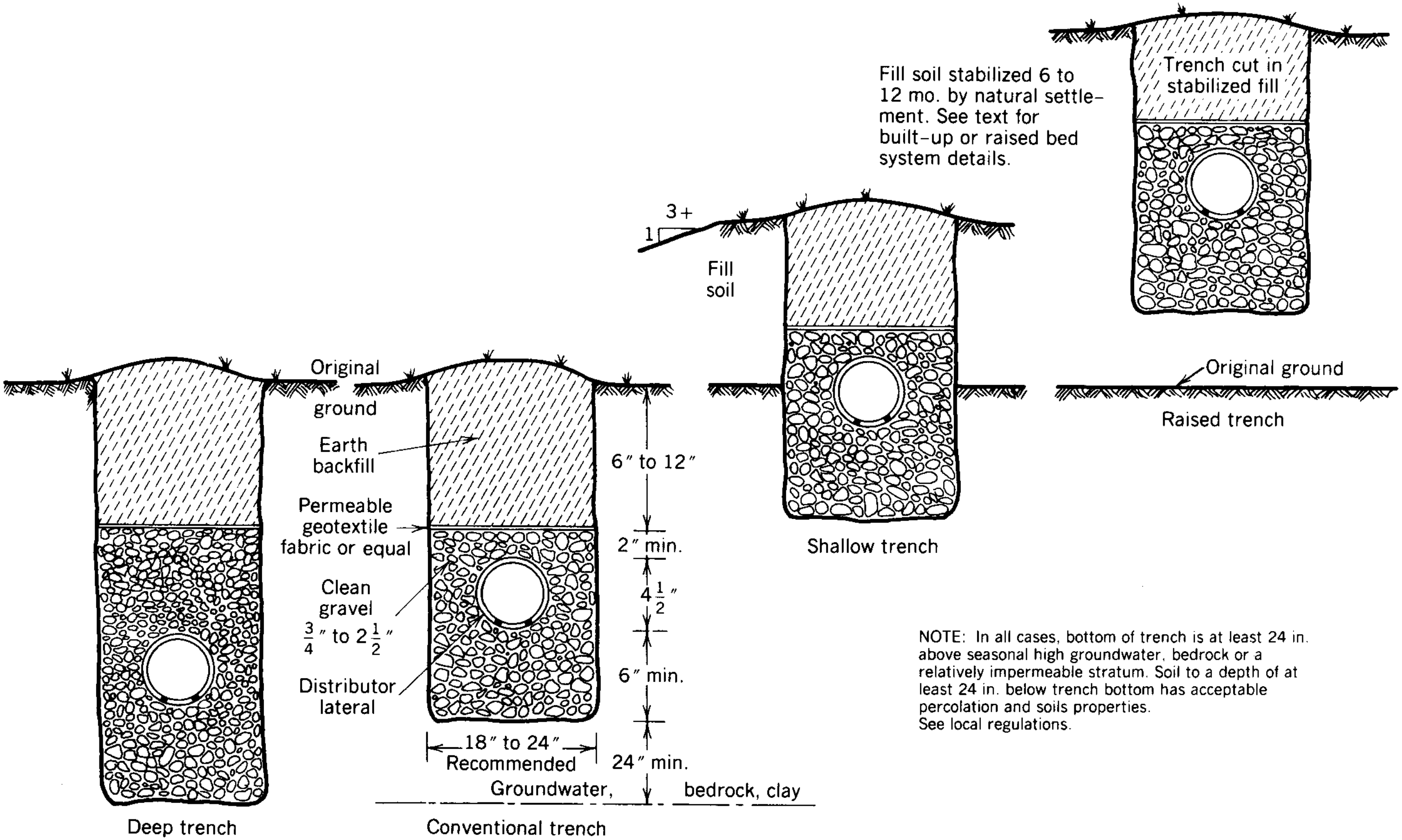


Figure 4-14 Possible distribution trench elevations to stay at least 24 in. above a limiting barrier condition.

siphons or pumps are used, the laterals should be laid on a slope of 3 in./100 ft. Absorption fields for steep sloping ground are shown in Figures 4-11 and 4-12, and layouts for level and gently sloping ground are shown in Figures 4-13 and 4-15. Hydraulic loading rates should be kept between 0.25 and 0.5 gpd/ft^2. Dosing, regardless of absorption field size, is recommended to ensure full distribution and use of the field, intermittent resting, and aerobic conditions.

An alternative to the traditional single absorption field is the use of alternating-drain fields, which involve the use of two or more smaller drain fields that are alternatively put into and taken out of service by means of a valve in the distribution box. Flow to the fields is typically switched from one to three times per year to allow for a resting period for the field that is not in service. This resting period allows for the regeneration of a field's absorptive capacity by giving soil bacteria time to back down (i.e., decompose) the

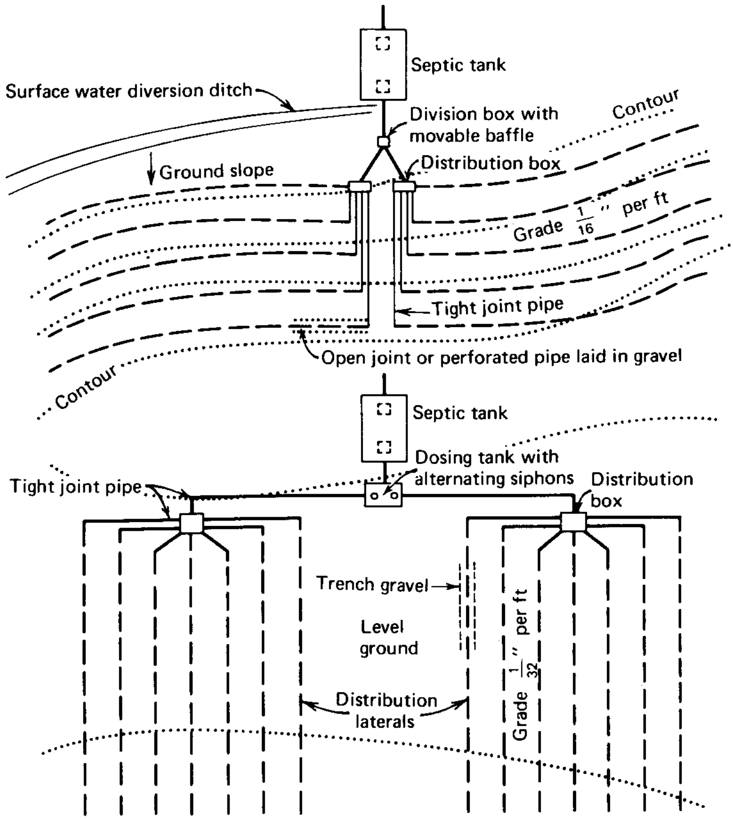


Figure 4-15 Absorption fields with division box, distribution box, and dosing tank. Lateral lengths: 75 ft maximum for gravity flow and 100 ft maximum if dosing siphon or pump is used. See also Figure 4-12 for sloping ground.

biological mat that develops in an active field. The second field can also serve as a backup system if the operational drain field needs to be repaired.

The disposal of septic tank effluent in a bed, rather than in separated lateral trenches, can cause operational problems. Groundwater table mounding is more likely to develop beneath the bed, particularly where the soil percolation is marginal and subsoil hydraulic conductivity is low, with consequent backup or surface seepage of sewage. This would also occur if the subsoil vertical and horizontal transmissivity does not exceed the rate at which the sewage effluent infiltrates the absorption bed bottom and walls and percolates through the soil and where the groundwater hydraulic gradient is relatively flat. It is recommended, and often required, that the bed area be twice that required for absorption trenches. In contrast, the use of lateral trenches and separated fields would permit dispersion and evapotranspiration of the effluent over a greater area, which would include a trench sidewall area. Similar precautions should be taken with large subsurface absorption systems, consisting of several fields or sections, to avoid their being located in a limited area and downgrade from one another.[80] In effect, water balance, soil permeability, transmissivity, and soils studies should be made over the total area impacted to ensure that the receiving soil has the capacity (hydraulic conductivity) to carry away and disperse the sewage effluent downward and laterally at a rate faster than it is applied, at all times of the year, without backup, surface seepage, or water mounding beneath or around the absorption field.

Leaching or Seepage Pit

Leaching pits, also referred to as seepage pits, are used for the disposal of settled sewage where the soil is suitable and a public water supply is used or where private well-water supplies are at least 150 to 200 ft away, at a higher elevation, and not likely to be affected. Leaching pits work like a vertical absorption field, although they lack the areal extent of such fields. Pits are usually 10 to 20 ft deep and 6 to 12 ft in diameter. The bottom of the pit should be at least 2 ft, and preferably 4 ft, above the highest groundwater level and channeled or creviced rock. If this cannot be ensured, subsurface absorption fields should be used. In special instances, where public water supply is available, suitable soil is found at greater depths, and groundwater can be protected, pits can be dug 20 to 25 ft deep or more using precast perforated wall sections. The soil percolation test is made at middepth, at changes in the soil profile, and at the bottom of the proposed leaching pit and interpreted for design purposes, as explained earlier in this chapter and in Table 4-5.

According to the October 1980 EPA *Design Manual Onsite Wastewater Treatment and Disposal Systems,* the weighted average of these percolation tests should be used to obtain a design figure. Soil strata whose test results exceed 30 min/in. should not, however, be used in calculating the effective absorption area. Hydraulic loading rates for leaching or seepage pits should generally be kept between 0.4 and 0.8 gpd/ft^2, although the EPA manual allows for up to 1.2 gpd/ft^2 depending on the results of the percolation tests and the soil type present. The effective leaching area provided by a pit is equal to the vertical wall area of the pit below the inlet. Credit is not usually given for the pit bottom. A leaching pit is usually round to prevent cave-in. If precast perforated units are not used, the wall below the inlet is drywall construction—that is, laid with open joints, without mortar. Field stones, cinder or stone concrete blocks, precast perforated wall sections, or special cesspool blocks are used for the wall construction. Concrete blocks are usually placed with the cell holes horizontal. Crushed stone or coarse gravel should be filled in between the outside of the leaching pit wall and the earth hole. Table 4-13 simplifies determination of the sizes of circular leaching pits. Sketches of leaching pits are given in Figures 4-16 and 4-17.

Since leaching pits concentrate pollution in a small area, their use should generally be avoided where the groundwater is a drinking water source. For this reason, use of such pits is frequently discouraged by regulatory agencies in favor of more diffuse systems, such as absorption fields.

Cesspool

Before septic tanks and absorption fields were widely used, sewage from individual dwellings was frequently discharged to cesspools. Cesspools are

TABLE 4-13 Sidewall Areas of Circular Seepage Pits by Depth of Effective Layer below Inlet in Feet[a]

Seepage[b] Pit Diameter (ft)	Sidewall Areas (ft^2)									
	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
1	3.1	6	9	13	16	19	22	25	28	31
2	6.3	13	19	25	31	38	44	50	57	63
3	9.4	19	28	38	47	57	66	75	85	94
4	12.6	25	38	50	63	75	88	101	113	126
5	15.7	31	47	63	79	94	110	126	141	157
6	18.8	38	57	75	94	113	132	151	170	188
7	22.0	44	66	88	110	132	154	176	198	220
8	25.1	50	75	101	126	151	176	201	226	251
9	28.3	57	85	113	141	170	198	226	254	283
10	31.4	63	94	126	157	188	220	251	283	314
11	34.6	69	104	138	173	207	242	276	311	346
12	37.7	75	113	151	188	226	264	302	339	377

Source: Design Manual, Onsite Wastewater Treatment and Disposal Systems, U.S. Environmental Protection Agency, Washington, DC, October 1980, p. 237.

[a] Areas for greater depths can be found by adding columns. For example, the area of a 5-ft-diameter pit 15 ft deep is equal to 157 + 79, or 236 ft.

[b] Diameter of excavation.

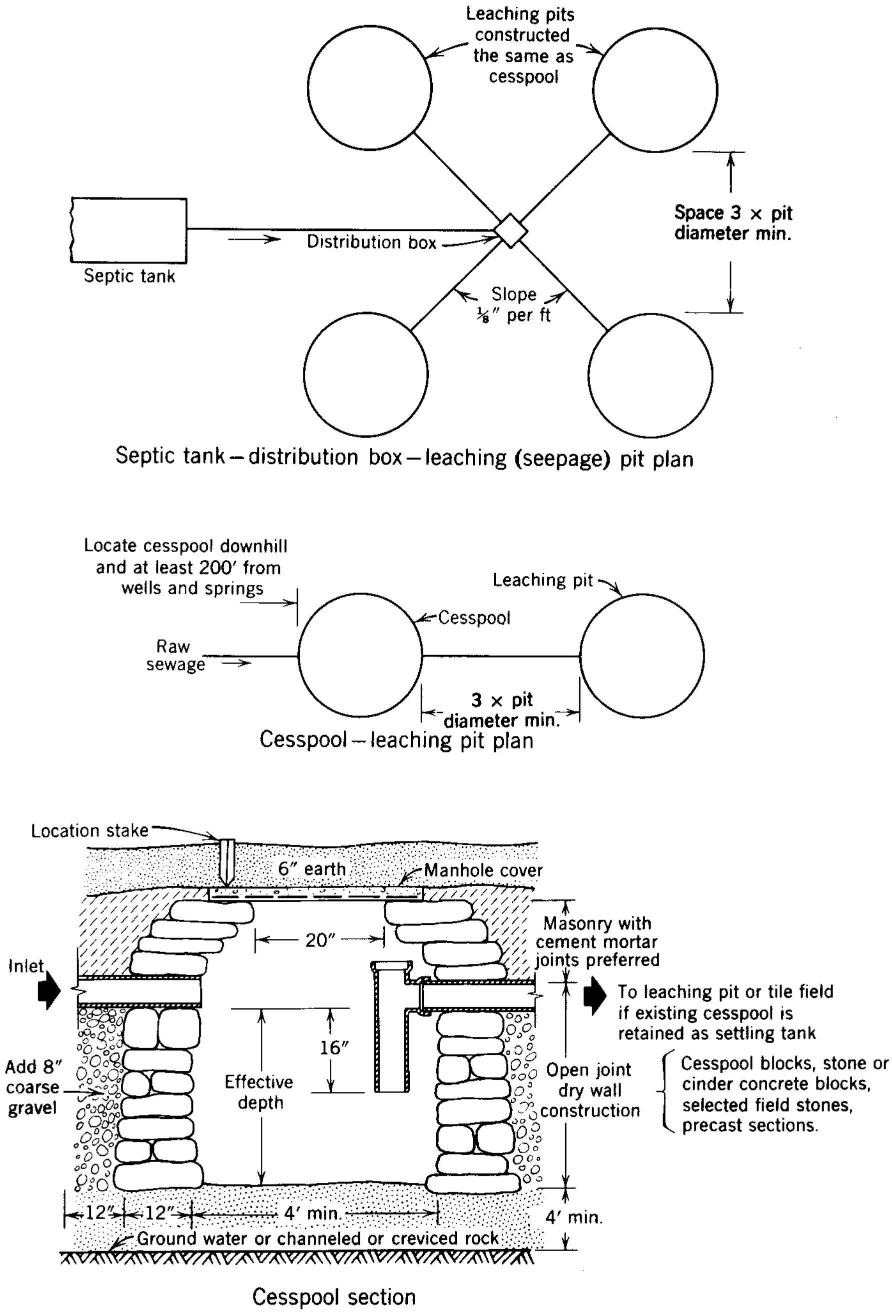


Figure 4-16 Leaching pit and cesspool details.

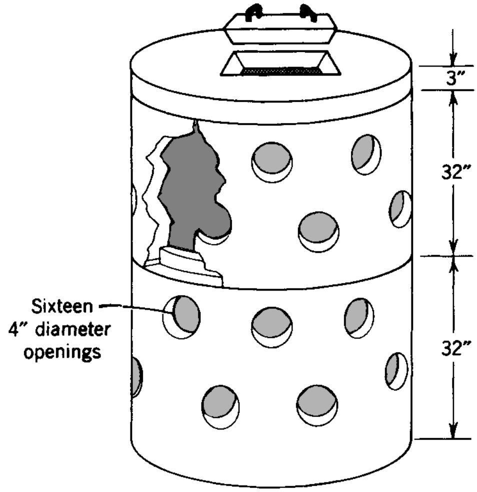


Figure 4-17 Precast leaching pit or dry well. Each section: 32 in. high, 4 ft inside diameter (available in larger sizes); 3-in.-thick walls—place 8 in. coarse gravel all around; 250-gal volume; 1100-lb weight. Cover weight: Approximately 400 lb. Manhole can be built up to grade using standard chimney blocks. (Courtesy of the Fort Miller Co., Inc., Fort Miller, NY.)

covered, open-joint, or perforated walled pits that receive raw sewage. Their use is not recommended where the groundwater serves as a source of water supply. Many health departments prohibit the installation of cesspools. Pollution could travel readily to wells or springs used for water supply. Where cesspools are permitted, they should be located downgrade from sources of water supply and 200 to 500 ft away. Even 500 ft may not be a safe distance in a coarse gravel unless the water-bearing stratum is below the gravel and separated by a thick clay or hardpan stratum. On the other hand, lesser distances may be permitted where fine sand and no groundwater is involved. In all cases, the bottom of the cesspool should be at least 4 ft above the highest groundwater level.

The construction of a cesspool is the same as a leaching pit, shown in Figure 4-16. In some areas, such as where sand and gravel deposits are found, cesspools have been in common use for many years before requiring cleaning. Cleaning the cesspool will not restore it to full use since the space and soil behind the wall cannot be effectively cleaned. Heavy chlorination may be of value. Special cesspool (or septic tank, as previously noted) cleaning compounds may contain toxic or carcinogenic chemical compounds and should not be used. These compounds may persist for many years and contaminate the groundwater aquifer serving as the source of drinking water. The cesspool system can be made more efficient under such circumstances by providing a tee outlet, as shown in Figure 4-16, with the overflow discharging to an absorption field or leaching pit. A preferable alternative would be replacement of the cesspool with a septic tank followed by an absorption field.

Dry Well

A dry well is constructed in the same way as a leaching or seepage pit and with identical care. A dry well is used where the subsoil is relatively porous, for the underground disposal of clear rainwater, surface water, or groundwater collected in footing, roof, and basement floor drains and similar places. Footing, roof, or basement floor drainage should never be discharged to a private sewage disposal or treatment system as the septic tank and leaching system would be seriously overloaded, causing exposure of the sewage and premature failure of the leaching system. It is uneconomical and unnecessary to design the sewerage system for this additional flow. If the soil at a depth of 6 to 10 ft or more is tight clay, gravel- or stone-filled trenches about 3 ft deep may be more effective. Dry wells should not be used for the disposal of toilet, bath, laundry, or kitchen wastes. These wastes should be discharged through a septic tank. In some cases, footing and roof drainage may be discharged to a nearby watercourse, combined sewer, storm sewer, or roadside ditch rather than to dry wells, if permitted by local regulations.

Dry wells should be located at least 50 ft from any water well, 20 ft from any leaching portion of a sewage disposal system, and 10 ft or more from building foundations or footings.

SMALL WASTEWATER DISPOSAL SYSTEMS FOR UNSUITABLE SOILS OR SITES

General

Waterborne wastewater treatment systems in this category, also referred to as alternative systems, are usually more complex in design and more costly than the conventional septic tank subsurface absorption systems previously discussed and described. These systems include the modified absorption system, the capillary seepage trench, the absorption–evapotranspiration system, the sand filter system, the aerobic treatment unit, the mound system, the raised-bed or built-up system, and the underdrained absorption system, and the evapotranspiration system as well as the oxidation pond system, the spray or ridge and furrow irrigation system, the overland flow system, the oxidation ditch system, and various combinations of the above. The sand filter and biological wastewater treatment systems require effluent disposal to a subsurface or land disposal system, if discharge to a stream or lake is not permitted or not possible. A NPDES permit may be required for a surface discharge.

Other alternatives where site area is limited are the use of a conventional biological treatment unit followed by (1) a sand filter and a granular activated carbon filter or (2) a membrane filter and a granular activated-carbon filter and then by disinfection usually with chlorine (also UV) to provide health protection and prevent slime growths in treated recycled wastewater. The use of low-flush toilets ($1\frac{1}{2}$ to $3\frac{1}{2}$ gal per flush) and recycling of treated wastewater for flushing toilets and urinals could be incorporated in the system design to minimize sewage flow. A dual-piping system, equalization tank, treated water storage tank, and pumps would also be needed. Care must be taken to prevent cross-connection with the potable water system. Consideration might also be given to the reuse of reclaimed wastewater for nonpotable purposes such as landscape irrigation and gardening where feasible and water conservation is an option (see Water Conservation, Chapter 3).

Final effluent disposal, primarily due to fixtures supplied with potable water, would be to a soil absorption or land disposal system, if discharge of treated effluent to a stream or lake is not permitted. Provision must be made for competent operation and control, periodic sludge removal and disposal, and an alternate source of power. In view of the complexities and uncertainties involved, professional advice should be obtained before proceeding.

Low-pressure, vacuum, and cluster systems may also be appropriate in certain situations. See Pressure, Vacuum, and Cluster Systems, this chapter.

Alternative systems are considered when a conventional system cannot be expected to function satisfactorily because of high groundwater and because rock, clay, or other relatively impervious formation is close to the surface and where space is limited or a highly porous formation exists and protection of nearby well-water or surface-water supplies is a major concern. In such situations, the local sanitarian or sanitary inspector is advised to consult with a staff sanitary or public health engineer or with the state health department or environmental protection agency. In the case involving a public place such as a hotel, motel, campground, recreational area, commercial operation, or realty subdivision, the owner should be referred to a consulting engineer for advice on how to best solve the problem. Plans, specifications, and an engineer's report are normally required for review and approval *prior to construction,* before any decisions are made. Alternative systems are usually quite expensive. Obtain cost estimates.

Modified Septic Tank Soil Absorption System

The conventional subsurface soil absorption system is usually designed on the basis of soil percolation rates not exceeding 1 in. in 60 min. Some regulatory agencies arbitrarily establish 1 in. in 30 min as the maximum rate beyond which construction is prohibited, unless an acceptable alternative system is permitted.

Design and Construction Details There is nothing sacred about the 60-min maximum soil percolation rate; most so-called "tight" soils are not entirely impermeable. This is simply common sense, which Ryon recognized in his original notes (ref. 56, p. 33). He recommended the following application rates for 60-min or poorer soils:

Time to Fall 1 in. (hr.)	Safe Application Rate (gpd/ft^2)
1	0.4
$1\frac{1}{2}$	0.3
2	0.2
3	0.14
5	0.07
10	0.03

Ryon further recommended that the required absorption area be doubled if an absorption bed is used instead of an absorption field.

The same precautions should be taken in the construction of a modified system as in the conventional system. Drainage of surface water and attention to possible high groundwater and its control become particularly important in view of the tighter soil involved. It is apparent that large absorption areas will be required, which for very tight soils may become impractical. The wastewater flow to be treated, the size of the absorption system, the problem to be resolved, the space available, and the cost will largely determine the practicality in individual situations.

Construction of the modified system would be similar to a conventional subsurface absorption field. Intermittent dosing (siphon, pump, tipping bucket) is usually required, particularly if the total length of distributors exceeds 500 ft. Siphons are preferred where topography permits. In any case, alternating dosage should be provided for lengths of 1000 to about 2500 ft.

An example showing a design for a "tight" soil site of fairly uniform composition to a depth of 4 ft or more follows.

The design for a relatively tight soil makes use of the conventional soil percolation test carried to the point of constant rate, beyond the 1 in./60 min. test. The moisture loss due to evaporation and transpiration is not credited but taken as a bonus.

Assume a soil with an actual percolation rate of $\frac{1}{4}$ in./hr. The application rate would be 0.10 gpd/ft^2, based on Ryon's[56] recommendations.

Example Design a subsurface leaching system for a daily flow of 300 gal. The soil test shows $\frac{1}{4}$ in./hr and a permissible settled sewage application of 0.10 gpd/ft^2:

$$\text{Required leaching area} = \frac{300}{0.10} = 300 \text{ ft}^2$$

If trenches 36 in. wide with 18 in. gravel underneath lateral distributors are provided, each linear foot of trench can be expected to provide 5 ft^2 of leaching area.

The required trench equals 3000/5 = 600 linear feet, or 8 laterals, each 75 ft long, spaced 9 ft on center. Provide a dosing arrangement.

The leaching area can also be provided by *two* gravel beds 50 × 60 ft to compensate for the loss of the sidewall trench infiltration and dispersion area. See Figure 4-18. Use an alternating dosing device. This occupies the same land area as the absorption field. Evapotranspiration can be enhanced by incorporating sand trenches or funnels in the gravel between the distributors. (See Figures 4-28 and 4-29 later in the chapter.)

Capillary Seepage Trench

Another alternative to traditional absorption field design is the use of a design modification known as the capillary seepage trench, which is widely used in Japan. The capillary seepage trench is similar to a conventional seepage trench except that it has an impermeable liner at the bottom of the trench, which extends part way up the trench's sidewalls. As a result, sewage effluent collects along the entire length of the trench and moves both upward and hori-

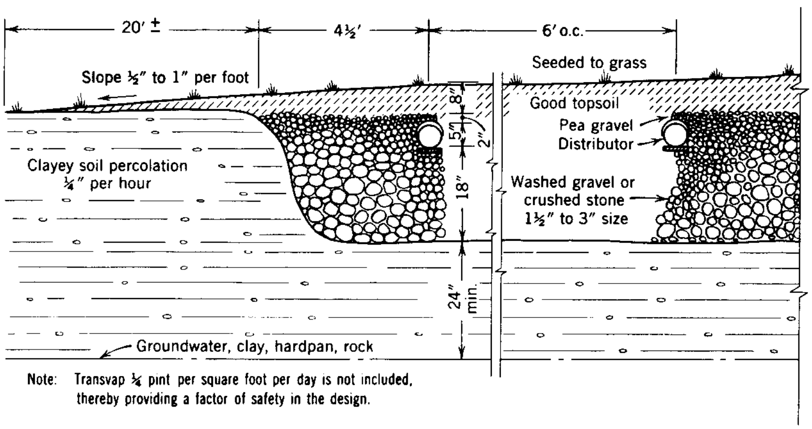


Figure 4-18 Absorption bed for a tight soil. Curtain drains may be needed to lower groundwater level. Crown bed to readily shed rain water. Add triangular sand [0.1 mm effective size (ES)] ridges between distributor laterals extending from the bottom of the bed to the topsoil to promote capillary action and evapotranspiration. See Figures 4-28 and 4-29 later in the chapter.

zontally by capillary action before percolating downward. This modification in trench design uses a larger area of the unsaturated soil matrix associated with the trench and results in a more even distribution and a longer time of contact. Fly ash is often used as the trench fill material because it allows for rapid capillary movement of the effluent waters and for increased surface area for microbial growth. This system reduces the likelihood of progressive failure, where portions of an absorption field become overloaded due to uneven distribution of effluent waters. However, because a capillary seepage trench does not use the bottom of the trench as an absorption area, the trenches need to be longer than a conventional absorption trench.

Built-Up or Raised-Bed Septic Tank Absorption–Evapotranspiration System

If clay, hardpan, groundwater, or channeled, creviced, or solid rock is found within and below 4 ft of the ground surface, disposal of sewage by means of a conventional subsurface absorption system is not recommended. For practical purposes, clay, hardpan, or solid rock cannot be expected to absorb sewage, and to dispose of sewage directly into the groundwater is to invite system failure and direct groundwater pollution, or, if into channeled or creviced rock or coarse gravel, sewage pollution of nearby and distant wells.

It is possible, if approved by the regulatory agency, to artificially build up an earth area for sewage disposal, *provided at least 12 to 18 in. of natural porous earth exists,* which has a percolation of at least 1 in. in 120 min. This will permit the dispersion of the percolating sewage over a large absorptive area. The type and characteristics of the fill soil is critical. A sandy, loamy, gravely soil is suggested, containing approximately 70 to 80 percent (by weight) medium to coarse sand (0.25–2.0 mm ES); 10 to 20 percent silt, fine sand, and clay (0.25 or less mm ES); and not more than 10 percent gravel (2.0 mm–7.5 cm ES). However, the final in-place soil percolation test after soil settlement will govern. (See Soil Characteristics and Clues earlier in this chapter.) Inspection of the borrow pit to obtain the best-quality fill soil is advisable. The soil selected should contain a mixture of topsoil (the upper layer of soil, usually darker and richer than the subsoil) and loam containing considerable coarse sand and some small stones, silt, and clay as previously described. Preliminary percolation tests in the undisturbed soil may be made to give an indication of its suitability. Since the original soil structure is radically changed in excavating, loading, transporting, dumping, and spreading, it is necessary to stabilize the fill soil at the site of the new absorption field. A long, narrow absorption field with fewer and longer laterals (75–100 ft), parallel to the contour and perpendicular to the groundwater flow will provide greater area for underground wastewater dispersion, minimize possible groundwater mounding, and make less likely seepage out of the toe of the feathered fill.

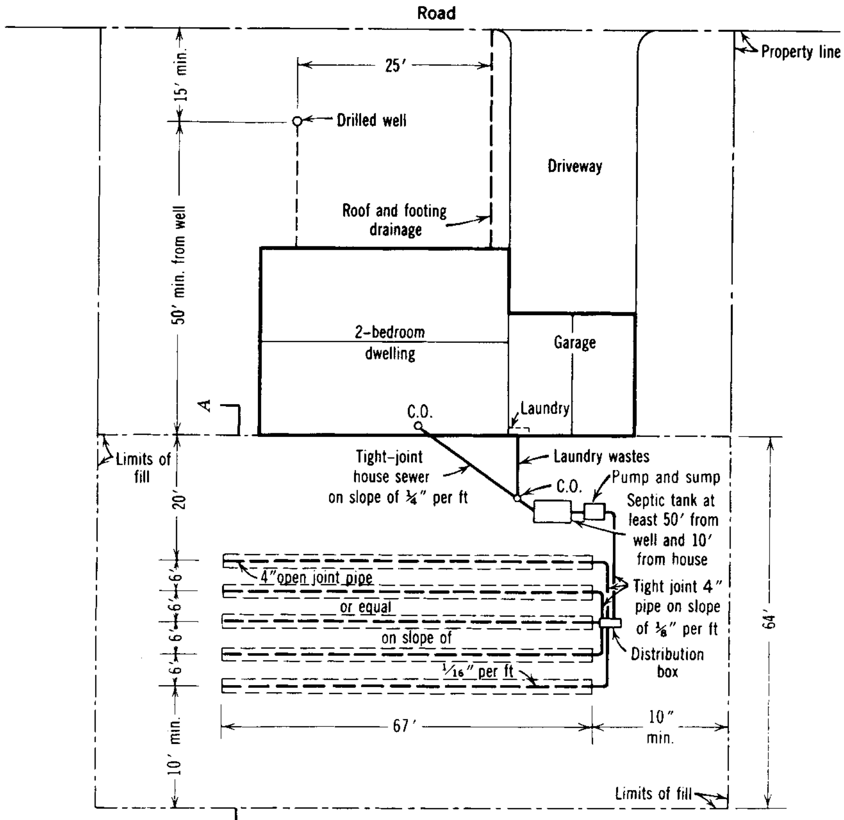
The fill soil is spread in 6-in. layers using a lightweight crawler tractor to achieve a uniform soil density without channels or holes. The soil is then allowed to stabilize by natural settlement for at least 6 months, preferably 9 to 12 months, to endure the seasonal climate changes such as freezing, thawing, rain, and drought. It is essential that the fill soil not be spread when it is wet (the soil is considered wet when if it is balled and squeezed in hand, free water becomes visible). The soil must not be compacted. Sufficient suitable soil must be brought in so that the bottom of the absorption trenches will be at least 2 ft above the highest ground water level, creviced rock, clay, or hardpan. The slope or dip of the rock, clay, or hardpan and the depth and limits of the fill and natural existing soil must be such as to make seepage of the sewage to the ground surface or directly into creviced rock improbable. The goal is eventual restoration of a permeable soil structure and texture with a healthy microbial population in the soil and a firm grass cover.

After soil stabilization, percolation tests are made in four to six locations, depending on the consistency of the results. The percolation rate should be between 1 in. in 8 min and 1 in. in 31 min (EPA). This should prevent premature clogging and permit effluent retention in the fill soil and unsaturated natural soil to obtain maximum purification of sewage effluent by natural physical, chemical, and biological means before reaching the groundwater or ground surface.

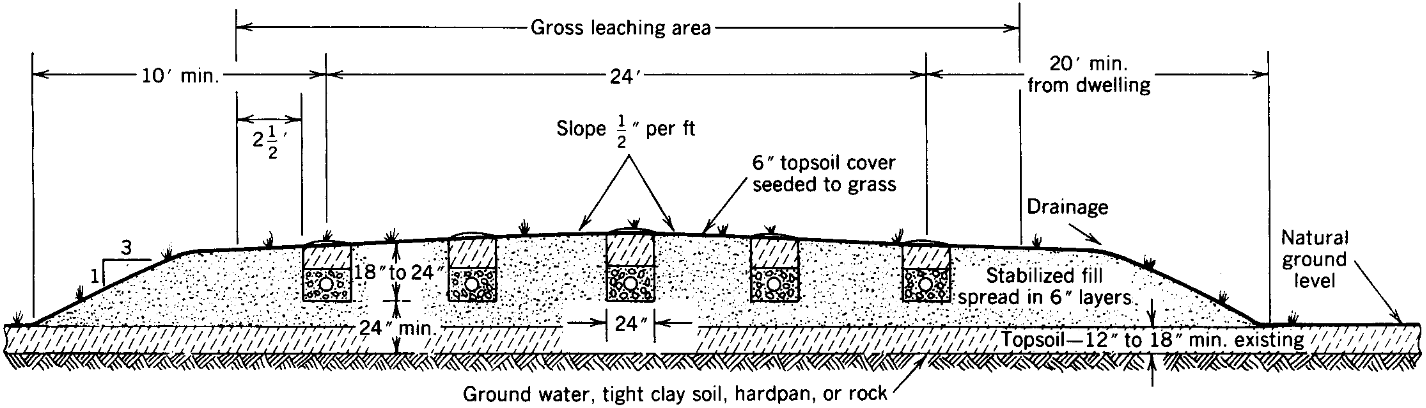
The natural, existing topsoil should not be removed but simply lightly plowed to provide a bond with the filled-in soil. The surface of the fill should be carefully graded to readily shed rain water, and the border around the sides of the built-up absorption field for a distance of about 10 ft or more should be feathered to the natural soil to keep the hydraulic gradient of wastewater entering the absorption trenches below the toe of the fill and ground surface. On sloping (steep) ground, the downgrade fill might have to be extended, as previously noted, as much as 40 ft or more, particularly where 12 to 18 in. of natural soil is not available to cover clay or rock, to prevent seepage to the ground surface. The entire surface of the absorption system and sides of the fill are covered with at least 6 in. of topsoil, graded to enhance runoff of precipitation, and seeded to grass.

A suggested built-up or raised-bed system that utilizes absorption and evapotranspiration is illustrated in Figure 4-19. The design is based on the percolation rate of the fill soil after stabilization and the ability of the natural soil to disperse and carry away the septic tank effluent without groundwater contamination or seepage to the ground surface, as previously mentioned. In view of the many uncertainties (changes in soil structure, uneven soil density and settlement, unreliability of soil percolation tests in fill soil, and need to provide retention in the unsaturated zone for natural purification), a conservative design basis is considered prudent. A fill percolation rate of 1 in. in 31 min or 0.45 gpd/ft^2 (EPA, Table 4–5) is suggested. This would correspond to a basal area application rate of 0.14 gpd/ft^2. The basal area on level ground for this purpose is the absorption field area extending 2.5 ft beyond the outer edges and ends of the distribution trenches.

The absorption system should be dosed two to three times per day (one-half to one-third the daily flow) using a pump or siphon. With a siphon and


Road
Property line
25′
15′ min.
Drilled well
Driveway
Roof and footing drainage
50′ min. from well
2-bedroom dwelling
Garage
A
C.O.
Laundry
Limits of fill
Tight-joint house sewer on slope of ¼″ per ft
Laundry wastes
C.O.
Pump and sump
Septic tank at least 50′ from well and 10′ from house
20′
4″ open joint pipe or equal on slope of 1/16″ per ft
Tight joint 4″ pipe on slope of ⅛″ per ft
Distribution box
6′
6′
6′
6′
64′
67′
10″ min.
10′ min.
Limits of fill

Plan



Section A–A

Figure 4-19 Built-up or raised-bed evapotranspiration–absorption sewage disposal system. House sewer and septic tank inverts must be established to provide gravity flow to septic tank. Design basis: 300 gpd and a transvaporation–percolation rate of 0.45 gpd/ft^2 or trench bottom (total of 335 ft, 2 ft wide) or 0.14 gpd/ft^2 of system gross leaching area (72 $\times$ 31 ft). Pump or siphon distribution is usually required to the absorption field. Dose field two or three times per day.

4-in.-diameter distribution lines, the dose is based on about 60 percent of the volume of the lines. With a pump, the volume pumped is established by the pump switch on–off settings in the pump well. The hydraulic head at the ends of the *capped* distribution lines ($1\text{–}1\frac{1}{2}$ in.) should not exceed 2 to 3 ft of water.

Intermittent operation will permit full dosage of the distributor laterals, which enhances purification and dispersion of the wastewater over the total absorption field and subsoil area. However, any time a pump is installed, the chance for malfunction, power failure, and inconvenience in the use of the household plumbing exists.

A diversion ditch or berm should be provided upgrade to divert surface runoff around the absorption–evapotranspiration system. A curtain drain around the bed to intercept and lower the groundwater table, with discharge to the surface, may be needed in areas of high groundwater if the bottom of the trenches cannot be kept at least 2 ft above groundwater. If clay or hardpan is intercepted, the curtain drain trench and collection pipe should extend at least 6 in. into the impervious formation. Drainage of an artesian-fed water table should not be attempted. See Figure 4-20.

Septic Tank Sand Filter System

The sand filter following a septic tank or aerobic unit may be earth covered or open. The covered filter is generally used for small flows. Sand filters have particular application where conventional subsurface absorption systems cannot be expected to function satisfactorily because of soil conditions or rock or where space is very limited and discharge to a surface water or ditch is permissible.

Settled sewage is distributed over the top of a sand filter bed by means of perforated, open-joint pipe, or other means, as shown in Figures 4-21 through 4-23.

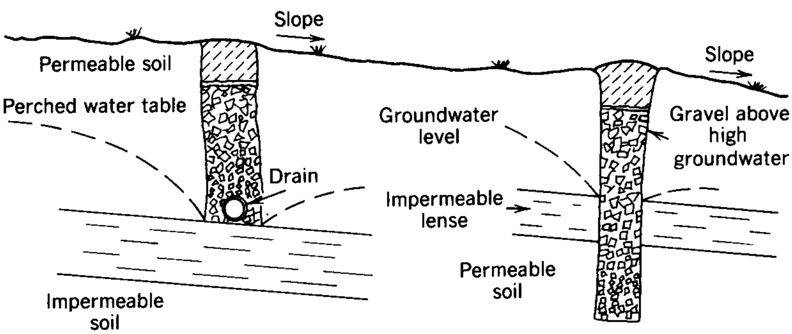
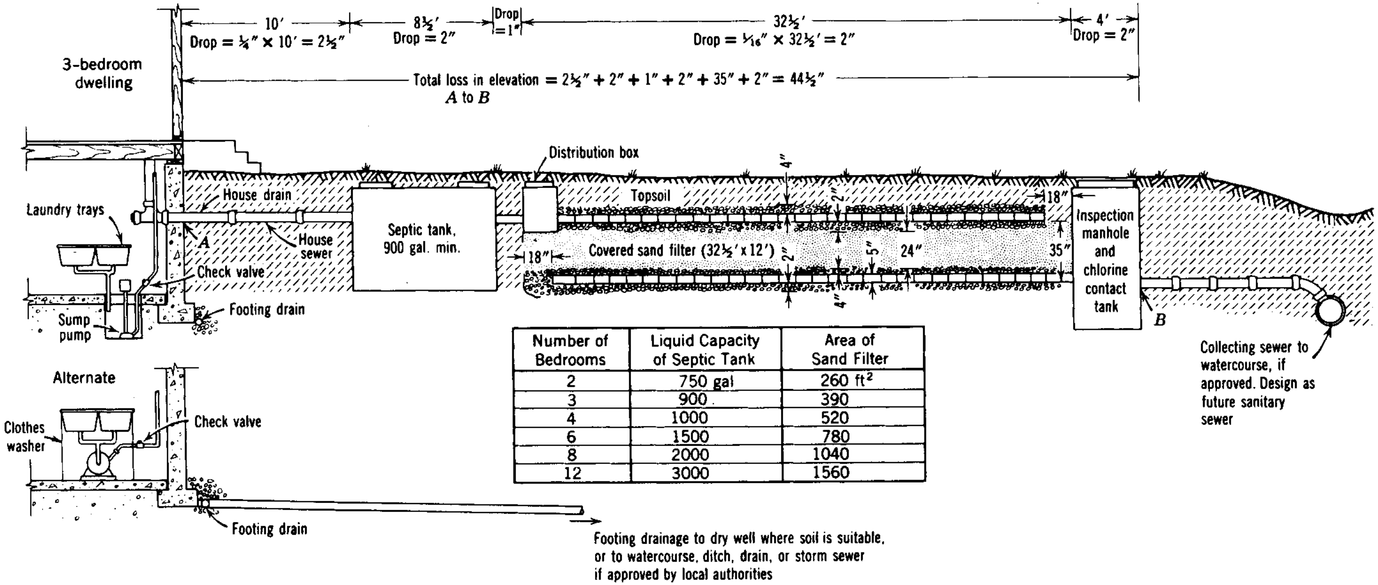
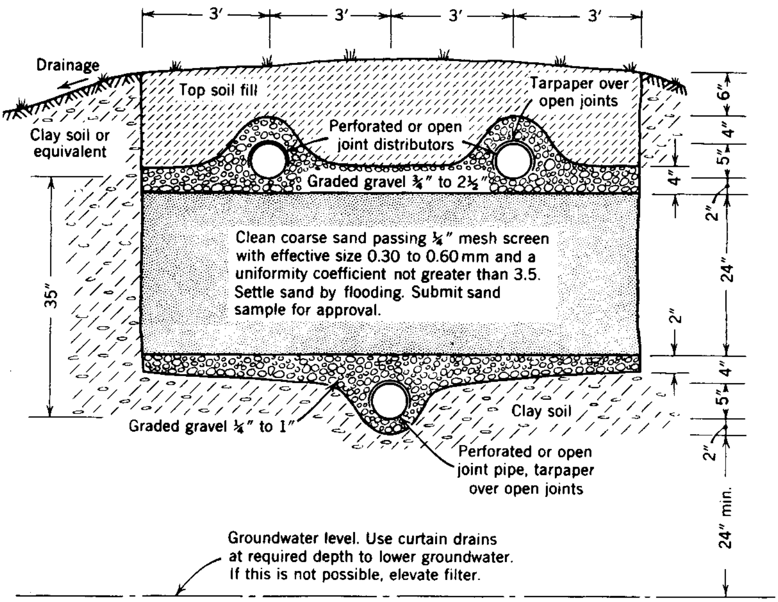


Figure 4-20 Curtain drains to lower groundwater level. The gravel or crushed stone *must* intercept the strata carrying the groundwater flow, and the collecting pipe *must* drain to the surface or to a lower drained permeable information; otherwise a pump is necessary. Collecting pipe is perforated.



Number of Bedrooms	Liquid Capacity of Septic Tank	Area of Sand Filter
2	750 gal	260 ft²
3	900	390
4	1000	520
6	1500	780
8	2000	1040
12	3000	1560

Figure 4-21 Section through covered sand filter system. Design basis is 150 gal per bedroom and filter rate 1.15 gpd/ft^2. Larger capacity septic tank (50–100 percent larger than minimum) is strongly recommended.



Number of Bedrooms	Capacity of Septic Tank	Size of Filter			Alternate Filter Size*		Sump Capacity Between Float Settings†
		Length	Width	Area	Length	Width	
2	750 gal	21½ ft	12 ft	260 ft²	43 ft	6 ft	20 gal
3	900	32½	12	390	65	6	30
4	1000	43	12	520	87	6	40
5	1250	54	12	650	—	—	50

* Use one distributor on top and one underdrain on bottom. † Where needed.

Required size of subsurface sand filter

Figure 4-22 Typical section of a subsurface sand filter. See Figure 4-21. The architect, builder, and contractors will determine invert elevations of the house sewer, septic tank outlet, distribution box, sand filter distributor and collector lines, chlorine contact tank, inspection manhole, and outlet sewer, drain, ditch, or watercourse to provide gravity flow through the system where possible. Exclude roof and footing drainage. Increase the volume of the septic tank by 50 percent if a garbage grinder is installed and the area of the filter by 30 to 60 percent if both garbage grinder and the home laundry machine are installed. Provide permeable geotextile fabric over gravel below topsoil and pea gravel between sand and bottom gravel. Spacing distributors 3 ft on center and pressure dosage are recommended.

The sewage is filtered and oxidized in passing through 24 to 30 in. of carefully selected sand. Greater sand depths do not produce significant, additional purification. A film containing aerobic and nitrifying organisms forms on the gravel and sand grains of the filter. Bacteria break down the organic

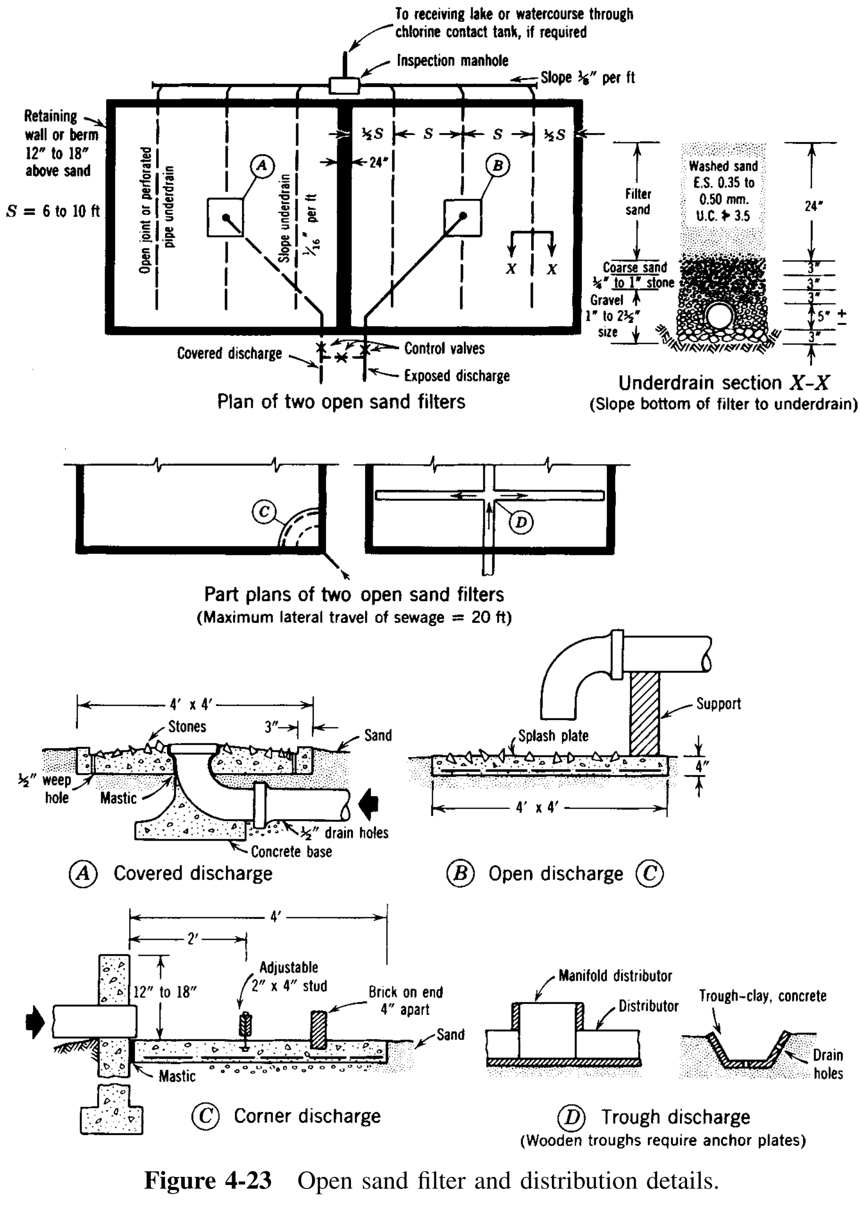


Figure 4-23 Open sand filter and distribution details.

matter in sewage. Protozoa and metazoa feed on bacteria, thereby preventing clogging of the bed. The annelid worms appear to be most important in consuming sludges and slimes and are largely responsible for keeping sand filters open and active.[81]

A sand filter is an efficient treatment unit. Typical analyses of sanitary sewage applied to and leaving subsurface sand filters and efficiencies are shown in Tables 4-14 and 4-15. A large reduction in bacteria, protozoa, helminths, turbidity, BOD, and suspended solids is obtained, in addition to a well-nitrified effluent containing dissolved oxygen. Such effluents would not cause a nuisance in undeveloped areas, but they should be chlorinated if discharged in locations accessible to children or pets because microorganisms associated with disease transmission, although greatly reduced, are still present.

The satisfactory operation of a sand filter is dependent on the rate and strength of sewage application and on the effective size and uniformity coefficient of the sand. It is essential that suspended solids carryover from the septic tank or aerobic unit be kept at a minimum. Passing the effluent through a $\frac{1}{8}$-in.-mesh basket screen is recommended. Some studies are reported here for guidance.

Filtration of an aerobic unit effluent at 3.5 gpd/ft^2 produced a good effluent with a 0.19-mm-effective-size and 3.31-uniformity-coefficient sand, which op-

TABLE 4-14 Typical Septic Tank and Subsurface Sand Filter Effluent

	Sewage Effluent[a]	
Determination	Septic Tank	Subsurface Sand Filter
Bacteria per ml, Agar, 36°C, 24 hr	76,000,000	127,000
Coliform group MPN	110,000,000	150,000
Color, mg/l	3.5	2
Turbidity, mg/l	50	5
Odor[b]	4.5	1
Suspended matter[b]	3	1
pH	7.4	7.4
temperature, °C	17	14
BOD, 5-day, mg/l	140	4
DO, mg/l	0	5.2
DO saturation, %	0	52
Nitrogen, total, mg/l	36	21
Free ammonia	12	0.7
Organic	12	3.4
Nitrites	0.001	0.02
Nitrates	0.12	17
Oxygen consumed, mg/l	80	20
Chlorides, mg/l	80	65
Alkalinity, mg/l	400	300
Total solids, mg/l	820	810
Suspended solids, mg/l	101	12

Source: J. A. Salvato, Jr., "Experience with Subsurface Sand Filters," *Sewage Ind. Wastes,* **27**(8), 909–916 (August 1955).

[a] Median results, using 51 samples from septic tanks and 56 from filters.

[b] 1 = very slight, 2 = slight, 3 = distinct, 4 = decided, 5 = extreme. Normal municipal domestic sewage has an MPN of 50–100 million coliform bacteria per 100 ml.

Note: Sand effective size 0.30–0.60 mm and uniformity coefficient not greater than 3.5.

TABLE 4-15 Typical Efficiencies of Subsurface Sand Filters[a]

Determination	Percent Reduction
Bacterial per ml, agar, 36°C, 24 hr	99.5
Coliform group, MPN/100 ml	99.6
BOD, 5-day, mg/l	97
Suspended solids, mg/l	88
Oxygen consumed, mg/l	75
Total nitrogen, mg/l	42
Free ammonia	94
Organic	72

Source: J. A. Salvato, Jr., ''Experience with Subsurface Sand Filters,'' *Sewage Ind. Wastes,* **27**(8), 909–916 (August 1955).

[a]Effluent will contain 5.2 mg/l dissolved oxygen and 17 mg/l nitrates.

erated 9 months before clogging. Filtration of a septic tank effluent at 5 gpd/ft^2 also produced a good effluent with a 0.45-mm-effective-size and 3.0-uniformity-coefficient sand, which operated for 3 to 5 months before clogging. Cleaning required the removal of the top 2 to 5 in. of sand and replacement, which is not practical with an earth-covered filter. The filters matured in about two weeks. Complete nitrification was reported.[82]

Covered septic tank sand filter systems with sand effective sizes of 0.15, 0.19, 0.24, 0.30, 0.60, 1.0, and 2.5 mm and uniformity coefficients varying from 1.2 to 4.4 were studied for 30 to 42 months. The filters with 0.15- and 0.19-mm sand and 2.8 and 4.4 uniformity coefficients clogged after 4 months and were discarded. The other six filters, with uniformity coefficients of 1.2 to 3.9, operated at 1 and 1.5 gpd/ft^2, respectively, and produced good results: BOD of 10.0 mg/l or less and suspended solids of 1.5 mg/l or less in 85 percent of the samples. The 2.5-mm media filter showed a BOD increase from 10 to 13 mg/l when operated at 1.5 gpd/ft^2. Phosphorous removal (0.24 mm grain size) containing a ''red mud'' with oxides of calcium aluminum and iron showed 73 to 90 percent phosphorous removal. The septic tank effluent, which was fed to the filters on a trickle pattern, averaged 237 mg/l BOD and 139 mg/l suspended solids.[83]

A study of open intermittent sand filters loaded at 3 gpd/ft^2 using filter sands with effective grain sizes of 0.20 to 0.60 mm and uniformity coefficients of 3.2 to 6.3 showed a good-quality effluent. The larger grain size filter (0.6 mm) produced lower removal of coliforms ($78\frac{1}{2}$ percent), COD (84 percent), and BOD (83 percent). The uniformity coefficient range studied did not seem to be critical to effluent quality.[84] A study in Ontario, Canada, showed that 58 percent of the annual precipitation on an experimental sand filter left the filter through evapotranspiration; 15.4 percent of the inflow to the septic tank left the filter through evapotranspiration. The study confirmed the importance of designing filters also for maximum possible runoff to reduce precipitation infiltration and for the high sun and wind exposure to maximize vegetative transpiration and soil evaporation. The degree of infiltration also affected the contaminant removal efficiency of the filter.[85]

Properly operated sand filters are reported to be very effective in the removal of viruses, cysts, and ova, in addition to bacteria (ref. 8, p. 61). The degree of nitrification, including free ammonia reduction, in the effluent is a good measure of filter efficiency.

Sand Filter Design

The recommended sizes of covered sand filters to serve private homes are shown in Figures 4-21 and 4-22. These systems are designed for a flow of 150 gpd per bedroom and a settled sewage application rate of 1.15 gal/ft^2 of sand filter area per day. It is extremely important to *use a proper sand,* one meeting the specifications given in Figure 4-22. The sand grains should be somewhat uniform in size, that is, *not graded in size* from fine to coarse, as this will surely cause premature clogging of the filter. Assistance and approval of the regulatory agency should be sought before a sand is purchased and then again when delivered to the job. Some sand and gravel companies are equipped to make sieve analyses of sand and stockpile approved sand. The sand filter must be carefully constructed and settled by flooding, with distributor and collector lines laid at exact grade. The use of 1 × 4-in. boards under farm tile or perforated pipe distributors, laid on gravel, assists greatly in placing the distributor lines at proper grade. A topsoil cover, preferably not exceeding 8 to 12 in., should be filled in over the gravel-covered distributor lines. Geotextile fabric is installed between the topsoil and gravel. With pressure distribution, for a private dwelling, use 1-in.-diameter PVC pipe with $\frac{1}{8}$-in. orifices spaced 2 ft on center.

Design details for open and covered sand filters are summarized below for easy reference.

Filter Rate Earth or gravel covered—50,000 gpd/acre for settled domestic sewage; 100,000 gpd/acre for temporary summer use if a recommended sand size is used and the effluent does not enter a water supply source. Open filter—75,000 to 100,000 gpd/acre for settled sewage and 200,000 to 400,000 gpd/acre for secondary treated sewage. Loading should normally not exceed 2.5 lb of either five-day BOD or suspended solids per 1000 ft^2/day. Recommended filter rates related to climate and sand size are also given in the *Manual of Septic-Tank Practice* (ref. 58, p. 66). Recirculating open filter rate is four to five times the daily design rate.

Dose A dosing device is recommended when the total length of distributor laterals exceeds 300 linear feet or the sand bed area exceeds 1800 ft^2. An alternating dosing device and separate beds are recommended when the length of distributor laterals exceeds 800 linear feet or sand bed exceeds 4800 ft^2. Dose should be at least 90 gpm/1000 ft^2 of filter area at average head.

Volume of dose with distributor laterals is 60 to 75 percent of volume of 4-in. distributors dosed. A 4-in. pipe holds 0.653 gal/ft. Volume on open filter is 2- to 4-in. flooding or 50,000 to 100,000 gal/acre. Design for one to three doses per day and a minimum 4-hr rest period between doses; 24-hr rest periods are recommended. Rotary distributors and spray nozzles have also been used to apply settled sewage to the sand beds.

Length of Lateral Distributor Earth or gravel covered—75 ft or less; 100 ft acceptable with dosing device. Open filter—maximum distance of sewage travel from splash plate to edge of filter bed, 20 to 30 ft. See Figure 4-23.

Sand Depth 24 to 30 in., effective size* recommended 0.35 to 0.50 mm, although 0.30 to 0.60 mm or 1.0 mm is usually acceptable. Uniformity coefficient† 3.5 or less is recommended. Use clean silica sand passing $\frac{1}{4}$-in. sieve. A sand analysis is shown in Figure 4-24. Representative sand sampling is essential at the source and as delivered. Run-of-bank sand is unacceptable. Recirculating filters use 0.4- to 1.5-mm-effective-size sand.

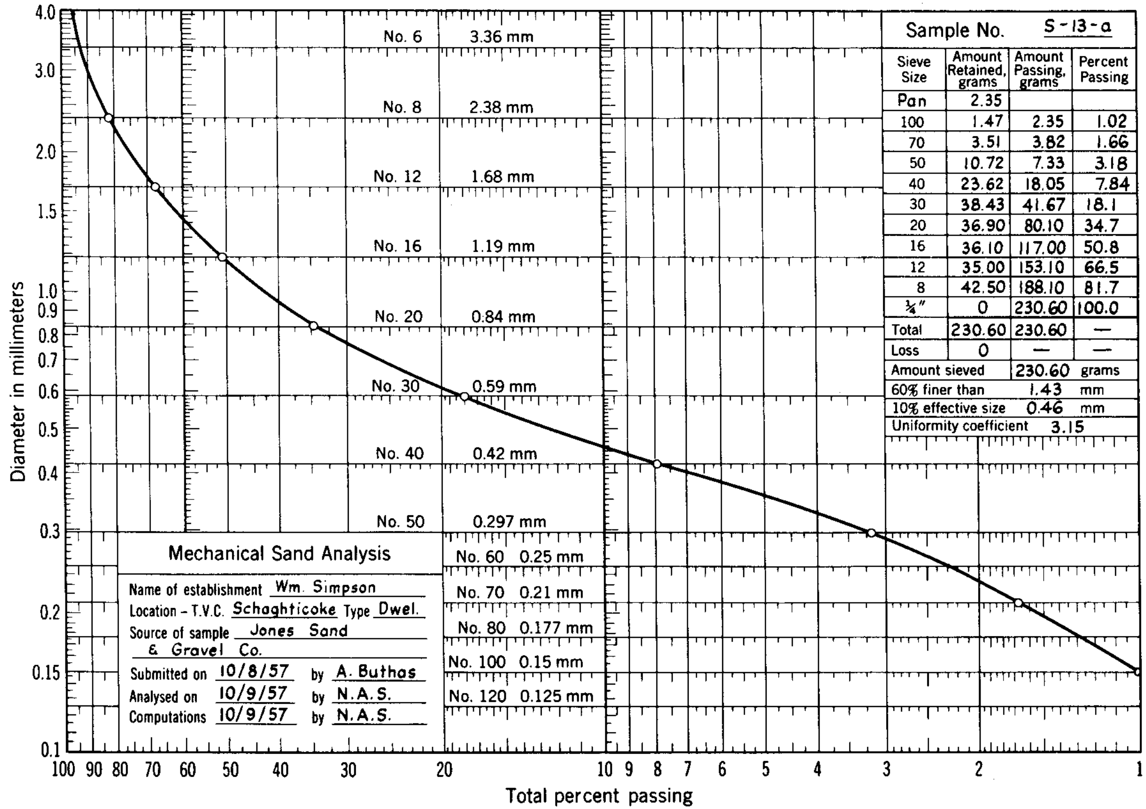
Grade of Lateral Distributor $\frac{1}{16}$ in./ft, but $\frac{1}{32}$ in./ft with dosing device.

In freezing weather, open filters will require greater operational control and maintenance. Scraping the sand before freezing weather into furrows about 8 in. deep with ridges 24 to 48 in. apart will help maintain continuous operation, as ice sheets will form between ridges and help insulate the relatively warm sewage in the furrows. Greenhouse covers are very desirable and will help ensure continuous operation of the filters; however, they are expensive. Wood frame covers may also be used. Regular maintenance is essential, including raking and weeding.

An experimental open recirculating 12 × 12-ft sand filter, for treatment of household septic tank effluent, produced an acceptable quality effluent (BOD 6–38 mg/l and SS 2 mg/l) during freezing as well as warm weather, for discharge to a subsurface absorption system. The design basis was 3 gpd/ft^2 using a sand bed 4 ft deep, ES 0.3 mm and uniformity coefficient (UC) about 4, with distribution through 2-in. PVC pipe and nylon-covered $\frac{1}{8}$-in. orifices 2.4 ft apart. Recirculation, from a 1000-gal tank, was one part septic tank

* *Effective* (*grain*) *size* is a measure of the diameter of particles, when compared to a theoretical material having an equal transmission constant. It is the dimensions of that mesh that will permit 10 percent of the sample to pass and will retain 90 percent. The size of the grain in millimeters such that 10 percent by weight are smaller.

† *Uniformity coefficient* is the ratio of the grain size that has 60 percent finer than itself to the size that has 10 percent finer than itself (effective size). See Figure 4-24.



Sieve Size	Amount Retained, grams	Amount Passing, grams	Percent Passing
Pan	2.35		
100	1.47	2.35	1.02
70	3.51	3.82	1.66
50	10.72	7.33	3.18
40	23.62	18.05	7.84
30	38.43	41.67	18.1
20	36.90	80.10	34.7
16	36.10	117.00	50.8
12	35.00	153.10	66.5
8	42.50	188.10	81.7
¼″	0	230.60	100.0
Total	230.60	230.60	—
Loss	0	—	—

Amount sieved 230.60 grams

60% finer than 1.43 mm

10% effective size 0.46 mm

Uniformity coefficient 3.15

Figure 4-24 Mechanical sand analysis.

effluent and four parts filter drainage.[86] Open recirculating filters may use 0.3- to 1.5-mm media with a UC less than 4, a recirculation ratio of 3:1 to 5:1, 5- to 10-min dosing every 30 min for small systems and 20 min every 2 to 3 hr for large systems, and dose volume equal to a depth of 2 in. over the bed. A hydraulic loading rate of 5 gpd/ft^2, based on the forward and not-recirculated flow, shall not be exceeded. The recirculation tank volume should be at least equal to a one-day wastewater flow.[87]

Aerobic Sewage Treatment Unit

Another type of treatment unit that can be used where subsurface absorption systems are not practical is the self-contained, prefabricated aeration unit. The effluent from a properly operating unit is low in suspended solids and BOD and high in nitrates but still requires further treatment and disposal. This may consist of sand filtration and/or chlorination prior to discharge to a stream, if approved by the local regulatory authority, or discharge to an oxidation pond or irrigation system. If there is an electrical failure or mechanical malfunction, the effluent from the aeration unit is no better than that from a septic tank. Routine maintenance and operation of the unit must be ensured by a maintenance contract or other means. Design details for extended aeration and activated sludge treatment plants are given later.

Small rotating biological contractors with 2- to 4-ft-diameter discs and for flows of 350 to 1500 gpd or more are also available. Their application and limitations are similar to the above aeration units. See Rotating Biological Contractors in this chapter.

In some locations, where tight soil exists and ample property is owned, the waste stabilization pond, irrigation, oxidation ditch, or overland flow system design principles may be adapted to small installations. Design information is given under Sewage Works Design—Small Treatment Plants in this chapter.

Septic Tank Mound System

The original mound system, called the NODAK system, was developed in North Dakota in late 1947. Variations and refinements of the mound system have been described by Goldstein and Moberg,[88] Salvato,[89] Bouma et al.,[90] and Converse et al.[91,92]

In the mound system, the absorption area is raised above the natural soil to keep the bottom of the trenches at least 2 ft above groundwater, bedrock, or relatively impermeable soil. In these respects, it serves the same purpose as the fill or built-up soil absorption system previously described. It differs, however, in the type of fill material, size, and method used to apply septic tank effluent to the mound system.

The fill soil will have a texture and structure related to pore or void size, distribution, and consistency. This affects the soil media tendency to clog and its purification capacity. The USDA soil classification has established sizes for the particles making up the soil. These are given in Table 4-4 and include the corresponding Tyler standard sieve numbers.

The Wisconsin mound system incorporates a 2-ft bed of clean coarse sand under the distribution trenches and a 1- to 1-$\frac{1}{2}$-in. perforated PVC pipe for pressure distribution of settled sewage. To avoid premature clogging, the sand should be coarse sand 0.5 to 1.0 mm effective size with less than 5 to 6 percent silt and clay and less than 15 to 16 percent fine and very fine sand. It should be washed and well sorted, not bank run.[93] A basic objective is to ensure that the mound system is constructed over permeable natural soil having sufficient depth and hydraulic conductivity and an area large enough to permit vertical and lateral spreading of the percolating wastewater without surface seepage. Two feet of sand and 1 ft of natural topsoil are reported to remove pathogenic bacteria and viruses from the wastewater, if properly applied.[94] The sand also promotes capillarity and evapotranspiration, as explained under Septic Tank Evapotranspiration System, this chapter. Experience indicates that subsurface absorption systems, including mound systems, can be constructed (1) wholly in the natural soil, (2) partly in the natural soil, or (3) completely above the natural ground surface. See Figures 4-14 and 4-25.

The design of a mound system, particularly a large one, is complex; it involves soil hydraulic conductivity determinations, hydraulic analyses, pump or siphon selection, and sand analyses. It should be done only by a qualified professional, preferably one who is experienced in designing mounds.

Mound System Design Considerations The EPA (ref. 40, pp. 239–255) some states,[87] Converse,[95] and others[90–93] give design and construction details, including tables, illustrations, and examples to simplify calculations and design:

1. To determine the absorption area (bottom of gravel trench or bed area), with a medium-to-coarse sand fill material, use a design infiltration application rate of 1.2 gpd/ft^2. Design for twice the daily water use is recommended. The required absorption area is the daily flow divided by 1.2.
2. The basal area required for *small* systems is the daily flow divided by the natural soil infiltration application rate. See 8a and 8b below and Table 4-16.
3. The basal area on *level* ground is the sand fill area beneath and between the gravel absorption trenches or beneath the gravel absorption bed plus the area beneath the sand mound front and back sloping sides, excluding the end areas.
4. The basal area on a *sloping* ground site is the sand fill area beneath and downgrade of the gravel absorption trenches or bed, excluding the end areas. Sloping ground is preferred because it provides a more

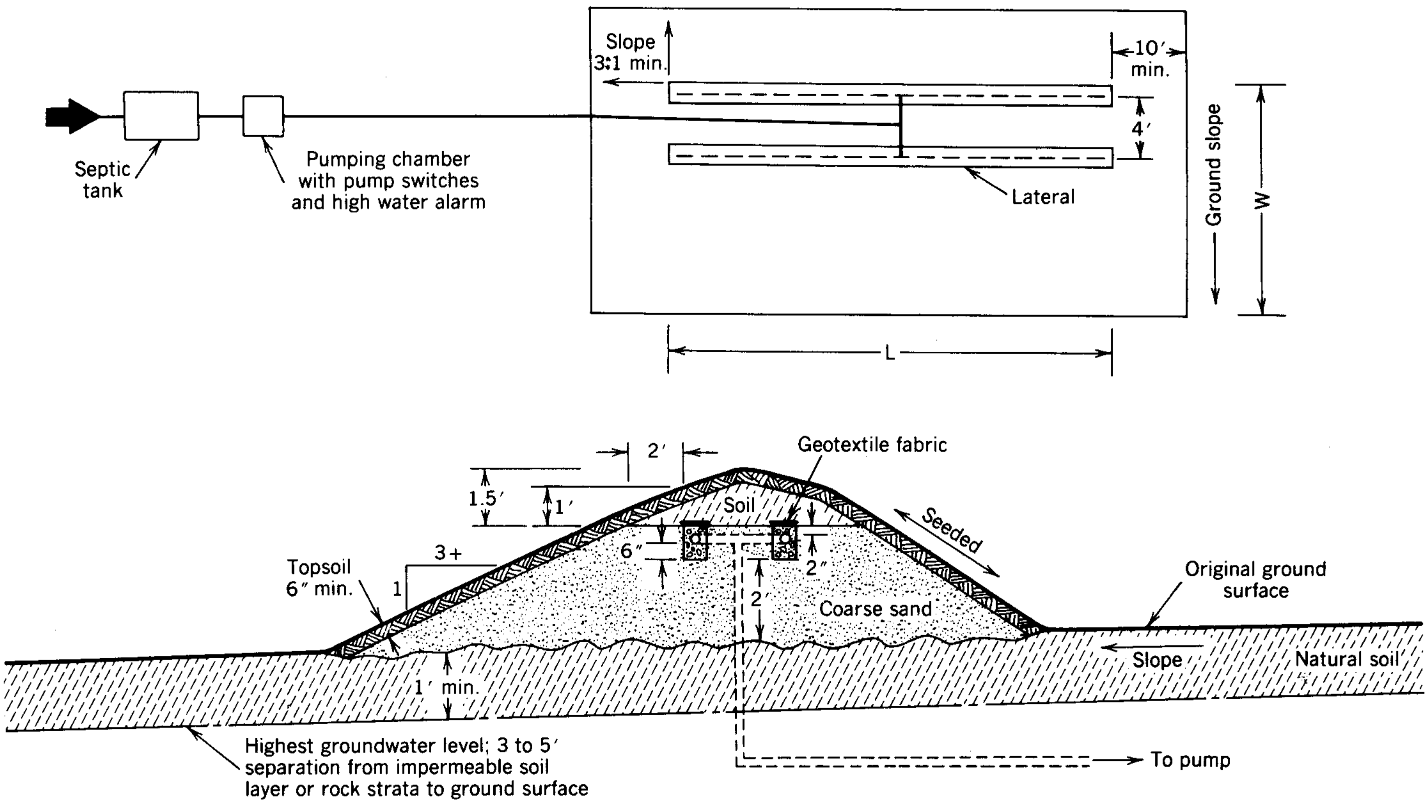


Figure 4-25 Details of a mound system using trenches. Basal area is length times width. Sloping ground. Laterals may be placed in a gravel bed.

TABLE 4-16 Suggested Settled Sewage Application Rates

Percolation Rate (min/in.)	Soil Type	Application Rate[a] (gpd/ft^2)	Hydraulic Conductivity[b] (gpd/ft^2)
<1	Gravel, coarse sand	Unsatisfactory	—
1–5	Coarse[d] to medium sand	1.2[c]	1200–9600[d]
6–15	Fine sand,[d] loamy sand	0.8	100–540[d]
16–30	Sandy loam, loam	0.6	20–100
31–60	Loam, porous silt loam	0.45	5–20
61–120	Silty clay loam, clay loam	0.2	0.1–1
≥121	Clay loam, clay	See Ryon, this chapter	—

[a] Approximate vertical hydraulic conductivity.
[b] Very approximate horizontal hydraulic conductivity. Make field or laboratory determination.
[c] Reduce to 0.8 gpd/ft^2 if groundwater supplies may be affected.
[d] F. G. Driscoll, *Groundwater and Wells,* Johnson Division, St. Paul, MN, 1986, p. 78. Coarse sand 0.84–1.17 mm size; fine sand 0.2–0.3 mm size.

positive hydraulic gradient to carry and disperse the underground wastewater flow from the septic tank. Basal area slope can be determined graphically.

5. Use a bed or parallel trenches:
   a. For a slowly permeable soil, use narrow parallel absorption trench(es) 2 ft wide.
   b. For permeable soil, use a rectangular absorption bed not greater than 10 to 15 ft wide.
   c. For shallow soils over bedrock, use bed or trenches.
   d. Sufficient depth and area of natural soil must be available so all of the effluent infiltrates the natural soil and is completely dispersed vertically and horizontally without surface discharge. The bottom of the trench(es) or bed must be level and at the same elevation.
6. Depth of mound and sand fill:
   a. A minimum unsaturated depth below the distributor is 3 ft, consisting of coarse sand fill and natural soil for proper operation and purification of the wastewater effluent; 4 ft or more is usually required over creviced bedrock or impermeable soil. The minimum natural soil depth above the highest groundwater level is 20 to 24 in.
   b. The fill material is a minimum of 2 ft of clean coarse sand 0.35 to 1.0 mm size. One foot may be acceptable.[93] (See Septic Tank Mound System, this chapter, for complete description.)

   c. A perforated inspection pipe extending through the gravel absorption trench or bed makes possible observation of any ponding. A pipe at bed edge can monitor groundwater.

7. The distribution trench or bed consists of 6 in. of gravel ($\frac{1}{2}$–2 in. or $\frac{3}{4}$–$2\frac{1}{2}$ in.) beneath the distribution pipe and 2 in. above the pipe. Cover the gravel with permeable geotextile fabric or equal, such as 3 to 4 in. of straw or marsh hay.
8. Determination of the basal area:
   a. For a *small* system, the percolation rate of the natural soil is used to determine the infiltration application rate (vertical hydraulic conductivity) and the *basal* area of the mound. A test hole is also dug 3 ft wide and 5 ft deep. If the soil changes, make percolation tests at the greater depth and use the slowest rate. If an impermeable formation is encountered within 5 ft, the application or infiltration rate should be reduced to 0.1 gpd/ft^2 or less. Some agencies recommend against construction.
   b. For a *large* system, both the vertical and horizontal hydraulic conductivities are used, particularly in soils having a slow percolation rate, such as 1 in. in 60 to 120 min. For horizontal hydraulic conductivity of different classes of soils, see Table 4-16, Figure 3-3, and Table 3-3. Field or laboratory tests are usually needed. For vertical conductivity rates, see Table 4-16. See also Example 2 (Large mound system on sloping ground).
   c. The natural soil beneath and around the mound and the dispersal area, must not be compacted or the dispersal area built on. Use a lightweight tractor and keep 6 in. of fill or soil beneath the tracks. Do not use a wheel tractor. If the soil at the 6- or 8-in. depth can be rolled into a ribbon or if water can be squeezed out, the soil is too wet to work. Postpone construction until the soil dries.
   d. Mound slopes are 3 or greater horizontal to 1 vertical.
9. Distribution lateral diameter and length, hole spacing, and hole diameter are selected to obtain uniform distribution of wastewater over the entire absorption area of the bed or trenches. See Table 4-17 and Converse.[95] Observe the flow distribution before covering distributors with gravel, and adjust hole diameter and/or spacing if needed. Holes less than $\frac{5}{32}$ in. in diameter are more likely to clog. The cap at the end of distributor laterals should have a horizontal hole near the crown for venting. Distributor holes point downward. Manifold should drain by gravity.
10. A dosing frequency of four times daily is recommended. The volume of each dose is therefore approximately one-quarter the daily flow. The pumped dosing volume should be not less than 10 times the total lateral pipe volume. The pump settings may have to be adjusted to

TABLE 4-17 Allowable Lateral Lengths for Three Pipe Diameters, Three Perforation Diameters, and Two Perforation Spacings (Machmeier, 1975)

Perforation Spacing (in.)	Perforation Diameter (in.)	Allowable Lateral Lengths by Pipe Diameter (ft)		
		1 in.	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.
30	$\frac{3}{16}$	34	52	70
	$\frac{7}{32}$	30	45	57
	$\frac{1}{4}$	25	38	50
36	$\frac{3}{16}$	36	60	75
	$\frac{7}{32}$	33	51	63
	$\frac{1}{4}$	27	42	54

Source: J. C. Converse, *Design and Construction Manual for Wisconsin Mounds*, Small Scale Waste Management Project, University of Wisconsin, Madison, WI, September 1978, p. 18.

Note: For flows from orifices under low heads, see Table 3-18.

achieve these guidelines. The pumping chamber reserve capacity should be at least equal to the daily design flow. A low head pump is selected to provide sufficient capacity (volume of dose) and head (2 ft at end of laterals, 5 ft maximum) to give good effluent distribution. Use 4-in.-diameter laterals with a siphon dosing, but dose at 60 to 75 percent of distributor volume. See Figure 4-30 later.

11. Place clay loam or silt loam soil over the permeable geotextile fabric covered gravel and the sand fill, to a minimum depth of $1\frac{1}{2}$ ft at the center and 12 in. at the outer edge of the absorption trench(es) or bed. Then cover the entire mound with at least 6 in. of good-quality topsoil, graded to provide positive runoff, without erosion and with minimum infiltration, and seed to grass. Side slopes of the mound should be no steeper than 3 horizontal to 1 vertical. On sloping ground, the mound downslope will have to be less steep, depending on the subsoil hydraulic conductivity and the site's natural ground slope.
12. Proper maintenance and operation of a mound system, as with all septic tank systems, is essential. This includes regular inspection and cleaning of the septic tank (see Table 4-11), inspection of baffle integrity, water conservation and use of low-flush toilets, maintenance of mound soil and grass cover, and diversion of surface water around and off the mound.

Example 1 *Design of a residential mound system on level ground for a flow of 300 gpd.* Natural soil has a percolation of 1 in. in 120 min or 0.2 gpd/ft^2:

1. Absorption area $= \dfrac{\text{daily flow}}{\text{sand infiltration rate}} = \dfrac{300}{1.2} = 250\ \text{ft}^2$.

   This area can be provided by two 2-ft-wide trenches 62.5 ft long.

2. Trench and lateral spacing = space laterals 4 ft on center.* Gravel trenches may be combined into one gravel bed (4 + 1 + 1) 6 ft wide.
3. Mound height (at center) = sand depth + gravel depth + soil cap and topsoil (see figure 4-25) = 2 + 0.75 + 1.5 = 4.25 ft.
4. Mound length = lateral length + end barriers (mound height × 3 on 1 slope) × 2 = 62.5 + (4.25 × 3) × 2 = 88 ft.
5. Mound width (including topsoil) = ($\frac{1}{2}$ × trench width × 2) + trench spacing on center + (mound height at edge of trench + 3 on 1 slope) × 2 = ($\frac{1}{2}$ × 2 × 2) + 4 + (3.75 × 3) × 2 = 2 + 4 + 22.5 = 28.5 ft.
6. Basal area: Required $\frac{300}{0.2} = 1500\ \text{ft}^2$.
   Provided 62.5 × 28.5 = 1781 ft^2, excluding end areas.
7. Distribution system: See Table 4-17 for lateral length and diameter and corresponding hole diameter and spacing. Make manifold 2 in. in diameter for pumping.
8. Pressure distribution: For pumping chamber volume, pump size, and dosing volume, see Converse,[95] and for siphon discharge, see Dosing Arrangements—Pressure Distribution, this chapter. Include valve on pump discharge line for fine adjustment of pump head and discharge.
9. Pumping chamber = 500-gal capacity for one-, two-, three-, or four-bedroom dwelling recommended.
10. Dose volume = $\frac{1}{4}$ daily flow and at least 10 times lateral volume when pump is used.
11. Pump size: The pumping head is the difference in elevation between pump and lateral invert plus friction loss in the pump discharge line, manifold, fittings, valve, laterals, and orifices plus head at end of lateral (2 ft). Pump capacity is 20 gpm for one bedroom (150 gpd) and $\frac{1}{4}$-in.-diameter orifice spaced 30 in. on center; 36 gpm for two bedrooms, 54 gpm for three bedrooms, and 70 gpm for four bedrooms. For $\frac{7}{32}$-in.-diameter orifice use a 15-gpm pump for one bedroom, 28-gpm for two bedrooms, 41-gpm for three bedrooms, and 54-gpm for four bedroom.[95] See Table 3-30 for pipe friction loss. Note adjustment for type

*A 1-in.-diameter pipe holds 0.041 gal, a $1\frac{1}{4}$-in. pipe 0.064 gal, a $1\frac{1}{2}$-in. pipe 0.092 gal, and a 2-in. pipe 0.164 gal.

of pipe. See Table 3-31 for valve friction loss, if used. See Table 3-17 for flows from orifices under low heads.

A 3-in. siphon may be used with a 4-in.-diameter distributor, with $\frac{1}{4}$-in. orifices, for a four–bedroom home.

Example 2[96] *Large mound system on sloping ground.* Design a mound for a site with a percolation rate of 60 min/in. The slope of the land is 15 percent, classifying the site as severe. The design flow rate is 5000 gpd of aerobically treated wastewater. Figure 4A-1 shows a schematic for this example.

1. Evaluate the site.

The soil horizon consists of an 18-in. layer of loam (the *A* horizon) and a 12-in. layer of fine silt loam (the *B* horizon) overlying a slow, permeable clay layer (the *C* horizon). The vertical and horizontal unsaturated hydraulic conductivities are listed below. Evidence of seasonally high groundwater exists at 15 in. below the ground surface.

	Unsaturated Hydraulic Conductivity (gpd/ft^2)	
Horizon	Vertical	Horizontal
A	0.7	60
B	0.6	40
C	0.25	1

2. Boundary conditions:
   a. If we assume that the clogging mat will be insignificant because of the extent of pretreatment, the vertical acceptance rates (VARs) can be considered equal to the vertical unsaturated hydraulic conductiv-

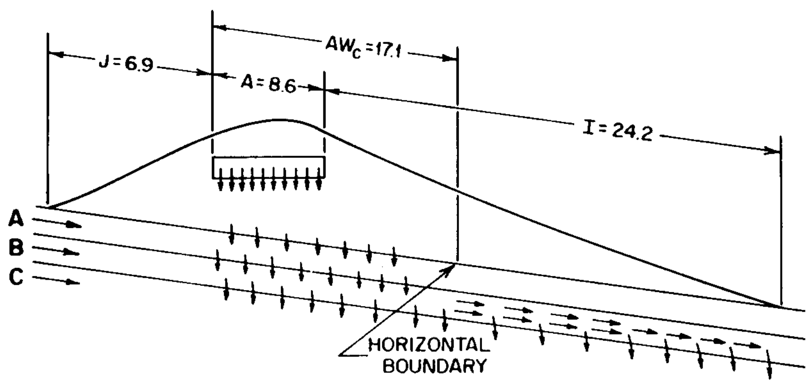


Figure 4A-1 Mound example.

ities. The vertical boundary is at the C horizon with a VAR of 0.25 gpd/ft^2.

b. The horizontal boundary will be at or downslope from the base of the mound. Using

$$\text{HAR} = KA \frac{dH}{dx}$$

where HAR = horizontal acceptance rate
K = horizontal hydraulic conductivity, 60 gpd/ft^2 in the A horizon and 40 gpd/ft^2 in the B horizon
A = area of horizontal flow, 1 ft^2
dH/dx = hydraulic gradient, 0.15

Thus, HAR_A = 9.0 gpd/ft and HAR_B = 6.0 gpd/ft. Since horizontal flow can be expected, the area downslope must be evaluated for any restrictions such as a stream and change in slope that will act as a horizontal boundary.

3. Determine the vertical wastewater application width. The horizontal and vertical loading rates must not exceed the HAR and VAR. The application width (AW) is the width over which the vertical flow is applied in the C horizon upslope from the horizontal boundary. To keep the toe of the mound from getting too wet, there should be no horizontal flow in the A horizon. The basal loading for the A horizon must not exceed the basal loading for the B horizon; thus, HAR_B is used in these calculations:

$$\begin{aligned}\text{AW}_C &= \frac{\text{HAR}_B}{\text{VAR}_B - \text{VAR}_C} \\ &= \frac{6 \text{ gpd/ft}}{0.6 - 0.25 \text{ gpd/ft}^2} \\ &= 17.1 \text{ ft}\end{aligned}$$

Thus, unless a restriction exists upslope from this point, the horizontal boundary will be at the edge of the application width.

4. Determine the linear loading rate (LLR) of the wastewater:

$$\begin{aligned}\text{LLR} &= \text{VAR}_C(AW_C) + \text{HAR}_B \\ &= (0.25 \text{ gpd/ft}^2)\ (17.1 \text{ ft}) + 6 \text{ gpd/ft} \\ &= 10.3 \text{ gpd/ft}\end{aligned}$$

5. Determine the basal width (BW) of each horizon.
   a. Basal width of *A*:

$$BW_A = \frac{LLR}{VAR_A} = \frac{10.3 \text{ gpd/ft}}{0.7 \text{ gpd/ft}^2}$$
$$= 14.7 \text{ ft}$$

Thus, the toe of the mound will end 2.4 ft upslope from the horizontal boundary. To allow a 3 : 1 slope, this can be extended to 24.5 ft:

   b. Basal width of *B*:

$$BW_B = \frac{LLR}{VAR_B} = \frac{10.3 \text{ gpd/ft}}{0.6 \text{ gpd/ft}^2}$$
$$= 17.1 \text{ ft}$$

   c. Basal width of *C*:

$$BW_C = \frac{LLR}{VAR_C} = \frac{10.3 \text{ gpd/ft}}{0.25 \text{ gpd/ft}^2}$$
$$= 41.2 \text{ ft}$$

Therefore, water will move an additional 24.1 ft downslope from the horizontal boundary, at which point all movement will be vertically downward. This area must be protected to prevent loss of infiltrative capacity.

6. Determine width of the absorption area:

$$A = \frac{LLR}{\text{fill infiltration rate}}$$

   The sand fill infiltration rate is 1.2 gpd/ft^2; therefore, $A = 8.6$ ft.

7. Determine length of absorption area:

$$B = \frac{\text{design flow rate}}{LLR}$$
$$= \frac{5000 \text{ gpd}}{10.3 \text{ gpd/ft}}$$
$$= 485 \text{ ft}$$

8. Mound height: The fill depth and natural soil should provide at least 3 ft of unsaturated soil below the distribution lines. Thus, a minimum of 21 in. of fill is necessary. Assuming a 1-in. pipe, the bed depth would be 9 in. The cap and top soil are 18 in. deep over the center of the absorption area and 12 in. deep over the edges. When allowances are made for the 15 percent slope, the mound height at the upslope edge of the absorption area is 3.5 ft, at the center 4.6 ft, and at the downslope edge 4.8 ft.
9. Mound width accounting for 3:1 side slopes:

$$\begin{aligned}\text{Upslope width } J &= \text{mound depth at upslope} \times 3 \\ &\quad \times \text{slope correction factor} \\ &= 3.5 \times 3 \times 0.66 \\ &= 6.9 \text{ ft}\end{aligned}$$

$$\begin{aligned}\text{Downslope with } I &= \text{Mounted depth of down slope} \times 3 \\ &\quad \times \text{slope correction factor} \\ &= 4.8 \times 3 \times 1.68 \\ &= 24.2 \text{ ft}\end{aligned}$$

Since the absorption area is 8.6 ft wide, the total mound width is 39.7 ft. Thus, the toe of the mound will end 8.4 ft upslope from the edge of the basal width in the *C* horizon (BW_C).

Because of its length, this mound should be constructed in several segments. At least 8.4 ft should be allowed between the toe of one mound and the upslope edge of another to prevent overlapping of the basal areas. Additional space should be included to allow maneuvering of construction equipment.

10. In contrast to a mound system, design of a mound system takes advantage of the horizontal movement of the wastewater as well as vertical movement. If a system were to be designed for this site on the basis of vertical transport only, it would need to be much longer. The loading rate would be limited by the vertical acceptance rate of the *C* horizon. Assuming that the width of the absorption area is the same as for the mound system,

$$\begin{aligned}\text{LLR} &= (\text{VAR}_C)(A) \\ &= (0.25 \text{ gpd/ft}^2)(8.6 \text{ ft}) \\ &= 2.15 \text{ gpd/ft}\end{aligned}$$

Since the wastewater flow rate is 5000 gpd, the total system length would be 2326 ft.

In view of the experiences with sand filters, sands with effective size less than 0.2 to 0.35 mm can be expected to clog with a dosage of 1 to 1.5 gpd/ft^2. Sand size can therefore be critical.[82,83] It is to be emphasized that there must be minimum equipment compaction of the sand fill and the natural soil under and around the dispersal area. See, this chapter, and Figure 4-25 for construction details and specifications.

Electric Osmosis System

This is a patented process in which septic tank effluent discharged to a conventional subsurface absorption system in a soil having a percolation slower than 1 in. in 60 min is disposed of by evapotranspiration. Mineral rock-filled anodes adjacent to the trench and coke-filled cathodes with graphite cores a short distance away generate 0.7 to 1.3 V potential, causing soil water, claimed to be removed by evapotranspiration, to move to the cathodes. These systems have been used successfully in several states (ref. 40, p. 268).

Septic Tank Evapotranspiration System

In evaporation, surface water, soil water, and precipitation falling and collecting on vegetation or other surfaces are converted to atmospheric moisture. The rate of evaporation depends mostly on temperature, relative humidity, barometric pressure, and wind speed; soil moisture, type of soil, and depth of moisture below the soil surface are also factors. In transpiration, water is taken in by plant roots, is used to build up plant tissue, moves up through the stem or trunk, and is released as vapor through the leaves. Empirical transpiration is shown in Figure 4-26 and land evaporation in Figure 4-27.

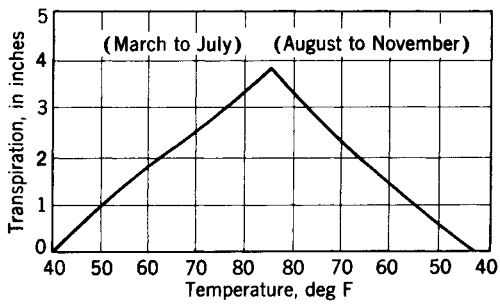


Figure 4-26 Empirical transpiration curve. The temperature scale refers to mean monthly air temperature and the transpiration scale refers to the corresponding transpiration in inches per month. [*Source:* "Computing Runoff from Rainfall and Other Physical Data," *ASCE Trans.,* **79,** 1094 (1915).]

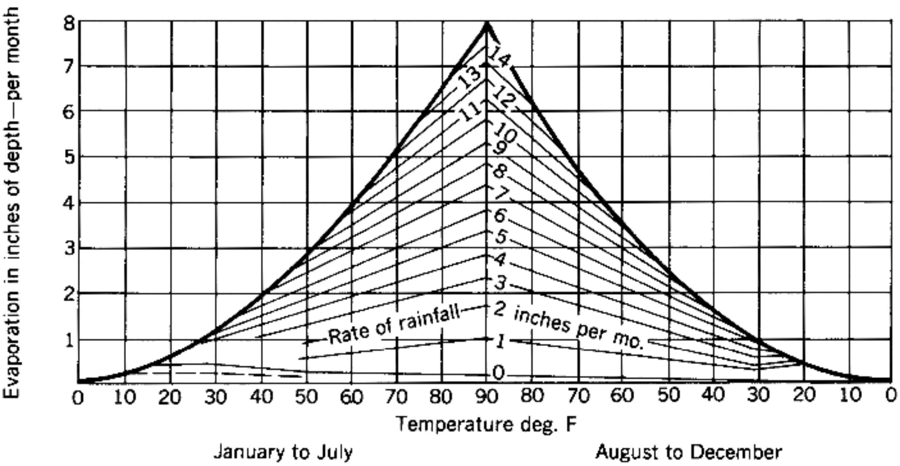


Figure 4-27 Evaporation from land areas for various temperatures and rates of rainfall. [*Source:* A. F. Meyer, *ASCE Trans.,* **79,** 1099 (1915).]

The quantity of water transpired and evaporated from a cropped area, or the normal loss of water from the soil by evaporation and plant transpiration, is known as the consumptive use or evapotranspiration ("transvap" for short). The largest proportion of consumptive use is usually transpiration. It is to be noted that evapotranspiration rates for crops and other vegetation in various areas of the world reflect the differences in meteorological conditions such as temperature, rainfall, humidity, and wind speed.

The evapotranspiration system can be used where the available soil has no absorptive capacity or where little or no topsoil exists over clay, hardpan, or bedrock, provided a water balance study shows the evapotranspiration plus runoff exceed precipitation infiltration plus inflow. It can also be built where the groundwater level is high, provided it is built with a watertight liner on the bottom and sides to exclude the groundwater from the evapotranspiration bed. If an impermeable liner is not provided, elevation of the bed or curtain drains may be necessary if seasonal high water is a problem. The evapotranspiration system should be a last resort.

Evapotranspiration The design of an evapotranspiration system is based on maintenance of a favorable input–output water balance. The precipitation less runoff (the infiltration) plus the wastewater flow must be less than the evaporation plus transpiration. The year-round use of an evapotranspiration system where the *average* daily temperature is below freezing is probably impractical.

Schwartz and Bendixen[97] reported that vegetation on the surface of subsurface sewage disposal systems doubled the hydraulic longevity of conventional septic tank absorption systems.

Phelps[98] states that evaporation from water surfaces varies from about 20 in. per year in the northeastern United States to 90 in. per year in the Imperial

Valley (with 100–120 in. in some southwestern areas) and that evaporation from land areas will be approximately one-third to one-half these values.[98] About two-thirds of the total annual evaporation takes place during the warm to cool months of the year. Phelps also gives the following transpiration figures for several types of vegetation for the period in leaf:

Grain and grass crops	9–10 in.
Deciduous trees	8–12 in.
Small brush	6–8 in.
Coniferous trees	4–6 in.

Brandes (ref. 85, p. 74) found that, over a 15-month period, 58 percent of the total precipitation on an experimental sand filter in Ontario, Canada, left the filter through evapotranspiration. Grass covered the filter during the warm season.

McGauhey[99] gives the following average hydrologic water recycling distribution:

Evaporation	30%
Evapotranspiration	40% (from soil mantle)
Surface runoff	20%
Groundwater storage	10%

Studies in England show that evaporation from a free water surface is $16\frac{1}{2}$ in. of water per year and $14\frac{1}{2}$ in. from bare soil.[100] Evapotranspiration loss from turf or grassland is 0.6 to 0.8 times that from an open water surface. Lake-water evaporation averages 27 in. per year in Portland, Maine, and Toronto; 30.7 in. in Syracuse, New York; 57 in. in Miami, Florida; 74 in. in Phoenix, Arizona; and 24 in. in Vancouver, British Columbia. See Weather Bureau for information on specific locations.

Blaney[101] has reported on the studies of a number of investigators giving the consumptive use figures for some crops in California. This information has been used in the development of Table 4-18. Table 4-19 gives some additional estimates of seasonal consumption of water by crops and vegetation. An example will show the possible use of these data for the design of a evapotranspiration system.

Capillarity For evaporation to take place, it is necessary to have upward movement of the water (capillarity) in the soil to the ground surface; for transpiration to take place, it is necessary for the capillary water (capillary fringe) to reach the surface vegetation root system.

Molecules within a liquid are attracted to one another (cohesion) and on a water surface create surface tension. Water molecules have a greater affinity for a solid they come into contact with than for other molecules (adhesion). The result is that water will climb up the surface of the solid to an extent

TABLE 4-18 Consumptive Use of Crops in California[a]

Crop	Evaporation (soil) and Transporation (plant)	Growing Season	Average Annual Transvaporation[b]
Alfalfa	5 in./month or 0.83 pt/ft^2/day	6 or 7 months	0.415 pt/ft^2/day
Truck garden	4 in./month or 0.66 pt/ft^2/day	5 months	0.275 pt/ft^2/day
Cotton	4 in./month or 0.66 pt/ft^2/day	7 months	0.38 pt/ft^2/day
Citrus orchard	3 in./month or 0.50 pt/ft^2/day	7 months	0.3 pt/ft^2/day
Deciduous orchard	5 in./month or 0.83 pt/ft^2/day	6 months	0.415 pt/ft^2/day

[a] Pints per square foot per day = pt/ft^2/day (8 pints = 1 gal).
[b] Soil evaporation for 5–7 months outside of growing season not included.

dependent on the diameter of the soil particle pore space or tube. This is referred to as capillary rise in soil and forms the capillary fringe above the underground water level or water table. Water rises higher in smaller pores. For example, water will rise by capillarity 28 cm in a soil having a cylindrical pore radius of 100 μm and 103 cm in a soil with a pore space of 30 μm. More specifically, a fill material consisting of uniform sand in the size range of 0.10 mm is capable of raising water about 3 ft by capillarity.[94] The approximate capillary rise in coarse sand (1.0–0.5 mm) is 12.5 cm, in medium sand (0.5–2.5 mm) 25.0 cm, in fine sand (0.25–0.1 mm) 40.0 cm, and in silt (0.25–0.002 mm) 100 cm.[102] No capillary action occurs in a saturated soil.

Fair et al.[103] give an example for a capillary tube 0.1 mm in diameter and water at a temperature of 50°F (10°C), resulting in a rise of 30.3 cm based on

$$h = \frac{\delta}{245d} = \frac{74.2}{245 \times 0.01} = 30.3 \text{ cm}$$

where h = capillary rise of the water, cm
d = tube diameter, cm
δ = surface tension, dyn/cm (74.9 at 5°C, 74.2 at 10°C, 73.5 at 15°C, and 72.8 at 20°C)

The equation assumes that the weight of air is insignificantly small and the weight of water close to unity.

Operation The successful operation of an evapotranspiration system is largely dependent on runoff, surface vegetation, soil cover, capillarity, and evapotranspiration, in addition to controlled wastewater flow *to maintain a*

TABLE 4-19 Approximate Evapotranspiration/Consumptive Uses

Growth[a]	Water[b] (in.)	Reference[c]
Alfalfa (Lucern grass)		
Brawley, CA—annual measured, Lysimeter	80	1
Kimberly, ID—April to October	55	4
Kimberly, ID—annual	53	1
Kimberly, ID—1 May to 30 September	36	1
Upham, ND—143 days observed	23	1
Reno, NV—124 days	40	1
Arvin, CA—annual	50	1
Mesa and Tempe, AZ—annual	74	1
Swift Current, Saskatchewan—annual	25	1
Colorado—annual	26	2
Alberta—annual	22	3
Trees		
Coniferous trees[d]	4–9	6
Deciduous trees[d]	7–10	6
Oak—54 ft high, 25 in. diameter, 34 gal summer, 6 gal winter[d,e]		
Pine—46 ft high, 15 in. diameter, 40 gal summer, 10 gal winter[d,e]		
Apple—15 ft high, 6 in. diameter, 18 gal summer, 3 gal winter[d,e]		
Eucalyptus, large, 25 gal[d]		
Fully grown tree, 70 gal[d]		
Grasses		
Seabrook, NJ—clipped grass, annual	38	1
Lompac, CA—hoed grass, annual	41	1
Davis, CA—hoed grass, annual	52	1
Copenhagen, Denmark—clipped clover and rye grass, annual	16	1
Aspendale, Australia—clipped clover and rye grass, annual	51	1
Alberta—pasture grass, annual	18	3
Colorado—meadow grass, annual	23	3
Meadow grass—season (bluegrass and fescue)	22–60	6
Lucern grass—season	26–55	6
Canarygrass—season		
Hay		
Coshocton, OH—grass legume hay, annual	40	1
South Park, CO—native hay, annual	22	1
Clover		
Aspendale, Australia—annual	51	1
Prosser, WA—23 May to 28 October	34	1

TABLE 4-19 (*Continued*)

[a] Well watered.
[b] Obtain more accurate data from local farm bureau or agricultural college; 1 in. of water = 0.623 gal/ft^2.
[c] *Source:* (1) M. E. Jensen (ed.), *Consumptive Use of Water and Irrigation Water Requirements,* Technical Committee on Irrigation Water Requirements, American Society of Civil Engineers (ASCE), New York, September 1973. See also E. L. Johns (Ed.), *Water Use by Natural Occurring Vegetation: An Annotated Bibliography,* Task Committee on Water Requirements of Natural Vegetation, Committee on Irrigation Water Requirements, ASCE, New York, 1989, pp. 17–22. (2) H. F. Blaney, "Water and Our Crops," *The Yearbook of Agriculture 1955 Water,* U.S. Department of Agriculture, Washington, DC, 1955. (3) J. R. Davis, *Evaporation ad Evapo-Transpiration Research in the United States and Other Countries,* American Society of Agricultural Engineers, December 1956. Based on report by W. L. Jacobson and L. G. Sonmor, Department of Agriculture Experiment Farms Service, Canada Department of Agriculture. (4) J. L. Wright and M. E. Jensen, "Peak Water Requirements of Crops in Southern Idaho," *J. Irrig. Drain. Div.,* ASCE, Proc. Paper 8940, June 1972. (5) A. P. Bernhart, *Treatment and Disposal of Waste Water from Homes by Soil Infiltration and Evapo-transpiration,* University of Toronto Press, Canada, 1973, p. 146. (6) L. C. Urquart, *Civil Engineering Handbook,* McGraw-Hill, New York, January 1950, p. 796.
[d] Transpiration per day.
[e] See also ref. 5 in note c.

favorable water balance. Plant roots can reach a depth of about 24 in. in well-developed absorption beds and take up wastewater. Needless to say, water conservation and the use of water-saving devices such as low-flush toilets, aerators on water outlets, water-saving shower heads, leak prevention, and water pressure and flow controls would reduce water use and wastewater volume to be treated. Maintenance of a permeable soil structure and microbial and macroscopic organisms are all essential to minimize system clogging and failure, as previously explained.

Design Examples Some examples will show the possible applications of evapotranspiration data during the growing season, at a summer dwelling, and at a year-round residence where the soil is totally unsuitable for a conventional system. Figures 4-28 and 4-29 give design and construction details of evapotranspiration disposal systems with sand and gravel beds to provide storage during the periods when transpiration and evaporation are low or zero. The sand ridges and sand bed are essential to provide capillarity. Soil evaporation can average one-third to one-half of lake evaporation for six months of a year in which average lake evaporation is 30 in./yr. Sublimation during the snow-covered nongrowing season, although small, can contribute to moisture removal from the system.

Example 3 Evapotranspiration design basis during growing season. Assume a 150-day (5-month) growing season using a soil cover of meadow or lucern grass and an evapotranspiration of 15- to 36-in. consumptive use (soil evaporation plus transpiration) dependent on location and vegetation. See Table

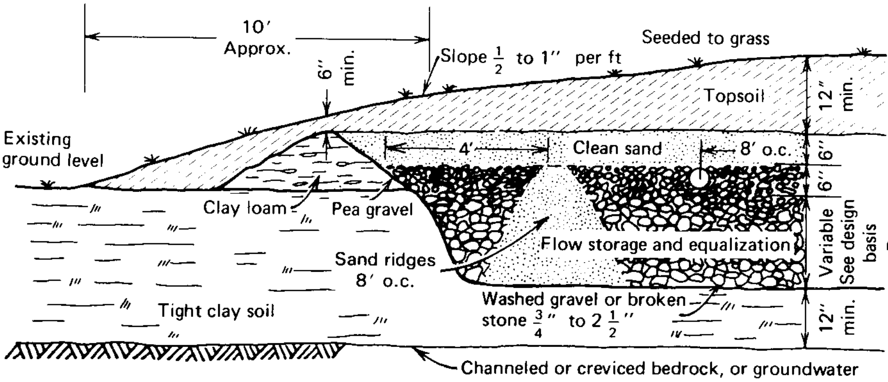


Figure 4-28 Evapotranspiration sewage disposal system in tight soil. (Raise bed as necessary if groundwater or bedrock is a problem). Clean washed sand, 0.1 mm effective size for up to 12 to 16 in. gravel and sand depth, and 0.05-mm sand for up to 24 in. gravel and sand depth. Sand ridges are necessary to obtain capillarity and promote evapotranspiration. Permeable geotextile fabric is recommended over the sand ridges and in place of the 6 in. of sand over the gravel. Add 6- or 8-in.-diameter perforated risers in and to bottom of gravel bed for inspection and emergency pumpout. Pressure distribution is usually required. Silt in sand will increase capillary rise. See also Figure 4-29.

4-19. The precipitation during the season is 10 in., of which 8 in. or less infiltrates a well-crowned evapotranspiration bed. See also climatological data published by the Weather Bureau, local sources, and the NOAA* for monthly

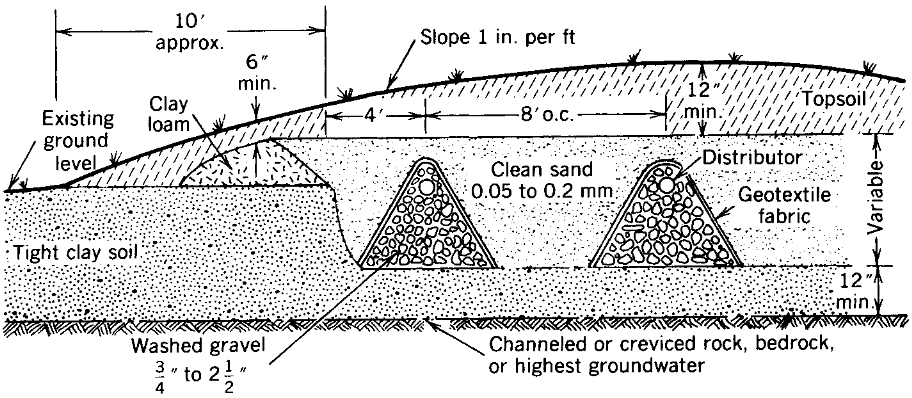


Figure 4-29 Alternate arrangements for evapotranspiration sewage disposal system in tight soil. See Figure 4-28.

*National Oceanic and Atmospheric Administration, "Climate of the States," Water Information Center, Port Washington, NY.

precipitation and evapotranspiration data. The water that can be disposed of *during the growing season* by evapotranspiration will range from

$$\frac{15 - 8 \times 0.623^*}{5 \times 30} = 0.029 \text{ gpd/ft}^2$$

$$\frac{36 - 8 \times 0.623}{5 \times 30} = 0.116 \text{ gpd/ft}^2$$

Example 4 Design a sewage disposal system in tight clay soil for a dwelling for seasonal occupancy only.

Design basis:

Location: northeastern United States.
Season: warm period, say six months.
Soil evaporation: 8 in. during six months.
Grass transpiration: 20 in. during six-month growing season.
Precipitation: 18 in. during six-month period, 1 in. precipitation = 0.623 gal/ft^2.
Infiltration: 80 percent of precipitation = 0.8 × 18 = 14.4 in.
Soil percolation: zero.
Daily sewage flow: 300 gpd.

Solution:

$$\begin{aligned} \text{Design transvap} &= (\text{evaporation} + \text{transpiration} - \text{infiltration}) \\ &\quad \times 0.623 \text{ gal/ft}^2\text{/in.} \\ &= (8 + 20 - 14.4) \times 0.623 \text{ gal/ft}^2 \\ &\quad \text{in 6-month period} \\ &= 8.473 \text{ gal/ft}^2 \text{ in 6-month period} \\ &= 0.0471 \text{ gal/ft}^2\text{/day average} \\ &\quad \text{during 6-month period} \end{aligned}$$

$$\text{Required transvap area} = \frac{300}{0.0471} = 6369 \text{ ft}^2$$

- For materials specifications and design details, see Figures 4-28 and 4-29 and Capillarity, this chapter.

*1 in. of water/ft^2 = 0.623 gal.

- Adjust design for local rainfall and runoff and evaporation and transpiration. See Tables 4-18 and 4-19.
- Uniform sand and gravel have 30 to 40 percent void space for flow storage and equalization.
- Bottom of bed 2 ft above groundwater recommended. Divert surface water around bed and provide curtain drain if needed and if bed cannot be raised. Crown bed 1 in/ft to promote runoff.
- Use water conservation fixtures.
- Bed depth *D* of 12 in. is adequate, providing about two months of storage. Actually no storage is needed for the six-month seasonal occupancy. See below.

Alternate solution: The required evapotranspiration area can also be determined from the formula[104]

$$A = \frac{Q}{\mathrm{ET} + E - I}$$

where A = area of the evapotranspiration bed, ft^2
Q = sewage flow, gal/yr
ET = evapotranspiration from the bed, gal/ft^2/yr
E = soil evaporation from the bed, gal/ft^2/yr
I = precipitation inflow, gal/ft^2/yr

Note that ET is the evaporation plus transpiration (consumptive use) during the growing season; *E* is the soil evaporation during the nongrowing season. Substituting the above figures for the *six-month* period gives

$$A = \frac{300 \times 6 \times 30}{0.623 \times 20 + 8 - 14.4} = 6373 \text{ ft}^2$$

$$\begin{aligned}\text{Storage } (Y) \text{ required} &= Q + (I - \mathrm{ET} - E)\,A \text{ for 6-month period} \\ &= 300 \times 6 \times 30 + (14.4 - 20 - 8) \times 6370 \times 0.623 \\ &= 54{,}000 + (-53{,}972) \\ &= 28 \text{ gal—nil}\end{aligned}$$

Example 5 Rational design of a an evapotranspiration sewage disposal system for year-round occupancy (ref. 104, pp. 653–657).

Design basis:

Sewage flow: 200 gpd = 6083 gal/month = 73,000 gal/year.

Bed surface cover: sandy, silty, clayey loam topsoil, and lawn grass, crowned 1 in./ft.

Use gravel bed (40 percent void space) with sand ridges or with gravel ridges. See Figures 4-28 and 4-29.

	Jan	Feb	Mar	Apr	May	Jun	Jul.	Aug	Sep	Oct.	Nov	Dec.
Precipitation (ppt), in.	2.2	2.1	2.6	2.7	3.3	3.0	3.1	2.9	3.1	2.6	2.8	2.9
Percent ppt infiltrating in bed	15	15	50	85	85	85	85	85	50	50	50	15
Infiltration ppt gal/ft^{2a}	0.206	0.196	0.810	1.430	1.748	1.589	1.642	1.536	0.966	0.810	0.872	0.271
Land evaporation, gal/ft^{2b}	0	0	0.934	in ET	in ET	in ET	In ET	In ET	0.934	0.934	0.934	0
Evapotranspiration, gal/ft^{2c}	0	0	0	3.12	3.12	3.12	3.12	3.12	0	0	0	0

Note: 0.623 = gal/ft^2 per in. precipitation.

Required area of evapotranspiration bed:

$$\text{Outflow} = \text{inflow}$$

$$\text{ET} \times A + E \times A = Q + I \times A$$

where ET = evaporaton from bed during the growing season, gal/ft^2 (as noted above)
A = area of bed, ft^2
E = land evaporation from bed during nongrowing period, except when the bed is frozen or snow covered, gal/ft^2 (as noted above)
Q = septic tank inflow, gal/year
I = infiltration, precipitation inflow, gal/ft^2 (as noted above)

The above equation may be rewritten as

$$A = \frac{Q}{\text{ET} + E - 1}$$

Using the above table,

$$A = \frac{200 \times 365}{3.12 \times 5 + .934 \times 4 - 12.076} = \frac{73{,}000}{7.26} = 10{,}055 \text{ ft}^2$$

Storage (Y) *required during the seven-month nongrowing period* (*J, F, M, S, O, N, D*) (or make monthly water balance study):

$$
\begin{aligned}
Y &= Q_1 + I_1 E_1 = \text{sewage flow} + \text{infiltration} - \text{soil evaporation} \\
&= 6083 \times 7 + (0.206 + 0.196 + 0.810 + 0.966 + 0.810 \\
&\quad + 0.872 + 0.271) \times 10{,}055(0.934 \times 4) \times 10{,}055 \\
&= 42{,}583 + 41{,}537 - 37{,}565 \\
&= 46{,}555 \text{ gal}
\end{aligned}
$$

Bed depth (D) to provide required storage is

$$
\begin{aligned}
D &= \frac{Y}{A \times 7.5 \text{ gal/ft}^2 \times \text{void space}} = \frac{46{,}555}{10{,}055 \times 7.5 \times 0.4} \\
&= 1.54 \text{ ft (this is within the fine-sand capillarity range)}
\end{aligned}
$$

The storage required can be determined by means of a water balance study[104] and by the graphical mass diagram or Rippl method. The weekly or monthly inflow (consisting of the precipitation minus runoff, or infiltration, plus wastewater input flow) and the outflow (evaporation and transpiration) are tabulated or plotted against time in weeks or months. The difference between cumulative inflow and cumulative outflow is the storage required at any point in time. See Figures 3-23 and 3-24 as well as mass diagrams in standard civil-sanitary engineering texts showing the design of impounding reservoirs and water storage tanks.[105]

Beck,[106] based on studies made in San Antonio, Texas, recommends an evapotranspiration rate of 0.482 gpd/ft^2 in raised sand beds. Lomax[107] found evapotranspiration systems satisfactory for the disposal of aerobic wastewater near Cambridge, Maryland, during a year in which the annual precipitation was 55 in. The bed was lined, designed to dispose of 0.08 gpd/ft^2 of bed with 1.65 ft depth of sand, crowned, and seeded to grass.[107]

Dosing Arrangements—Pressure Distribution This size of a dosing tank is determined by the total length and diameter of the distribution laterals, or area of a sand filter, to be dosed at any one time and the dosing frequency. The volume of the dose should equal 60 to 75 percent of the volume of 4-in.-diameter lines dosed, or one-quarter to one-half of the daily design flow when the distribution lines are less than 4 in. in diameter. A more frequent dosage, lesser volume, is recommended when the soil has a rapid percolation. This will reduce the flow in the distribution trench and rate of infiltration into the bottom and sidewalls, thereby increasing retention and purification of the effluent before reaching the groundwater. When the soil has a slower percolation capacity, a less frequent dosage is recommended. See also Mound System Design Considerations, this chapter. In general, siphon or pump dosing should be provided when the total length of the absorption field laterals exceeds 300 to 500 ft and when the sand filter distributor laterals exceed 300 linear feet or the area of the sand bed exceeds 1800 ft^2. Alternating dosage is recommended when the absorption field laterals exceed 1000 ft and when the sand filter distributors exceed 800 linear feet. Pressure distribution of septic tank effluent, using a low-head pump or siphon, is recommended for all soil absorption and sand filter systems, regardless of size, and is usually required for built-up or raised-bed, evapotranspiration–absorption, evapotranspiration (transvap), and mound systems. The ends of the distribution lines should be capped.

Dosing tanks are usually designed to operate automatically. Dosage is accomplished by a siphon, pneumatic ejector, tipping bucket,[108–110] or pump, including a high- and low-water alarm. A submersible pump is used on small installations. Do not locate electrical equipment in a sump or wet well; switches fail and explosive gases may accumulate. Comply with the National Electrical Code. Hand-operated gates, float valves, and motorized valves are also used for flow control. The system should be designed, if possible, to permit gravity flow through the dosing tank or pump well to the absorption field or filter in case of pump or power failure and while repairs are being made. If this cannot be done, a standby gasoline engine-driven pump should be provided, in addition to a high-water alarm to warn of pump or siphon failure. In larger systems, two siphons, or two pumps with proper float setting, are installed, each feeding a separate absorption field or sand filter section in alternation. When a pump is used in a septic tank system, a $\frac{1}{4}$-in. drain hole should be drilled in the discharge line inside the pump sump to permit emptying of the line and prevent freezing. The drain hole will require periodic cleaning. Provide one day's storage above the high-water alarm setting. Select the most reliable on–off pump control available, such as a magnetic weighted float control or mercury float switch. Do not enter the pump sump, wet well, or dosing tank to make repairs without first taking adequate safety precautions as cautioned above. Pumps and water-level controls require periodic maintenance. The pump sump and siphon dosing tank should be inspected at least annually, as well as when the septic tank is cleaned and accumulated scum and sludge are removed. Do not enter the pump sump. See *Safety* in Index.

The size siphon or other dosing device that has a minimum discharge rate at least 125 percent greater and preferably twice the probable maximum rate at which settled sewage might enter the dosing tank is selected. This is necessary in order to exceed the rate of flow of the incoming sewage and vent the siphon, making possible its continued automatic operation. Where open sand beds are dosed, rapid discharge of the sewage gives better distribution over the sand bed. The head or fall available will also determine the size siphon that can be used. Special designs incorporating given drawdowns can be obtained from the manufacturer. The dosing device should be capable of applying the required volume on the filter in less than 10 min. Some design details of the Miller siphon are given in Figure 4-30. Prefabricated metal dosing tanks incorporating single or alternating siphons are also available.[111]* The diameter of the carrier line, that is, the line between the dosing tank and

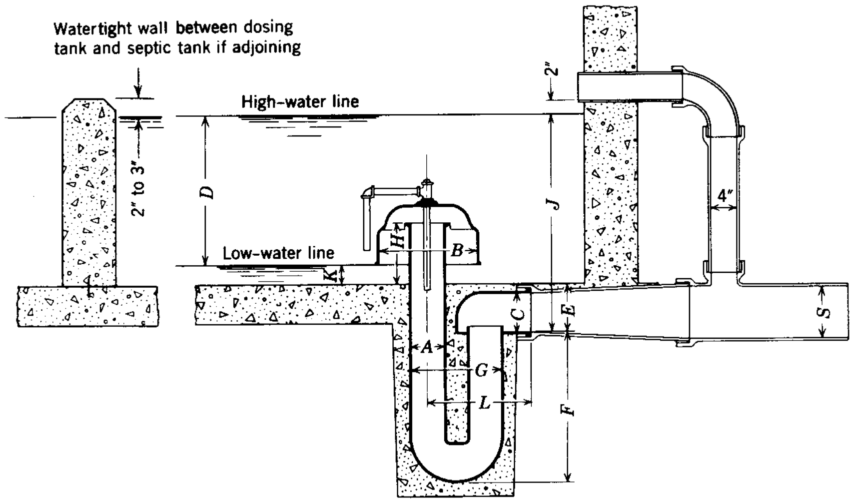


Figure 4-30 Design details of the Miller siphons. (See manufacturer's direction.) Two single siphons of this type set side by side in the same tank will alternate. The draft *D* will be 1 to 2 in. less in this case. One foot of 4-in. pipe holds 0.653 gal. Approximate dimensions (in.).

Diameter of siphon	*A*	3	4	5	6
Drawing depth	*D*	13	17	23	30
Diameter of discharge head	*C*	4	4	6	8
Diameter of bell	*B*	10	12	15	19
Invert below floor	*E*	$4\frac{1}{4}$	$5\frac{1}{2}$	$7\frac{1}{2}$	10
Depth of trap	*F*	13	$14\frac{1}{4}$	23	$30\frac{1}{4}$
Width of trap	*G*	10	12	14	16
Height above floor	*H*	$7\frac{1}{4}$	$11\frac{3}{4}$	$9\frac{1}{2}$	11
Invert to discharge = $D + E + K$	*J*	$20\frac{1}{4}$	$25\frac{1}{2}$	$33\frac{1}{2}$	44
Bottom of bell to floor	*K*	3	3	3	4
Center of trap to end of discharge ell	*L*	$8\frac{5}{8}$	$11\frac{3}{4}$	$15\frac{1}{2}$	$17\frac{1}{8}$
Diameter of carrier	*S*	4	4–6	6–8	8–10
Average discharge rate (gpm)	—	72	165	328	474
Maximum discharge rate (gpm)	—	96	227	422	604
Minimum discharge rate (gpm)	—	48	102	234	340
Shipping weight (lb)	—	60	150	210	300

*San-Equip, Syracuse, NY; Kaustine Co., Perry, NY; Pacific Flush-Tank Co., Chicago, IL; Fluid Dynamics, Longmont, CO; McCutchen Mfg., Santa Fe, Englewood, CO.

the absorption field, can be developed with the aid of Figure 4-31, since the maximum discharge rate of the siphon is given in Figure 4-30.

Manufacturers' detail drawings of the specified siphon shown should be obtained and carefully followed during construction and critical elevations staked out. The siphon trap must be filled with water when the system is to be placed in operation. The small vent pipe on the bell must have airtight joints, with the bell perfectly level. Sometimes the floor under the siphon bell is depressed 4 or 6 in. below the dosing tank floor with satisfactory results. Another acceptable alternative is to move the siphon forward in the dosing tank and install a tee extension on the discharge or carrier line in the dosing tank extending about 2 in. above the high-water line. This can take the place of the vent and overflow line passing through the dosing tank wall. Either the open tee or overflow is essential, however, to prevent siphoning out the water seal in the siphon trap and ensure continuous automatic operation of the siphon.

A tipping bucket, a simple device used many years ago, can provide intermittent dosage.

Lift Station

As in the case of the siphon, pump manufacturers' working drawings should be followed when a design calls for the installation of pumps. Typical sump

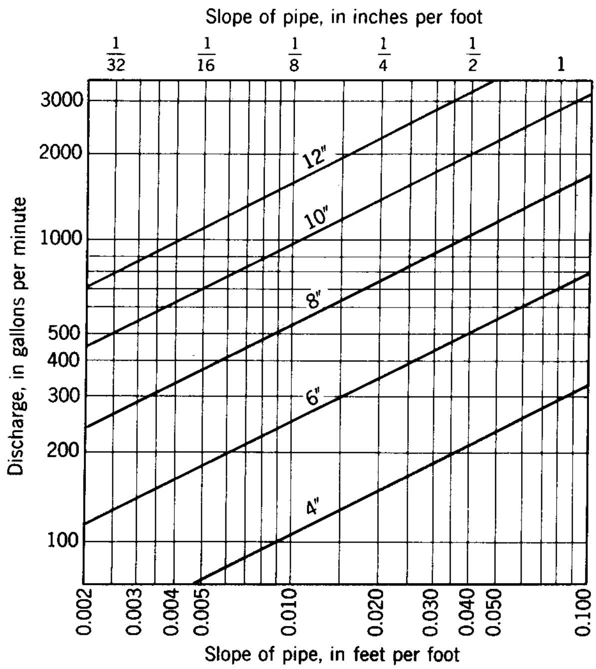


Figure 4-31 Discharge of clay pipe sewers. Discharge is based on Manning formula: $Q = (1.486/n)R^{2/3}S^{1/2}$, with $n = 0.013$, sewer full.

pump details are shown in Figures 4-32 and 4-33 and Figure 4-40 later. Horizontal pumps are also available and are sometimes preferred; a vacuum pump and air-relief valves permit automatic operation. Pumps should be selected to operate for at least 10-min intervals. Compressed-air-operated sewage ejectors may be used to advantage. Obtain the manufacturers' recommendations for the most efficient pump and motor horsepower to meet job requirements. Submersible pumps are also available for pumping small and large quantities of settled sewage. Normally at least two pumps, each being capable of handling the maximum flow, should be provided for large installations. A reserve storage capacity (Figure 4-32) equal to a one-day design flow is advised.

Pressure, Vacuum, and Cluster Sewer Systems

Low-pressure, vacuum, and cluster systems are possible alternatives to serve housing areas where septic tank absorption systems are inappropriate or failing. Unsuitable soil, high groundwater, small lots, hilly terrain, and high-density recreational areas are situations where such systems may have application.

There are two general types of pressure sewer systems. In one, the septic tank effluent from one or more dwellings flows by gravity to a pumping station, if needed, from which the sewage is pumped through small-diameter pipe to an existing sewer or a new central treatment plant. The individual septic tanks require periodic cleaning on a planned basis, such as every three

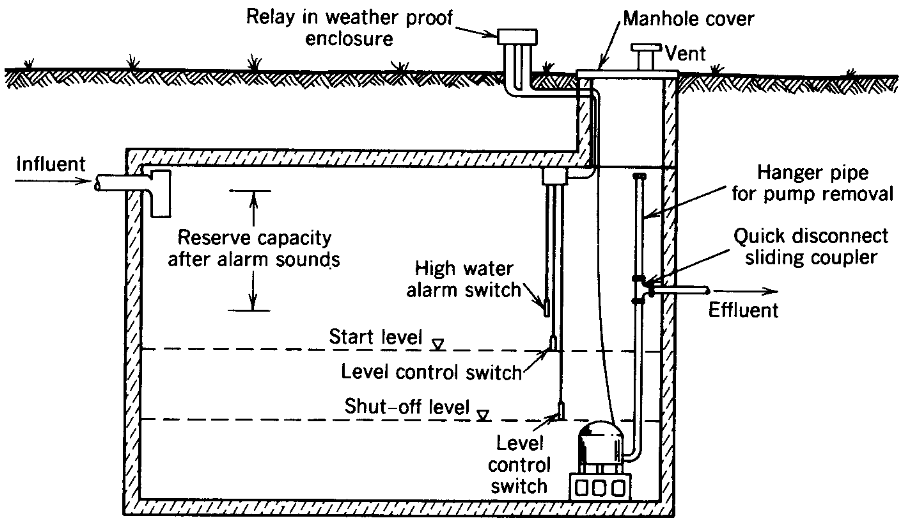


Figure 4-32 Typical dosing chamber with pump. (*Source: Design Manual, Onsite Wastewater Treatment and Disposal Systems,* U.S. Environmental Protection Agency, Office of Water Program Operations, Cincinnati, OH, October 1980, p. 329.)

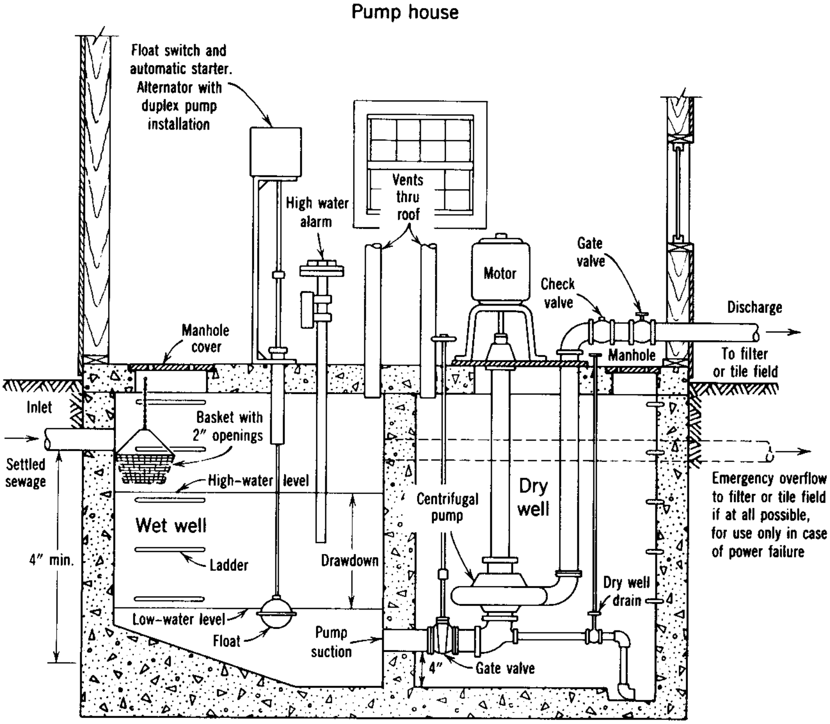


Figure 4-33 Sump pump for dosing large sand filter or absorption field. When the dry well is omitted, the pumps are submerged in the wet well. Sump may be attached to septic tank. (A comminutor may be substituted for the basket screen with raw sewage. Exhaust fans with lower inlets will provide more positive ventilation. Provide battery-powered alarm in case of electric power failure.)

years with a district service contact. In the other design, the individual septic tank is eliminated and a special collection tank-grinder pump and check-valve assembly are used. Sewers, usually 2 to 4 in., may be curved and on a variable gradient.

In the vacuum system, a vacuum pump creates a vacuum in collector pipes. A valve opens when sewage from a dwelling or several dwellings presses against it. Sewage and a plug of air behind it enter the collection pipe. Air (vacuum) forces sewage to a collection tank. A sewage pump then pumps sewage from the tank to a treatment plant. Special vacuum valves and intermediate sumps (usually) are needed.

In the cluster system, a group of dwellings is served by a common treatment and disposal system. Each dwelling makes a connection to a common treatment system or each house has its own septic tank or aerobic tank that connects to a sewer and common absorption field or other approved system. The septic tanks require periodic cleaning, usually under contract.

Both the pressure system and vacuum system require maintenance. All of the systems need to have a sewer district or the equivalent to ensure continued maintenance and operation.

Detailed information on the design, construction, operation, maintenance, and management of pressure, vacuum, and small-diameter gravity sewer systems is available.[112–114]

Water Conservation

While not technically a disposal system, the use of water conservation can provide a simple and economic way to reduce the hydraulic load on an existing septic system that is having operational difficulties due to presence of low-permeability soils or organic clogging of otherwise acceptable soils. Water conservation measures include the installation of low-flow fixtures, such as toilets and faucet aerators, which in and of themselves can reduce wastewater flows by up to 50 percent, maintenance of proper water pressures, elimination of leaks and drips, and discontinuation of the use of garbage disposals.

SEWAGE WORKS DESIGN—SMALL TREATMENT PLANTS

Preparation of Plans and Reports

The design should be tailor made to fit the local conditions and take into consideration probable future additions. Before construction is started, designs for small sewage treatment plants should be prepared by licensed professional engineers experienced in sanitary engineering work and approved by the regulatory agency involved. Designs for typical small installations are sometimes made available through state or county health or environmental protection departments. For small jobs, pencil sketches drawn to scale with dimensions of all units and critical elevations can be prepared for checking by the approving agency. Changes during construction may be very costly. The line of demarcation between large and small sewage works is usually an arbitrary one and subject to local interpretation based on the value of the work, its difficulty, the danger to health and safety, and the reasonableness of requiring the services of a professional engineer or registered architect. A practical dividing point might be 25 persons or a sewage flow of 1500 to 2500 gpd. In some states, when the value of the work exceeds $5000 or $10,000 or danger to health and safety is involved, it is required that plans be submitted by a licensed engineer or architect.

Most states require approval of plans and have rules, regulations, and standards to guide the designing engineer in the preparation of satisfactory plans. The review of preliminary drawings with the local sanitary engineer official will usually expedite approval of final plans. Federal permits (NPDES) are needed. In some instances, states implement the federal permit program.

Plans submitted for approval should give all information necessary for review of the design and construction of the disposal or treatment system as designed. The more complete the plans, the closer bids received for the job will be. Plans should include construction details, engineer's report, application or statement of information, specifications, and a topographic map showing the location of the disposal plant and outlet, if any. The first step, therefore, when a sewerage system is to be constructed, is to engage the services of an experienced licensed professional engineer to prepare preliminary plans and cost estimates, followed by complete plans for approval by the agency having jurisdiction and for construction of the system. The plans and engineer's report should include the following information:

1. A plot plan giving the boundaries of the property, drawn to a scale of 20 to 100 ft to the inch, showing contour lines or critical elevations, streams, swamps, lakes, rock outcrops, wooded areas, structures, roads, play areas, and other significant features. Existing and proposed structures are also shown.
2. Location of existing and proposed sewer and water lines and other utilities, sources of water supply and storage facilities, grease traps, manholes, septic tanks, aeration tanks, other disposal or treatment units, and outfall sewers if any.
3. Ground elevations and sizes, materials, slopes, and invert elevations of existing and new sewer lines leaving buildings and entering and leaving manholes, grease traps, septic tanks, siphons, trickling filters, settling tanks, aeration tanks, sludge tanks, drying beds, pump pits, distribution boxes, distributing laterals, sand filters, inspection manholes, and chlorine contact tanks as well as the flood level of receiving streams. A profile through the sewerage system is very valuable.
4. Population served and present and future capacity. Where food or drink is served, the seating capacity, number of sales, and meals served should be taken into consideration.
5. Number of different plumbing fixtures, including dishwashers, potato peelers, laundry machines, and continuously running and automatic flushing devices. Commercial and industrial devices should also be shown.
6. Location, depth, and results of soil percolation tests, with findings of tests made 2 or 3 ft deeper and, if a soil absorption system is proposed, a description of the type of soil to a depth of at least 10 ft.
7. Construction details and size of all sewerage units, including structural details and specifications. The size of large septic tanks should be increased to compensate for peak flows, and absorption fields should

be increased to compensate for higher biochemical oxygen demand and total suspended solids in the septic tank effluent.

8. Design basis, sewage strength and characteristics, and minimum receiving stream flow.
9. The highest groundwater levels, time of the year when tests were made, and how determined.
10. Location and yield or adequacy of the source, storage, and distribution of water. Actual or estimated daily water consumption and water pressures should also be given. Where the source of water is one or more wells or springs, the type of well or spring, strata penetrated, depth, and size, in addition to capacity and type of pump and motive power, should be included.
11. An environmental impact analysis, possible effects of treated sewage discharge on the aquifer if a subsurface absorption system is proposed, and possible effects downstream and on lakes and streams and their uses, if a surface discharge is proposed. See also approving agency instructions and *Recommended Standards for Sewage Works*.[115]

Design Details

Effluent discharge to a stream requires a permit from the appropriate regulatory agency. Treatment is usually based on the minimum average seven-day flow expected to recur once in 10 years (MA7CD10), upstream and downstream discharges, and downstream uses. Secondary treatment (minimum) should generally remove 85 percent of the biochemical oxygen demand (BOD_5), and suspended solids (SS) should not exceed 30 mg/l. Where a receiving stream goes dry periodically or the (MA7CD10) stream flow is less than 0.1 cfs, the effluent BOD_5 should not exceed 5 mg/l and SS 10 mg/l; dissolved oxygen should equal or exceed 7.0 mg/l; and the effluent ammonia, pH, and chlorine levels should meet the concentrations established by the regulatory agency.

The provision of bar screens or comminutors and grit chambers ahead of pumping equipment or settling tanks is strongly recommended.

Pumping equipment is readily accessible for inspection and servicing when located in a dry pump pit. For lift stations, the pneumatic ejectors and "bladeless" sewage pumps seem to be the most suitable for small plants.

If secondary treatment will be needed, primary treatment units should be designed, if possible, with the water level at a sufficient height to permit gravity flow to trickling filters, rotating biological contractors, aeration units, oxidation ponds, or sand filters and to the receiving stream without additional pumping.

Trickling-filter units for small installations may be built at ground level. The stone may be contained by reinforced concrete, heavy fencing, concrete block with reinforcing, or cypress or pressure-treated pine staves held with iron hoops or similar arrangements. Make provision for recirculation for treatment and filter fly control.

The secondary settling tank should be constructed with a sloping bottom. A bottom shaped like an inverted four-sided truncated regular pyramid will permit gravity collection and concentration of sludge for removal. Provide for a 2-ft hydrostatic head and proper diameter sludge drawoff pipe to give a flushing velocity when the control valve is opened and pumping started.

Chlorination of the final effluent can be accomplished in a chlorine contact tank or in the secondary settling tank. In small installations, manual control continuous-feed chlorinators are sometimes used. Proportional-feed automatic chlorinators are found to be more economical in larger installations. Other means of chlorination include dosing tank and pump-activated controls.

The location of the treatment plant should take into consideration the type of plant and available supervision, the location of the nearest dwelling, the receiving watercourse, the availability of submarginal low land not subject to flooding, prevailing winds and natural barriers, and the cost of land. A distance of 400 ft from the nearest dwelling is frequently recommended, although distances of 250 to 300 ft should prove adequate with good plant supervision. Some equipment manufacturers and design engineers feel that covered sand filters, aeration-type plants, and high-rate trickling filters can be located closer to habitation without danger of odors or filter flies. Oxidation ponds and lagoons should be located at least $\frac{1}{4}$ to $\frac{1}{2}$ mile from habitation.

Some of the more common flow diagrams for small sewage treatment plants are illustrated in Figure 4-34 to suggest the different possibilities, dependent on local factors. Predesigned and prefabricated units are available.

Disinfection—Chlorination

Disinfection of sewage effluent is not always necessary. The need for disinfection should be predicated on the probability of disease transmission by the ingestion of contaminated water or food, including shellfish, by contact, and by aerosols. This should be balanced against the effects on aquatic life.[116] The disease agent may be microbiological or chemical. (See Disease Hazard, this chapter.) It is known that wastewater treatment plants, including industrial, experience operational problems that occasionally require the release of untreated or inadequately treated wastewater. In addition, heavy rains may require a bypass of the treatment plant or sewer overflow to the receiving stream. Hence, the design of sewers and treatment plants should recognize these realistic factors and provide adequate disinfection facilities, including retention basins, to protect downstream drinking water sources, fish and shellfish waters, recreational areas, and human habitation to the extent needed. In situations where the receiving stream is a drinking water source or dilution is low, more complete wastewater treatment beyond secondary may be required. Normal chlorination does not destroy or inactivate all pathogenic viruses, fungi, bacteria, protozoa, and helminths. Disinfection practices have

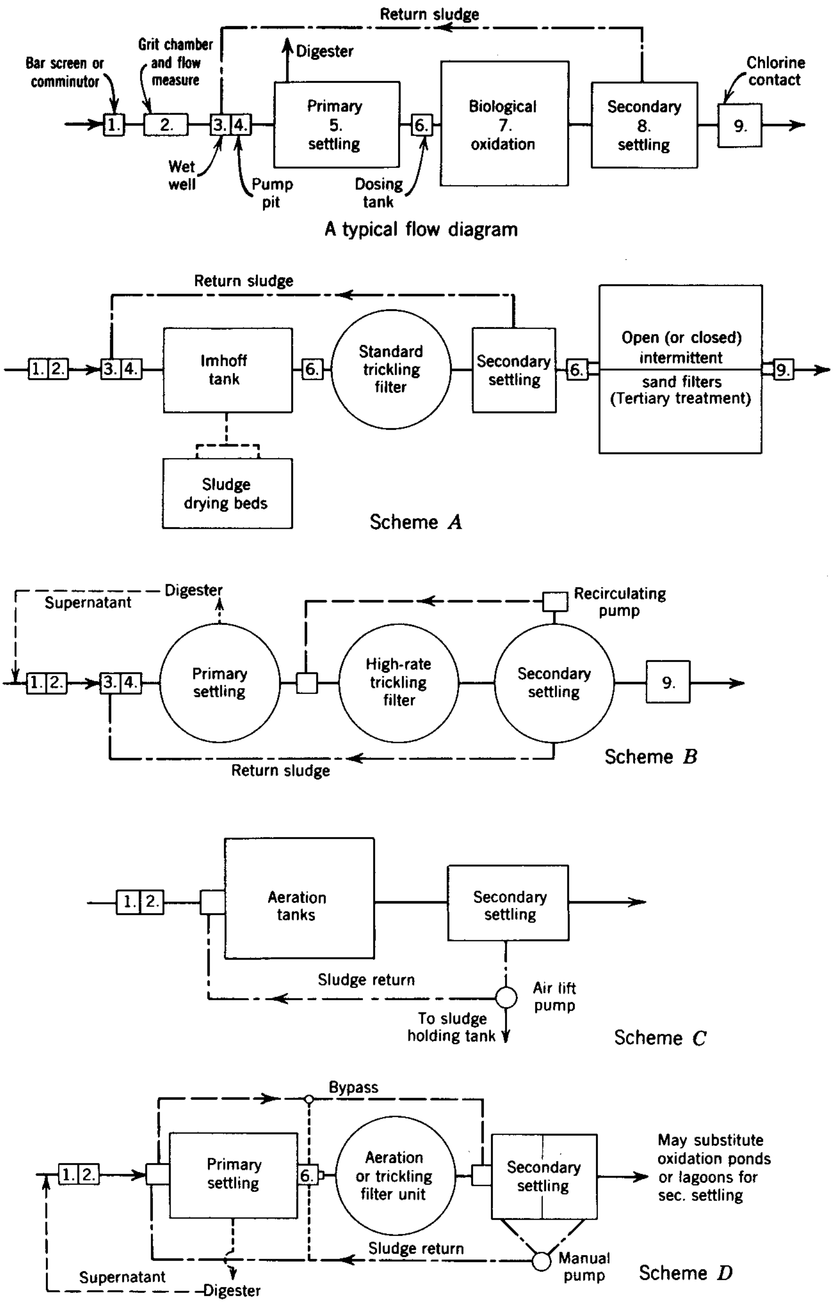


Figure 4-34 Typical flow diagrams.

been reviewed periodically. They point out the possible deleterious effects of chlorination on the aquatic ecosystem and identify factors that should be considered in a wastewater disinfection policy.[117,118] Although chlorine as a disinfectant is discussed here, it does not preclude dechlorination or the use of other disinfectants where indicated and permitted by the regulatory authority. Disinfection is not a substitute for adequate wastewater treatment; it is an added safeguard to reduce the risk of disease transmission where the probability exists. However, the wastewater must be adequately treated in the first place for the disinfectant (usually chlorine) to be effective.

The effectiveness of disinfection depends on the degree of treatment the sewage has received, the amount of chlorine used and residual chlorine maintained, the mixing and retention period, and the condition of the sewage, including the pH, temperature, nitrogen compounds, and organic and suspended matter. Sometimes chlorine is also added to sewage to control odors, undesirable growths, sewage flies, septicity, activated sludge bulking, digester foaming, and chemical or bacterial reactions unfavorable to the treatment process. Chlorination will also reduce the BOD of the raw, settled, or final effluent, roughly in the ratio of one part chlorine to two parts BOD. Chlorine dosage may vary from 0.5 to 2.0 lb of chlorine to remove 1 lb of BOD.

Chlorination treatment of raw sewage is not reliable for the destruction of pathogenic organisms since solid penetration is limited. The required dosage of chlorine to produce a 0.5-mg/l residual after 15 min contact has been approximated in Table 4-20 for different kinds of sewage. Studies made using domestic sewage show that less than 250 coliform organisms per 100 ml can be obtained in treated sewage 100 percent of the time if a chlorine residual of 2.0 to 4 mg/l is maintained in the effluent after 10 min contact.[119] Other experiments show that if the chlorine is first mixed with the sewage and the treated sewage is allowed to stand 10 min, an MPN of 300 coliform organisms per 100 ml or less can be obtained 100 percent of the time if a chlorine residual of 1.1 mg/l is maintained in the effluent.[120] These tests also show that with no mixing at least twice the chlorine residual must be maintained in the treated sewage for 10 min to give results approximately equal to the results obtained with mixing. Another study shows that a most probable number (MPN) of around 1000 per 100 ml can usually be expected in the effluent if the product of the combined chlorine residual and detention time in minutes (based on average flow) is equal to or greater than 20.[121] Eliassen[122] also reports a reduction in the MPN of after-growth values in a brackish water tidal basin following discharge of a chlorinated combined sewage of from 10 to 30 percent of those that would develop without chlorination. Normal chlorination will have little effect, as previously noted, on viruses, protozoan cysts, and helminths. Secondary sewage treatment may have to be supplemented by adequate tertiary treatment where a downstream water usage indicates its necessity. See Survival of Pathogens, Chapter 1, and Disease Hazard, this chapter.

Combined chlorine, mostly monochloramine, is normally produced in the conventional chlorination of sewage effluent. This is to be expected since most

TABLE 4-20 Probable Chlorine Dosages to Give a Residual of at Least 0.5 mg/l After 15 min Retention in Average Sanitary Sewage or Sewage Effluent[a]

Type of Sewage Effluent	Suggested Chlorine Dosages (mg/l)[b]							
	NY State[c]	Dunham[d]	White[e]	Griffin[f]	Imhoff and Fair[g]	Metcalf Eddy[h]	GLUMRB[i]	EPA[j]
Raw sewage	—	—	8–15 15–30	6–12 fresh to stale 12–25 septic	6–25 fresh to stale	6–25	8–15 fresh	
Septic tank	—	10–25	—	12–24	—	—	—	30–45
Imhoff tank or settled sewage	20–25	5–20	8–15	5–10 fresh to stale 12–40 septic	5–20	5–20	20	
Trickling filter	15	3–15	3–10	3–5 normal 5–10 poor	3–20	3–15	15	—
Activated sludge	8	—	2–8	2–4 normal 5–8 poor	2–20	2–8	8	10–15 package plant
Intermittent sand	6	2	1–5	1–3 normal 3–5 poor	1–10	—	6[k]	1–5
Chemical precipitation	—	—	—	3–6	3–20	2–6	—	—

[a]WHO suggests 0.5 mg/l free residual chlorine after 1 hr to inactive viruses (after secondary treatment) with turbidity <1.0 JTU. Combined chlorine, mostly monochloramine, is normally produced, which is a slow-acting disinfectant. Eight to 10 mg/l of chlorine is needed to neutralize each milligram per liter of ammonia before free chlorine is produced. Most secondary effluents contain more than 1.0 mg/l ammonia.

[b]12 mg/l = 1 lb per 10,000 gal. Each milligram per liter of chlorine in sewage effluent reduces the BOD about 2 mg/l. No appreciable industrial wastes.

[c]*Manual of Instruction for Wastewater Treatment Operators,* Vol. 1, N.Y. State Department of Environmental Conservation, Albany, NY, May 1979, pp. 6–9.

[d]Dunham, *Military Preventive Medicine,* Military Publishing, Harrisburg, PA, 1940.

[e]White, *Handbook of Chlorination and Alternative Disinfectants,* Van Nostrand Reinhold, New York, 1992.

[f]Griffin, *Public Works Magazine,* Ridgewood, NJ. October 1949, p. 35; *Operation of Wastewater Treatment Plants,* Water Pollut. Control Fed., Washington, DC, 1970, p. 144.

[g]Imhoff and Fair *Sewage Treatment,* Wiley, New York, 1956.

[h]*Wastewater Engineering Treatment Disposal Reuse.* G. Tchobanoglous, rev. ed., McGraw-Hill, New York, 1979, p. 376.

[i]*Recommended Standards for Sewage Works,* Great Lakes–Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, Albany, NY, 1997.

[j]*Design Manual, Onsite Wastewater Treatment and Disposal Systems,* U.S. Environmental Protection Agency, Washington, DC, October 1980, p. 165.

[k]Tertiary filtration effluent and for nitrified effluent.

secondary effluents contain substantially more than 1 mg/l of ammonia, which alone requires 8 to 10 mg/l of chlorine for neutralization, before there is a free residual chlorine. Nevertheless, although slow-acting, combined chlorine is effective in reducing fecal coliforms to 200 mg/l or less with sufficient contact time. It is important to note, as found by Jolley[123] and reported by Smith,[124] that conventional chlorination of municipal wastewater to the combined chlorine residual level yields relatively small concentrations of chlorinated organic compounds suspected of being carcinogenic. This is in contrast to the chlorination of surface-water supplies for drinking water to the free chlorine residual level with the formation of relatively high concentrations (200–500 ppb) of chlorinated organic compounds such as trihalomethanes, in some instances. Hence, controlled chlorination of sewage, where this is indicated, to below the free residual chlorine level would seem to have public health and economic merit, although free chlorine is recognized as the more rapid, effective disinfectant. However, this would have to be balanced against possible deleterious effects.

Chlorine is available as a relatively pure liquid in steel cylinders under pressure having a net weight of 100 or 150 lb. Larger cylinders such as ton containers and tank cars are also available. When the pressure is released, the liquid turns to a gas, in which form it is added (mixed with or without water) to sewage by means of a control and measuring device known as a chlorinator. Liquid chlorine is not ordinarily required or economical to use at very small sewage treatment plants. A separate gas-tight room above ground, a building with separate ventilation, an outside entrance, and special gas mask or self-contained breathing apparatus would be required. See Gas Chlorinator, Chapter 3, for safety precautions. Calcium hypochlorite, which is a powder containing 70 percent or less available chlorine, or sodium hypochlorite, which is a solution containing 15 percent or less available chlorine, is more generally used. Both the powder and solution are mixed and diluted with water to make a 0.5 to 5.0 percent solution, in which form it is added to the sewage by means of a solution feeder known as a hypochlorinator. Chlorine powder and solution must be stored and handled with care. Positive-feed hypochlorinators are preferred to other types because of their greater dependability. Gravity flow stack or tablet erosion-type chlorinators are also available to treat small flows.

Chlorine should be added in a manhole, approximately 20 ft ahead of the chlorine contact tank, or in a mixing box, in a manner that provides good mixing of the chlorine and sewage. The chlorine contact tank should be designed to provide 30 to 60 min retention at peak hourly flows. Detention time and the chlorine residual are usually specified by the regulatory agency. Chlorine contact tanks should be constructed with over-and-under or round-the-end baffles or equivalent obstructions to ensure the required contact period and avoid short circuiting. Serpentine flow with channel length-to-width ratio of 40:1 or 70:1 is reported to be most efficient. Perforated baffles perpendicular to flow increase the efficiency. Provision should be made in the design for the collection of samples. Sometimes the required contact time can be obtained in a long outfall sewer or by adding chlorine in a final sedimentation tank when secondary treatment is provided. A minimum chlorine residual of 0.5 mg/l after 15 min contact time at peak flows is usually required to meet coliform standards. Dechlorination may also be required.

Chlorine, chloramines, and other chlorine products formed are toxic to freshwater, marine, and estuarine aquatic organisms in minute concentrations. (See Doudoroff and Katz, Control of Microorganisms, Chapter 3.) Maximum total residual chlorine limits of 0.002 mg/l in salmonoid fish areas and 0.01 mg/l for marine and other freshwater organisms have been recommended by the EPA. Dechlorination with sulfur dioxide will remove essentially all residual toxicity to aquatic life from chlorination. Sodium thiosulfate and other sulfite-based compounds (especially sodium biosulfite) are also used. Although dechlorination is generally believed to be beneficial, the toxicity of the water prior to chlorination, toxic compounds formed after chlorination, toxicity of the dechlorinating agent, and toxicity of compounds formed as a result of dechlorination leave many questions unresolved. Because of this, pilot plant studies are advised, including possible use of alternative disinfectants.[125]

Alternative disinfectants include ozone, ultraviolet (UV) radiation, ozone plus UV, and chlorine dioxide. Some viruses, bacterial spores, and protozoan cysts survive normal UV doses. Prior filtration of the effluent may be necessary. In UV radiation, the rays must penetrate the microorganism to damage or kill it. The microorganism may be protected within particulates. Municipal wastewater receiving tertiary treatment can be treated efficiently and in a cost-effective manner.[126] Ozone is nontoxic to aquatic organisms, is a good virucide, and adds dissolved oxygen to treated wastewater effluents. Ozone has been receiving greater consideration as a wastewater disinfectant in the United States. It has been found to be reliable and effective.[127] An ozone dosage of 1.5 mg/l was found adequate to meet fecal coliform permit requirements at an activated-sludge plant including nitrification. Its cost is higher than chlorine disinfection. Chlorine dioxide added to wastewater does not result in the formation of appreciable concentrations of trihalomethanes. Excess sulfur may cause a drop in pH and dissolved oxygen, requiring treatment adjustment. The setting of an acceptable total residual chlorine concentration of 5 to 2000 μg/l in a receiving stream after adequate dilution of the effluent—less than 10:1, 10:1 to 100, and 100:1 to 400:1—has been proposed depending on stream classification and the design MA7CD10 stream flow. There needs to be a balance between public health protection and environmental protection.

Trickling Filter

A trickling filter may be used following a primary settling tank, a septic tank, or an Imhoff tank to provide secondary treatment of the sewage. Habitation should not be closer than 400 ft. Some odors and filter flies can be expected with a standard rate filter. Filter flies can be controlled by weekly chlorination (1 mg/l in effluent for 4–8 hr), flooding (24 hr), increased hydraulic loading, and insecticide treatment. A receiving stream providing adequate dilution and supervision over operation is required. Seeding of the filter stone and development of a gelatinous film of aerobic microorganisms is necessary before good results can be produced. High BOD reduction is obtained within seven days of starting a trickling filter, but as long as three months may be required to obtain equilibrium, including high nitrification.[128] Nitrification is an aerobic process in which the ammonia from sewage is acted upon by the oxygen in the air to form nitrate and carbon dioxide. Continuous operation, particularly during cold months of the year, is necessary to maintain nitrification efficiency. High nitrification is important in reducing the nitrogenous oxygen demand downstream in a body of receiving water.

Small standard-rate trickling filters are usually 6 ft deep and designed for a dosage of 200,000 to 300,00 gpd/acre-ft, or not more than 1,800,000 gal for a 6-ft-deep filter. Filter loading is also expressed, with greater accuracy, in terms of five-day BOD in the sewage applied to the filter. It is usually assumed that 35 percent of the BOD in a raw sewage is removed by the primary settling unit. Standard-rate trickling filters are dosed at 200 to 600 lb of BOD/acre-ft/day. Average loadings are 400 lb in northern states and 600 lb in southern states. Since dosage must be controlled, dosing siphons or tipping trays may be used for very small filter and dosing tanks with siphons or pumps containing revolving distributors or stationary spray nozzles on the usual filter. Periodic dosing with interim resting usually produces a better effluent than continuous dosing. Continuous dosage at a higher rate, with recirculation of part of the effluent, may be suitable where good supervision is available and operation can be controlled to produce the intended results. Lower rate dosage results in a higher quality effluent. Filter flies are reduced with recirculation. Good natural or forced ventilation of the filter is necessary.

A trickling filter should be followed by a secondary settling or humus tank to remove the biological growths sloughed off the filter stone; this unit will require the removal of sludge at least twice a day. The sludge is removed by pumping or by gravity flow if possible, usually to the sludge digester or Imhoff tank, depending on the plant design. The discharge of the raw sludge to a sand drying bed is not advisable, as sludge drying will be slow and odors will result.

For odor control or disinfection of the sewage effluent for bacterial reduction, chlorination of the final effluent is an additional and often required treatment. Trickling-filter treatment can be supplemented by sand filtration, oxidation pond, solids contact basin, flocculator-clarifiers, or chemical coagulation and settling where a higher quality effluent is necessary. Variations of the standard-rate trickling filter include the high-rate filter with recirculation; the biological tower (20–30 ft), which uses a plastic media; biological aerated filter, which uses a submerged media and forced air; and rotating biological contractors.

Flow diagrams including trickling filters are illustrated in Figure 4-34. A typical design of an Imhoff tank standard-rate trickling-filter plant is shown under Typical Designs of Small Plants (especially Design for a Small Community), this chapter. Other combinations are used.

Rotating Biological Contactors

Rotating biological contactors, reactors, or surfaces, have closely spaced plastic disk drums about 25 ft long on horizontal shafts that are rotated at 2 to 5 rpm and are about 40 percent submerged in wastewater that has received primary treatment. It is common to have at least four stages to achieve secondary treatment standards. In most instances, prior trash and grit removal is considered necessary,[129] in addition to primary settling tanks. The contactors are followed by final settling tanks providing at least $1\frac{1}{2}$ hr detention, a maximum surface settling rate of 600 gpd/ft^2, and an overflow rate not greater than 5000 gpd/linear foot (ref. 87, p. 438).

The biological growth (biomass) that forms on the wetted area of the disk surfaces, through contact with organic material in the wastewater, is maintained aerobic only by the rotation and air contact that makes possible oxygen transfer to the wastewater as it trickles down the disks. Variable shaft speed and provision for aeration increase operating flexibility for maximum efficiency. The process is similar to that in a trickling filter. Some of the growth is stripped or sloughed off from the disk as it passes through the moving wastewater and is removed in the secondary settling tank.

Design is based on organic and hydraulic loading using pilot plant or full-scale data with the particular wastewater. Hydraulic loading rates are generally from 2 to 4 gpd/ft^2 of contactor surface. However, organic loading per stage of 1 to 4 lb BOD/day/1000 ft^2 should also determine design. A loading of 2.5 to 3.0 lb soluble BOD is recommended. Lower design loading (1 gpd/ft^2) is needed to produce a high-quality (10 mg/l BOD and suspended solids) effluent. Multiple-stage design and operation of contactors with equal loading per square foot of disk and maintenance of aerobic conditions should be the objective.[129] Better effluent BOD quality and nitrification are possible with control of pH (8.4), dissolved oxygen, and raw-wastewater alkalinity.[130]

Plant efficiency of 85 percent BOD removal or higher can be expected if not overloaded but is reduced below 55°F (13°C). The rotating biological contactors (RBCs) are required to be covered or enclosed to protect them not only from low temperatures but also from rainfall and heavy winds, which would flush off growths, and sunlight, which would embrittle the plastic disks and promote the growth of algae. On the other hand, complete enclosure would promote accumulation of hydrogen sulfide and high humidities with resultant corrosion if not adequately ventilated. Access to the shafts for maintenance and repair of radial arms, shafts, bearings, disks, and drive system must also be provided. Heating may be needed.

The process is reported to be reliable and to withstand shock loading. But when the peak flow may exceed $2\frac{1}{2}$ times the average daily flow or when large organic loading may occur, appropriate flow equalization or more disks should be added. Rotating biological contactors are also suitable to treat small residential sewage flows.

The RBCs may be used for carbonaceous removal in terms of BOD, COD, and TOC, in addition to nitrification and sulfide and methane removal. Smaller diameter disks, 2 to 4 ft, transfer more oxygen with greater BOD removal than larger diameters. Soluble and particulate components are removed. Operation and maintenance costs are reported to average less than activated sludge but more than trickling filters.[131]

Physicochemical Treatment[132,133]

Physicochemical treatment involves chemical coagulation, flocculation, sedimentation, filtration, and possibly activated-carbon adsorption, in addition to prior grit removal and comminution. The unit processes through filtration remove suspended matter; the activated carbon removes soluble organics. Phosphorus is normally removed by coagulation. Reduction to 0.5 to 1.0 mg/l may be required. Nitrogen can also be removed by adding to the process ammonia stripping with air, ion exchange, and breakpoint chlorination. Disposal of the large quantities of sludge resulting from coagulation can be a problem. However, the need for biological treatment may be eliminated.

Chemicals used for coagulation include polyelectrolytes; ferric chloride or ferric sulfate, typically 45 to 90 mg/l ferric chloride for 85 to 90 percent phosphorous reduction; aluminum sulfate (alum) and sodium aluminate, typically 75 to 250 mg/l alum for 55 to 90 percent phosphorous reduction; and lime in amounts dependent on wastewater alkalinity and hardness. Lime adds to the sludge load. At a pH of 9.5 the orthophosphate is converted to an insoluble form. Typically, lime doses range from 200 to 400 mg/l, with pH at 10 to 11; polymers used alone are more costly but are attractive as settling and filtration aids when used in conjunction with the coagulants previously mentioned. At average flow, rapid mix should be 2 min, flocculation 15 min, and sedimentation 900 gpd/ft^2 (1400 gpd/ft^2 at peak hourly flow). When alum or lime is used, pH control is necessary before filtration.

Filtration using a mixed media at a rate of 5 gpm/ft^2 is advised, but up to 10 gpm/ft^2 may be used. A flow equalization pond ahead of the filter would permit filtration at a relatively constant rate. Gravity and pressure filters are used. Granular carbon adsorption is designed to provide about 30 min wastewater contact time in open tanks in either an upflow or downflow pattern or in upflow countercurrent carbon columns in steel tanks. The countercurrent pattern is said to provide more efficient utilization of the carbon. The carbon is backwashed as needed and regenerated when its adsorption capacity is exhausted.

Typical physicochemical treatment for the removal of heavy metals includes flash mix using calcium hydroxide or sodium hydroxide, flocculation, clarification, and sand filtration. Lime coagulation, mixed-media filtration, and activated-carbon filtration will greatly reduce EPA priority pollutants.

Weber[134] has prepared a very comprehensive book on the principles and application of chemicals and physicochemical methods of water and wastewater treatment.

Extended Aeration

Extended aeration plants, also referred to as aerobic digestion plants, have particular application for relatively small installation serving subdivisions, trailer parks, motels, shopping centers, and the like. Some basic design data are given below and in Table 4-21 for conventional activated-sludge and other aerobic processes. A three-month adjustment period is needed to produce an acceptable effluent. Therefore, extended aeration plants are not recommended for seasonal operations such as camps and schools.

Average Sewage Flow 400 gal/dwelling or 100 gpd/capita. See Table 3-14 for other unit flows.

Screening and Comminutor Recommended, bar screen minimum.

Aeration Tanks At least two to treat flows greater than 40,000 gpd, 24- to 36-hour detention period at average daily flow, not including recirculation, and 1000 ft^3 per $7\frac{1}{2}$ to 15 lb of BOD, whichever is greater. Raw sewage goes directly to aeration tank; primary tank is omitted. Provide 18-in. freeboard.

TABLE 4-21 Permissible Aeration Tank Capacities and Loading

Process	Aeration Tank Organic Loading, (lb BOD_5/day)/ 1000 ft^3	F/M[a] Ratio, (lb BOD_5/day)/ lb MLVSS[b]	MLVSS[c]
Conventional, step aeration, complete mix	40	0.2–0.5	1000–3000
Contact stabilization	50[d]	0.2–0.6	1000–3000
Extended aeration, oxidation ditch	15	0.05–0.1	3000–5000

Source: Recommended Standards for Sewage Works, Great Lakes–Upper Mississippi River Board of State Sanitary Engineers, Health Research, Health Education Service Division, Albany, NY, 1978, pp. 80–86.

[a]Food to microorganism ratio (F/M).

[b]Mixed liquor volatile suspended solids (MLVSS).

[c]MLVSS values are dependent upon the surface area provided for sedimentation and the rate of sludge return as well as the aeration process.

[d]Total aeration capacity, includes both contact and reaeration capacities. Normally the contact zone equals 30–35% of the total aeration capacity.

Air Requirements 3 cfm/ft of length of aeration tank or 2000 to 4000 ft^3/lb of BOD entering the tank daily, whichever is larger. Additional air is required if air is needed for air-lift pumping of return sludge from settling tank.

Settling Tanks At least two to treat flows greater than 40,000 gpd; 4-hr detention period based on average daily sewage flow, not including recirculation. For tanks with hopper bottoms, upper third of depth of hopper may be considered as effective settling capacity.

Rate of Recirculation At least 1:1 return activated sludge based on average daily flow.

Measurement of Sewage Flow By V-notch weir or other appropriate device. Recording devices required for larger installations.

Sludge Holding Tanks Provide 8 ft^3/capita. Sludge holding tanks should be required for all plants. A minimum of 1000 gal capacity per 15,000 gal design flow and 20 to 40 days retention. Tanks should be aerated.

Daily operation control is essential. Air blowers must be operated continuously and sludge returned. Clogging of the air lift for return sludge is a common cause of difficulty. Grease that accumulates on the surface of settling tanks should be skimmed off and disposed of separately, not to the aeration tank. Aeration tubes or orifices require periodic cleaning. Dissolved oxygen level in the aeration tank and the mixed-liquor suspended-solids concentration must be watched. Odors should be minimal. A 90 to 97 percent BOD and suspended solids removal and good nitrification of ammonia nitrogen can be expected with proper control.

Oxidation Ditches

Some guidelines for the design of oxidation ditches include the following (ref. 87, p. 48):

Pretreatment Grinder (comminutor) or fine screen for raw sewage.

Ditch Design Capacity Based on 24 hr detention of design flow or 1000 ft^3 per 15 lb BOD applied, whichever is greater.

Aeration Usually partially submerged rotating brush.

Final Settling Not less than 4 hr detention. Overflow rate 10,000 gpd/linear foot. Surface settling rate not greater than 1000 gpd/ft^2.

Return Sludge Pumped or air lifted. Pump suction and discharge at least $2\frac{1}{2}$ in. Air lifts at least 3 in. in diameter. Return piping at least 3 in. diameter.

Waste Sludge At least six months storage.

Stabilization Pond

In areas where ample space is available, 1000 ft or more from habitation with consideration to the prevailing winds, a waste stabilization pond may be a relatively inexpensive and practical solution to a difficult problem. It is reported that small systems at resorts or motels designed with a septic tank ahead of the oxidation pond have never produced an odor problem.[135]

Stabilization ponds or lagoons, also called oxidation ponds, are operated as high-rate aerobic ponds, aerobic–anaerobic (facultative) ponds (which are most common), aerated ponds (which are mechanically aerated), or anaerobic ponds (lagoons).

Facultative ponds with a minimum of three cells in series and 20 days actual detention time and aerated ponds with a separate settling pond prior to discharge, provide more than adequate helminth (ascaris, trichuris, hookworm, tapeworm) and protozoa (giardia, amoeba) removal. The physical, chemical, and biological activities in the ponds, as well as competing organisms, all serve to reduce the numbers of surviving enteric bacteria and viruses.*

A pond can be designed for zero discharge based on a water balance analysis and where the pond surface area provides an annual net evaporation (less precipitation) greater than the wastewater inflow.

Primary treatment with grit chamber, comminutor and rack, and ponds or cells arranged for series operation are recommended. A BOD removal of 85 to 90 percent is not unusual. Removal of viruses, bacteria, protozoa, and helminths is reported to be very high. Nitrogen removal can be significant. Ponds in open areas and in series (a minimum of three) give best results with additional detention time. Pond performance is affected by temperature, solar radiation, wind speed, loading, actual detention time, and other factors.[136,137] A summary of design criteria for facultative-type waste stabilization ponds follows.

Pond Loading 15 to 35 lb of BOD/acre/day, depending on climatic conditions; 3 ft^2/gal settled sewage for *small* system. See also Table 4-22.

Detention Time 90 to 180 days, depending on climatic conditions; 180 days for controlled discharge pond; 45 days minimum for small systems.

Liquid Depth 5 ft plus 2 ft freeboard. Minimum liquid depth 2 ft.

Embankment Top width 6 to 8 ft; inside and outside slope 3 horizontal to 1 vertical. Use dense impervious material; prepare bottom surface. Liner of clay soil, asphaltic coating, bentonite, plastic or rubber membrane, or other material required if seepage can be expected.

* "Wastewater Stabilization Ponds, An Update on Pathogen Removal," EPA, Washington, DC, August 1985.

TABLE 4-22 Types of Lagoons

Type	Detention[a] (days)	Depth (ft)	Loading (lb/5-day/ BOD/acre/day)	BOD Removal or Conversion (%)
High-rate aerobic pond	2–6	1–1.5	60–200	80–95
Facultative pond	7–50	3–8 (2–5)[b]	15–80	70–95
Anaerobic pond	5–50	Variable[c]	200–1000	50–80
Maturation pond[d]		3–8	<15	Variable
Aerated lagoon	2–10	Variable[c]	Up to 400	70–95

Source: Upgrading Lagoons, EPA-625/4-73-00 lb, U.S. Environmental Protection Agency, Washington, DC, August 1973, p. 1.

[a] W. W. Eckenfelder, Jr., *Water Quality Engineering for Practicing Engineers,* Barnes & Noble, New York, 1970, p. 210.

[b] These depths are more common.

[c] Usually 10–15 ft deep.

[d] Generally used for polishing effluents from conventional secondary treatment plants.

Pond Bottom Level, impervious, no vegetation. Soil percolation should be less than $\frac{1}{4}$ in./hr after saturation.

Inlet 4 in. diameter minimum, at center of square or circular pond; at one-third point if rectangular, with length not more than twice width. Submerged inlet 1 ft off bottom on a concrete pad or at least $1\frac{1}{2}$ ft above highest water level.

Outlet 4 in. minimum diameter; controlled liquid depth discharge using baffles, elbow, or tee fittings; drawoff about 6 and 12 in. below water surface to control and avoid short circuiting and minimize algae removal; permit drainage of pond and discharge to concrete or paved gutter.

General Round-pond corners; provide fencing, warning signs, and means for flow measurement. Locate in isolated area. Seed top and sides of embankment to grass from above waterline. Keep grass cut and prevent growth of weeds, trees, and shrubs. Liners on inside slopes will prevent weed growth and permit good mixing of pond water by wind action. Four-foot fence to keep out livestock and discourage trespassers. Post area.

Normally, the stabilization pond is aerobic at the surface and to some depth depending on surface aeration, microbial activity, wastewater clarity, sunlight penetration (algae), and mixing. In deeper ponds, the wastewater at lower layers becomes facultative and then anaerobic at greater depths with anaerobic digestion of solids on the bottom and gas production. Anaerobic and aerated ponds are usually followed by aerobic ponds to reduce suspended solids and BOD to acceptable levels for surface discharge. In general, increased detention will increase BOD removal, and decreased BOD areal loading will increase BOD removal. Hence, the required BOD and suspended-solids removal and effluent quality will determine the detention time and areal loading. Pond efficiency can be improved by recirculation, inlet and outlet arrangements, supplemental aeration and mixing, and algae removal by various methods such as coagulation–clarification, filtration, and land treatment of the effluent.[138] Table 4-22 summarized types of "lagoons," depths, loadings, and efficiencies. A design permitting parallel operation of ponds will simplify sludge removal.

Algae formed in ponds and lagoons and the seasonal blooms are the main cause of solids carryover and increased oxygen demand in receiving streams due to the algae decomposition. Further treatment of pond effluent may therefore be required to remove the algae before discharge to a stream. Possible treatment might consist of coagulation, settling, and filtration, as previously noted; centrifugation; and microstraining. It is also possible to prevent algal growths by copper sulfate treatment in the final cell, covering, or application of a chemical to intercept sunlight. Other measures include effluent withdrawal from below the surface and effluent disposal by overland flow to a wetland or a wastewater reuse facility.

The state regulatory agency, Soil Conservation Service, local health department, or other regulatory agency may be of assistance in connection with needed soils studies, design, and effluent standards to be met.[139]

The practicability of using waste stabilization ponds, lagoons, or land treatment should be investigated in light of local conditions. The effect of possible odor nuisance or health hazard should be evaluated before a treatment process is adopted. These processes should not be dismissed too quickly as they may sometimes provide an acceptable answer when no other treatment is practical and at a reasonable cost. Control of aquatic vegetation, embankment weeds, and floating mats is necessary to minimize mosquito and other insect breeding. The top minnow, *Gambusia affinis,* is also effective as it feeds on insect eggs and larvae. Degradable insecticides may also be used if permitted.

High-Rate Filtration

High-rate filtration is generally used for tertiary or polishing treatment of secondary treatment plant effluent where a consistent higher quality effluent is required (ref. 87, p. 50). Chemical coagulation and settling of the secondary effluent might be necessary prior to filtration if the suspended solids exceed 10 mg/l.

Type of Filter Usually gravity.

Filtration Rate Not greater than 3 gpm/ft^2.

Backwash Minimum of 10 min and 20 percent bed expansion. Wastewater will require treatment.

TABLE 4-23 Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture[a]

Category	Reuse Conditions	Exposed Group	Intestinal Nematodes[b] (arithmetic mean of eggs per liter[c])	Fecal Coliforms (geometric mean per 100 ml[c])	Wastewater Treatment Expected to Achieve Required Microbiological Quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	≤1	≤1000[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture, and trees[e]	Workers	≤1	No standard recommended	Retention in stabilization ponds for 8–10 days or equivalent helminth and fecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

Source: Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture, WHO Technical Report Series No. 778, WHO Scientific Group, World Health Organization, Geneva, 1989. Reproduced with permission. See also D. Mara and S. Cairncross, *Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture,* World Health Organization, Geneva, 1989.

[a] In specific cases, local epidemiologic, sociocultural, and environmental factors should be taken into account and the guidelines modified accordingly.

[b] *Ascaris* and *Trichuris* species and hookworms.

[c] During the irrigation period.

[d] A more stringent guideline (≤200 fecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

[e] In the case of fruit trees, irrigation should cease 2 weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigationh should not be used.

Filter Media Sand ES 1.0 to 4.0, UC 1.7 or less, sand depth 48 in. Anthracite ES 1.0 to 2.0, UC 1.7 or less, anthracite depth 20 in. Dual media: Sand ES 0.5 to 1.0, depth 12 in; anthracite ES 1.0 to 2.0, depth 20 in.

Filter Design See Rapid Sand (Granular Media) Filter, Chapter 3.

Wastewater Reuse and Aerosol Hazards

The treatment given wastewater to be reused should meet applicable regulatory requirements to protect the public health and natural resources. As noted under Water Reuse in Chapter 3, treated (renovated or reclaimed) wastewater may be used directly for *nonpotable* purposes or indirectly when discharged to surface water or groundwater. The extent to which wastewater is reused will depend on the availability and cost of other suitable water, the wastewater treatment required for the proposed reuse and for its disposal, and the quality of the wastewater and its treatability.[140] The hazards involved and treatment to minimize the risks to the public health are discussed below.

Public Health Hazard and Disease Transmission Aspects The public health hazards associated with the land disposal of wastewater effluent include the following:

1. Possible inhalation of aerosols containing pathogenic microorganisms, particularly bacteria and viruses from spray irrigation, activated sludge, and trickling-filter treatment systems. Also contact with and ingestion of pathogens in nondisinfected wastewater by workers.
2. Consumption of raw or inadequately cooked vegetables from crops irrigated with wastewater and the possible ingestion of heavy metals or other toxic materials taken up by crops during growth.
3. Contamination of groundwater through infiltration and percolation of wastewater microorganisms and chemicals into a groundwater aquifer serving as a source of drinking water.
4. Runoff, from land areas receiving wastewater effluent, to surface waters used as sources of drinking water, shellfish, bathing water, or other recreational purposes.
5. Possible cross-connection between potable and nonpotable water systems.
6. Buildup of detrimental chemicals in the soil.

Although not strictly a public health hazard, odors, aesthetics, and nuisance factors should be considered for they call attention to a land wastewater disposal facility and suggest psychosomatic illnesses. In addition, public accessibility to the disposal area could permit exposure and accidental ingestion of wastewater, particularly where wastewater has not been adequately treated and disinfected. Fencing to exclude livestock and prevent trespassing and appropriate warning signs around the site would be indicated. Fly and mosquito breeding could also become a problem. The role of wildlife, including migratory birds, in carrying infectious organisms great distances is not known.

As previously noted, pathogenic microorganisms in wastewater generally include certain viruses, bacteria, protozoa, helminths, and fungi. Experience shows that essentially all microbiological contaminants can be removed from wastewater as it infiltrates and percolates through an adequate distance of unsaturated fine sand (0.3 mm size), loamy, or sandy clay soil. However, microorganisms can travel several hundred feet in saturated soil and 1500 to 2000 ft or more in coarse gravel and creviced rock. Tight soils and fine sand are obviously more effective than sandy and gravelly soils. It is difficult to predict the effectiveness of different soils for the removal of bacteria and viruses. Heavy rains, for example, could cause viruses to be rapidly carried to the groundwater and then to well-water supplies. Protozoa cysts and helminth eggs can be expected to survive for relatively long periods but are not likely to migrate.

Acidic conditions and the lack of organics and certain elements such as iron, manganese, aluminum, and calcium in soil are reported to increase water pollution potential.

Chemical contaminants in wastewater might include heavy metals (cadmium, copper, nitrates, lead, mercury, zinc, nickel, and chromium), pesticides (insecticides, fungicides, herbicides, rodenticides, nematicides, and other organic and inorganic chemicals used to control animal and plant pests), and numerous commercial and industrial wastes. Mercury, PCB, kepone, mirex, and trichloroethylene are well-known examples. In addition, the nitrification of organic material in sewage will add nitrate nitrogen to the groundwater if not utilized immediately by plants and endanger sources of drinking water used by infants (methemoglobinemia). Sodium accumulation may also be of concern. In a study of the effects of 20 years of irrigation with secondary *domestic sewage* effluent (population 3800) containing no major industrial wastes, soil analyses showed no accumulation of nitrogen, lead, copper, zinc, nickel, chromium, or cadmium. There was a measurable increase in phosphorus; there was no harmful accumulation of heavy metals in alfalfa.[141]

The natural removal of organic chemicals from wastewater by land treatment is dependent on the physical, chemical, and biological factors in the environment favorable to the degradation, movement, and simplification of the complex substances in the wastewater. The natural removal of inorganic chemicals is dependent on the clay and organic content of the soil through which the liquid percolates, but the removal process is reversible. Land treatment and disposal of certain hazardous wastes to the topsoil makes possible contact with air, soil particles, nutrients, and microbes and decomposition of the waste. The rate of waste degradation must exceed its mobility through the soil. Wastes treatable on land include solvents such as toluene, chloroform, trichloroethylene and related organics, waste oils and greases, pesticides, and, to a limited extent, polychlorinated biphenyls (PCBs), polybrominated biphenyls (PPBs), inorganic chemicals, and heavy metals.[142] However, it is best to eliminate the source of heavy metals and organic chemicals entering the wastewater treatment plant.

Knowing that conventional wastewater and water treatment processes are ineffective, or only partially effective, in removing toxic organic and inorganic chemical contaminants, it is apparent that the land disposal of wastewater should not be permitted unless groundwater aquifers that may serve as sources of drinking water and soils used for growing crops or pasturage are positively protected and carefully monitored to meet existing health standards and guidelines. This requires peripheral monitoring wells around land disposal sites and that industrial waste discharge variations in quality and quantity be continuously monitored as a precondition to discharge, if approved. The burden for the removal of chemical contaminants from wastewater should remain at the plant source. Until this can be guaranteed, water treatment plants are in fact serving as the final wastewater treatment plant unit process.

In view of the many pathogens normally found in wastewater, it is recognized that irrigation and spraying of crops with wastewater may be a source of infection to humans and animals. Hence, if used, wastewater should be restricted to those foods that are not eaten raw. It has been suggested that wastewater receiving conventional secondary treatment, including chlorination, could be applied to crops eaten raw. As previously noted, this is not advisable since many pathogenic microorganisms pass through activated-sludge and trickling-filter plants, although greatly reduced in number. Furthermore, it is again emphasized that chlorination as normally practiced does not destroy all pathogenic viruses, bacteria, protozoa, and helminths.

Many metals and organic pollutants normally found in wastewater and applied to crops do not appear to be a problem in the food chain as they are not significantly absorbed by plant roots but may be ingested by grazing animals.[143] However, some heavy metals (cadmium, copper, molybdenum, nickel, and zinc) may accumulate in soil and become toxic unless good management practices are followed and the source is practically eliminated. Sewage sludges can be expected to contain higher concentrations of heavy metals. Crop tissue and grain analyses should therefore be required to monitor vegetation uptake. These include tobacco and food crops and pasture, forage, and feed grain for animals whose products are consumed by humans. Late-crop irrigation with wastewater high in nitrate leads to a high-nitrate concentration in both the soil and the crop. Excessive concentrations of nitrate (in forage) are injurious when fed to animals, resulting in cyanosis. Phosphates in wastewater should not be considered dangerous to crops.[144] Boron, on the other hand, a component of many commercial laundry detergents that is not normally removed by conventional wastewater treatment, is a well-known toxicant to citrus crops.[145]

There is always a risk of wastewater runoff from land treatment systems, depending on topography, seasonal factors, heavy rains and thaws, wastewater loading, and soil characteristics. Such runoff can be expected to contain considerable amounts of pathogens. It therefore poses a hazard to downstream surface-water supplies serving as sources of drinking water, to bathing beaches, to shellfish growing areas, and to recreational areas. Algae production may also be stimulated. Adequate dependable design and management safeguards are therefore required to prevent surface runoff from entering or leaving the land disposal site.

Wastewater Aerosol Hazard The potential hazard from aerosols is related primarily to wastewater treatment by the activated-sludge, trickling-filter, and spray irrigation processes. The presence of microbiological pathogens in sewage and its aeration products downwind for a short distance has been well and repeatedly documented (particularly for *E. coli*). The particle size is such that it would allow both upper and lower respiratory tract implantation. It is well known that susceptible individuals may be successfully infected by very small numbers of organisms for several diseases. The major gap in knowledge is the lack of evidence that this type of exposure does, in fact, represent a human disease hazard. The only way to answer this question is through appropriately designed epidemiological studies. This is not an easy task, since the groups of human diseases likely to be involved have widely fluctuating seasonal patterns and characteristics, and subclinical infection may have immunized the exposed population (particularly wastewater treatment plant workers), making assessment difficult. Although pathogens can be recovered in aerosols from the spray irrigation of treated wastewater indicating a disease risk, human disease from the aerosols has not been clearly demonstrated.[146] However, an increased risk among workers exposed to nondisinfected effluent application and/or spray irrigation has been demonstrated in India.[147] A study of medical records (1963–1976) at kibbutzim showed little or no excess enteric disease in communities within 820 to 3281 ft (250–1000 m) of fields sprinkler irrigated with quality stabilization pond effluent. However, an apparent seasonal increase was noted in the zero- to four-year-old age group.[148] The disease hazard from downwind exposure to the spray irrigation aerosol from a poor-quality trickling-filter wastewater was slightly higher for viral infections among members of a study population who had a high degree of aerosol exposure. Enteric viruses were repeatedly recovered 144 to 197 ft (44–60 m) downwind. Aerosols settled out 230 to 262 ft (70–80 m) downwind, but ambient levels of microorganisms were elevated for at least 656 ft (200 m) downwind. However, no obvious connection was observed between the self-reporting of acute illness and the degree of aerosol exposure.[149] In view of the potential, chlorination of the wastewater and adequate buffer zones (1000 ft or more) are advised as a precautionary measure.

Regulation Many agencies and individuals have suggested standards and guidelines controlling the land disposal and use of wastewater.[145,150] See Table 4-23. Those established by the California Department of Public Health are among the most explicit.[151] Their standards cover "wastewater constituents which will assure that the practice of directly using reclaimed wastewater for the specified purposes does not impose undue risks to public health."*

Fecal coliform standards for reclaimed water in California are complete wastewater treatment for direct discharge, including disinfection and tertiary treatment to less than 2.2 MPN/100 ml where public access is possible; less than 23 MPN/100 ml for secondary effluent used for golf courses, cemeteries, and landscaping; and less than 2.2/100 ml where water is used at parks, schoolyards, and playgrounds or near residential areas for irrigation.

Wolman[152] has suggested seven constraints that can serve as a model to guide professional judgment in the review of proposals for wastewater disposal by land treatment:

1. careful, efficient, and continuous management;
2. appropriate site—permeable and porous soil;
3. holdover storage for wet weather;
4. crops not eaten raw;
5. undue hazard to groundwater or drainage prevented;
6. potential hygienic risks are detected and controlled; and
7. the process is cost effective.

These brief comments emphasize the public health aspects of wastewater disposal to the land. The disease hazards associated with the ingestion of contaminated water and food or the inhalation of aerosols have been noted. Proper wastewater treatment, including secondary treatment, coagulation, clarification, filtration, and effective disinfection, as indicated by the microbiological and chemical constituents remaining in the wastewater will minimize the aerosol, crop, groundwater, and hygienic health risks associated with the disposal of wastewater to the land. Each proposal must be carefully evaluated to avoid preventable health hazards and irreparable damage to the land groundwater sources, particularly in regard to the fate of organic chemicals, heavy metals, and viruses in percolation through saturated and unsaturated soils.

Health Risks to Wastewater Treatment Plant Workers The wastewater treatment plant worker is exposed to all of the community pathogens surviving in the wastewater. These include enteric viruses, bacteria, protozoa, helminths, yeasts, and fungi. See Figure 1-2 and (a) Chlorine Treatment for Operation

* "Reclaimed wastewaters" means waters, originating from sewage or other waste, which have been treated or otherwise purified so as to enable direct beneficial reuse or to allow reuse that would not otherwise occur. "Disinfected wastewater" means wastewater in which the pathogenic organisms have been destroyed by chemical, physical, or biological methods.

and (b) Microbiological Control and Disease Hazard, this chapter. There is no evidence of the transmission of the human immunodeficiency virus (HIV) or the legionella bacteria through wastewater, but hygienic precautions are nevertheless strongly advised.[153]

There appears to be some increased risk of hepatitis A and other viral infections, gastrointestinal illnesses, leptospirosis (minimal), parasitic (protozoa and helminths) infections, skin disorders, and possibly fungus infection due to *Aspergillus* spp. associated with wastewater sludge composting operations. The probability of infection and illness seems to be directly related to the personal hygiene practices of the worker, with the inexperienced more vulnerable, and to plant sanitation. This emphasizes the need for the wastewater treatment plant worker to avoid contact with wastewater, to wash hands after performing chores and before smoking and eating, and to shower and change into clean clothing, including shoes, at the end of each day.[153]*

Wastewater Disposal by Land Treatment and Reuse

Land treatment and disposal comprise a managed system that relies on natural biological, physical, and chemical processes in the soil. Methods include spray or sprinkler irrigation; ridge-and-furrow and border strip (flooding) irrigation, including subsurface and contour ditch irrigation; land overland flow; subsurface disposal in a soil absorption system or subsurface sand filter; wetland treatment; and possibly a waste stabilization pond or lagoon. Careful evaluation of the site soils, hydrogeologic and geographical conditions, regulatory and public involvement, and management practices are necessary to prevent heavy runoff and erosion, overloading, groundwater and surface water pollution, and nuisance conditions. Vegetation, soil, and evapotranspiration can play an important role in removing nutrients and reducing deep percolation of the wastewater. Planning and design details for various land treatment processes are briefly reviewed here. Health risk and water balance analyses are also necessary.[146,154–156] See Wastewater Reuse and Aerosol Hazards in this chapter.

Table 4-24 compares design features for land treatment processes, and Table 4-25 shows expected quality of treated wastewater from land treatment processes. The degree of treatment required for the use of wastewater (renovated water) in agriculture is given in Table 4-23. Subsurface disposal, sand filters, and waste stabilization ponds have been previously discussed.

Irrigation Spray irrigation is the most common method of applying wastewater to land. Ridge-and-furrow and border strip irrigation are also used. Application of wastewater in spray irrigation is generally limited to 8 hr

*See also "Update on Adult Immunization," *MMWR,* November 15, 1991, p. 8, for indicated vaccinations.

TABLE 4-24 Comparison of Design Features for Land Treatment Processes

	Principal Processes			Other Processes	
Feature	Slow Rate	Rapid Infiltration	Overland Flow	Wetlands	Subsurface
Application techniques	Sprinkler or surface[a]	Usually surface	Sprinkler or surface	Sprinkler or surface	Subsurface piping
Annual application rate, ft	0.5–6	6–125	3–20	1.2–30	2.4–27
Field area required, acres[b]	23–280	3–23	6.5–44	4.5–113	5.3–57
Typical weekly application rate, in.	1.3–10	10–240	6–15[c] 15–40[d]	2.5–64	5.1–51
Minimum preapplication treatment provided in United States	Primary sedimentation[e]	Primary sedimentation	Grit removal and comminution	Primary sedimentation	Primary sedimentation
Disposition of applied wastewater	Evapotranspiration and percolation	Mainly percolation	Surface runoff and evapotranspiration with some percolation	Evapotranspiration, percolation, and runoff	Percolation with some evapotranspiration
Need for vegetation	Required	Optional	Required	Required	Optional

Source: Process Design Manual for Land Treatment of Municipal Wastes, U.S. Environmental Protection Agency, Cincinnati, OH, October 1977 and October 1981, pp. 2-2 and 1-3.

Notes: 1 cm = 0.394 in., 1 m = 3.28 ft, 1 hectare = 2.47 acre.

[a] Includes ridge-and-furrow and border strip.

[b] Field area in acres not including buffer areas, roads, or ditches for 1 million gpd (43.8 l/s) flow.

[c] Range for application of screened wastewater.

[d] Range for application of lagoon and secondary effluent.

[e] Depends on the use of the effluent and the type of crop.

TABLE 4-25 Expected Quality of Treated Water from Land Treatment Processes (mg/l)

Constituent	Slow Rate[a]		Rapid Infiltration[b]		Overland Flow[c]	
	Average	Maximum	Average	Maximum	Average	Maximum
BOD	<2	<5	2	<5	10	<15
Suspended solids	<1	<5	2	<5	10	<20
Ammonia nitrogen as N	<0.5	<2	0.5	<2	0.8	<2
Total nitrogen as N	3	<8	10	<20	3	<5
Total phosphorus as P	<0.1	<0.3	1	<5	4	<6

Source: Process Design Manual for Land Treatment of Municipal Wastewater, U.S. Environmental Protection Agency, Army Corps of Engineers, and Department of Agriculture, Washington, DC, October 1977, p. 2–4.

[a] Percolation of primary or secondary effluent through 5 ft (1.5 m) of soil.
[b] Percolation of primary or secondary effluent through 15 ft (4.5 m) of soil.
[c] Runoff of comminuted municipal wastewater over about 150 ft (45 m) of slope.

followed by a 40-hr rest period to permit drainage of the soil, reaeration, plant nutrient uptake, and microbial readjustment. Other operating cycles are also used. Wastewater disposal is by evapotranspiration and percolation, except that for high-rate irrigation, percolation plays the major role. Phosphorus and cadmium are accumulated by plants; cadmium, in particular, may be hazardous in edible crops. Physical, biological, and chemical treatment takes place during percolation, particularly in the upper soil, including BOD and COD removal. Dissolved solids and chlorides may cause a soil problem where the wastewater is high in these constituents. Cadmium levels should be kept below 2.5 mg/kg in the soil. Sewage and soil analyses should be made as a soil pH below 7.0 facilitates cadmium uptake by crops.

Ridge-and-furrow ditches are on a grade from 100 to 1500 ft in length. Depth and spacing vary with type of crop and soil ability to transmit water laterally. Border strips are 30 to 60 ft long.[157]

The low-rate spray irrigation rate is 0.5 to 4 in. per week depending on soil permeability, climate, and wastewater strength. The ground slope should be less than 20 percent on cultivated land and less than 40 percent on noncultivated land. Soil permeability should be moderately slow to moderately rapid* and the depth to groundwater a minimum of 2 to 3 ft, although 5 ft is preferred.

*0.2–6.0 or more inch per hour permeability corresponding roughly to a soil percolation rate of 1 in. in 45 min to less than 10 min.

High-rate spray irrigation is 4 to 40 and up to 120 in. per week, depending on soil permeability, climate, and wastewater characteristics. The soil permeability should be rapid, and the permeable soil depth preferably 15 ft or more. Crops are not usually grown. Nitrogen and phosphorous removal is not complete. Treated water may be used for groundwater recharge and subsequent reuse, subject to regulatory control and approval, or to protect groundwater from salt water intrusion.

Application rates for ridge-and-furrow (gpm/100 ft) and border strip irrigation are similar to spray irrigation and will vary with soil permeability, spacing, and slope of the furrow. The wastewater is discharged directly to the furrows or strips between elevated rows of crops.

Overland Flow Wastewater is applied to slope (2–8 percent), grassed, slightly permeable ground surface as sheet flow during which physical (grass filtration and sedimentation) and chemical–biological (oxidation) treatment is accomplished. Treated runoff is collected in ditches and discharged to a watercourse. Surface runoff may be 50 percent or more. Grasses, which have high nitrogen uptake capacity,* are usually chosen for cover vegetation. Viruses and bacteria are not removed. Overland flow treatment is more effective during warm weather.

Wetland Treatment Wetlands include marshes, bogs, wet meadows, peatland, and swamps; they are not lakes but have enough water to prevent most agricultural and silviculture uses. Secondary wastewater effluent may be applied to existing wetlands, artificial wetlands, and peatlands, if approved by regulatory authorities having jurisdiction. An environmental impact analysis may be required. Hyacinths have been used in wetland lagoons to effect the removal of BOD, suspended solids, and nutrients. Design data are being accumulated.

Advanced Wastewater Treatment

Advanced wastewater treatment (tertiary treatment) may be needed in some instances to protect the water quality of the receiving groundwaters and surface waters from added undesirable nutrients, toxic and hazardous chemicals, or pathogenic organisms not removed or inactivated by conventional biological secondary wastewater treatment. For example, nitrogen and phosphorus in plant effluent may promote the growth of plankton and nitrates may contaminate groundwater; toxic organic and inorganic chemicals may endanger fish and other aquatic life, contaminate edible fish and shellfish, and endanger

*Bent grass, Bermuda grass, Reed Canary grass, Sorghum-Sudan, vetch; also alfalfa, clover, orchard grass, broome grass, and Timothy.

the quality of sources of water for water supply, recreation, and shellfish growing; and pathogens such as the infectious hepatitis virus, giardia, entamoeba, ascaris, and certain worms not removed or destroyed by the usual sewage treatment, including chlorination, place an additional burden on water treatment plants and increase the probability of waterborne disease outbreaks.

Figure 4-35 shows the wastewater treatment unit process including advanced or tertiary treatment. See Physicochemical Treatment in this chapter for nonbiological pretreatment.

Advanced wastewater treatment may include combinations of the following unit processes, following secondary treatment, depending on the water quality objectives to be met. These are examples and are not intended to be all inclusive.

For Nitrogen Removal

Breakpoint chlorination—to reduce ammonia nitrogen level (nitrate and organic are not affected).

Ion exchange, after filtration pretreatment—to reduce nitrate nitrogen and ammonium levels using selective resin for each; phosphate also reduced.

Nitrification followed by dentrification, ammonia if present removed or converted to nitrate and then to nitrogen gas—ammonia stripping* (degasifying) to remove ammonia nitrogen or biological oxidation of ammonia in the activated-sludge process to nitrate; denitrification (organic nitrogen) achieved by filtration through sand or GAC or by biological denitrification, usually under anaerobic conditions, following activated-sludge treatment (nitrification and denitrification). (See design text.)

Methanol—to reduce nitrate level.

Reverse osmosis, following treatment to prevent fouling of membranes—to reduce total nitrogen level; also dissolved solids.

Electrodialysis, following pretreatment—to reduce ammonia, organic, and nitrate nitrogen levels; also dissolved solids.

Oxidation pond—to reduce total nitrogen level.

Land treatment, low-rate irrigation to overland flow—to reduce total nitrogen level; also phosphorus. Rapid infiltration also effective.

*Wastewater pH is raised to 10.0–10.5 or above, usually by the addition of lime or sodium hydroxide, at which pH the nitrogen is mostly in the form of ammonia, which can be readily removed by adequate aeration, but pH adjustment of the effluent will be needed to meet stream standards. Organic or nitrate nitrogen is not removed. Ammonia stripping equipment includes tray towers, cascade aerators, step aerators, and packed columns.

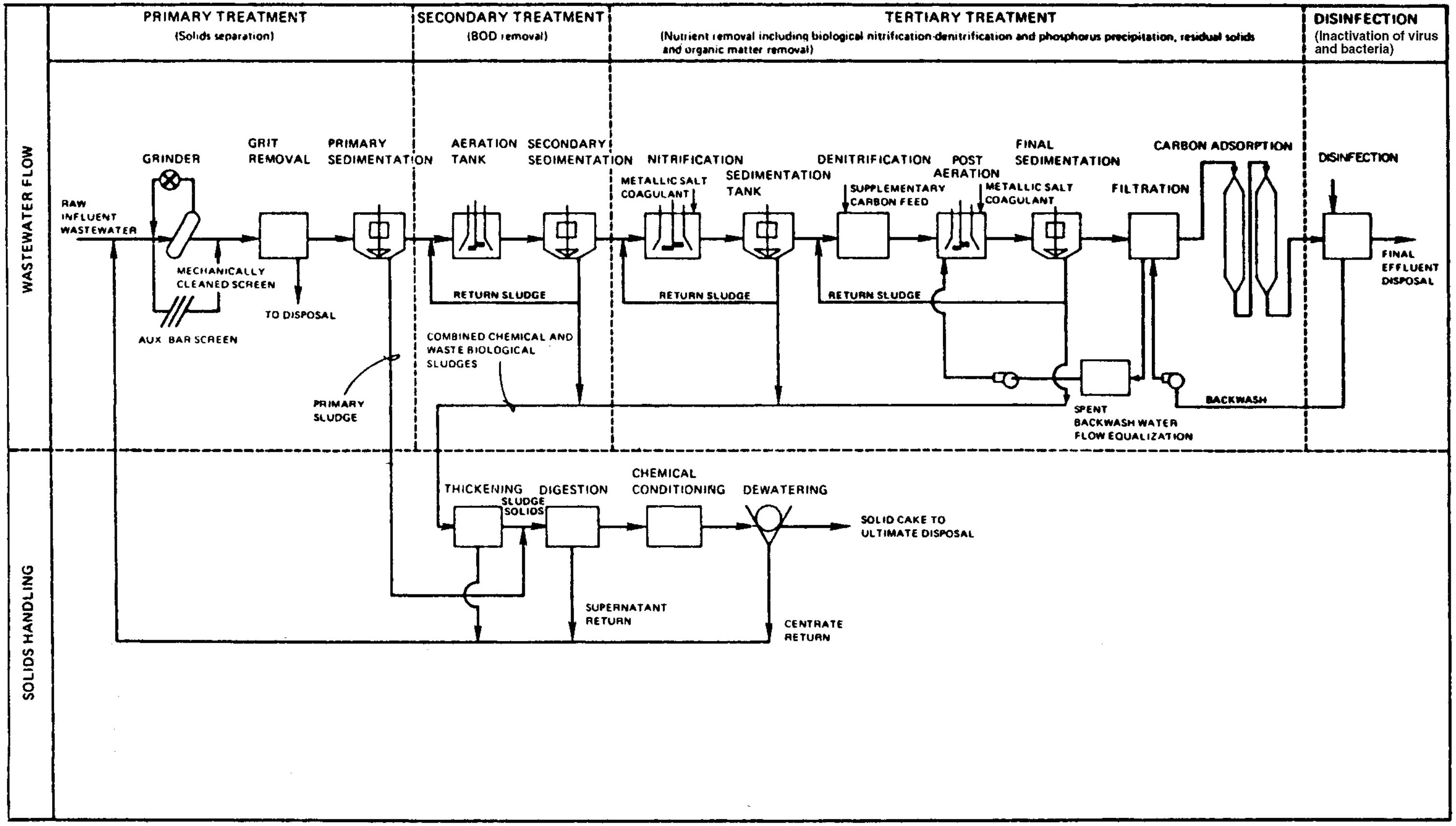


Figure 4-35 Typical schematic flow and process diagram. (*Source: Operation of Wastewater Treatment Plants,* MOP 11, Water Pollution Control Federation, Washington, DC, 1976, p. 17. Copyright 1976 by the Water Pollution Control Federation. Used with permission.

For Phosphorous Removal

Coagulation (lime, alum, or ferric chloride, also polyelectrolyte) and sedimentation—to reduce phosphate level, total dissolved solids (TDS) increased, additional nitrogen removal, also some heavy metals.

Coagulation, sedimentation, and filtration (mixed media)—to further reduce phosphate level; also suspended solids, TDS increased, additional nitrogen also removed.

Lime treatment, after biological treatment, followed by filtration—to reduce phosphorus (pH above 11), also suspended solids.

Ion exchange, with selected specific resins—to reduce phosphate, also dissolved solids and nitrogen.

For Dissolved Organic Removal

Activated carbon (granular or powdered) absorption, following filtration—to reduce COD, including dissolved organics; also chlorine.

Reverse osmosis, following pretreatment—to reduce dissolved solids.

Electrodialysis following pretreatment—to reduce dissolved solids.

Distillation, following pretreatment—to reduce dissolved solids.

Biological wastewater treatment—to reduce dissolved organics.

Aeration—to remove volatile organics.

For Heavy-Metal Removal

Lime treatment—to reduce heavy-metal level.

Coagulation and sedimentation—to reduce heavy-metal level.

For Dissolved Inorganic Solids Removal (*Demineralization*)

Ion exchange, using anionic and cationic resins, following pretreatment—to reduce total dissolved solids.

Coagulation and sedimentation—to reduce heavy metals.

Reverse osmosis—to reduce TDS.

Electrodialysis—to reduce TDS.

For Suspended-Solids Removal

Filtration (sand, lime, or ferric chloride and possible polyelectrolytes), sedimentation, filtration—to reduce suspended solids, also ammonia nitrogen, and phosphate if high alum or lime dosage used; adding ammonia stripping will reduce total nitrogen further; adsorption using activated carbon will reduce dissolved organics and total nitrogen.

For Recarbonation

Carbon dioxide addition—to reduce pH where wastewater pH has been raised to 10 to 11; this is necessary to reduce deposition of calcium carbonate in pipelines, equipment, or the receiving watercourse.[158]

For Heat Removal

Open reservoir or evaporative cooler—to lower temperature of wastewater prior to discharge.

Removal of toxic or hazardous substances must start at the source with in-house process change if possible, waste reclamation and reuse, waste control, and pretreatment before discharge to a municipal sewer or watercourse.

Inspection During Construction

The best design is no better than the construction and, one could add, operation. On installations for which engineering or architectural plans are prepared, it is advisable to make arrangements for retaining competent inspection and supervision during construction. This would include the checking of grades and elevations and pipe bedding, inspection of quality of material and construction, infiltration tests, and full compliance with the treatment plant, pumping station, and sewerage plans and specification. On the small installations, the regulatory agency, if properly staffed, may be able to perform some of the inspection, but only in an advisory capacity for general compliance with design.

Operation Control

A common weakness in both small and large wastewater treatment plants is the failure to properly operate and maintain a well-designed and constructed plant. It is important for the design engineer to impress upon the owner, be it an individual, corporation, or a municipality, that wastewater treatment plants require daily attention by a qualified person. Repairs should be made promptly and preventive maintenance should be the rule. If this is not done, the money spent is wasted; major damage requiring expensive repairs can result before the cause is detected, and the purpose of the treatment plant to prevent water pollution is nullified. Adequate salaries and good working conditions are essential to attract and keep competent people.

Whenever a treatment plant is in use, an operation report should be kept and entries made daily. The regulatory agency usually provides forms for this purpose. This will help ensure daily inspection and continuous operation of the plant as it was designed to function. An equipment maintenance schedule or checklist is also found to be very worthwhile in reducing expensive repairs and equipment replacement. A complete set of spare parts for pumps, special dosing devices, and chlorinators is necessary if extended interruptions are to be kept at a minimum.

TYPICAL DESIGNS OF SMALL PLANTS

Design for a Small Community

Design analyses are given below for a plant to serve 150 persons at 100 gal per capita per day (gpcd) = 15,000 gpd.

Standard-Rate Trickling-Filter Plant with Imhoff Tank

1. Flowing through the channel provides $2\frac{1}{2}$ hr detention. Then,

$$\frac{15{,}000}{24} \times 2 = 1250 \text{ gal} = 167 \text{ ft}^3$$

2. Sludge storage at 5 ft^3/capita = 5 × 150 = 750 ft^3.
3. Sludge drying beds at 1.25 ft^2/capita = 150 × 1.25 = 188 ft^2.
4. Trickling-filter loading at 4000 lb of BOD/acre-ft = 0.25 lb/yd^3. Loading based on 0.17 lb of BOD/capita with 35 percent removal in primary settling = 150 × 0.17 × 0.65 = 16.6 lb/day. The filter volume required = 400/43,560 = 16.6/x; x = 1800 ft^3. Hence, the required filter diameter, assuming a 6-ft depth, is

$$D = \sqrt{\frac{1800 \times 4}{\pi \times 6}} = 19.5 \text{ ft}$$

$$\text{Volumetric loading} = \frac{15{,}000/(\pi \times 20 \times 20)}{4} = \frac{x}{43{,}500} \text{Here, } x$$

= 2,080,000 gpd/acre on a 6-ft-deep filter.

5. Final settling provides 2 hr detention; 15,000/24 × 2 = 1250 gal = 167 ft^3, with a surface settling rate of 500 gpd/ft^2 = (180 × tank depth)/2 hr detention; tank depth = 5.6 ft.
6. If the BOD in the raw sewage is 200 mg/l and the Imhoff tank removes 35 percent, the applied BOD is 0.65 × 200 = 130 mg/l. According to the National Research Council Sanitary Engineering Committee for-

mulas,* a filter loaded at 400 lb BOD/acre-ft will produce an average settled effluent containing 14 percent of that applied, or $0.14 \times 130 = 18$ mg/l.

High-Rate Trickling-Filter Plant with Imhoff Tank

1. Flowing through channel is the same as with standard-rate filter, 209 ft^3.
2. Sludge storage at 8 ft^3/capita $= 8 \times 150 = 1200$ ft^3.
3. Sludge drying beds at 1.50 ft^2/capita $= 150 \times 1.50 = 225$ ft^2.
4. Trickling-filter loading at 3000 lb BOD/acre-ft = 1.86 lb/yd^3. Loading based on 0.17 lb BOD/capita with 35 percent removal in primary settling $= 150 \times 0.17 \times 0.65 = 16.6$ lb/day. The BOD in the raw sewage is $150 \times 0.17 = 25.5$ lb. Filter volume required $= 3000/43{,}560 = 25.5/x$; $x = 370$ ft^3. Hence, the required filter diameter, assuming 3.25-ft depth, is $D = \sqrt{(370 \times 4)/(\pi \times 3.25)} = 12.0$ ft. The volumetric surface loading on a 12-ft-diameter filter with influent and recirculation [$(I + R = 1 + 1 = 2)$ or 2(15,000)] = 30,000 gal/day is $x = 11{,}500{,}000$ gpd/acre on a 3.25-ft-deep filter.
5. Final settling provides 2 hr detention at flow $I + R$. Then

$$\frac{30{,}000}{24} \times 2 = 2500 \text{ gal} = 334 \text{ ft}^3$$

6. Without recirculation, an applied BOD of 130 mg/1 (0.65×200) at a rate of 3000 lb/acre-ft will be reduced to $0.32 \times 130 = 42$ mg/l in the settled effluent. With recirculation of $R/I = 1$, the efficiency of the high-rate filter and clarifier can be determined from the following formulas[159]:

$$F = \frac{1 + \frac{R}{I}}{\left(1 + 0.1\frac{R}{I}\right)^2}$$

where F = recirculation factor
R = volume of sewage recirculated, = 1
I = volume of raw sewage, = 1
$F = (1 + 1)/(1 + 0.1^2) = 1.65$

*$E = 100/(1 + 0.0085\sqrt{u})$, where E = percent BOD removed, standard filter and final clarifier, and u = filter loading, lb of BOD per acre-ft.

$$u = \frac{w}{VF}$$

where u = unit loading on high-rate filter, lb BOD/acre-ft
w = total BOD to filter, lb/day, =16.6
V = filter volume, acre-foot based on raw sewage strength, = 0.0084
F = recirculation factor, =1.65
u = 16.6/0.0084 × 1.65 = 1.98 lb/acre-ft

$$E = \frac{100}{1 + 0.0085\sqrt{u}}$$

where E, the percent BOD removed by a high-rate filter and clarifier, is given as

$$E = \frac{100}{1 + 0.0085\sqrt{1198}} = 77\%$$

Hence, the BOD will be reduced to (1 − 0.77)130 = 30 mg/l.

Intermittent Sand Filter Plant with Imhoff Tank or Septic Tank

1. Flowing through the channel of the Imhoff tank provides $2\frac{1}{2}$ hr detention = 209 ft^3.
2. Sludge storage at 4 ft^3/capita = 4 × 150 = 600 ft^3.
3. Sludge drying bed provides 188 ft^2, or septic tank provides 24 hr detention = 15,000 gal = 2000 ft^3.
4. Sand filter, covered, designed for loading of 50,000 gpd/acre. Filter area is

$$\frac{50{,}000}{43{,}560} = \frac{15{,}000}{x} \qquad x = 13{,}000 \text{ ft}^2$$

If the filter is open, the required area is 6550 ft^2. Make filters in two sections. Provide dosing tank to dose each covered filter section at volume equal to 75 percent of the capacity of the distributor laterals or to dose each open filter section to depth of 2 to 4 in. If the efficiency of BOD removal of a sand filter is 90 percent, the BOD of the effluent would be 130 × 0.10 = 13 mg/l.

Children's Camp Design

A typical sewerage layout to serve a camp dining room and central bathhouse is shown in Figure 4-36. This boys' camp is assumed to be located on the watershed of a public water supply. The soil is a clay loam. There are no unusual plumbing fixtures at the camp. A basis for the design is given below.

1. Camp capacity is 96 campers and 27 staff = 123 total.
2. Design flow based on 40 gal/capita:

$$123 \times 40 = 4920 \text{ gpd}$$

3. Septic tank capacity designed for a 12-hr detention period. Total flow takes place in 16 hr. Liquid volume = x:

$$\frac{4920 \text{ gal}}{16 \text{ hr}} = \frac{x \text{ gal}}{12 \text{ hr}} \qquad x = 3690 \text{ gal}$$

   Make septic tank 6 × 17 × 5 ft liquid depth. See Table 4-10 and Figure 4-9. A tank twice the calculated volume is recommended.
4. Grease trap is designed for $2\frac{1}{2}$ gal/person served at mealtime:

$$\text{Capacity} = 2\tfrac{1}{2} \times 123 = 308 \text{ gal}$$

   Make grease trap $2\frac{1}{2} \times 7 \times 2\frac{1}{2}$ ft liquid depth. See Figure 4-7.
5. Sand filter is designed for filtration rate of 1.15 gpd/ft^2:

$$\text{Total required area} = \frac{4920}{1.15} = 4278 \text{ ft}^2$$

   Make in two sections, each 2160 ft^2 = 2(30 × 72). Each section will consist of five distributors 69 ft long, 6 ft apart. See Figures 4-22 and 4-36. See also open-filter alternate, Figure 4-23.
6. Dosing tank to be provided with alternating siphons. Volume of dose is to be 60 percent of volume of 4-in. distributors in each section, or (5 × 69) × (0.653 × 0.60) = 135 gal.
7. Size of siphon is twice the maximum flow to the dosing tank. Probable maximum flow is assumed as one-half the daily flow in 1 hr: $4920 \times \frac{1}{2}/60 = 41$ gpm (Check with fixture unit basis.) A 4-in. siphon has a minimum discharge of 102 gpm. Use a 4-in. siphon; it has a drawdown of 17 in. If the dosing tank is made 6 ft wide and the discharge liquid depth is 17 in. or 1.41 ft, the dosing tank length is

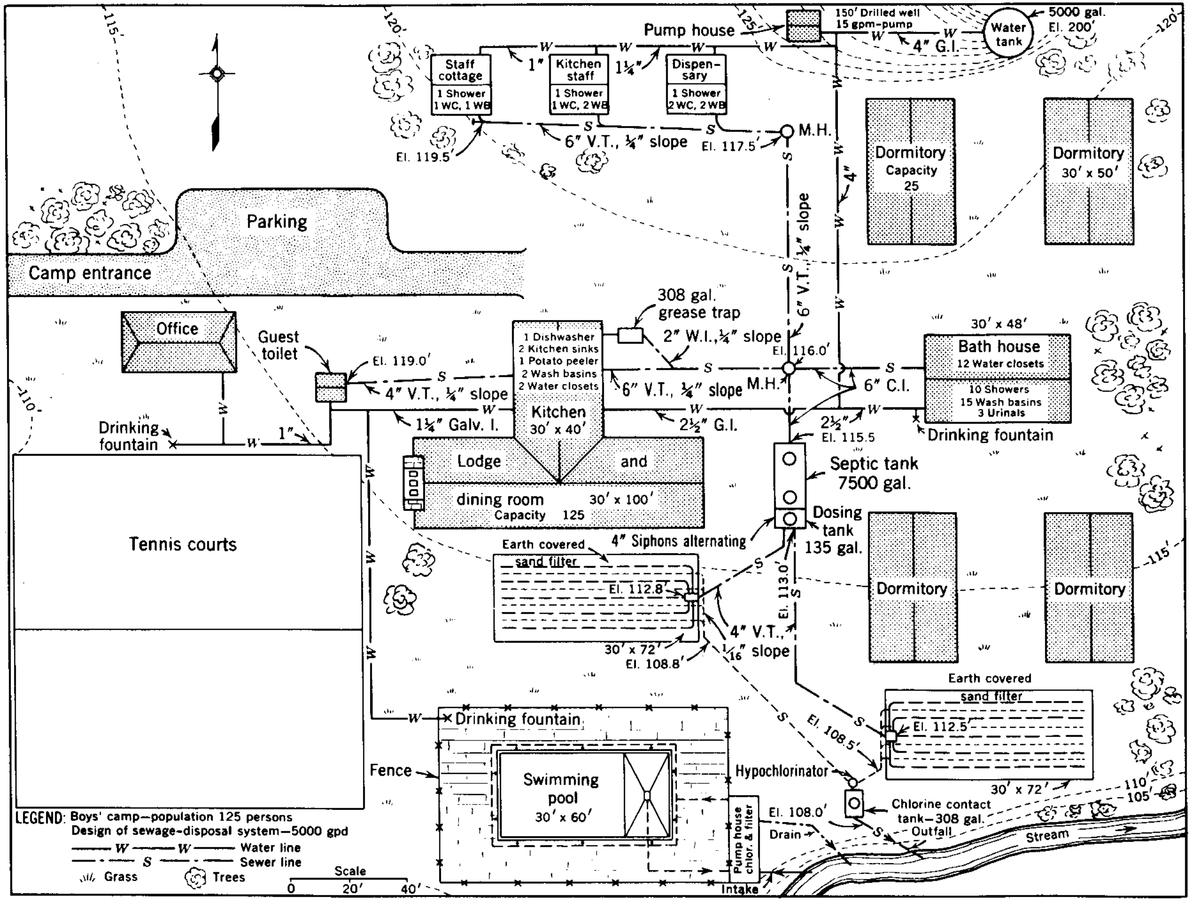


Figure 4-36 Typical camp compressed plan showing sanitary details. (Add recreational building, craft shop, nature lodge, garage, recreational area, council ring, etc.) See also Figure 3-37.

$$\frac{135}{7.48} \times \frac{1}{6} \times \frac{1}{1.41} = 2.14 \text{ ft}$$

See Figure 4-30.

8. Provide a chlorine contact tank giving a minimum detention of 15 min. Say flow conditions given in paragraphs 6 and 7 are leveled off through the filter and reach contact tank at an average rate of 20.5 gpm under peak conditions; make the contact tank equal to

$$20.5 \times 15 = 308 \text{ gal}$$

9. Chlorination treatment will be required to protect the receiving stream, which serves as a source of domestic water supply. Provide a hypochlorinator for the flow to be treated, having positive feed and operating continuously, with point of application in inspection manhole receiving filter drainage, 20 ft ahead of chlorine contact tank.
10. Increase the volume of the septic tank by 50 percent and the area of the sand by 20 percent if a kitchen garbage grinder is installed.

Referring to the above design, an alternate design based on soil percolation tests in clay loam is also investigated. Tests made in the proposed area for sewage disposal gave percolations of 1 in. in 40 min, 1 in. in 50 min, 1 in. in 10 min, and 1 in. in 60 min. Discard the 10-min test as not being representative. Use 1 in. in 50 min or 0.6 gpd/ft^2 in the design. A design based on a subsurface absorption system for the camp mentioned above follows:

1. Camp capacity = 123.
2. Design flow = 4920 gpd.
3. Septic tank capacity (double this capacity is recommended) = 3690 gal.
4. Grease trap capacity = 308 gal.
5. Absorption area required:

$$\frac{4920}{0.6} = 8200 \text{ ft}^2$$

Make in *two* sections *each* having an area of 4100 ft^2. This can be obtained if each section consists of 2050 linear feet of perforated pipe in trenches 2 ft wide. Space trenches 6 ft apart.

6. Dosing tank to be provided with alternating siphons. Volume of dose to be 60 percent of volume of 4-in distributors in each section:

$$2050 \times 0.653 \times 0.6 = 803 \text{ gal} \quad \text{(for 2-ft-wide trench)}$$

With a 6-ft-wide dosing tank and a 4-in. siphon having a drawdown of 1.41 ft, for an 803-gal discharge, the tank length is

$$\frac{803}{7.48} = \frac{1}{6} \times \frac{1}{1.41} = 12.7 \text{ ft}$$

7. The size of the siphon should be twice the maximum flow to the dosing tank. Use a 4-in. siphon.
8. Increase the volume of the septic tank by 50 percent and the area of the tile field by 20 percent if a kitchen garbage grinder is installed.

Compare the cost of installation operation and maintenance of the sand filter system, including chlorination and the subsurface absorption field system, to determine which system to install. Other alternatives such as a trickling-filter or aeration unit may also be studied and compared before a decision is made.

Specific construction details of grease traps, manholes, septic tanks, dosing tanks, sand filters distribution boxes, and chlorine contact tanks are given elsewhere in this chapter.

Town Highway Building Design

1. Population: 70 persons
2. Fixtures: 5 showers
   5 water closets (flush valve)
   6 washbasins
   2 urinals (flush valve)
3. Soil tests: Percolation zero, tight clay soil
4. Design flow—Different bases:
   a. Fixture unit basis (see Table 4-7)

$$\begin{aligned} \text{5 showers at 3} &= 15 \\ \text{5 water closets at 8} &= 40 \quad \text{(flush valved operated)} \\ \text{6 washbasins at 2} &= 12 \\ \text{2 urinals at 4} &= \underline{\ 8} \\ \text{Total} &= 75 \text{ fixture units} \end{aligned}$$

   For 8 hr operation, say one fixture unit = 35 gal; hence, 75 × 35 = 2625 gpd.

   b. Usage-per-capita basis:

$$\text{70 persons at 30 gcd} = 2100 \text{ gpd}$$

c. Fixture hourly flow basis (from Table 4-6):

$$\begin{aligned} 5 \text{ showers at } 150 \text{ gal/hr} &= 750 \\ 5 \text{ water closets at } 36 \text{ gal/hr} &= 180 \\ 6 \text{ washbasins at } 15 \text{ gal/hr} &= 90 \\ 2 \text{ urinals at } 10 \text{ gal/hr} &= \underline{20} \\ \text{Total} &= 1040 \text{ gal/hr} \end{aligned}$$

With an hourly peak in the morning and afternoon and usage during the day, say practically all flow takes place in $2\frac{1}{2}$ hr:

$$\text{Daily flow} = 1040 \times 2\tfrac{1}{2} = 2600 \text{ gpd}$$

d. The average estimated flow is then $\frac{1}{3}(2625 + 2100 + 2600) = 2442$ gpd, say 2500 gpd.

5. Septic tank: Since all flow takes place in 8 hr, provide a minimum 2500-gal septic tank. (See Table 4-10 and Figure 4-9.) Make the septic tank 6 ft wide, $14\frac{1}{2}$ ft long, 4 ft liquid depth. Dimensions are inside.
6. Sand filter:

$$\text{Required area} = \frac{2500}{1.15} = 2170 \text{ ft}^2$$

Make bed: 36 × 60 ft. (See Figures 4-21 and 4-22.)

7. Dosing tank: Dose field to 70 percent of interior capacity of distributors, which extend to within 18 in. of end of bed, 6 ft on center, 3 ft from edge of bed:

$$\begin{aligned} &6 \text{ laterals} \times 57 \text{ ft long} \times 0.653 \text{ (vol. 1 of 4-in. pipe)} \times 70\% \\ &= 6 \times 57 \times 0.653 \times 0.7 = 156 \text{ gal} \end{aligned}$$

8. Size of siphon: Siphon should preferably have minimum capacity $1\frac{1}{2}$ to 2 times peak flow. Using National Bureau of Standards probability curves in Figure 3-26 with 75 fixture units, demand = ± 60 gpm. Use a 4-in. Miller siphon, which has a drawdown of 17 in. and a total head loss from high water to invert of discharge pipe of $25\frac{1}{2}$ in. (See Figure 4-30.) Make the dosing tank 6 ft wide and 2.45 ft long, attached to septic tank, with 17 in. liquid drawdown.
9. Size of chlorine contact tank, if required: Provide for at least 15 min detention. Make the tank equal to the dosing tank dose, or 156 gal.

Small Restaurant and Hotel Designs

Figure 4-37 shows a similar design for a sand filter to serve a small restaurant and Figure 4-38 shows a leaching pit system.

Elementary School Design

1. Design basis: Number of persons, 600. Soil tests—rock at 12 to 30 in; soil gravelly loam with clay; shallow soil tests = 1 in. in 20 min. Suitable porous fill containing topsoil and gravelly loam is required to bring bottom of leaching system at least 2 ft above rock. Use assumed percolation rate of 0.5 gpd/ft^2. Pumping is required.
2. Design flow: 600 persons at 20 gcd = 12,000 gpd.
3. Septic tank: Minimum size to provide 12-hr detention period, assuming all flow takes place between 8:30 a.m. and 5:30 p.m., a period of 9 hr = x. Then 12,000/9 = x/12; x = 16,000 gal.

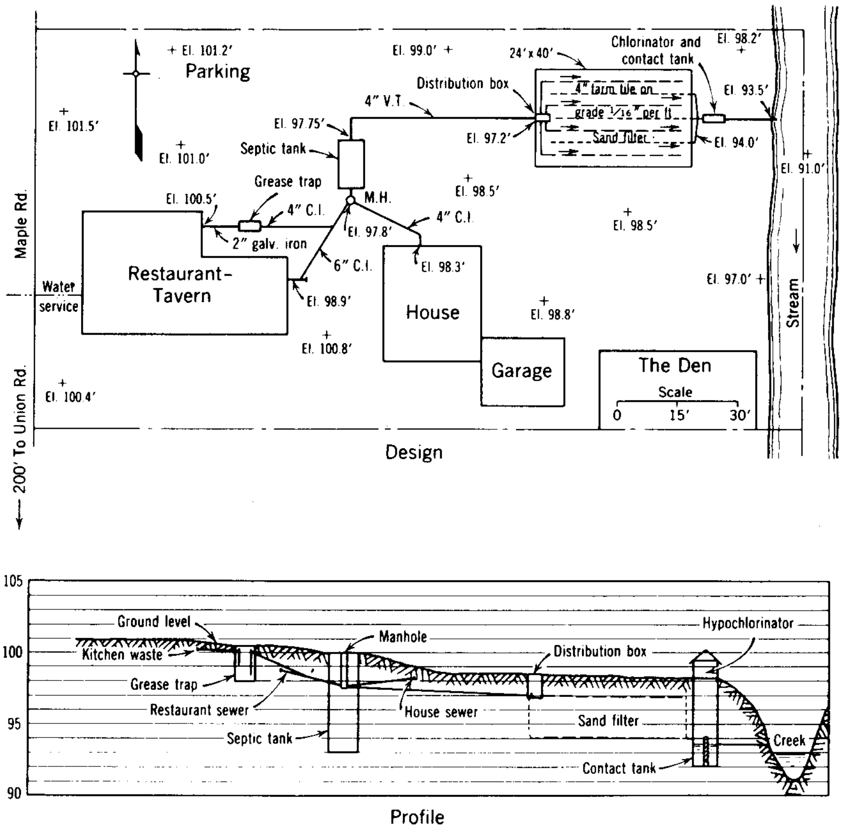


Figure 4-37 Typical plan and profile of restaurant treatment plant.

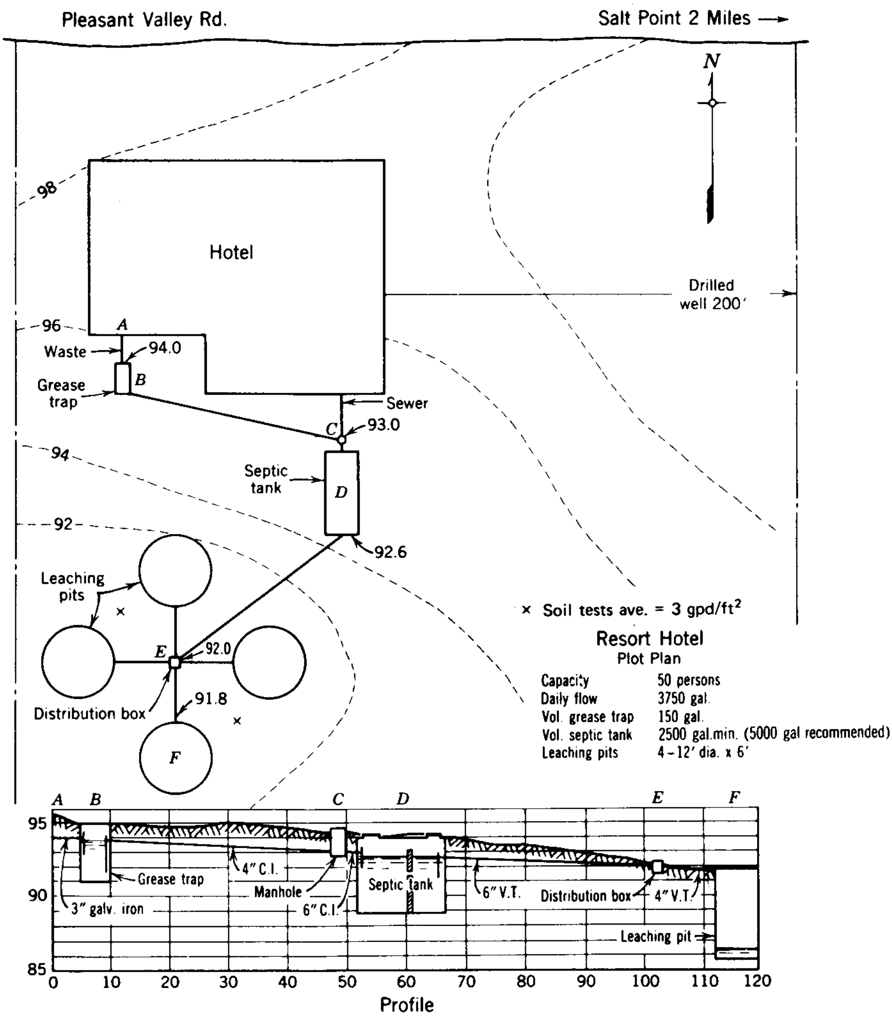


Figure 4-38 Plan and profile of hotel sewage disposal system.

4. Absorption field:

$$\frac{12{,}000}{0.5\ \text{gpd/ft}^2} = 24{,}000\ \text{ft}^2 = 12{,}000 \text{ linear feet in 24-in. trench}$$

Divide into three sections, 4000 linear ft each

5. Absorption field dose:

$$4000\ (\text{linear feet}) \times 0.653\ (\text{gal/ft 4-in. perforated pipe}) \times 0.75\ (\text{percent dose}) = 1960\ \text{gal (make pump sump ample size)}$$

6. Pump capacity: Probable flow on fixture basis using Table 4-7.

$$
\begin{aligned}
5 \text{ urinals at } 4 &= 20 \\
28 \text{ water closets at } 8 &= 224 \\
38 \text{ washbasins at } 2 &= 76 \\
27 \text{ service sinks at } 3 &= 81 \\
12 \text{ showers at } 3 &= 36 \\
4 \text{ drinking fountains at } \tfrac{1}{2} &= 2 \\
\text{Total} &= 439 \text{ fixture units}
\end{aligned}
$$

Probable maximum flow = 135 gpm. See Figure 3-26. Make pump capacity 150 gpm.

7. Controls: Provide three 150-gpm pumps, each discharging to a separate absorption field section and one standby hooked up and valved for series operation to each field. Provide high-water alarm and timer in series with motor to shut off and throw in the next pump after 13 min of continuous operations. *Notes*:
   a. No receiving stream or sewer in vicinity.
   b. If a kitchen garbage grinder is installed, increase the volume of the septic tank by 50 percent and the area of the absorption field by 20 percent and provide grease trap on kitchen waste line ahead of septic tank.

Design for a Subdivision

See Figures 4-39 through 4-41 (Imhoff tank, standard-rate filter with secondary settling):

1. Design population: 100 one-family homes = 350 persons.
2. Sewage flow: 100 gcd = 35,000 gpd.
3. Strength of sewage: 200 mg/l 5-day BOD or 0.17 lb 5-day BOD/capita.
4. Design flow: Assume total flow reaches plant in 16 hr.
5. Imhoff tank design: Required volume of settling compartment to provide $2\frac{1}{2}$ hr detention:

$$\frac{35{,}000}{16} \times 2.5 \times \frac{1}{7.48} = 732 \text{ ft}^3$$

Required sludge storage to provide 8 ft^3/capita:

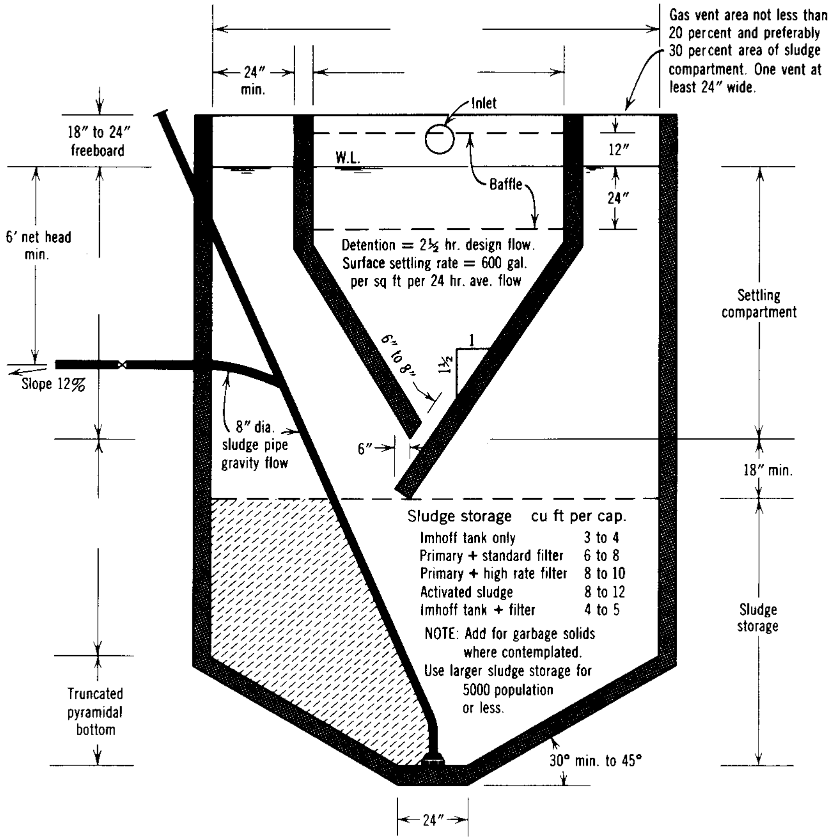


Figure 4-39 Section through Imhoff tank, with design details.

$$350 \times 8 = 2800 \text{ ft}^3$$

6. Trickling-filter design: Volume of filter stone required to provide a loading of 400 lb BOD/acre-ft/day and not more than 300,000 gpd/acre-ft. Organic loading basis, assuming 35 percent BOD removal in the Imhoff tank = x:

$$\frac{0.65 \times 200}{1{,}000{,}000} = \frac{x}{35{,}000 \times 8.34} \qquad x = 380 \text{ lb BOD/day}$$

Volume of filter stone required based on organic load = Y_1:

$$\frac{400}{43{,}560} = \frac{38.0}{Y_1} \qquad Y_1 = 4130 \text{ ft}^3$$

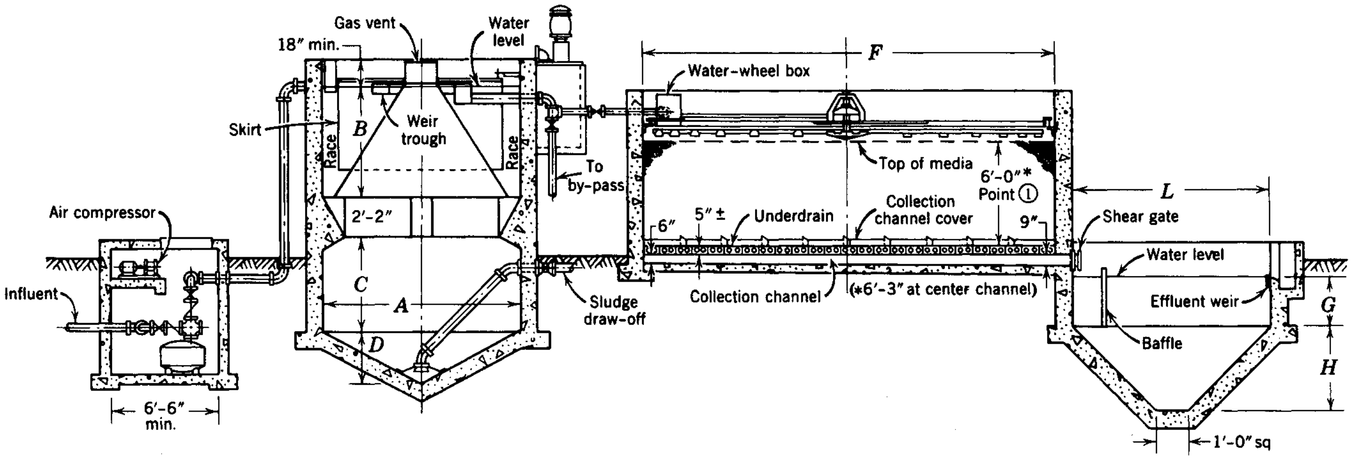


Figure 4-40 Typical arrangement of spiragester—"water-wheel" distributor system for complete treatment. (Courtesy of Yeomans Brothers Co., Melrose Park, IL.)

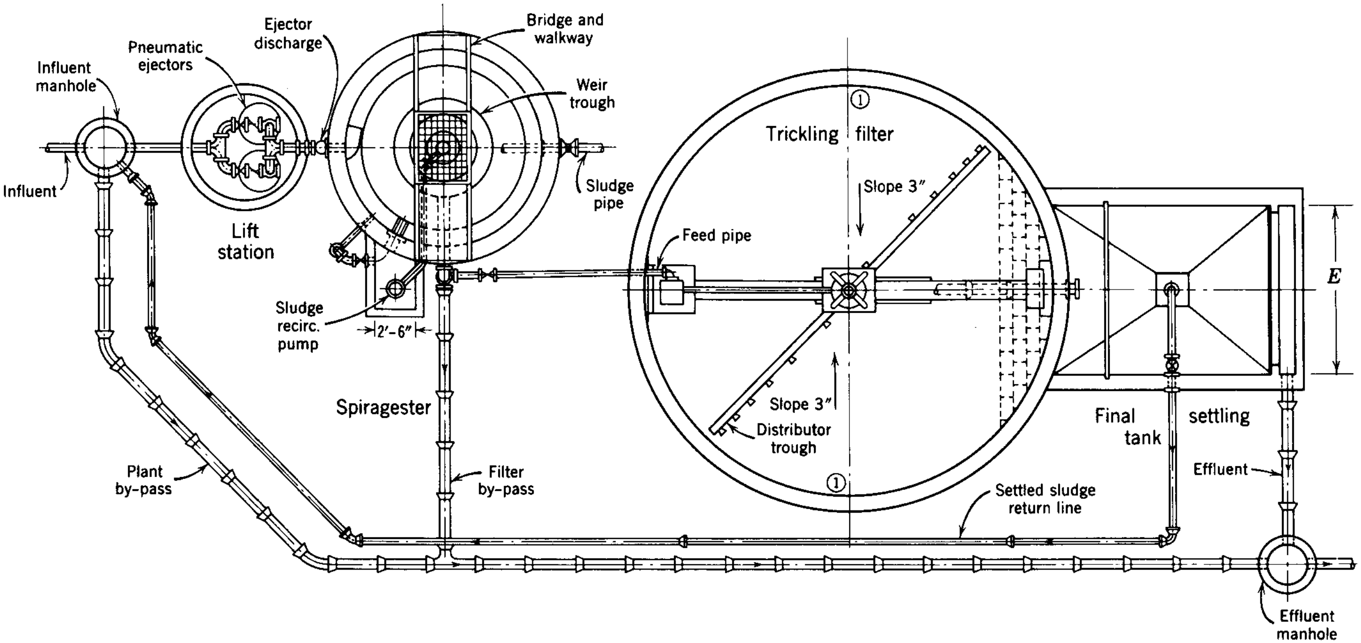


Figure 4-41 Plan view of spiragester—“water-wheel” distributor system.

Volume of filter stone required based on volumetric load = Y_2:

$$\frac{300{,}000}{43{,}560} = \frac{35{,}000}{Y_2} \qquad Y_2 = 5070 \text{ ft}^3$$

Diameter of 6-ft-deep filter to provide, say, 5000 ft^3 = D:

$$5000 = \frac{3.14 \times D^2}{4} \times 6 \qquad D = \sqrt{\frac{5000 \times 4}{3.14 \times 6}} = 32.6 \text{ ft}$$

If two filters are proposed, each filter would have a diameter equal to

$$\sqrt{\frac{2500 \times 4}{3.14 \times 6}} = 23 \text{ ft}$$

7. Secondary settling: Required volume about sludge hopper to provide 2 hr detention:

$$\frac{35{,}000}{16} \times 2 \times \frac{1}{7.48} = 585 \text{ ft}^2$$

The surface settling rate is 1000 gpd/ft^2 = 180 × tank depth/2 hr detention; depth = 11.1 ft Diameter = 8.2 ft. Make the hopper bottom for temporary sludge storage and slope the walls at 45°. Pump sludge to Imhoff tank inlet.

8. Sludge drying bed: Provide 1.25 ft^2 of open sand bed per capita. The required area is 350 × 1.25 = 438 ft^2. Provide two beds each 11 ft × 20 ft. See Design for a Small Community, this chapter, to calculate plant efficiency and effluent BOD using National Research Council (NRC) formulas.

Toll Road Service Area Design

1. Wastes containing high concentrations of grease and detergents, typical of superhighway service areas, cannot be successfully treated on sand filters unless first given adequate preliminary treatment. High concentrations of detergents cause the emulsification of grease and an increase in the amount of material in colloidal suspension, thereby resulting in a carryover of grease and solids with consequent clogging. On the other hand, if the design in a small installation provides for proper grease separation and primary septic tank treatment of two to three days, the carryover of solids is reduced. Of course, careful maintenance is essential. An Imhoff tank plant preceded by adequate grease separation, such as a septic-tank-type grease trap, has merit

in the larger installation. Septic tank subsurface absorption systems are used for small systems where soil is suitable and groundwater is not a problem.

2. Dixon and Kaufman[160] report satisfactory results if the sewage is passed through an anaerobic digestion tank before being given high-rate trickling-filter treatment with recirculation at a high ratio of final effluent to the primary settling rank following the digester. A 24-hr displacement period based on average daily sewage flow is provided in the digester maintained at a temperature of 70°F (21°C). A 40 percent BOD reduction is reported in the digester.

3. Design of service areas in connection with toll roads was based on a BOD of 500 mg/l, suspended solids of 300 mg/l, grease of 130 mg/l, and commercial detergent concentration of 350 mg/l. The following design flows were used:

Flows	Per Counter Seat	Per Table Seat
Daily average	350	150
Peak day	630	270
Extreme peak	1890	810
Minimum flow	0	0

4. Experience with superhighway service and restaurant area sewage treatment plants indicates that the design flows and sewage strengths given above are somewhat high. It also appears that because of the extreme variations in flows there is considerable advantage in the recirculation of primary and secondary settling tank effluents to the primary inlet. This would prevent the development of anaerobic conditions in these tanks and also add to the degree of treatment.

5. A Kansas turnpike sewage treatment plant design used the following criteria[161]:

Flow = 350 gpd/counter seat plus 150 gpd/table seat. Ten percent of the cars passing a service area will enter and will contribute 15 to 20 gal/person or customer. The design flow is assumed to equal the water consumption. The flow is 200 percent of the daily average at noon and 160 percent of the daily average at 6 p.m.

Sewage characteristics: BOD = 600 mg/l, suspended solids = 300 to 450 mg/l with 90 percent volatile matter, pH = 9.5, grease = 100 mg/l, active detergent = 100 mg/l, temperature = 70 to 85°F.

Treatment: To consist of comminutor, Imhoff tank with overflow rate 1000 gpd/ft^2, trickling filter loaded at not greater than 650 lb BOD/acre-ft, final settling overflow rate not greater than 1000 gpd/ft^2 based on maximum rate of raw sewage flow, continuous sludge removal, and recirculation not less than 1:1. Sand filter dosage not greater than 80,000 gpd/acre when open and 40,000 gpd/acre when covered. Sand ES 0.5 to

0.75 mm. Grease trap on kitchen waste line, three compartments and 500-gal capacity.

6. A study of New York Thruway service areas showed the following[162]:

Average water use: 9.16 gal/vehicle stopping with a range of 7.38 to 11.58.

Average stay in parking area: 30 min/vehicle, 25 min for coffee shop, and 20 min for snack bar.

Peak-hour factor: 8 percent of peak-day traffic.

Peak capacity of women's facilities: 52 persons/hr for water closet.

Rest room usage: 53 percent women at peak periods; 42.5 percent at off-peak periods.

7. Another report gives the following information[163]:

Average flow from eight service areas: 100 gpm.

Recirculation flow: 100 gpm.

Five-day BOD: 500 mg/l.

Suspended solids: 200 mg/l.

Two-stage trickling filter: recirculation through primary settling tank and directly to secondary filter for continuous dosage; raw sewage enter digester for anaerobic digestion of grease and detergents.

Removal: BOD 95 to 99 percent, suspended solids 90 to 99 percent.

Final settling tank: detention 127 min, surface settling rate 841 gpd/ft^2.

Chlorine contact time: 21 min.

Sludge drying bed: 1.1 ft^2/capita.

Combined settling digestion tank: 4.7 ft^3/capita, surface rate 568 gpd/ft^2, detention time 400 min.

Primary trickling filter: 159 gpd/ft^2, BOD 1.5 lb/yd^3.
Secondary trickling filter: 159 gpd/ft^2, BOD 0.39 lb/yd^3.

8. A study for the Federal Highway Administration[164] proposes the following design criteria:

Average daily traffic entering the rest area: 9 percent of vehicles passing by, based on six peak three-day weekends or three peak months.

Average water use per vehicle: 6.7 gal.

Sixty-seven percent of average water use occurs between 8 a.m. and 4 p.m.

Peak hourly demand: 16 percent of average daily traffic entering the rest area times average water use per vehicle.

Design wastewater flow: 5.5 gal/vehicle.

Average BOD: 125 to 175 mg/l.

Average suspended solids: 125 to 200 mg/l.

9. Aeration-type plants do not adequately handle peak flows if designed for average flows and do not handle average flows if designed for peak flows, unless the design permits operation flexibility.

SEWAGE WORKS DESIGN: LARGE SYSTEMS

General

A sewage (wastewater) treatment plant must be designed in accordance with federal and state water pollution control standards for sewage works and meet established receiving water classification.

The need for sewerage studies that take into consideration the broad principles of comprehensive community planning and environmental impact analysis is discussed in Chapter 2. Also discussed is the importance of regional and areawide sewerage planning (preliminary) that recognizes the extent of present and future service areas and alternative solutions with their first costs and total annual costs. This information is needed to assist local officials in making a decision to proceed with the design and construction of a specific sewerage system, including treatment plant. These are essential first steps to ensure that the proposed construction will meet community, state, and national goals and objectives.

The degree and type of treatment and the plant effluent limits are dependent on many factors, including the regulatory permit requirements (NPDES) and water quality standards established for the receiving water. Also important, however, is the future as well as the existing upstream and downstream water usage, the minimum stream flows,* the types of sewers and wastewater characteristics, the assimilative capacity of the receiving water,[165] nonpoint source pollutant load, and the capability of the community to finance, operate, and maintain the treatment facility as intended.

The design details of large sewage treatment and sewer systems is beyond the scope of this text. Some of the major design elements, however, are given here for general information. Federal and state regulatory agencies have recommended standards and guidelines[166] (see also EPA requirements).

A preliminary basis of design, which has been used for many years where drinking water supplies are not directly involved and other local factors are adversely affected, is given below. This dilution principle by itself is no longer acceptable in the United States.

*Minimum average 7-consecutive-day flow of the receiving stream at a recurrence interval of 10 years (MA7CD10) or the minimum average 30-consecutive-day flow at a recurrence interval of 10 years (MA3OCD10), to protect the public health.

Dilution Water Available[a]	Required Degree of Treatment	Dilution Factor[b]
3.5–5.0 ft^3/sec or more	Effective sedimentation	22.6–32.3
2.0–3.0 ft^3/sec	Chemical precipitation	12.9–19.4
1.0–2.0 ft^3/sec	High-rate trickling filters	6.5–12.9
1.0–1.5 ft^3/sec	Conventional trickling filters	6.5–8.7
0.5–1.0 ft^3/sec	Activated sludge	3.2–6.5
0.1–0.5 ft^3/sec	Intermittent sand filter	0.65–3.2

[a] Per 1000 equivalent population
[b] Based on 100 gpcd

The dilution water available is assumed to be 100 percent saturated with oxygen. Under special conditions, a lesser volume of dilution water may be sufficient to prevent the development of unsatisfactory conditions, such as when the stream has a turbulent flow or joins a larger watercourse after only a few hours flow. On the other hand, five times the given dilution may be required if flow is through a densely populated area. In the final analysis the public health hazard, aquatic stream life, usage, and classification will determine the degree of treatment required. Present opinion in the United States is that all sewage should receive a minimum of secondary treatment.

In Britain, the Ministry of Housing and Local Government reaffirmed in 1966 the Royal Commission's "general standard" as a "norm" for sewage effluents: five-day BOD 20 mg/l and suspended solids 30 mg/l with a dilution factor of 9 to 150 volumes in receiving watercourse having not more than 4.0 mg/l BOD.[167] A higher effluent standard of 10 mg/l BOD and suspended solids may be required if indicated, such as when the dilution is less than 8 or 9. For dilution of 150 to 500, a suspended solids not greater than 100 mg/l may be permitted; for dilutions greater than 500, very little treatment may be required. In any case, sewage effluents should not contain any matter likely to render the receiving stream poisonous or injurious to fish.

The EPA defined secondary treatment on June 3, 1985, as one producing 85 percent monthly removal in an effluent with a maximum monthly average of 30 mg/l and a maximum weekly average of 45 mg/l for BOD and suspended solids. Special consideration is given to treatment plants using the trickling-filter or waste stabilization pond treatment process since these types normally cannot achieve the above limits. Such plans must provide at least 65 percent removal of BOD, with effluent averages of 45 mg/l monthly and 65 mg/l BOD and suspended solids weekly.

For fecal coliform bacteria, the goal is a monthly maximum average of 200/100 ml and the weekly average 400/100 ml, which would probably require seasonal or year-round disinfection for certain water uses. The pH of the effluent shall be within the range of 6 to 9. Standards for phosphorus, oil, grease, and COD are also established. Some EPA discharge limits for certain heavy metals, in milligrams per liter, are lead 50, cadmium 10, zinc 5000, manganese 50, arsenic 50, barium 1000, chromium 50, mercury 2, selenium 10, silver 50, and copper 100. Biological monitoring using aquatic organisms is an added measure of effluent quality not measured or detectable by the usual organic and chemical parameters. See Biomonitoring in this chapter.

A stream having a flow of less than 0.1 ft^3/sec is assumed to periodically go dry. In such circumstances a suggested standard for treated wastewater effluent is 5 mg/l BOD, 10 mg/l suspended solids, and 7 mg/l dissolved oxygen, in addition to other standards or criteria that may apply. (Industrial waste is discussed at the end of this chapter.)

Sewage treatment processes and bases of design are summarized in simplified form in Figure 4-42 and Tables 4-20, 4-21, and 4-26. They are not meant to be complete. Recommended standards for the design and preparation of plans and specifications for sewage works are given in government standards and various texts. Plant efficiencies are give in Table 4-27. A secondary sewage treatment process is shown in Figure 4-43. Typical flow diagrams are shown in Figures 4-34 and 4-35.

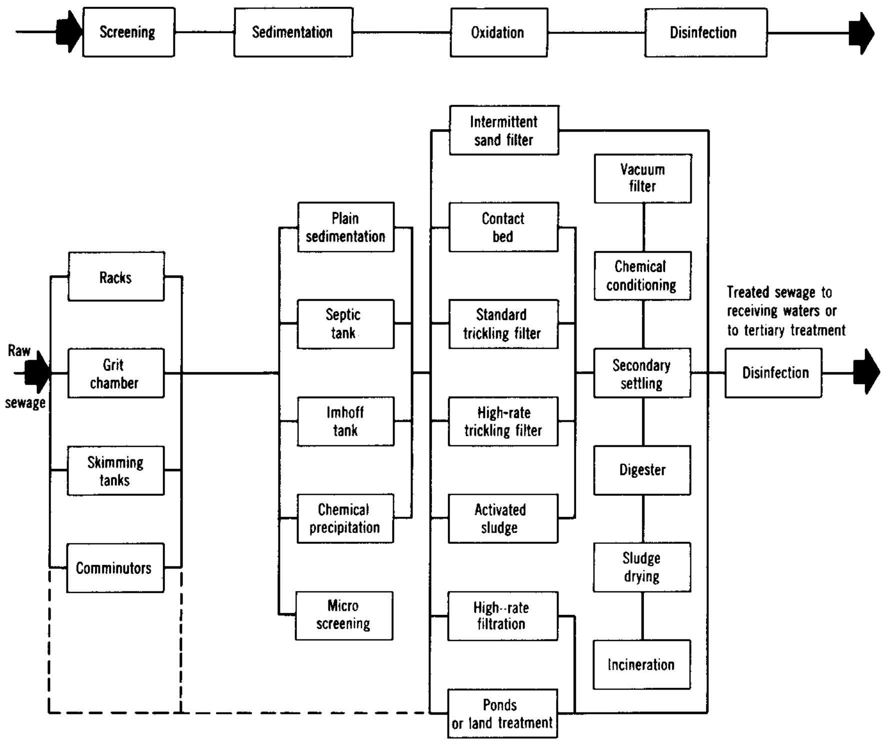


Figure 4-42 Conventional sewage treatment unit processes. Tertiary treatment may include denitrification, phosphorous removal; coagulation, sedimentation, and/or filtration; and adsorption, ion exchange, electrodialysis, reverse osmosis, or any combination of processes depending on the end use of the renovated wastewater.

Plans and Report

Plans of the area to be sewered should be complete and should include specifications and an engineering report giving the problem, objectives, and design details. The plans must be prepared by a licensed professional engineer, drawn to a scale of 1 in. equal to not less than 100 ft or more than 300, with contours at 2- to 10-ft intervals. The discussion that immediately follows deals with sanitary sewers. Combined sewers should be redesigned as separate storm and sanitary sewers insofar as possible; extensions should be separate sewers.

TABLE 4-26 Conventional Sewage Treatment Plant Design Factors

Preliminary Treatment	Coagulation and Sedimentation Treatment
Racks Area: 200% plus sanitary sewer; 300% plus combined sewer. Bar space: $1\text{–}1\frac{3}{4}$ in., dual channels.	*Sedimentation* Surface settling rates at peak flows: primary and intermediate set—tanks 1500 gpd/ft^2; final set—tanks 1200 gpd/ft^2 after trickling filters or rotating biological contactors and for activated sludge for conventional, step aeration, contact stabilization, and carbonaceous staged of separate-stage nitrification; following extended aeration 1000 gpd/ft^2; for physicochemical treatment using lime: 1400 gpd/ft^2. Weir rates: 10,000 gpd per linear foot for average flows to 1.0 mgd and up to 15,000 for larger flows Sludge hopper: 1 horizontal to 1.7 vertical. Sludge pipe: 6 in./min.
Screens Net submerged area: 2 ft^2/mgd for sanitary sewer; 3 ft^2/mgd for combined sewer. Slot opening $\frac{1}{8}$ in. min. Dual units, preceded by racks.	*Chemical Precipitation* Rapid mix, coagulation, sedimentation. Ferric chloride, ferrous sulfate, ferric sulfate, alum, lime, or a polymer.
Grit Chamber Sewage velocity: 1 fps mean, $\frac{1}{2}$ fps, minimum. Detention: 45–60 sec, floor 1 ft below outlet. Minumum of 2 channels.	*Imhoff Tank* Detention period: $2\text{–}2\frac{1}{2}$ hours. Gas vent: 20% total area of tank minimum. Bottom slope: $1\frac{1}{2}$ vertical to 1 horizontal. Sludge compartment: 3–4 ft^3 per capita 18 in. below slot; 6–10 ft^3 per capita secondary treatment. Bottom slope: 1 to 1 or 2. Slot and overlap: 8 in. Sludge pipe: 8 in. minimum under 6 ft head. Velocity: 1 fpm. Surface settling rate: 600 gpd/ft^2
Skimming Tank Air or mechanical agitation with or without chemicals. Detention: 20 min for grease removal, 5–15 min for aeration, 30 min for flocculation.	*Tube and Inclined Plate Settlers* PVC or metal tubes, at 45° 60°. from horizontal, 2 in. × 2–6 in., 4 ft long. May be installed in existing basin.
Comminutors Duplicate or bypass, downstream from grit chamber.	
Flow Basis 100 gal per capita plus industrial wastes. Usual to assume total flow reaches small plants in 16 hr.	
Flow Equalization Based on 24-hr plot to smooth out hydraulic and organic loading.	
Chemical Treatment For odor control, oxidation, corrosion control, neutralization.	

Note: Surface setting rate $= \text{gpd/ft}^2 = \dfrac{180 \times \text{tank depth in ft}}{\text{detention, hr}}$.

TABLE 4-26 (*Continued*)

See federal and state standards.

Biological Treatment

Intermittent Sand

Filter rate: 50,000–100,000 (gpad)[b] with plain settling and 400,000 gpad with trickling filter or activated sludge. Sand: 24 in. all passing $\frac{1}{4}$-in. sieve, Effective size 0.35–0.6 mm. Uniform coefficient <3.5.

Contact Bed

Filter rate: 75,000–100,000 gpad/ft.

Trickling Filter

Standard rate: 400–600 lb BOD/acre-ft/day; or 2–4 mgad,[c] 6 ft deep. High rate: 3000+ lb BOD/acre-ft/day, or 30 mgad for 6 ft deep. Minimum filter depth 5 ft, maximum 10 ft.

$1\frac{3}{4}$ ft^2 with activated sludge and 2 ft^2 with chemical coagulation. Glass covered: reduce area by 25%.

Activated Sludge

See Table 4-21. Normally 2 hr retention in primary and final sedimentation and 6–8 hr aeration.

Rapid Filtration—Tertiary Treatment

2–5 gpm/ft^2, 1–4 mm sand, 48 in., backwash 15–25 gpm/ft^2.[d]

Land Treatment

See text.

Stabilization Pond—Facultative

15–35 lb BOD/acre-ft/day, 3–5 ft liquid depth, center inlet; variable withdrawal depth, 3-ft freeboard, detention 90–180 days; multiple units; winter flow retention. Use up to 50 lb BOD loading in mild climate and 15–20 lb in cold areas. See Table 4-15.

Rotating Biological Contactors

See text.

Disinfection

Chlorine, ozone: see text.

Sludge Treatment

Digester[a]

Capacity: with plain sedimentation 2–3 ft^3 per capita heated or 4–6 ft^3 unheated. With standard trickling filter 3–4 ft^3 heated and 6–8 ft^3 unheated; 4–5 ft^3 heated and 8–10 ft^3 unheated with a high-rate filter. With activated sludge 4–6 ft^3 per capita heated and 8–12 ft^3 unheated. Bottom slope: 1 on 4, gravity.

Sludge Drying Bed

Open: 1 ft^2 per capita with plain sedimentation, $1\frac{1}{2}$ ft^2 with trickling filter.

Vacuum Filtration

Pounds per square foot per hour dry solids. Primary 6 to 10, trickling filter 1.5–2.0, activated sludge 1–2.

Centrifuging

Flow rate based on gallons per minute per horsepower.

Wet Combustion

Sludge thickener: loading of 10 lb/day/ft^2.

Land Disposal

Stabilized sludge only. See text.

Incineration

Tons per hr depending on moisture and solids content. Temperature 1250–1400°F. Pyrolysis temperature higher.

Gas Production

A properly operated heated digester should produce about 1 ft^3 of gas per capita per day from a secondary treatment plant and about 0.8 ft^3 from a primary plant. The fuel value of the gas (methane) is about 640 Btu/ft^3.

[a] Anaerobic sludge digestion will require approximately 65 days at 55°F, 56 days at 60°F, 42 days at 71°F, 27 days at 86°F, 24 days at 95°F, 20 days at 113°. The optimum temperature is 86–95°F. Mixing of sludge can reduce digestion time up to 50%. In large plants, sludge is usually digested in two stages. Temperature of 140°F causes caking on pipes.
[b] Gallons per acre per day = gpad.
[c] Million gallons per acre per day = mgad.
[d] For multimedia, see state standards.

TABLE 4-27 Sewage Treatment Plant Unit Combinations and Efficiencies: Approximate Total Percent Reduction

Treatment Plant	Suspended Solids	Biochemical Oxygen Demand
Sedimentation plus sand filter	90–98	85–95
Sedimentation plus standard trickling filter, 600 lb BOD/acre-ft maximum loading	75–90	80–95
Sedimentation plus single-stage high-rate trickling filter	50–80	35–65[a]
Sedimentation plus two-stage high-rate trickling filter	70–90	80–95[a]
Activated sludge	85–95	85–95
Chemical treatment	65–90	45–80
Preaeration (1 hr) plus sedimentation	60–80	40–60
Plain sedimentation	40–70	25–40
Fine screening	2–20	5–10
Stabilization (aerobic) pond	—	70–90
Anaerobic lagoon	70	40–70

[a]No recirculation. Efficiencies can be increased within limits by controlling organic loading, efficiencies of settling tanks, volume of recirculation, and number of stages; however, effluent will be less nitrified than from standard rate filter but will usually contain dissolved oxygen. Filter flies and odors are reduced. Study first cost plus operation and maintenance.

Sewers

The locations of the sewers, with surface elevations at street intersections and changes in grade, are indicated on the general plan. The size of sewers, outfalls, slope, length between manholes, and invert elevations of sewers and

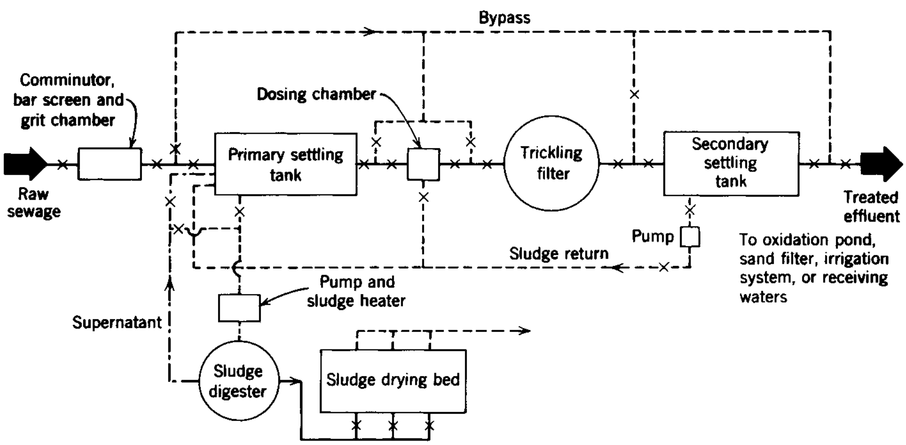


Figure 4-43 A secondary sewage treatment plant. (Units are usually in duplicate.)

manholes to the nearest 0.01 ft are also shown on the general plan, and the vertical scale is not smaller than 1 in. equal to 10 ft. Detail plans to a suitable scale are required of all appurtenances, manholes, flushing manholes, inspection chambers, inverted siphons, regulators, pumping stations, and any other devices, to permit thorough examination of the plans and their proper construction. The total drainage area and the area to be served by sewers should be shown on a topographic plan.

Sewers are usually designed for a future population 30 to 50 years hence and for a per-capita flow of not less than 400 gpd for submains and laterals and 250 gpd for main, trunk, and outfall sewers, plus allowance for industrial wastes. Intercepting sewers are designed for not less than 350 percent of the average dry-weather flow. See the local regulatory agency. Sewer systems are designed for average daily flow of not less than 100 gpd/capita.

Diameter of Sewer	Grade (percent)			Full Capacity	Population Served[a]	
(in.)	$n = 0.013$[b]	$n = 0.012$	$n = 0.011$	(mgd)	At 250 gpd/capita	At 400 gpd/capita
4	0.65	0.625	0.60	0.12		
6	0.60	0.51	0.42	0.27		
8	0.40	0.32	0.25	0.46	1840	1150
10	0.28	0.23	0.18	0.72	2880	1800
12	0.22	0.18	0.14	1.00	4000	2500
15	0.15	0.125	0.10	1.60	6400	
18	0.12	0.10	0.08	2.30	9200	
21	0.10	0.08	0.063	3.20	12,800	
24	0.08	0.066	0.053	4.00	6,800	

[a]Courtesy Kestner Engineers, P.C., Consulting Engineers, Troy, NY.
[b]At minimum slope, $n = 0.013$, velocity 2 fps; n is the value in the Manning or Kutter formula.

Street sewers should not be less than 8 in. in diameter and at a depth sufficient to drain cellars, usually 6 to 8 ft. Vitrified clay or concrete sewers are designed for a mean velocity of 2 fps when flowing full or half full, based on Kutter's formula, with $n = 0.013$. When ABS, PVC, PE, or cement- or enamel-lined cast-iron pipe is used, $n = 0.011$ or $n = 0.012$ may be used in design if permitted. In general, sewers should be laid on grades not less than those in the chart shown above.

In some special situations, there may be justification for the use of 6-in. sanitary sewers with full knowledge of the limitations.[168] Compression-type joints for pipe 4 to 12 in. in diameter are highly recommended. Vitrified clay and cast-iron pipe have a life of more than 50 years.

Manholes should not be more than 400 ft apart for 15-in. pipe or smaller and not more than 500 ft apart for 18- to 30-in. pipe. Manholes are installed at the end of each line, intersections, and changes in size, grade, or alignment.

"Y" connections should be installed for each existing and future service connection as the sewer is being laid. A tight connection must be ensured.

Inverted Siphons

Where required, inverted siphons should not be less than 6 in. in diameter or less than two in number. Sufficient head should be available to provide velocities of not less than 3 fps in sanitary sewers or 5 fps in combined sewers at average flows. Accessibility to each siphon and diversion of flow to either one would permit inspection and cleaning. An inverted siphon is used to pass under a stream, depression, or other obstruction.

Pumping Stations

Pumping plants should contain at least three pumping units of such capacity to handle the maximum sewage flow with the largest unit out of service. The pumps should be selected to provide as uniform a flow as possible to the treatment plant. Two sources of motive power should be available. Small lift stations, under 1 mgd capacity, should have duplicate pumping equipment or pneumatic ejectors with auxiliary power. All stations should have an alarm system to signal power or pump failure. Every effort should be made to prevent or minimize overflow.

In all cases raw-sewage pumps should be protected by screens or racks unless special devices are approved. Housing for electric motors above ground and in dry wells should provide protection against flooding and good ventilation, preferably forced air, and accessibility for repairs and replacements. All electrical equipment and wiring shall meet the National Electrical Code requirements. Wet wells or sump pumps should have sloping bottoms and provide for convenient cleaning. See Figure 4-33. Select water-level pump controls with care because they are the most frequent cause of pump failure.[169]

Sewage Treatment

Sewage treatment works should be designed for a population at least 10 years in the future, although 15 to 25 years is preferred, and a per-capita flow of not less than 100 gpd plus institutional wastes and *acceptable* industrial wastes. Actual flow studies, population trends and density, zoning, growth potential and other factors should govern. Plants should be accessible from highways but as far as practical from habitation and wells or sources of water supply and be protected from damage at the 100-year flood level. The required degree of treatment should be based on the water quality standards and objectives established for the receiving waters and other factors, as pointed out earlier.

The two major sewage treatment design parameters are the 5-day BOD and suspended solids of the wastewater to be treated and the removal expected in the treatment process.

The 5-day BOD is usually assumed to be 0.17 lb/capita/day and the suspended solids 0.20 lb with the average daily flow 100 gpd/capita for domestic wastes. Adjust the design basis and treatment for garbage grinders and industrial wastewater flows where indicated. Studies at 78 cities suggest 0.20 lb BOD, 0.23 lb suspended solids, and 135 gpd/capita as being more representative. Design should be based on actual wastewater strength, characteristics, and flow.[170]

Scale drawings of the units comprising the sewage treatment works, together with such other details as may be required to permit review of the design, examination of the plans, and construction of the system in accordance with the design, must be prepared and submitted to the regulatory agency having jurisdiction. Provision for measuring the flow and sampling the sewage and an equipped laboratory for examinations to control operation should be included in the original plans. The design must include adequate treatment and disinfection of the plant effluent if the receiving stream or body of water in the vicinity of the outfall is used for water supply, shellfish propagation, recreation, or other purposes that may be detrimentally affected by the sewage disposal.

Plants employing trickling filters, activated sludge, aeration, or spray irrigation and those where dried sludge is handled present a possible health hazard to plant workers and people downwind through inhalation of airborne microorganisms. See Wastewater Reuse and Aerosol Hazards, this chapter.

Biosolids Treatment and Disposal

The EPA established standards for the use and disposal of biosolids (i.e., sewage sludge and septage) in 1993.[171] These standards, which are referred to as the Part 503 Rule, set pollutant limits and operating/management guidelines for biosolids that are applied to land, placed in a surface disposal site, or fired in an incinerator.

Pollutant limits for pathogens and metals are specifically mandated under the Part 503 Rule. For biosolids that are applied to the land, limits on pathogen and metal levels must be met. Requirements for pathogens vary depending upon the type of land application. Class A pathogen requirements must be met when biosolids are applied to a lawn or home garden or given away for such a use. Under these requirements, sludge pathogens such as *Salmonella* sp. bacteria, enteric viruses, and viable helminth ova must be reduced below detectable levels. Class B pathogen requirements, which only require that pathogens be reduced to levels that are not likely to pose a threat to public health or the environment, also require compliance with various site restrictions. For example, lands receiving Class B biosolids must prohibit human access to or animal grazing of the site for a specified period of time. Similarly, crops from farmlands receiving Class B biosolids must not be harvested until a set time has elapsed after sludge application has ceased. The Class B pathogen requirements and site restrictions have to be met when biosolids are applied to farmlands, forests, public contact sites (i.e., parks or sports fields), or reclamation sites. Numerical limits for 10 metals frequently found in biosolids are also specified under the Part 503 Rule and are presented in Table 4-28.

The Part 503 Rule stipulates that various management practices must be met when biosolids are applied to the land (i.e., either sold or given away in bags for home or garden use or applied in bulk to farmlands or parks). For bagged biosolids, certain labeling requirements must be met. For bulk biosolids, prohibitions against its application on frozen or flooded ground or within 10 m of surface waters are required. The EPA also has identified a number of methods for reducing the potential for vector attraction that is frequently associated with biosolids as well as alternative methods for reducing pathogen levels.

The EPA requirements for biosolids placed in a surface disposal site vary depending upon whether the biosolids are placed in a landfill that only accepts biosolids (i.e., a monofill) or are codisposed with municipal solid waste and on whether the disposal site is lined and has a leachate collection system. In most instances, liners and leachate collection systems are only used in association with codisposal sites. For sites not having liners and leachate collection systems, biosolids must meet pollutant limits for arsenic, chromium, and nickel. These limits vary depending upon the distance between the boundary of the active biosolids disposal area and the actual property line of the disposal site. For example, the limits for arsenic range from 30 mg/kg at distances less than 25 meters up to 73 mg/kg for distances greater than 150 meters. The limits for chromium and nickel also vary in a similar fashion (i.e., 200–600 mg/kg for chromium and 210–420 mg/kg for nickel). For sites with relatively impermeable liners with hydraulic conductivity values of 10^{-7} cm/sec or less and leachate collection systems, the above limits do not apply.

TABLE 4-28 Metal Concentration Limits for Biosolids Applied to Land

Parameter	Ceiling Concentration (mg/kg)	Monthly Average Concentration (mg/kg)	Annual Loading Rate (kg/ha-yr)	Cumulative Loading Rate (kg/ha)
Arsenic	75	41	2.0	41
Cadmium	85	39	1.9	39
Chromium	N/A	N/A	N/A	N/A
Copper	4300	1500	75	1500
Lead	840	300	15	300
Mercury	57	17	0.85	17
Molybdenum	75	N/A	N/A	N/A
Nickel	420	420	21	420
Selenium	100	100	5.0	100
Zinc	7500	2800	140	2800

Note: Concentrations and loading rates are on dry-weight basis. A February 25, 1984, *Federal Register* notice deleted chromium, deleted the molybdenum values for all but the ceiling concentration, and increased the selenium limit for monthly average concentration from 36 to 100.

Biosolid disposal sites must also comply with certain siting criteria and management practices under the Part 503 Rule. For example, biosolid landfills cannot impede the flow of a 100-year flood or be located in geologically unstable areas or a wetland unless a special permit is obtained. The landfill must also be able to collect and divert runoff from a 25-year, 24-hr storm event.

The EPA requirements for biosolids that are incinerated include limits on metal concentrations and total hydrocarbons. Levels of beryllium and mercury emitted from biosolid incinerators must meet the National Emission Standards for Hazardous Air Pollutants. Arsenic, cadmium, chromium, and nickel must meet risk-specific concentrations, which range from 0.023 to 2.0 $\mu g/m^3$ and are based on a combination of biosolid feed rates, dispersion factors, and incinerator control efficiencies. Total hydrocarbon emissions from biosolid incinerators must also meet a specified limit.

Biosolid treatment and disposal can be costly and present disposal problems. Biosolid handling prior to final disposal on land, in landfills, or by incineration may involve the collection, thickening, stabilization, conditioning, dewatering, heat drying, air drying, lagooning, composting, and final disposal of the sludge.[172,173] Figure 4-35 shows some sludge treatment processes and Table 4-26 gives some treatment design parameters. Sludges, including septage (septic tank sludge), can be expected to contain numerous organic and inorganic chemicals and pathogens that can pose a hazard to agricultural produce, grazing animals, surface water, groundwater, and human health if not properly handled. Anaerobically digested sludge has been found to contain ascaris, toxocara, and trichuris ova, which remained viable in storage lagoons for up to five years.[174] *Giardia lamblia* cysts can almost always be found in raw sewage, in view of the relatively high carrier rate. Activated sludge treatment is very efficient, more efficient than trickling-filter treatment in removing the cysts. However, the cysts are concentrated in the sludge.

Biosolid thickening processes include gravity settling, flotation, and centrifugation. Biosolid stabilization is usually accomplished by aerobic or anaerobic digestion, lime treatment, or composting. Digestion results in the production of methane and the reduction of the organic solids and pathogens in the sludge. Anaerobic two-phase (first digester acid, second digester methane producer) digestion of municipal wastewater treatment sludge at 127.4°F (53°C) for 10 days "reduces to essentially undetectable levels indicator bacteria (fecal coliforms, *Escherichia coli,* fecal streptococci), enterovisuses, and viable *Ascaris* eggs,"[175] Lime treatment and composting also reduce pathogen concentrations. The sludge is usually heated and mixed to accelerate the digestion. Sludge is usually added at a rate of about 200 lb volatile solids per 1000 ft^3 per day. There are various digester mixing systems.[176]

Biosolids can be conditioned, prior to thickening or dewatering, by the addition of chemicals. Heat treatment by means of a furnace or dryer reduces the moisture content of the sludge. Dewatering is accomplished by means of drying beds, centrifuges, vacuum filters, continuous belt presses, plate and frame presses, or evaporation lagoons. The ultimate disposal and use of sludge should determine the conditioning and treatment processes selected.

Final disposal of biosolids may be composting and bagging or give-away, incineration usually by multiple-hearth or fluidized bed (Figures 4-44 and 4-45), pyrolysis, sanitary landfill,* subsurface injection, land application, land reclamation, forest application, or sod growing. Composting may be by (1) the window method, including five turnings over 15 days, with mixture temperature not less than 131°F (55°C) 6 to 8 in. below the surface maintained under aerobic conditions; (2) the aerated static pile method in which the pile is kept insulated and at a temperature of not less than 130°F (55°C) for at least three consecutive days; or (3) the enclosed vessel method in which the mixture is maintained at a temperature not less than 130°F (55°C) throughout for at least three consecutive days.[177] A sewage sludge composting process could consist of gravity thickening, polymer addition, dewatering on a belt

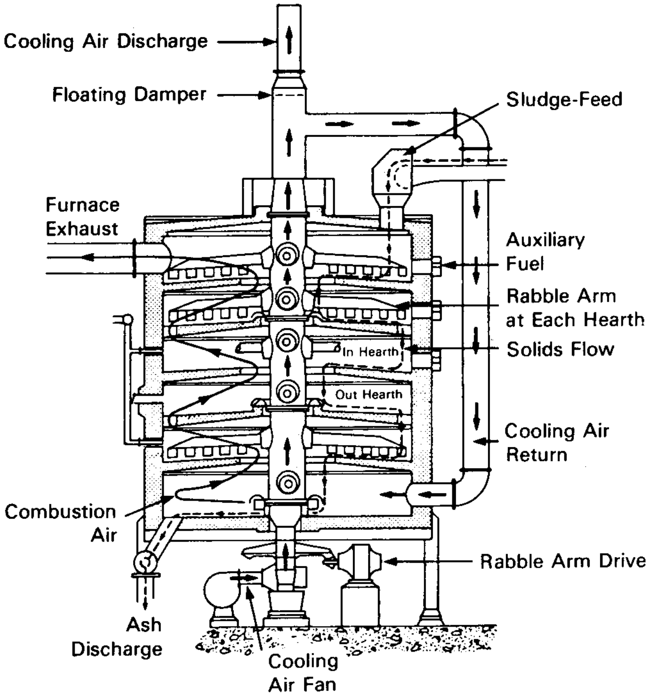


Figure 4-44 Cross section of a multiple-hearth sludge incineration furnace. Temperature 1400 to 1500°F (769–816°C) in middle hearths. (*Source: Environmental Regulations and Technology, Use and Disposal of Municipal Wastewater Sludge,* U.S. Environmental Protection Agency, Washington, DC, September 1984, p. 49.)

*Sludge dewatered to at least 20 percent solids.

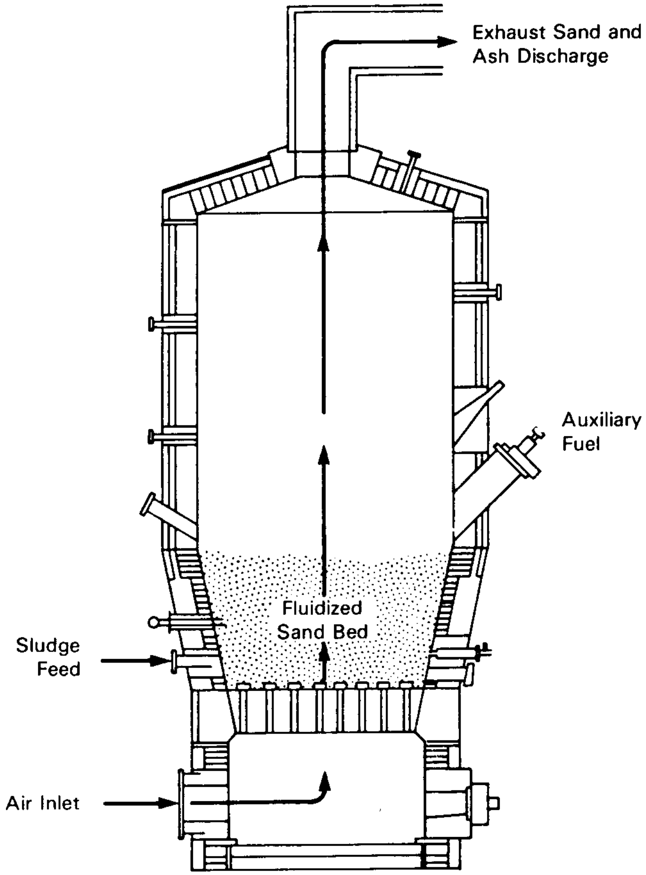


Figure 4-45 Cross section of a fluidized-bed sludge incineration furnace. Temperature of bed 1400 to 1500°F (769–816°C). (*Source: Environmental Regulations and Technology, Use and Disposal of Municipal Wastewater Sludge,* U.S. Environmental Protection Agency, Washington, DC, September 1984, p. 49.)

filter press, enclosed vessel composting, and on-ground curing. Sawdust is mixed with the finished compost. Reactor time is 14 days, and on-ground curing 8 weeks.[178]

Codisposal of biosolids with other solid wastes by means of composting and by incineration with energy recovery are also possibilities. Odor (hydrogen sulfide and ammonia) from sludge composting and storage can be controlled by passing exhaust gas through a sodium hypochlorite scrubber plus activated-carbon columns as well as through a packed-bed fiberglass tower with calcium hypochlorite spray on top.[179] All these processes require careful environmental control to prevent disease transmission, nuisances, air pollution, surface-water and groundwater pollution, and the buildup of nitrates, synthetic organics, and metals in the soil, food crops, and groundwater and must comply with Part 503 Rule requirements. Sludge disposal by incineration, pyrolysis, land application, sanitary landfill, and composting require plans and approval by the regulatory agency having jurisdiction.

Incineration can be combined with other industrial processes, such as cement manufacturing, to reduce the cost of disposal. This approach has been used by the Los Angeles County Sanitation district to dispose of a portion of the 1250 tons of biosolids that they produce each day. Since 1996, the county has an agreement with a major local cement manufacturer to provide it with between 240 and 480 tons of biosolids per day. The biosolids are injected into the cement plant's hot exhaust gases where they are completely consumed while helping to reduce air pollutant emissions from the plant. The ammonia present in the biosolids reacts with nitrogen oxides in the exhaust gases to form nitrogen, reducing plant nitrogen oxide emissions by up to 45 percent.

The disposal of stabilized sludge on the land can promote the growth of vegetation and control wind and water erosion, but certain precautions must be taken to ensure that contaminants in sludge not endanger the public health. Investigation should also include human, animal, air, groundwater, and surface-water effects of pathogenic viruses, bacteria, protozoa, helminths, and fungi as well as various heavy metals.[180] Cadmium and zinc, for example, are known to cumulate in food crops grown on sludge disposal sites, and pathogens, although reduced, can still be identified. Nitrates and metal concentration, such as for mercury, cadmium, nickel, and benzene, build up and require surveillance. To keep the risks low, the EPA has set limits under the Part 503 Rule for both maximum and average monthly metal levels that are not to be exceeded (see Table 4-28) for biosolids that are applied to the land.

Authority for implementation of the EPA Part 503 Rule biosolid disposal requirements is in the process of being delegated to the states. As of 1998, 3 states had received full authority, 7 were seeking full authority, and 16 were seeking partial authority. In addition, a number of states had imposed more restrictive limits for the specified pollutants (13 states) and required testing for additional pollutants (22 states).[181]

Ocean dumping of biosolids was prohibited after 1991 under the Ocean Dumping Ban Act. However, some authors have argued that the feasibility of ocean disposal should be reconsidered because the levels of contamination allowed in biosolids for land application are higher than those allowed for dredged sediments for ocean disposal.

Hydraulic Overloading of Sanitary Sewers and Treatment Plants

The importance of sanitary sewer inspection before backfilling has not been given sufficient emphasis. Too many properly designed plants have created problems almost as serious as those they were intended to correct due to infiltration and illegal connections. Some plant flows have been known to equal or exceed the design flow before the system is completed because of improper sewer, manhole, and house connection construction; roof, footing, basement, sump pump, and area drainage connections; street drainage and storm-sewer connections; cooling water discharges, and drainage from springs and swampy areas; and similar practices. Inspection during construction should ensure tight service connections, manholes, and sewer construction by requiring full compliance with pipe, joint, bed, and backfill specifications. Precast concrete or poured-in-place manholes with watertight joints and sewer connections are acceptable. Brick, concrete, or cinder block manholes, lined or unlined, and without reinforcement have been found unacceptable.

Combined Sewer Overflow

The average dry-weather flow of sanitary sewers is approximately equal to the discharge rate of runoff from a rainfall having an intensity of 0.01 in./hr.[182] But 0.02 to 0.03 in. of rainfall is needed to wet the ground before there is a runoff. Camp concludes that the rate of flow in a combined sewer is approximately equal to 100 times the rainfall intensity in inches per hour times the dry-weather flow, up to the capacity of the sewer.[183] Therefore, if the average dry-weather flow is 1 mgd and the rainfall intensity is 2 in./hr for a sufficient time to cause runoff from the area under consideration, the rate of flow would be 200 mgd. The economic futility of trying to design a treatment plant to treat combined sewer flows is obvious. On the other hand, combined sewers contribute significant amounts of sediment, oil, salts, and organic matter. Discharge, or overflow from combined sewers, immediately after a heavy rain may have a BOD of several hundred milligrams per liter and an MPN of hundreds of thousands of coliform organisms. Even after the initial flushing, the pollution discharge is still substantial. Hence, complete stream pollution control cannot be realized unless combined sewer and storm-sewer overflows are temporarily retained and/or adequately treated before discharge, in addition to maximization of agricultural and nonprofit sources of pollution.

On the other hand, it is believed that the discharge of diluted sewage and street drainage overflow from combined sewers to rain-swollen rivers or other bodies of water would be assimilated with transitory surface-water degradation. Combined sewers are usually found in older cities in which only the dry-weather flow is treated. Construction of combined sewers is no longer permitted. Separate sanitary sewers and storm sewers are required. The EPA has requested municipalities to identify combined sewer overflow outlets, provide storage and/or treatment, and remove floatables, *as needed,* to minimize the impact on receiving waters to an acceptable level. Combined sewer overflows require a discharge permit.

Separate Storm Sewers

In view of the pollution contributed to receiving waters by separate storm-sewer systems, the EPA developed regulations to control municipal and industrial stormwater discharges (storm sewers, drains, ditches, and stormwater runoff), as required by the Federal Clean Water Act. Stormwater flow, particularly from urban areas, and storm sewers with possibly illegal connections have the potential to degrade water quality. Under the 1987 amendments to the Clean Water Act, the EPA requires municipal stormwater systems and certain types of industrial activities (e.g., construction sites) to obtain a NPDES stormwater discharge permit. The stormwater permit program required 220 medium and large municipal stormwater systems (i.e., those serving more than 100,000 people) and operators of 11 industrial activities, which disturbed more than 5 acres and discharge stormwater runoff to surface waters, to comply with EPA stormwater regulations by 1998. Municipalities and industries covered by phase I of the program were required to submit NPDES stormwater applications and implement stormwater pollution prevention plans. These plans were to use "best management practices" such as filtering systems and infiltration/retention basins to reduce pollutant loads. Phase II of the program will expand permit requirements to include small municipal stormwater systems and selected industrial activities affecting 1 to 5 acres of land. These entities will be required to obtain NPDES stormwater permits by March 2003. In certain instances, general permits, which prescribe a common set of requirements to a group of dischargers, may be obtained. Otherwise, site-specific permits, which prescribe specific requirements for a specific discharger or group of dischargers, are required. Due to their complexity, the site-specific permits require submittal of more information on the part of the discharger.

Sanitary Sewer Infiltration and Connection Control

Infiltration flow tests in wet ground (high groundwater or wet weather) and television inspection of each line before acceptance or exfiltration flow tests in dry ground will determine compliance with specifications. The exfiltration test is a more severe test; large volumes of water are needed and must be disposed of.[184] Under a head of 2 ft of water, the exfiltration was found to be 4.8 percent greater than shown by the infiltration test; under a 4-ft head, 19.8 percent greater; and under a 6-ft head 27.3 percent greater. A low-pressure air test at 3.0 psi with air loss not greater than 0.0030 cfm/ft^2 of internal pipe surface has certain advantages and can also be used.[185]

The total leakage should not exceed 150 gpd/mi/in. of internal diameter of pipe over a 24-hr test period in a well-laid line. *Recommended Standards for Sewage Works* (see Bibliography) states that leakage shall not exceed 200 gpd/mi/in. of pipe diameter. An infiltration rate up to 1500 gpd/mi/in. may be acceptable. A figure of 200 to 400 gal/acre of sewered area per day is also used. Rubber ring joints or the equivalent on vitrified clay tile, concrete, PVC, ABS, and PE pipe and hot-poured joints in dry trenches can give good results.

A community, camp, institution, factory, school, or other establishment that constructs sanitary sewers and treatment plants should immediately set up rules and regulations prohibiting sewer connections by anyone other than responsible individuals. This must be supplemented by effective enforcement to guarantee exclusion of groundwater, surface water, rainwater, and other unauthorized wastewater from the sanitary sewer system in order to protect the investment made and accomplish the objective of the treatment plant. Sanitary sewers that, in effect, become combined sewers almost always cause backing up in basements after storms and sometimes overflow though manholes onto the street and into stores, basements, and so on, with resultant damage to oil burners, electric motors, and personal property. Cellars remain damp and become contaminated with sewage. Treatment plants become overloaded, requiring the bypassing of diluted sewage to the receiving stream or body of water, resulting in danger to water supplies, recreational areas, fish life, and property values. This, of course, nullifies in part the purpose of sewage treatment. Greater attention has been given to the proper construction of sanitary sewers and to the elimination of roof leader connections to the sanitary sewer, a major cause of hydraulic overloading.[186]

The effect of roof leader and submerged manhole flows is more fully appreciated by some comparisons. Four inches of rainfall in 24 hr can be expected in the United States roughly south of the Ohio River, once in five years. If 180 dwellings (1000 ft^2 roof area) connected their roof leaders to the sanitary sewer, the resultant flow would equal the capacity of an 8-in. line—that is, 460,000 gpd with a slope of 0.4 ft/100 ft. Six manhole covers with six vent and pick holes under 6 in. of water will also admit enough water to fill an 8-in. sewer. Sixteen manholes under 1 in. of water will do the same.

Methods used to analyze sewer infiltration and inflow include dry-weather and wet-weather sewer and plant flows and rainfall measurements, physical inspection and smoke testing, groundwater level and dye testing, internal inspection, and closed-circuit television. Smoke testing is a very effective tool to show illegal sanitary sewer connections—storm sewers, catch basins, roof leader, foundation, cellar, and yard drains as well as broken sewers, sewer connections, and manholes permitting infiltration of surface water and groundwater. Odor problems due to untrapped interior fixtures and drains are also discovered. Smoke generators or bombs are used. Homeowners and residents, the media, and the police and fire departments should be notified prior to testing.

Methods to reduce infiltration may include rehabilitation of manholes, excavation and repair of faulty building laterals and connections to the sewer, elimination of illegal connections including storm sewers, industrial cooling water, and area, basement, and roof drains. Other measures include sewer line replacement where needed, grouting and cement lining of sewer lines and joints, and polyethylene relining (sliplining) of sewer lines. When planning an infiltration control program of an existing sewer system, it is extremely important to also take into consideration and resolve the problems it may create. The very probable rise in groundwater level, the flooding of basements and the need for alternate disposal of basement and footing drains as well as roof leaders, and surface drainage that formerly found its way into the sanitary sewer are some of the factors requiring solution.[187,188] Not to be forgotten is the necessity to rigidly enforce a sanitary sewer connection ordinance. Failure to do so will only cause repetition of sewer overloading and sewage overflows and backup with the attendant health, political, social, and economic ramifications.

Odor and Corrosion Control

Hydrogen sulfide is a common odor problem associated with septic sewage and sludge handling. Industrial wastes may also carry sulfur compounds, including hydrogen sulfide, and other odorous chemicals related to certain manufacturing processes. Hydrogen sulfide is formed when anaerobic bacteria convert sulfur compounds (sulfates) in wastewater, particularly sewer slimes and sludges, to sulfide (H_2S). The formation of hydrogen sulfide in flowing sewers, usually at less than 2 ft/sec, is increased by high temperatures, long sewers, low velocities, and low pH as well as by strong sewage, high sulfate concentration, and anaerobic conditions in the submerged pipe wall slime.[189] Turbulence facilitates the release of the hydrogen sulfide, which combines with oxygen, if present, and with the moist air in the space above the flow line to form sulfur and water. The sulfur in turn is converted by thiobacillus bacteria, normally present, to sulfuric acid. The acid formed attacks metal pipe, concrete and asbestos–cement pipe, and the concrete and mortar in pipe joints and brick masonry manholes above the flow line.[190] Corrosion can be a serious problem in arid climates. Where flow velocity, high temperatures, and septicity cannot be controlled, coal-tar epoxy, epoxy resins, and glass-reinforced linings, properly applied, have been generally effective in protecting pipe.[191] Vitrified clay pipe jointed with acid-resistant material (not cement mortar), PVC, ABS, and PE pipe are all resistant to sulfuric acid attack. It should be noted that if suitable anaerobic conditions exist in the sewer, methane is also produced, which, under certain conditions, may reach explosive concentration. Hydrogen sulfide is toxic. See the discussion on safety in the next section.

Control of odors requires identification of potential odor sources and odor causes at a wastewater treatment plant and in the collecting sewer, such as noted above. The cause or source may also be related to deficiencies in plant design, operation, or maintenance or to oxygen depletion below 1 mg/l in the mains, trunk, or outfall sewers. Some industrial wastes may require pretreatment for odor control.

Odor control at a treatment plant requires cleanliness and good housekeeping at all treatment units, pumping wells, and flow channels, including prompt removal of grit and screenings, skimmings, slimes, and sludge deposits. The storage of septic sludge will result in hydrogen sulfide odors. Odor control in sewers usually depends on upstream chemical treatment if the causes of anaerobic conditions cannot be eliminated. Chemicals used in gravity flow sewers include oxygen, chlorine, hydrogen peroxide, sodium nitrate (particularly at lagoons), zinc sulfate, potassium permanganate, ferrous chloride, activated carbon, calcium carbonate (lime), and sodium hydroxide. Effectiveness is related to the specific problem and full-scale studies. Activated-carbon filters on indoor ventilating systems and filters containing potassium permanganate or activated alumina are effective in absorbing odors. Wet scrubbing and ozonation are also effective in conjunction with housing and air blowers over treatment units. If used, ozone contractors must be continuously monitored. Sometimes odor-masking or odor modification compounds are used; however, this is hazardous if toxic gases such as hydrogen sulfide are present and masked.

Oxygen as injected compressed air, in air lift, or as aspirated (air alone or in conjunction with hydrogen peroxide) and commercial oxygen are used in gravity sewers and force mains to neutralize sulfide and prevent sulfide buildup. The EPA and others have made exhaustive studies of sulfide and odor control in sewers and plants.[192,193] Hydrogen sulfide does not form in aerobic waters.

Chlorination of sewage to remove hydrogen sulfide present and inhibit bacterial action is also commonly used for odor control. Dosage ranges from 10 to 50 mg/l in sewer systems and from 10 to 20 mg/l for plant prechlorination.[189] Chlorine may be added as calcium or sodium hypochlorite or as liquid chlorine.

Hydrogen peroxide can oxidize a number of toxic and noxious substances in wastewater, particularly hydrogen sulfide. It is an excellent source of dissolved oxygen; it attacks anaerobic organisms that produce sulfides; and hydrogen sulfide and mercaptans are readily oxidized. Industrial-strength hydrogen peroxide comes in 50 and 35 percent solutions (70 percent solution is hazardous).[194] Hydrogen peroxide has also been found effective in neutralizing hydrogen sulfide odors resulting from a pond gone septic. Hydrogen peroxide (50 percent) was injected in the pump discharge to recirculated pond water.[195] The addition of hydrogen peroxide upstream from a wastewater treatment plant, under controlled conditions, was found to be effective in eliminating hydrogen sulfide odors in wastewater.[196] Doses of 1 and 2 mg/mg of sulfide present have been found adequate.[189] The theoretical addition is estimated at four to eight parts hydrogen peroxide per part of sulfide.[192] A dosage of 40 mg/l was found adequate to control odors resulting from oxygen-deficient sludge from an activated sludge plant.[197] Potassium permanganate is also effective in removing hydrogen sulfide from sludge when added prior to sludge dewatering.

Sodium nitrate at the rate of 10 lb for each pound of sulfide in wastewater and oxidation ponds has been successful for odor control.[189] Maintenance of a scum blanket on the surface of an anaerobic lagoon was effective in eliminating and maintaining control of odor problems.[198] A dosage of 7.6 kg ferrous chloride per 1.0 kg sulfide provided acceptable sulfide and odor control in a long interceptor in a warm climate.[199]

Little hydrogen sulfide is present at a pH above 8 to 9. The addition of calcium carbonate or sodium hydroxide to achieve that pH level will control hydrogen sulfide as well as other odors.

With sludge incineration, an exhaust gas temperature of 1500 to 1600°F (816–871°C) is necessary to effectively oxidize or burn off the offending odors. An alternative for odor control is passage of the gas through a wet scrubber tower using sodium hypochlorite and sodium hydroxide. Objectionable odors have also been removed by passing the gas through a soil or compost bed 3 to 10 ft deep.

A recent innovation in the realm of odor control is the use of UV light oxidation. In a 1997 test, UV units were found to have higher removal efficiencies at a lower cost for odor-causing hydrogen sulfide, total reduced sulfur, and volatile organic compounds than two other conventional technologies (i.e., catalytic carbon and packed towers) that are used in odor control.

Safety

Gases in sewers, manholes, wet wells, lift stations, digesters, and other unventilated or confined spaces associated with sewerage systems (and other utilities) may be poisonous, asphyxiating, or explosive. The poisonous and asphyxiating gases include hydrogen sulfide, sulfur dioxide, chlorine, carbon dioxide, carbon monoxide, and volatile gases from industrial wastes entering the sewers. The explosive types, which may also burn, include methane, gasoline vapor, hydrogen sulfide, hydrogen, ammonia, carbon monoxide, and combinations of various sewer gases. An oxygen-enriched atmosphere (above 21 percent) will cause flammable materials, such as clothing and hair, to burn violently when ignited.[200] Methane is produced in sewers under anaerobic conditions. Sewers may also carry very corrosive, highly volatile, hazardous liquids from industrial plants.

Hydrogen sulfide can be very toxic. The permissible maximum 8-hr occupational exposure level is 20 ppm, but 50 ppm for only 10 min exposure.[201] The NIOSH recommends that an area be evacuated if the concentration of hydrogen sulfide exceeds 50 ppm.[202] The NIOSH recommends a ceiling of 10 ppm (for 10 min).[203] About half the deaths are would-be rescuers.[204] Methane is explosive in the range of 5 to 15 percent by volume. The oxygen concentration should be 20 percent by volume (air contains 20.94 percent), not less than 19.5 percent.[200] Carbon dioxide as low as 6 percent can be fatal in less than 1 hr. Carbon monoxide is a common asphyxiant. The permissible OSHA 8-hr exposure level is 50 ppm. Note that hydrogen sulfide is heavier than air, methane is lighter than air, and carbon monoxide is the same as air.

Workers should not enter manholes, pump pits, or other enclosed spaces unless first assured that the space is thoroughly ventilated, that safety precautions are taken, and that calibrated detection equipment is used for oxygen and toxic gases. Smoking in the vicinity of manholes or other enclosed spaces should, of course, be prohibited. A first step is the lowering of a calibrated gas detector at different levels (to measure the concentration of methane, hydrogen sulfide, oxygen, or other gas suspected of being present) with alarm into the work area to determine its safety; the detector should remain in place until all work is completed. The manhole or other confined or limited-access space should be ventilated with a blower and *kept in operation* with the blower hose extending to within 3 ft of the work space bottom. The worker entering the manhole should carry an emergency air pack, for immediate use in case the detector alarm goes off, and wear a full-body harness. The harness is connected to a pulley and tripod that is supervised by two other workers. In some instances, an air pack with a breathing mask connected to an air hose and air cylinder is used if a sufficient supply of air is not available. A self-contained breathing apparatus with a 45-min air supply is used for rescue operations.[205] Continuous hazardous gas monitoring systems for sewage treatment facilities can detect the presence of methane and hydrogen sulfide, the lack of oxygen, and the concentration of carbon monoxide and flammable gas. The equipment includes portable, work area, and remote audio and visual indicators of unsafe conditions. Concern for safety must be combined with accident prevention training, including safe work practices, elimination of unsafe conditions, electrical safety, proper hazardous chemical handling, firm supervision, and current effective emergency response plans.[200,206,207] See also Care of Septic Tank and Subsurface Absorption Systems (Safety and Other Precautions) earlier in this chapter and *Safety* in the Index. The involved reader is urged to obtain and be guided by the safety references given here as well as by occupational health and safety requirements.

Cost of Sewage Treatment and Sewerage

Cost estimates can vary widely because of location, labor and materials costs, volume of construction, season of the year, local characteristics, state of the economy, and degree of treatment required. In general, the cost can be divided into two parts: (1) treatment and collection and (2) operation and maintenance. Financing methods are discussed in Chapter 2. Cost estimates can be adjusted to present-day costs using the *Engineering News-Record* or other appropriate construction cost index. (See Table 4-30 below.)

To arrive at the total project construction cost, it is necessary to add to the construction cost 10 to 15 percent for contingencies; call this *A*.* Then add 15 to 20 percent of *A* for engineering costs and 2 to 3 percent of *A* for legal and administrative costs; call this *B*. An additional cost is financing during construction, about 3 percent of *B* making a total of *C*, plus interest during

**A* is the total construction cost plus contingencies.

construction, about 3 percent of *C*, depending on the cost of money. Therefore, the total project cost can result in adding 36 to 48 percent to the construction cost. The added cost components can be expected to vary depending on the preliminary planning, cost of a project, and its complexity.

Suggested general design periods for sewers and treatment plans and capacities are given earlier in this chapter and by regulatory agencies. The actual design period, however, should be related to the projected growth and land use of the tributary area, the cost of the additional sewer and treatment capacity, interest rate, and the local institutional arrangement.

Sewage Treatment Costs Comparison of sewage treatment costs should consider the total annual costs—that is, the initial cost of construction and the cost of operation and maintenance (O&M). This includes the annual principal and interest to pay off the bond issue, the cost of site development, engineering and legal fees, and the annual cost of operation and maintenance. The total cost of sewer service would be the cost of treatment plus the cost of all sewers, manholes, lift stations, and house connections.

Construction, annual, and unit costs of sewage treatment are given in Table 4–29. The economy of scale is very apparent. Economic comparison formulas are given in Appendix II.

Sometimes advanced wastewater treatment (AWT; Figure 4-35) is desired or required without fully realizing the large additional total cost to obtain a small incremental increase in plant efficiency. Advanced wastewater treatment to remove an additional 3.8 to 10 percent BOD, 5.2 to 13 percent suspended solids, and approximately 61 to 68 percent phosphorus and ammonia–nitrogen was found to increase capital costs by 42 to 99 percent and O&M costs by 37 to 55 percent.[208] This suggests that the other more cost-effective alternatives should be explored where advanced wastewater treatment is requested, if in fact it is actually needed.

Many wastewater treatment operators have already installed computer-based monitoring and control systems in an effort to reduce their operational costs. However, the recent Internet revolution has offered additional means for not only accessing real-time operational data but also managing work and purchase orders and customer relations and billings more efficiently.

Because of the risk-averse nature of treatment plant operators—and regulators—implementation of such management innovations has been slow. As noted in a 1998 Environmental Law Institute report, treatment plant operators are generally slow to install innovative technologies whether they be management tools like the Internet or technological innovations, such as ozonation, UV disinfection, enzyme treatment, or biological nutrient removal.

Sewerage Costs* The approximate costs (2000 adjusted cost) of sewers, manholes, pumping stations, septic tanks, absorption trenches, and related appurtenances are given below. This information is for guidance and com-

*The assistance of Kestner Engineers, Troy NY, is gratefully acknowledged in arriving at the cost estimates.

TABLE 4-29 Estimated Total Annual and Unit Costs for Alternative Treatment Processes with a Design Flow of 1.0 Mgd

Process	Initial Capital Cost ($2000)[a,b]	Annual Cost[b] ($2000)			Unit Cost (cents/1000 gal)[b]
		Capital[c]	O&M[d]	Total	
Imhoff tank	1,030,000	113,084	42,070	155,154	42.5
Rotating biological disks	2,170,000	238,244	156,570	394,814	108.1
Trickling-filter processes	2,440,000	267,888	158,740	426,628	116.9
Activated sludge processes					
With external digestion	2,710,000	297,531	201,200	498,731	136.6
With internal digestion[e]	1,360,000	149,314	132,460	281,774	77.2
Stabilization pond processes[f]	680,000	74,657	64,280	138,937	38.1
Land disposal processes[g]					
Basic system	920,000	101,007	112,760	213,767	58.6
With primary treatment	2,550,000	279,965	221,330	501,295	137.3
With secondary treatment	3,370,000	369,537	314,730	682,267	186.9
Land disposal processes					
Basic system[h]	540,000	59,287	68,130	127,417	34.9
With primary treatment	2,170,000	238,244	176,710	508,350	139.2
With secondary treatment	2,710,000	297,531	270,110	567,641	155.5

Source: G. Tchobanoglous, "Wastewater Treatment for Small Communities," in *Water Pollution Control in Low Density Areas*, W. J. Jewell and R. Swan (Eds.), University Press of New England, Hanover, NH, 1975, p. 424. Reprinted from *Water Pollution Control in Low Density Areas,* edited by William J. Jewell and Rita Swan, by permission of University Press of New England. © 1975 by Trustees of the University of Vermont.

[a] Estimated average cost.
[b] Based on *Engineering News-Record* (ENR) Building Cost index of 1900. Original costs (1975) were adjusted to 2000 costs using ENR index.
[c] Capital recovery factor = 0.10979 (15 years at 7%).
[d] Average (2000) values for process O&M costs are based on 1975 costs multiplied by 271% (i.e., ratio of 2000 and 1975 ENR index values).
[e] Extended aeration, aerated lagoon, oxidation ditches.
[f] High-rate aerobic, facultative, and anaerobic.
[g] Irrigation and overland flow.
[h] Infiltration–percolation.

parative purposes only in view of the many variables encountered in practice. Table 4–30, as updated, will be found useful in making costs adjustments and comparisons.

Manhole, precast (4 ft diameter)	0–8 ft deep each	$1500–2000
	8–10 ft	1600–2200
	10–12 ft	1800–2300
	12–14 ft	2200–2600
Drop inside manhole	—	100–200
8-in. sewer, ABS or PVC	0–8 ft cut, per ft	30–40

TABLE 4-30 Cost Indices (Average per Year)

Year	Marshall & Stevens Installed Equipment Indices: 1926, 100 (All Industry)	*Engineering News-Record* Construction Index: 1913, 100	Handy-Whitman Index for Water Treatment Plants[a]: 1936, 100		*Engineering News-Record* Building Cost Index: 1913, 100	Chemical Engineering Plant Construction Index: 1957–1959, 100	EPA Sewage Treatment Plant Construction Index: 1957–1959, 100
			Large Plant	Small Plant			
1950	168	510	210	213	375	74	
1951	180	543	225	229	401	80	
1952	181	569	235	235	416	81	
1953	183	600	246	246	431	85	
1954	185	628	251	251	446	86	
1955	191	660	258	257	469	88	
1956	209	692	275	276	491	94	
1957	225	724	288	289	509	99	
1958	229	759	296	296	525	100	102
1959	235	797	311	309	548	102	104
1960	238	824	317	317	559	102	105
1961	237	847	315	315	568	101	106
1962	239	872	324	322	580	102	107
1963	239	901	330	327	594	102	109
1964	242	936	340	336	612	103	110
1965	245	971	350	346	627	104	112
1966	252	1019	368	362	650	107	116
1967	263	1070	380[b]	374[b]	672	110	119
1968	273	1155	398	389	721	114	123
1969	285	1269	441	424	790	119	132
1970	303	1385	480	462	836	126	143

1971	321	1581	948	132	160
1972	332	1753	1048	137	172
1973	344	1895	1138	144	182
1974	398	2020	1204	165	217
1975	444	2212	1306	182	250
1976	472	2401	1425	192	262
1977	491[c]	2577	1545	199[d]	271[d]
1978		2776	1674		
1979		3003	1819		
1980		3159	1932		
1981		3500	2100		
1982		3800	2240		
1983		4050	2380		
1984		4160	2420		
1985		4200	2440		
1986		4290	2480		
1987		4450	2580		
1988		4600	2660		
1989		4680	2680		
1990		4760	2740		
1991		4854	2757		

TABLE 4-30 (*Continued*)

Year	Marshall & Stevens Installed Equipment Indices: 1926, 100 (All Industry)	*Engineering News-Record* Construction Index: 1913, 100	Handy-Whitman Index for Water Treatment Plants[a]: 1936, 100		*Engineering News-Record* Building Cost Index: 1913, 100	Chemical Engineering Plant Construction Index: 1957–1959, 100	EPA Sewage Treatment Plant Con struction Index: 1957–1959, 100
			Large Plant	Small Plant			
1992		4992			2845		
1993		5252			3038		
1994		5409			3107		
1995		5484			3114		
1996		5617			3190		
1997		5863			3392		
1998		5921			3382		
1999		6076			3460		
2000		6225			3545		
2001		6404			3625		

Source: Process Design, Wastewater Treatment Facilities for Sewered Small Communities, EPA-625/1-77-009 U.S. Environmental Protection Agency, Environmental Research Information Center Technology Transaction, Cincinnati, OH, October 1977, p. 17-9; also *Engineering News-Record,* March 20, 1980, p. 113.

Note: Index 1981–1990 approximate; see source. Example: 1990 index ÷ 1980 index = multiplier to obtain 1990 cost for a 1980 project cost.

[a] Based on July of year.
[b] Based on January of year.
[c] Based on first quarter of year.
[d] Based on March of year.

pipe (installed):*	8–10 ft	34–42
	10–12 ft	38–43
	12–14 ft	42–47
	14–16 ft	46–51
Y branch	—	52–78
6-in. house service pipe	—	23–27
8-in. sewer, ductile iron pipe	0–8 ft cut, per ft	38–43
	8–10 ft	42–47
	10–12 ft	46–48
	12–14 ft	49–55
	14–16 ft	53–59
	—	57–66
Rock excavation, per yd^3	Blasting	90
		40
	Soft rock	
	Air hammer	420
Restoring gravel and shoulder pavement, per yd^2	—	12
Restoring asphalt–concrete pavement, per ton	—	110
Top soil and seeding, per yd^3	—	10–16
Pumping station, below ground, including standby generator, dehumidifier, sump pump, and all necessary controls	1.0–3.0 mgd	228,000–338,000
	0.25–1.0	163,000–228,000
	0.05–0.25	137,000–159,000
Pumping station, above ground, including building and all necessary controls and equipment	—	566,000–683,000
Submersible pump station—small	—	\$33,000–52,000

The above costs are based on construction on unencumbered land. Where sewers are to be installed in an existing built-up area served by electricity, gas, streets, and perhaps water, the total cost of an 8-in. sewer including manholes and repairs may run to \$80 to \$120 per foot using ABS or PVC pipe.

Septic Tank Systems The cost of an individual septic tank absorption system will vary with the size of the dwelling, local conditions, and type and size of the absorption or treatment system. Approximate costs estimates (2000), including labor and material, are given for rough comparisons:

*Polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), and polyethylene (PE) are resistant to sulfuric acid attack. Check with manufacturer regarding internal abrasive wear.

Septic tank precast (delivered)	750 gal	$488
	1000 gal	520
	1250 gal	667
	2000 gal	1170
		630
Grease trap same as for septic tank		
Excavation for septic tank or grease trap		$195–310
Leaching pit or dry well, within 8-in. washed stone, precast units, including cover; inside diameter		
4 ft diameter and 5 ft deep		$600–650
6 ft diameter and 9 ft deep		955–1030
8 ft diameter and 5 ft deep		915–980
Distribution box: 3 outlets		50
6 outlets		60
8 outlets		90
10–12 outlets		135
Extension collar for septic tank or distribution box, 24-in. diameter per ft		42
Sheeting and bracing, left in place, per ft^2		25
Absorption trench, including perforated pipe and 12-in. washed stone, per ft:		
24-in. trench		9
30-in. trench		10–12

Type of System	O&M ($/year)	Initial cost (2000 adjusted)
Septic tank—absorption system	43	$2925–3250*
Septic tank—built-up absorption system (excluding pumping station)	43	15,600–22,100†
Septic tank—subsurface sand filter, including chlorine and contact tank	59	10,400–13,650‡
Aerobic system—excluding absorption field: including service contact[209] (estimated updated costs)	675	8320–18,200
Chemical recirculation toilet[210] (updated costs)	—	7800–11,700
Incinerator toilet	—	2200–2500
Composting toilet—excluding gray water	7	3400–6600

* 3-bedroom home. *Note:* Septic tanks pumped out every 3 years.
† 9,000 to 10,000 ft^2
‡ 390 to 520 ft^2

The assistance of the Division of Environmental Health, Albany County Health Department, in estimating septic tank system unit costs is gratefully acknowledged.

LOW-COST SANITATION

Problem

The population of developing countries has been estimated at 1721 million in 1970 and 2280 million in 1980. However, only about 20 percent had "adequate" excreta disposal facilities such as a public sewer, privy, septic tank system, or bucket latrine in 1970.[211] Cultural, social, economic, and institutional factors as well as hygiene education and community participation in project planning, construction, and maintenance play an extremely important role in obtaining user acceptance and maintenance of sanitary latrine facilities in developing countries. In many instances, experience has shown that the technologies employed have not been appropriate.

The U.S. Bureau of the Census found that, in 1990, 76,455,211 (75 percent) housing units were served by public sewers; 24,670,877 (24 percent) by septic tanks, cesspools, or chemical toilets; and 1,137,590 (1 percent) by other facilities. Sixty-five million people depended on septic tank, cesspool, or septic toilet systems, and almost 2 million depended on other individual facilities.[212] This does not include facilities at highway rest areas, parks, camps, and family vacation homes. The 1971 Census of Canada[213] showed that 17.0 percent of the 6.0 million dwellings were served by septic tanks and 9.6 percent by other on-site disposal facilities.

Public sewers and treatment plants are not necessarily the indicated or universal solution for all situations, particularly in developing areas of the world. Their construction, operation, maintenance, and repair costs can be prohibitive or impractical.[214] The unavailability of piped water, scattered housing, local customs, and slow economic and technological development may make low-cost alternative methods of excreta and wastewater disposal more feasible at a particular point in time when coupled with a plan for sequential improvements. These include the various types of privies and latrines designed for eventual upgrade to waterborne sewerage. Communal facilities for groups of homes are not, as a rule, maintained in a clean and sanitary condition and are not recommended. They may be suitable at public places if the responsibility for proper maintenance can be established. See WHO publications.[215–218]

Privies, Latrines, and Waterless Toilets

Many types of privies, latrines, and waterless toilets have been in use all over the world for many years. If properly located, constructed, and maintained, they can be acceptable, economical, and sanitary devices for the disposal of human excreta where waterborne sewage disposal systems are not provided or not practical and particularly for temporary installation. The suitability, location, construction, and maintenance of various types of privies and latrines are summarized in Table 4-31. Figures 4-46, 4-47, and 4-48 illustrate essential design and construction features.

In developing countries, where pit latrines are constructed, they should be planned and designed to promote their conversion to aqua privies, pour-flush latrines, septic privies, or septic tanks. It would be preferable, if this is possible, to construct a concrete block or poured concrete vault in the first instance with a tee outlet. A leaching pit, soaking pit, or absorption trench could then be easily added as water supply became more readily available, indoor plumbing is added, and people's social aspirations change. Eventually, the pit or trench could be abandoned and connection made to a small-diameter or conventional community sewer and treatment plant.[219,220]

Biological additives, bacteria, or enzymes do not appear to eliminate odors and reduce mass. Proper vault and latrine cleanliness, coupled with improved ventilation including a minimum 4 in. diameter vent carried 18 in. above the roof, will minimize odors.

Low-Cost Treatment

Studies show that waterborne sewage disposal systems including an oxidation pond can be provided at a cost that compares very favorably with a removal pail privy system.[221–223] Where aqua privies (with retention tanks) are acceptable, it is possible to collect the tank effluents and carry or conduct the wastewater to an oxidation pond for treatment. Operation is improved by connecting the laundry tub, the shower, and washbasin drains to the aqua privy to maintain the water seal, thus preventing odors and fly and mosquito breeding. Since solids are removed in the aqua privy tank, 4-in. sewers designed for a flow velocity of 1 fps may be used. The flat grade makes reduced excavation cost possible, but odors may be a problem. A 4-in. sewer designed for 15 gpd/capita and for peaks three times the mean flow can serve a population of up to 1000. Oxidation ponds can also be used for the disposal of night soil. A loading of 145 lb BOD/acre/day appears reasonable. Conventional oxidation pond or lagoon design details have been given earlier. Other low-cost systems include land treatment systems such as irrigation systems and oxidation ditches.

In China, tightly sealed excreta vats have been used for many years to store excreta for use as fertilizer. The vats produce ammonia and albuminoid nitrogen under anaerobic conditions, which is reported to kill parasite ova and thereby reduce transmission of parasitic and infectious diseases. It was required that the vats be moved away from river banks to prevent water contamination. A later development was the three-compartment fermentation-settling tank. These tanks permit the ova (schistosome, ascaris, and hook-

TABLE 4-31 Sanitary Excreta Disposal Methods

Facility	Suitability	Location
Sanitary earth pit privy	Where soil available and groundwater not encountered; earth mounded up if necessary to bring bottom of pit 2 ft above groundwater or rock	Downgrade, 100 ft or more from sources of water supply; 100 ft from kitchens; within 50–150 ft of users; at least 2 ft above groundwater; 50 ft from lake, stream
Masonry vault privy	To protect underground and surface-water supplies	Downgrade and 50 ft or more from sources of water supply; 100 ft from kitchens; within 50–150 ft of users
Septic privy (Lumsden, Roberts, and Stiles: LRS privy)	Where cleaning of pit is a problem, odors unimportant, and water limited	Same as pit privy
Excreta disposal pit	For disposal of pail privy and chemical toilet contents	Downgrade and 200 ft from sources of water supply; 100 ft from kitchen
Chemical toilet (cabinet and tank type)	A temporary facility; to protect water supply, where other methods impractical; temporary camp, vehicle, boat	May adjoin main dwelling; tank type same as masonry vault privy; cabinet type usually within facility
Incinerator toilet	Where electricity or gas available; airplanes, boats, fairgrounds, camps	Within facility
Recirculating toilet		Within facility
Removable pail privy (bucket latrine) (portable toilet)	A temporary facility; to protect water supply, where pit privy impractical; for large gatherings; developing areas.	Same as masonry vault privy
Portable box, earth pit, latrine	At temporary camps	Same as pit privy' Army recommends latrine 100 yd from kitchens
Bored-hole latrine	In isolated place or when primitive, inexpensive, sanitary facility is needed.	Same as earth pit privy

TABLE 4-31 (*Continued*)

Facility	Suitability	Location
Straddle trench latrine	At temporary camp for less than 1 day	Same as earth pit privy
Cat hole	On hikes or in field	Same as earth pit privy
Squatting latrine	Where local conditions and customs permit	Same as pit privy
Recirculating oil[a] flush toilet	Where water is unavailable or soil unsuitable	Within facility
Aqua privy	Where water is limited and local customs permit	Same as pit privy
Composting toilet	To conserve water; to convert excreta and garbage (food waste) to humus	Storage chamber in basement or adjacent to house

Construction	Maintenance
Deep pit; insects, rodents, and animals excluded; surface water drained away; cleanable material; attractive; ventilated pit and building. Pit 3′ × 4′ × 6′ deep serves average family 3–5 years.	Keep clean and flytight; supply toilet paper. Apply residual fly spray to structure. Natural decay and desiccation of feces reduce odors. Keep wastewater out. Scrub seat with hot water and detergent. Use commercial seat.
Watertight concrete vault; flytight building; cleanable material; ventilated vault and building. Capacity of 6 ft^3 per person adequate for 1 year.	Keep clean, flytight, and attractive. Supply toilet paper. Apply residual spray. Clean pit when contents approach 18 in. of floor. Scavengers can be used.
Watertight vault with tee outlet to leaching pit, gravel trench, filter, vault, etc. Provide capacity of 250 gal plus 20 gal for each person over 8 years.	Add 1–2 gal of water per seat per day. Keep clean and flytight. Supply toilet paper. Agitate after use. Clean vault when depth of sludge and scum is 12–18 in.
Shored pit with open-joint material; tight top and access door	Keep flytight and clean. Drain surface water away.
Same as masonry vault privy. Tank may be heavy-gauge metal with protective coating. Provide capacity of 125–250 gal per seat. Cabinet-type seat and bucket usually prefabricated.	Use $\frac{1}{4}$ lb lye for each ft^3 of vault capacity made up to 6-in. liquid depth in vault, or 25 lb caustic per seat in 15 gal of water. Keep clean. Clean vault when two-thirds to three-fourths full.[b] Agitate after each use. Empty bucket in pit or sewer.
Enclosed compartment, vent, and blower	Keep clean and supply toilet paper.

Enclosed prefabricated unit, with filter and hand or mechanical pump	Keep clean. Empty contents in approved facility and recharge with chemical.
Same as masonry vault privy. Provide easily cleaned pails. Available as prefabricated unit.	Provide collection service, excreta disposal facility or pit, and cleaning facilities, including hot water (backflow preventer), brushes, detergent, drained concrete floor.
Earth pit with portable prefabricated box	Same as earth pit privy. Provide can cover to keep toilet tissue dry.
Bored hole 14–18 in. diameter and 15–25 ft deep with bracing if necessary. Seat structure may be oil drum, box, cement, or clay tile riser with seat or use squatting plate. Platform around hole.	Same as earth pit privy. Line upper 2 ft of hole; in a caving formation line hole to support earth walls.
Trench 1 ft wide, $2\frac{1}{2}$ ft deep, and 4 ft long for 25 men	Frequent inspection. Keep excreta covered. Provide toilet paper with water proof cover.
Hole about 1 ft deep	Carefully cover hole with earth.
Similar to privy or bored-hole latrine. See Fig. 4-46.	Same as privies and latrines
Special unit with tank, mineral oil, filter, chlorine, Teflon-coated bowl	Replace mineral oil and chlorine crystals every 6 months; remove sludge as needed.
Squatting plate or hopper over tank, same as septic privy	Keep clean. Maintain water seal in tank about 4 in. above bottom of plate or hopper drop pipe. See sketch.
Watertight tank with sloping bottom and chutes to kitchen and to toilet room	Tank needs heat (70°F), moisture, and aeration to operate properly. Humus removed after 2–4 years. No wastewater.

Criteria: Confines excreta; excludes insects, rodents, and animals; prevents contamination of water supply; provides convenience and privacy; clean and odor free.

Note: If privy seat is removable and an extra seat is provided, it is easier to scrub seats and set aside to dry. A commercial plastic or composition-type seat is recommended in place of improvised crudely made wooden seats. Deodorants that can be used if needed include chlorinated lime, cloroben, iron sulfate, copperas, activated carbon, and pine oil. Keep privy pits dry.

[a] May be wastewater receiving complete treatment.

[b] Solutions for chemical toiulets include lye (potassium hydroxide), caustic soda or potash (sodium hydroxide), chlorinated lime (1 lb in $2\frac{1}{2}$ gal water), and copper sulfate (1 lb in $2\frac{1}{2}$ gal water). Handle chemicals with care.

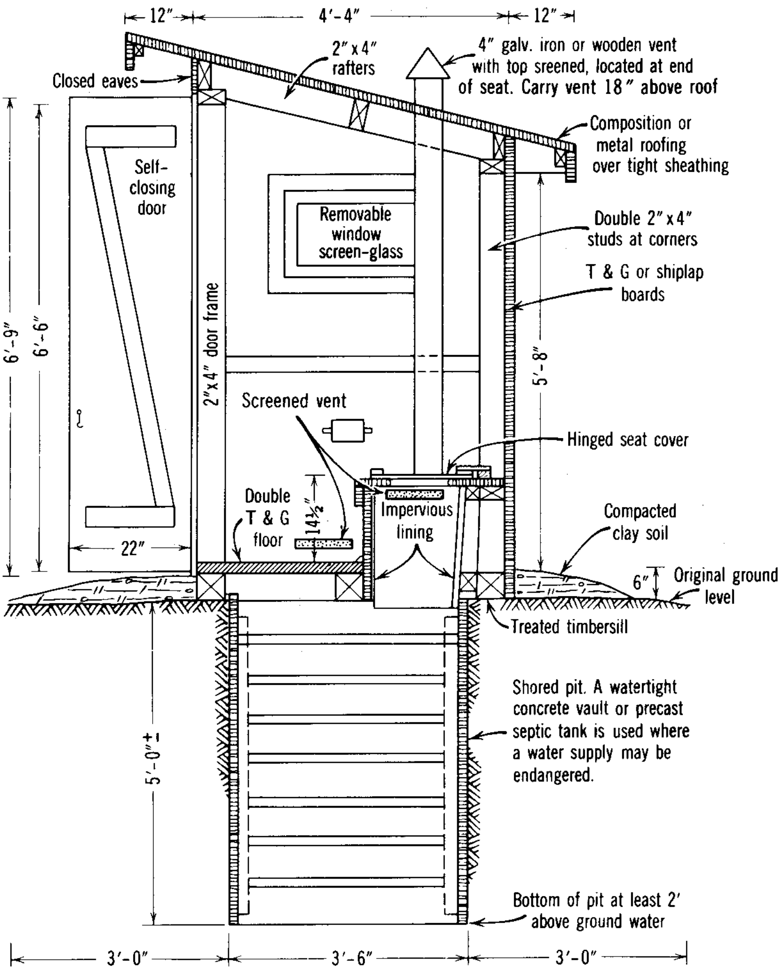


Figure 4-46 Construction details of a sanitary earth pit privy. Privy construction may also be concrete or cinder block, brick, stone, or other masonry, with reinforced concrete floor and riser. Make privy 3-ft wide for one seat or 6 ft wide for two seats. Locate privy within 150 ft of users, 100 ft or more from kitchens, 50 ft from any lake or waterhouse, and not in direct line of drainage to or closer than 200 ft of any water supply.

worm) to settle out in about 30 days. The number of eggs was reduced 90 to 100 percent.

The latest development is the biogas tank. These tanks are tightly sealed and permit fermentation and settling of excreta, livestock manure, crop stalks, weeds, and tree leaves. About 60 percent of the gas produced is methane with a heat value of 5500 to 6500 kcal/m^3. The methane from a family unit is used for cooking. The management of human excreta together with protection

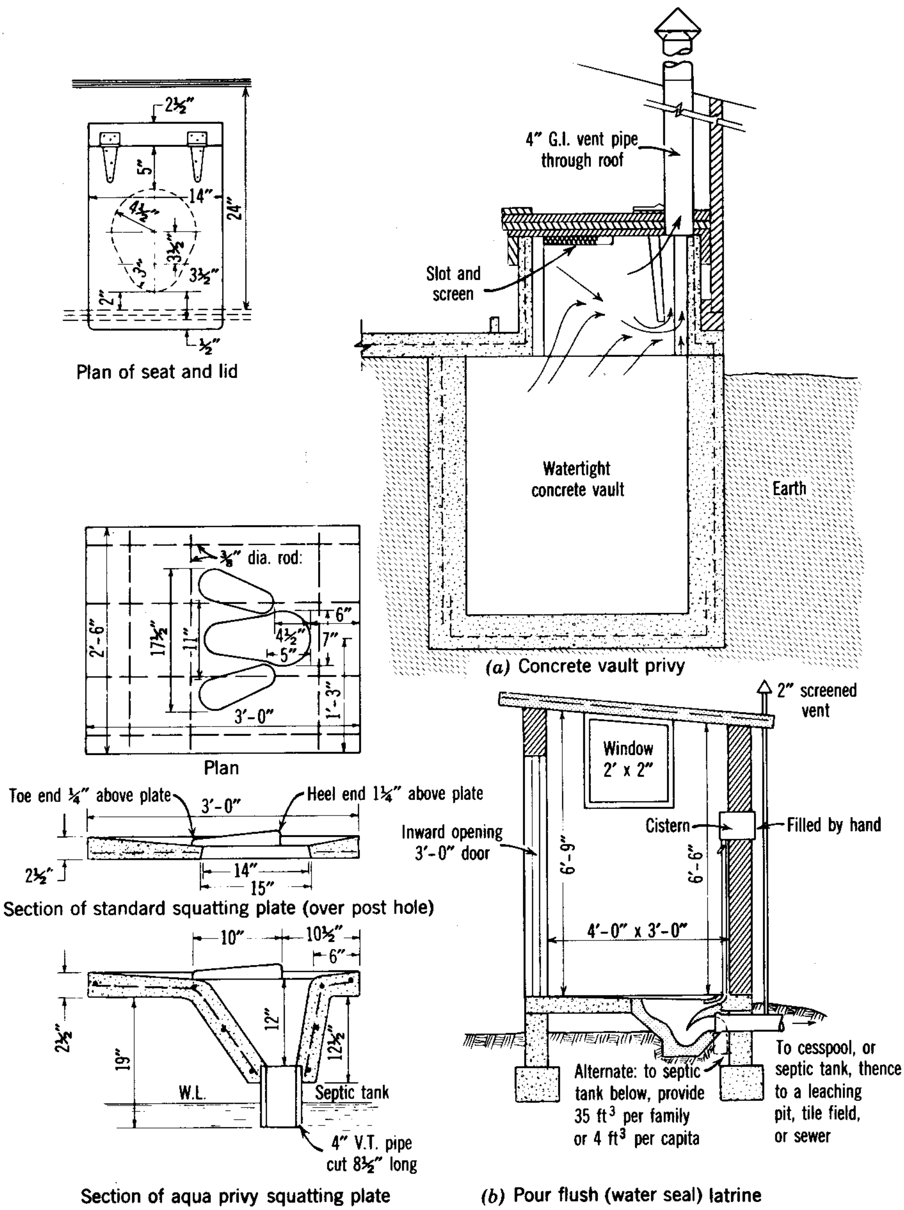


Figure 4-47 (*a*) Concrete vault and (*b*) squatting-type latrines. (Squatting latrine types adapted from O. J. S. Macdonald, *Small Sewage Disposal Systems,* H. K. Lewis, London, England, 1951.)

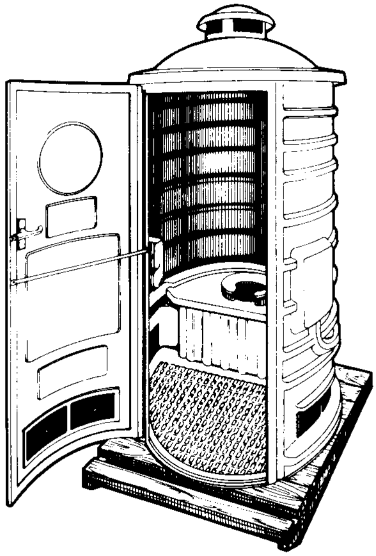


Figure 4-48 Portable toilet. (*Source: Environmental Health Practice in Recreational Areas,* Department of Health, Education, and Welfare, Public Health Service, Washington, DC, 1977, p. 26.)

of drinking water sources, food sanitation, and other measures has played a role in controlling and eliminating enteric diseases.[224]

See Table 3-14 for estimated water usage in developing areas of the world.

INDUSTRIAL WASTES

Industrial Wastewater Survey and Waste Reduction

The design of new plants should incorporate separate systems for sewage, cooling water, industrial wastes, and stormwater or surface-water drainage. In some cases, a combination of sewage and liquid industrial waste is possible, but this is dependent on the type and volume of waste and sludge produced. At an existing plant and at a new plant, a flow diagram should be made showing every step in a process and every drain, sewer, and waste line. Dye or temperature tests will help confirm the location of flows. Radioactive isotopes or chemical tracers might also be used under controlled conditions. Where pipelines are exposed, they can be painted definite colors to avoid confusion. In general, clean water from coolers, roof leaders, footing and area drains, and ice machines can be disposed of without treatment. Water conservation such as the use of cooling towers and recirculation of the water, use of air-cooled exchangers, process modification, and industrial wastewater pretreatment, reclamation, and reuse will reduce the wastewater problem.

If cooling water is heated, direct discharge to a stream may affect the biological life and the dissolved oxygen of the stream. The impact must be mitigated. All municipalities are required to have industrial wastewater pretreatment programs and comply with effluent limitations to protect receiving waters.

A knowledge of the industrial process is fundamental in the study of a waste problem. The volume of flows from each step in a process, the strength, chemical characteristics, temperature, source, and variations in flow are some of the details to be obtained. Product recovery should receive primary consideration. The existing or proposed methods of disposal and opportunities for wastage, drippage, and spillage should be included. Sometimes revision of raw material or a chemical process can eliminate or reduce a waste problem. Possible waste control measures are salvage, in-plant waste reduction, reclamation and reuse, concentration of wastes, flow equalization, use of separators, and filters. The recovery of materials such as copper, cadmium, aluminum, iron, and silver or liquids with specific gravity less than or greater than wastewater from industrial wastes can help industry meet effluent standards and offset some of the treatment costs. All of these possibilities should be evaluated. Industrial waste cooperative waste exchange for certain wastes has great potential.

Hazardous and Toxic Liquid Wastes

Hazardous wastes have been defined in Public Law 94–580, The Solid Waste Disposal Act, and by the EPA. These wastes are usually the byproducts of the chemical industry, which, if not recovered, require proper treatment and disposal. Toxic wastes are chemical substances that present an unreasonable risk of injury to public health or the environment. A toxic substance[225] is one that kills or injures an organism through chemical, physical, or biological action, having an adverse physiological effect on humans. Examples include cyanides, pesticides, and heavy metals. The terms *toxic* and *hazardous* are sometimes used interchangeably.[226]

Dilution per se cannot be accepted as the means to solve a pollution problem. Treatment requirements should meet effluent standards, water quality standards of the receiving waters, and, if discharged to a municipal system, the requirements of the publicly owned wastewater treatment plant. Water quality should not be degraded but rather restored to and maintained in its natural state. Toxic substances must be reduced to the point they are not toxic to human, other animal, or aquatic life. In this regard, effluent analyses should consider ''whole-effluent toxicity,'' and perhaps several suspected toxics, as it is usually impractical to analyze routinely for all the individual unknown toxic chemicals. As in BOD measurement, we do not analyze for each constituent that contributes to oxygen demand; hence, we should not as a rule have to measure for each constituent that contributes to overall toxicity. Additive, antagonistic, and synergistic effects should also be recognized.

The EPA has published national recommended water quality criteria for 157 toxic pollutants pursuant to Section 304(a) of the Clean Water Act and more may be added in the future. These criteria are used by states as the basis for setting water quality standards. These standards are also used in a number of federal and state environmental programs, including their use in setting discharge limits for the NPDES permits. Steam biomonitoring, using small aquatic invertebrate animals that live on the stream bottom, is also useful to assess water quality in flowing waters.

The Clean Water Act requires designated states and authorities operating pretreatment programs to notify industrial and commercial users of hazardous wastes of their responsibilities under the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). However, hazardous wastes when mixed with sewage are excluded from RCRA requirements but are regulated under the Clean Water Act pretreatment programs. Since the federal and state requirements are quite complex, persons affected should become informed. The EPA has numerous regulations governing industrial waste pretreatment. As a rule, waste disposal must not transfer a hazardous waste from one environmental medium (land, air, water) to another.

Pretreatment

Industrial and commercial wastes that are hazardous or that cannot be treated by the municipal treatment plant must be excluded unless given adequate pretreatment. Also to be excluded are synthetic organic wastes and inorganic wastes that interfere with operation or treatment; are toxic; are ignitable; emit hazardous fumes; damage the wastewater treatment plant, pumping stations, or sewer system; endanger personnel; are explosive; pass through the treatment process; or contaminate sewage sludge. Toxics of priority concern generally include mercury, cadmium, lead, chromium, copper, zinc, nickel, cyanide, phenol, and PCBs[227] as well as oil and grease and possibly cobalt, iron, and manganese. In addition, other metals and numerous organics may be prohibited or regulated. In some instances, the joint treatment of industrial wastes and municipal wastewater may be mutually advantageous and should be considered on an individual basis.[228] Municipalities must develop and enforce their own pretreatment programs.

A method of simplifying a waste problem is to spread its treatment and disposal over 24 hr rather than over a 4- or 6-hr period. This can be accomplished through the use of a holding tank to equalize flows and strength of waste, accompanied by a constant or proportional discharge over 24 hr. Where needed, aeration will prevent septic conditions and odors. If necessary, chemical mixing can be incorporated to pretreat or neutralize a waste, followed by settling and uniform drawoff of supernatant by means of a flexible or swing-joint pipe. The pipe may be lowered uniformly by mechanical means such as a clock mechanism or motor, or a float with a submerged orifice may be used, to give the desired rate of discharge. The mass diagram approach may be used to determine the required storage to give a constant flow over a known length of time. Sludge, which may contain heavy metals, is drawn from the hopper bottom of the settling tank to a drying bed or a treatment device before disposal.

Separate Treatment or Discharge to a Municipal Plant

After investigating all possibilities of preventing or reducing the wastewater problem at the source, including raw material and process changes, waste volume and toxicity reduction, and waste recovery and reuse, the next step would be provision of the required degree of treatment, based on existing laws and standards and competent engineering advice. Receiving waters' classification, minimum average 7-consecutive-day flow once in 10 years of the receiving stream, and effluent standards (permit requirements) will largely determine the type and degree of treatment required for direct discharge to a stream or a municipal treatment plant. Black[229] proposed that the approving agency consider the following items in its review of engineering reports, plans, and specifications for industrial waste treatment systems.

Engineering Report (Part I)

- Project delineation:
  1. Type of industry
  2. Waste pollution load
  3. Receiving waters
  4. Waste treatment requirements
  5. Waste abatement plans
  6. Map of environment
  7. Plot plan and hydraulic profile
- Plant and process description:
  8. General description of factory
  9. Description of principal wet processes
  10. Process flow diagram showing sources of liquid waste
  11. Sewer map and process connections
  12. Liquid waste control measures
  13. Experimental and new processes
  14. Byproduct recovery systems
- Factory operations:
  15. Finished products and processes
  16. Production in 24 hr—rated and actual
  17. Principal raw materials
  18. Sources of water supply
  19. Water quantity and quality requirements

20. Process water reuse
21. Employees, shifts, days per week
22. Expansion—planned and potential

- Development of design criteria:

23. Comprehensive industrial waste surveys
24. Parameters specific for the industry
25. Segregation of cooling water
26. Diversion of stormwater
27. In-Plant improvements and waste reduction
28. Waste characterization and treatability studies
29. Pilot plant investigations
30. Avoidance of nuisance to the environment
31. Design liberal and flexible

- Combined treatment with domestic waste:

32. Standards and regulations for controlling the use of municipal sewers
33. Pretreatment at the factory
34. Surcharge agreements
35. Industrial effluent monitoring systems
36. Influence on sewage treatment efficiency

Engineering Report (Part II)

37. Solids removal and disposal
38. Chemical precipitation
39. Chemical treatment
40. Aerobic biological treatment
41. Anaerobic biological treatment
42. Role of incineration
43. Alternate proposals
44. Chronological steps for submission

The types of industrial wastes are of course numerous. Treatment processes, such as mentioned above, may vary from recovery, solids removal, and disposal to involved physical, chemical, and biological processes. Possibilities for recovery of waste oils include separators, air flotation, and ultrafiltration. Methods for the recovery of metals include evaporation, reverse osmosis, ultrafiltration, and ion exchange. Treatment of organic waste might consist of biological or chemical processes, activated-carbon filtration, or air stripping. Possible solids removal processes include sedimentation, chemical treatment, and filtration. The sludge collection will require special handling, possibly further treatment such as dewatering, disposal to an approved facility, or incineration. More detailed information concerning the treatment of specific wastes can be obtained from standard texts, periodicals, and other publications devoted to this subject.[230,231]

See Hazardous Wastes, Chapter 5, for additional discussion of this subject, including treatment and disposal.

Strength of Waste A common method of expressing the strength of organic wastes is in milligrams per liter or parts per million of five-day BOD, suspended solids, and chlorine demand as well as pH. Another parameter is the COD. These are by no means the only measures of waste strength, as the particular waste and its characteristics must be considered. Specific organic, inorganic, and bioassay tests may also be indicated. For example, pollutants in effluents measured at textile plants discharging to streams may include chromium, COD, sulfides, total phenols, BOD, total suspended solids, and pH.

The BOD of an organic waste is frequently converted to its population equivalent. Since the waste from one person is said to equal 0.17 lb of five-day BOD, the population equivalent X of, say, 1000 gal of a waste having a BOD of 600 mg/l is expressed by the proportion

$$\frac{600}{1{,}000{,}000} = \frac{X(0.17)}{1000 \times 8.34} \quad \text{or } X = 29 \text{ persons}$$

To determine the suspended-solids population equivalent, substitute 0.20 for 0.17.

The actual volume and strength of a waste should be individually determined. Many municipalities levy a charge for the handling and treatment of industrial wastes to help pay the cost of operating and maintaining the municipal treatment works. The basis for rental or assessment of cost should be volume and strength of the waste as determined by periodic analyses. Measures used are COD, BOD, chlorine demand, certain organic and inorganic compounds, and other parameters. It is also common to require pretreatment in case the characteristics of waste exceed certain predetermined values; if the waste as released may damage the facility, upset the treatment process, or is not amenable to treatment in a municipal treatment plant; and if the waste would cause a hazardous condition in the sewers or create a water quality problem in the receiving water.

The Water Environment Federation manuals of practice (see Bibliography) suggest standards and recommendations for local sewer ordinances, treatment of industrial wastes, and plant operation. The manuals provide sound regulations to exclude hazardous materials, protect sewers, and control the discharge of wastes to the sewer that may upset the municipal treatment plant operation. Unacceptable wastes include large volumes of uncontaminated wastes that may cause hydraulic overloading, stormwaters, acid and alkaline wastewaters, explosive and flammable substances, toxic substances, large volumes of organic wastes unless adequately pretreated, oil, and grease.

In the United States, national guidelines for industrial wastes generally prohibit disposal solely by dilution.

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5 Solid Waste Management

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Aesthetic, land-use, health, water pollution, air pollution, and economic considerations make proper solid waste management an ongoing concern for municipal, corporate, and individual functions that must be taken seriously by all. Indiscriminate dumping of solid waste and failure of the collection system in a populated community for two or three weeks would soon cause many problems. Odors, flies, rats, roaches, crickets, wandering dogs and cats, and fires would dispel any remaining doubts of the importance of proper solid waste management.

Solid waste management is a complex process because it involves many technologies and disciplines. These include technologies associated with the generation (including source reduction), on-site handling and storage, collection, transfer and transportation, processing, and disposal of solid wastes. All of these processes have to be carried out within existing legal, social, and environmental guidelines that protect the public health and the environment and are aesthetically and economically acceptable. To be responsive to public attitudes, the disciplines that must be considered in integrated solid waste management include administrative, financial, legal, architectural, planning, environmental, and engineering functions. For a successful integrated solid waste management plan, it is necessary that all these disciplines communicate and interact with each other in a positive interdisciplinary relationship.

In the material that follows, the major issues involved with the management of solid waste are presented and discussed. These issues include the elements of integrated solid waste management; the sources, characteristics, and quantities of solid waste; on-site storage and handling, solid waste collection; transfer and transport; waste reduction, recycling, and processing; composting; sanitary landfill planning design and operation; and incineration and haz-

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0-471-41813-7

ardous waste. However, before discussing these topics, it will be useful to define the terminology used in the field of solid waste management. Additional details on solid waste management may be found in the U.S. Environmental Protection Agency (EPA) (1989, 1995b), Tchobanoglous et al. (1993), Hickman (1999), and Tchobanoglous and Kreith (2002).

DEFINITION OF TERMS

To understand the elements and technologies involved in integrated solid waste management it is useful to define some of the more commonly used terms (Salvato, 1992).

Ash Residue All the solid residue and any entrained liquids resulting from the combustion of solid waste or solid waste in combination with fossil fuel at a solid waste incinerator, including bottom ash, boiler ash, fly ash, and the solid residue of any air pollution control device used at a solid waste incinerator.

Biodegradable Material Waste material capable of being broken down, usually by bacteria, into basic elements. Most organic wastes, such as food remains and paper, are biodegradable.

Commercial Waste Solid waste generated by stores, offices, institutions, restaurants, warehouses, and nonmanufacturing activities at industrial facilities.

Composting The controlled biological decomposition of organic solid waste under aerobic (in the presence of oxygen) conditions. Organic waste materials are transformed into soil amendments such as humus or mulch.

Fly Ash The ash residue from the combustion of solid waste or solid waste in combination with fossil fuel that is entrained in the gas stream of the solid waste incinerator and removed by air pollution control equipment.

Garbage Putrescible solid waste including animal and vegetable waste resulting from the handling, storage, sale, preparation, cooking, or serving of foods. Garbage originates primarily in home kitchens, stores, markets, restaurants, and other places where food is stored, prepared, or served.

Geomembrane An essentially impermeable membrane used with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a man-made structure or system designed to limit the movement of liquid or gas in the system.

Geonet A type of a geogrid that allows planar flow of liquids and serves as a drainage system.

Geotextile Any permeable textile used with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a man-made structure or system designed to act as a filter to prevent the flow of soil fines into drainage systems, provide planar flow for drainage, serve as a cushion to protect geomembranes, or provide structural support.

Groundwater Water below the land surface in the saturated zone of the soil or rock. This includes perched water separated from the main body of groundwater by an unsaturated zone.

Hazardous Waste Defined in this chapter.

Incinerator A facility designed to reduce the volume and weight of solid waste by a combustion process with or without a waste heat recovery system. Auxiliary equipment provides feed, ash handling, and environmental controls.

Industrial Waste Solid waste generated by manufacturing or industrial processes. Such waste may include, but is not limited to, the following manufacturing processes: electric power generation; fertilizer/agricultural chemicals; inorganic chemicals; iron and steel manufacturing; leather and leather products; nonferrous metals; explosives; manufacturing/foundries; organic chemicals; plastics and resins manufacturing; pulp and paper industry; rubber and miscellaneous plastic products; stone, glass, clay, and concrete products; textile manufacturing; transportation equipment; and water treatment. This term does not include oil or gas drilling, production, and treatment wastes (such as brines, oil, and frac fluids); overburden, spoil, or tailings resulting from mining; or solution mining brine and insoluble component wastes.

Infectious Waste Includes surgical waste from a patient on isolation; obstetrical waste from a patient on isolation; pathological waste; biological waste from a patient on isolation; discarded materials from treatment of a patient on isolation; waste discarded from renal dialysis, including needles and tubing; discarded serums and vaccines that have not been autoclaved; discarded laboratory waste that has come in contact with pathogenic organisms not autoclaved or sterilized; animal carcasses exposed to pathogens in research, their bedding, and other waste from such animals that is discarded; and other articles discarded that are potentially infectious, that might cause punctures or cuts, and that have not been autoclaved and rendered incapable of causing punctures or cuts. [See Centers for Disease Control and Prevention (CDS), EPA, and state definitions.]

Integrated Solid Waste Management A practice of disposing of solid waste that utilizes several complementary components, such as source reduction, recycling, composting, waste-to-energy, and landfill.

Leachate A liquid resulting from precipitation percolating through landfills containing water, decomposed waste, and bacteria. In sanitary landfills, leachate is collected and treated to prevent contamination of water supplies.

Municipal Solid Waste Includes nonhazardous waste generated in households, commercial establishments, institutions, and light industrial wastes; it excludes industrial process wastes, agricultural wastes, mining wastes, and sewage sludge.

Photodegradable A process whereby the sun's ultraviolet radiation attacks the link in the polymer chain of plastic. The breaking of this link causes the plastic chain to fragment into smaller pieces, losing its strength and ability to flex and stretch. As the photodegradable plastic is subjected to the effects of the natural environment, the material is flexed, stretched, and disintegrated into plastic dust.

Recycling A resource recovery method involving the collection and treatment of a waste product for use as raw material in the manufacture of the same or another produce (e.g., ground glass used in the manufacture of new glass).

Residuals Sludge, sewage sludge, septage, air pollution control facility waste, or any other such waste having similar characteristics or effects and solid waste remaining after the processing of solid waste by composting methods that was not made into compost suitable for use.

Resource Recovery A term describing the extraction and utilization of materials that can be used as raw material in the manufacture of new products or as values that can be converted into some form of fuel or energy source. An integrated resource recovery program may include recycling, waste-to-energy, composting, and/or other components.

Sanitary Landfill A method of disposing of solid waste on land without creating nuisances or hazards to public health or safety. Careful preparation of the fill area, including the use of clay and/or synthetic liners and control of water drainage, is required to ensure proper landfilling. To confine the solid waste to the smallest practical area and reduce it to the smallest practical volume, heavy equipment is used to spread, compact, and cover the waste daily with at least 6 in. of compacted soil. After the area has been completely filled and covered with a final 2- or 3-ft layer of soil and seeded with grass, the reclaimed land may be turned into a recreational area such as a park or golf course. Sanitary landfills have leachate collection systems, methane gas controls, and environmental monitoring systems.

Solid Waste Includes any garbage, solid waste, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations and from community activities but does not include solid or dissolved material in domestic sewage or solid or dissolved materials in irrigation return flows or industrial discharges, which are point sources subject to permit under Section 402 of the Federal Water Pollution Act (as amended), or source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954, as amended. Also excluded are agricultural wastes, including manures and crop residues returned to the soil as fertilizers or soil conditioners and mining or milling wastes intended for return to the mine.

Solid Waste Management The systematic administration of activities that provide for the collection, source separation, storage, transportation, transfer, processing, treatment, and disposal of solid waste.

Source Reduction Refers to reducing the amount of waste generated that must eventually be discarded, including minimizing toxic substances in products, minimizing volume of products, and extending the useful life of products. Requires manufacturers and consumers to take an active role in reducing the amount of waste produced.

Source Separation The segregation of various materials from the waste stream at the point of generation for recycling. For example, householders separating paper, metal, and glass from the rest of their wastes.

Transfer Station A facility with structures, machinery, or devices that receives deliveries of solid waste by local collection vehicles and provides for the transfer of the waste to larger vehicles that are used to deliver the waste to a recycling, treatment, or disposal site.

Waste-to-Energy Incineration Disposal method in which municipal solid waste is brought to a plant where it is burned either as received or after being processed to a more uniform fuel to generate steam or electricity. Waste-to-energy plants can decrease volume by 60 to 90 percent while recovering energy from discarded products. Mass burn, modular combustion units, and solid-waste-derived fuel are the three basic waste-to-energy plants used.

INTEGRATED WASTE MANAGEMENT

Integrated waste management (IWM) can be defined as the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals. Because numerous state and federal laws have been adopted, IWM is also evolving in response to the regulations developed to implement the various laws. The EPA has identified four basic management options (strategies) for IWM: (1) source reduction, (2) recycling and composting, (3) combustion (waste-to-energy facilities), and (4) landfills. As proposed by the EPA, these strategies are meant to be interactive, as illustrated in Figure 5-1*a*. It should be noted that some states have chosen to consider the management options in a hierarchical order, as depicted in Figure 5-1*b*. For example, recycling can only be considered after all that can be done to reduce the quantity of waste at the source has been done. Similarly, waste transformation is only considered after the maximum amount of recycling has been achieved. Further, the combustion (waste-to-energy) option has been replaced with waste transformation in California and other states. Interpretation of the IWM hierarchy will, most likely, continue to vary by state. The management options that comprise the IWM are

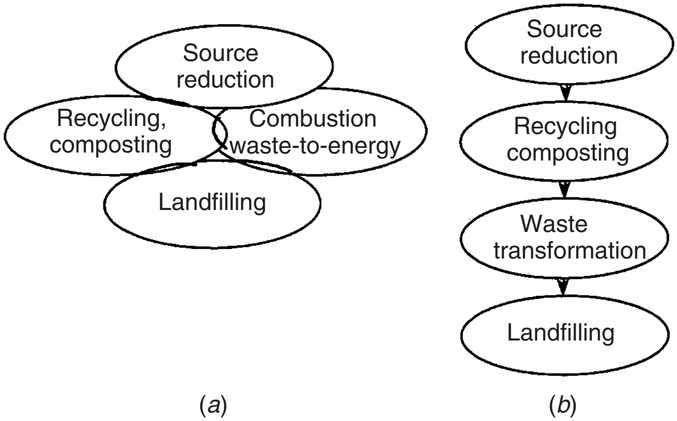


Figure 5-1 Definition sketch for integrated solid waste management: (*a*) interactive; (*b*) hierarchical.

considered in the following discussion. The implementation of IWM options is considered in the remaining sections of this chapter (Tchobanoglous et al., 2002).

Source Reduction

Source reduction focuses on reducing the volume and/or toxicity of generated waste. Source reduction includes the switch to reusable products and packaging, the most familiar example being returnable bottles. However, legislated bottle bills only result in source reduction if bottles are reused once they are returned. Other good examples of source reduction are grass clippings that are left on the lawn and never picked up and modified yard plantings that do not result in leaf and yard waste. The time to consider source reduction is at the product/process design phase.

Source reduction can be practiced by everybody. Consumers can participate by buying less or using products more efficiently. The public sector (government entities at all levels: local, state, and federal) and the private sector can also be more efficient consumers. They can reevaluate procedures that needlessly distribute paper (multiple copies of documents can be cut back), require the purchase of products with longer life spans, and cut down on the purchase of disposable products. The private sector can redesign its manufacturing processes to reduce the amount of waste generated in the manufacturing process. Reducing the amount of waste may require closed-loop manufacturing processes and the use of different raw materials and/or different production processes. Finally, the private sector can redesign products by increasing their durability, substituting less toxic materials, or increasing product effectiveness. However, while everybody can participate in source reduction, it digs deeply into how people go about their business, something that is difficult to mandate through regulation without getting mired in the tremendous complexity of commerce.

Source reduction is best encouraged by making sure that the cost of waste management is fully internalized. *Cost internalization* means pricing the service so that all of the costs are reflected. For waste management, the costs that need to be internalized include pickup and transport, site and construction, administrative and salary, and environmental controls and monitoring. It is important to note that these costs must be considered, whether the product is ultimately managed in a landfill, combustion, recycling facility, or composting facility. Regulation can aid cost internalization by requiring product manufacturers to provide public disclosure of the costs associated with these aspects of product use and development (Tchobanoglous et al., 2002).

Recycling and Composting

Recycling is perhaps the most positively perceived and doable of all the waste management practices. Recycling will return raw materials to market by separating reusable products from the rest of the municipal waste stream. The benefits of recycling are many. Recycling saves precious finite resources, lessens the need for mining of virgin materials, which lowers the environmental impact for mining and processing, and reduces the amount of energy consumed. Moreover, recycling can help stretch landfill capacity. Recycling can also improve the efficiency and ash quality of incinerators and composting facilities by removing noncombustible materials, such as metals and glass.

Recycling can also cause problems if it is not done in an environmentally responsible manner. Many Superfund sites are what is left of poorly managed recycling operations. Examples include de-inking operations for newsprint, waste oil recycling, solvent recycling, and metal recycling. In all of these processes, toxic contaminants that need to be properly managed are removed. Composting is another area of recycling that can cause problems without adequate location controls. For example, groundwater can be contaminated if grass clippings, leaves, or other yard wastes that contain pesticide or fertilizer residues are composted on sandy or other permeable soils. Air contamination by volatile substances can also result.

Recycling will flourish where economic conditions support it, not just because it is mandated. For this to happen, the cost of landfilling or resource recovery must reflect its true cost and must be at least $40 per ton or higher. Successful recycling programs also require stable markets for recycled materials. Examples of problems in this area are not hard to come by; a glut of paper occurred in Germany in the 1984 to 1986 time frame due to a mismatch between the grades of paper collected and the grades required by the German papermills. Government had not worked with enough private industries to find out whether the mills had the capacity and equipment needed to deal with low-grade household newspaper. In the United States, a similar loss of markets has occurred for paper, especially during the period from 1994 through 1997. Prices have dropped to the point where it actually costs money to dispose of collected newspapers in some parts of the country.

Stable markets also require that stable supplies are generated. This supply-side problem has been problematic in certain areas of recycling, including metals and plastics. Government and industry must work together to address the market situation. It is critical to make sure that mandated recycling programs do not get too far ahead of the markets.

Even with a good market situation, recycling and composting will flourish only if they are made convenient. Examples include curbside pickup for residences on a frequent schedule and easy drop-off centers with convenient hours for rural communities and for more specialized products. Product mail-back programs have also worked for certain appliances and electronic components.

Even with stable markets and convenient programs, public education is a critical component for increasing the amount of recycling. At this point, the United States must develop a conservation, rather than a throwaway, ethic, as was done during the energy crisis of the 1970s. Recycling presents the next opportunity for cultural change. It will require us to move beyond a mere willingness to collect our discards for recycling. That cultural change will require consumers to purchase recyclable products and products made with recycled content. It will require businesses to utilize secondary materials in product manufacturing and to design new products for easy disassembly and separation of component materials (Tchobanoglous et al., 2002).

Combustion (Waste-to-Energy)

The third of the IWM options (see Figure 5-1) is combustion (waste-to-energy). Combustion facilities are attractive because they do one thing very well; they reduce the volume of waste dramatically up to ninefold. Combustion facilities can also recover useful energy either in the form of steam or in the form of electricity. Depending on the economics of energy in the region, this can be anywhere from profitable to unjustified. Volume reduction alone can make the high capital cost of incinerators attractive when landfill space is at a premium or when the landfill is distant from the point of generation. For many major metropolitan areas, new landfills must be located increasingly far away from the center of the population. Moreover, incinerator bottom ash has a promise for reuse as a building material. Those who make products from cement or concrete may be able to utilize incinerator ash.

The major constraints of incinerators are their cost, the relatively high degree of sophistication needed to operate them safely and economically, and the fact that the public is very skeptical concerning their safety. The public is concerned about both stack emissions from incinerators and the toxicity of ash produced by incinerators. The EPA has addressed both of these concerns through the development of new regulations for solid waste combustion (waste-to-energy) plants and improved landfill requirements for ash. These regulations will ensure that well-designed, well-built, and well-operated facilities will be fully protective from the health and environmental standpoints (Tchobanoglous et al., 2002).

Landfills

Landfills are the one form of waste management that nobody wants but everybody needs. There are simply no combinations of waste management techniques that do not require landfilling to make them work. Of the four basic management options, landfills are the only management technique that is both necessary and sufficient. Some wastes are simply not recyclable, because they eventually reach a point where their intrinsic value is dissipated completely so they no longer can be recovered, and recycling itself produces residuals.

The technology and operation of a modem landfill can assure protection of human health and the environment. The challenge is to ensure that all operating landfills are designed properly and are monitored once they are closed. It is critical to recognize that today's modern landfills do not look like the old landfills that are on the current Superfund list. Today's operating landfills do not continue to take hazardous waste. In addition, they do not receive bulk liquids. They have gas control systems, liners, leachate collection systems, and extensive groundwater monitoring systems; perhaps most importantly, they are better sited and located in the first place to take advantage of natural geological conditions.

Landfills can also turn into a resource. Methane gas recovery is occurring at many landfills today and CO_2 recovery is being considered. After closure, landfills can be used for recreation areas such as parks, golf courses, or ski areas. Some agencies and entrepreneurs are looking at landfills as repositories of resources for the future; in other words, today's landfills might be able to be mined at some time in the future when economic conditions warrant. This situation could be particularly true of monofills, which focus on one kind of waste material like combustion ash or shredded tires (Tchobanoglous et al., 2002).

Implementing Integrated Solid Waste Management

The implementation of IWM for residential solid waste, as illustrated in Figure 5-2, typically involves the use of a several technologies and all of the management options discussed above. At present, most communities use two or more of the municipal solid waste (MSW) management options to dispose of their waste, but there are only a few instances where a truly integrated and optimized waste management plan has been developed. To achieve an integrated strategy for handling municipal waste, an optimization analysis com-

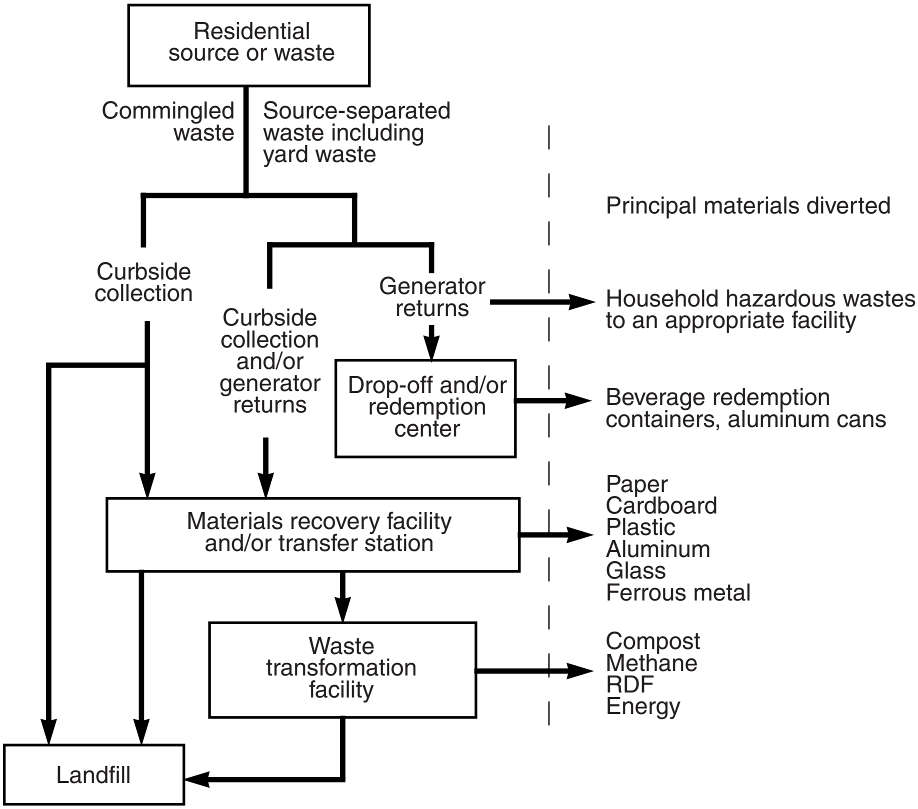


Figure 5-2 Implementation of IWM for management of residential solid wastes. Similar diagrams apply to commercial and institutional sources of solid waste (Tchobanoglous et al., 2002).

bining all of the available options should be conducted. However, at present, there is no proven methodology for performing such an optimization analysis (Tchobanoglous et al., 2002).

SOURCES, CHARACTERISTICS, AND QUANTITIES OF SOLID WASTE

In developing solid waste management programs, it is important to identify the sources, characteristics, and quantities of solid waste. Information on these subjects, as discussed in this section, is of fundamental importance in determining the types of collection service, the types of collection vehicles to be used, the type of processing facilities, and the disposal method to be used. Construction and demolition debris and special wastes that must be collected and processed separately are also considered.

Sources of Solid Waste

Sources of solid wastes in a community are, in general, related to land use and zoning. Although any number of source classifications can be developed, the following categories have been found useful: (1) residential, (2) commercial, (3) institutional, (4) construction and demolition, (5) municipal services, (6) treatment plant sites, (7) industrial, and (8) agricultural. Typical waste generation facilities, activities, or locations associated with each of these sources are reported in Table 5-1. As noted in Table 5-1, *municipal solid waste* is normally assumed to include all community wastes with the exception of wastes generated from municipal services, water and wastewater treatment plants, industrial processes, and agricultural operations. It is important to be aware that the definitions of solid waste terms and the classifications of solid waste vary greatly in the literature and in the profession. Consequently, the use of published data requires considerable care, judgment, and common sense (Tchobanoglous et al., 2002).

Characteristics of Solid Waste

Important characteristics of solid waste include the composition, quantities, and specific weight.

Composition Typical data on the general characteristics of municipal solid waste are presented in Table 5-2. Averages are subject to adjustment depending on many factors: time of the year; habits, education, and economic status of the people; number and type of commercial and industrial operations; whether urban or rural area; and location. Each community should be studied and actual weighings made to obtain representative information for design purposes.

Quantities Various estimates have been made of the quantity of solid waste generated and collected per person per day. The amount of municipal solid waste collected is estimated to be 6 lb/capita · d, of which about 3.5 lb is residential. Additional details on the quantities and characteristics of the solid waste generated in the United States may be found in Franklin Associates (1999, and yearly updates) and U.S. EPA (1999, 2001). Community wastes are not expected to exceed 1 ton/capita · yr—with the emphasis being placed on source reduction (such as less packaging) and waste recovery and recycling (such as of paper, metals, cans, and glass), the amount of solid waste requiring disposal is reduced. Recovery and recycling of hazardous wastes and toxicity reduction by substitution of less hazardous or nonhazardous materials should also be emphasized. Typical data on the quantities of waste generated from specific sources are presented in Table 5-3. Typical data on the quantities of waste generated from miscellaneous nonresidential sources are presented in Table 5-4. Typical data on the quantities of waste generated from industrial and agricultural sources are presented in Tables 5-5 and Table 5-6, respec-

TABLE 5-1 Sources Where Solid Wastes Are Generated within a Community

Source	Typical Facilities, Activities, or Locations Where Wastes Are Generated	Types of Solid Wastes
Residential	Single-family and multifamily dwellings; low-, medium-, and high-rise apartments	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood glass, tin cans, aluminum other metal, ashes, street leaves, special wastes (including bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires), household hazardous wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations and auto repair shops	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes (see above), hazardous wastes
Institutional	Schools, hospitals, prisons, governmental centers	As above for commercial
Industrial (nonprocess wastes)	Construction, fabrication, light and heavy manufacturing, refineries chemical plants, power plants, demolition	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes (see above), hazardous wastes
Municipal solid waste	All of the above[a]	All of the above[a]
Construction and demolition	New construction sites, road repair renovation sites, razing of buildings, broken pavement	Wood, steel, concrete, dirt
Municipal services (excluding treatment facilities)	Street cleaning, landscaping, catch-basin cleaning, parks and beaches, other recreational areas	Special wastes, rubbish, street sweepings, landscape and tree trimmings, catch-basin debris; general wastes from parks, beaches and recreational areas
Treatment plant sites	Water, wastewater, and industrial treatment processes	Treatment plant wastes, principally composed of residual sludges and other residual materials

TABLE 5-1 (*Continued*)

Source	Typical Facilities, Activities, or Locations Where Wastes Are Generated	Types of Solid Wastes
Industrial	Construction, fabrication, light and heavy manufacturing, refineries chemical plants, power plants, demolition	Industrial process wastes, scrap materials; nonindustrial waste, including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, hazardous waste
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms	Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes

Source: Tchobanoglous et al. (1993).

[a] The term *municipal solid waste* (*MSW*) normally is assumed to include all of the wastes generated in the community with the exception of waste generated from municipal services, treatment plants, industrial processes, and agriculture.

tively. The data presented in Tables 5-3 through 5-6 are meant to be used as a general guide to expected quantities for the purpose of preliminary planning and feasibility assessment. In all cases the quantity information in these table must be verified before final design.

TABLE 5-2 Approximate Composition of Residential Solid Wastes in 1977, 1989, and 2000

Component	Percent by Weight[a]		
	1977	1989	2000
Food waste	16–18	7–10	6–8
Paper products	30–35	36–42	34–42
Rubber, leather, textiles, wood	7–9	6–9	4–8
Plastics	3–4	6–8	8–12
Metals	9–10	7–9	6–8
Glass and ceramics	9–12	7–9	7–9
Yard wastes	16–20	16–18	16–18
Rock, dirt, miscellaneous	1–4	1–3	1–3

Source: Adapted in part from Salvato (1992).

[a] Figures do not include junked vehicles, water and wastewater treatment plant sludges, waste oil, pathological wastes, agricultural wastes, industrial wastes, mining or milling wastes.

TABLE 5-3 Approximate Solid Waste Generation Rates from Various Sources in the United States

Source of Waste	Unit	lb/unit · day
Municipal	Capita	4.0
Household	Capita	3.5
Apartment building	Capita per sleeping room	4.0
Seasonal home	Capita	2.5
Resort	Capita	3.5
Camp	Capita	1.5
School		
With cafeteria	Capita	1.0
Without cafeteria	Capita	0.5
University	Student	0.86 to 1.0
Institution, general	Bed	2.5
Hospital	Bed	12–15
	Occupied bed and 3.7 if staff added	9.5
Nurses' or interns' home	Bed	3.0
Home for aged	Bed	3.0
Rest home	Bed	3.0
Nursing home, retirement	Bed	5.0
Infectious waste		
Hospital	Bed	4.0
Residential health care facility	Bed	0.5
Diagnostic and treatment center	Patient per week	0–6.5
Hotel		
First class	Room	3.0
Medium class	Room	1.5
Motels	Room	2.0
Day use facility, resort	Capita	0.5
Trailer camp	trailer	6–10
Commercial building, office	100 ft^2	1.0
Office building	Worker	1.5
Department store	100 ft^2	40
Shopping center	Survey required	Survey required
Supermarket	100 ft^2	9.0
Supermarket	Person	2.4
Restaurant	Meal	2.0
Cafeteria	Capita	1
Fast food	Capita	0.5
Drugstore	100 ft^2	5.0
Airport	Passenger	0.5
Prison	Inmate	4.5
Retail and service facility	1000 ft^2	13.0
Wholesale and retail facility	1000 ft^2	1.2
Industrial building, factory	400–3000 employees	7
	100–400 employees	3
Warehouse	Per 100 ft^2	2.0

TABLE 5-3 (*Continued*)

Source of Waste	Unit	lb/unit · day
National Forest recreational area		
Campground	Camper	1.2–1.4
Family picnic area	Picnicker	8.0–1.2
Organized camps	Occupant	1.4–2.2
Rented cabin, with kitchen	Occupant	1.2–1.8
Lodge, without kitchen	Occupant	0.2–0.8
Restaurant	Meal served	0.5–1.2
Overnight lodge, winter sports area	Visitor	1.5–2.1
Day lodge, winter sports area	Visitor	2.4–3.4
Swimming beach	Swimmer	0.02–0.05
Concession stand	Per patron	0.10–0.16
Job Corps, Civilian Conservation		
Corps camp, kitchen waste	Per corpsman	1.8–3.0
Administrative and dormitory	Per corpsman	0.5–1.2

Source: Adapted from Salvato (1992).

TABLE 5-4 Miscellaneous Solid Waste Generation

	Solid Waste Generation Rate	
Type	Unit	Range of Values
Tires	Tires discarded per capita per year	0.6–1.0
Waste oil	5 gal per vehicle per year	2.0–3.0
Wastewater sludge, raw	Tons per day per 1000 people, dewatered to 25% solids, with no garbage grinders	0.3–0.5
	Tons per day per 1000 people, dewatered to 25% solids, with 100% garbage grinders	0.7–0.9
Wastewater sludge, digested	Tons per day per 1000 people, dewatered to 25% solids, or 3 lb per capita per day dry solids	0.20–0.30
Water supply sludge	Pounds per million gallons of raw water, on a dry-weight basis, with conventional rapid-sand filtration using alum; raw water with 10 Jackson turbidity units (JTU)	200–220
Scavenger wastes	Gallons per capita per day	0.25–0.35
Pathological wastes	Pounds per bed per day—hospital	0.6–0.8
	Pounds per bed per day—nursing home	0.4–0.6
Junked vehicles	Number per 1000 population—2002	40–80

Source: Adapted in part from Malcolm Pirnie Engineers (1969).

TABLE 5-5 Typical Solid Waste Generation Rates for Industrial Sources by SIC Code[a]

SIC Code	Industry	Waste Production Rate (tons/employee · yr)
201	Meat processing	6.2
2033	Cannery	55.6
2037	Frozen foods	18.3
Other 203	Preserved foods	12.9
Other 20	Food processing	5.8
22	Textile mill products	0.26
23	Apparel	0.31
2421	Sawmills and planing mills	162.0
Other 24	Wood products	10.3
25	Furniture	0.52
26	Paper and allied products	2.00
27	Printing and publishing	0.49
281	Basic chemicals	10.0
Other 28	Chemical and allied products	0.63
29	Petroleum	14.8
30	Rubber and plastic	2.6
31	Leather	0.17
32	Stone, clay	2.4
33	Primary metals	24
34	Fabricated metals	1.7
35	Nonelectrical machinery	2.6
36	Electrical machinery	1.7
37	Transportation equipment	1.3
38	Professional and scientific institutions	0.12
39	Miscellaneous manufacturing	0.14

Source: Weston (1970).

[a]Standard Industrial Classification (SIC) Code.

Specific Weight The volume occupied by solid waste under a given set of conditions is of importance, as are the number and size or type of solid waste containers, collection vehicles, and transfer stations. Transportation systems and land requirements for disposal are also affected. For example, the specific weight of loose solid waste will vary from about 100 to 175 lb/yd^3. Specific weights of various solid waste materials are given in Table 5-7. The variabilities in the reported data are due to variations in moisture content.

Commercial and Household Hazardous Waste

The "contamination" of ordinary municipal waste by commercial and household hazardous wastes has exacerbated the potential problems associated with the disposal of municipal waste by landfill, incineration, and composting.

TABLE 5-6 Typical Agricultural Solid Waste Production Rates

	Annual Waste Production Rate	
Category	Unit	Range of Values
Wet manures		
Turkeys	Tons/1000 birds	180
Chickens (fryers)	Tons/1000 birds	6–8
Hens (layers)	Tons/1000 birds	60–70
Hogs	Tons/head	3.2
Horses	Tons/head	12
Beef cattle (feedlot)	Tons/head	10.9
Dairy cattle	Tons/head	14.6
Sheep	Tons/head	0.8
Fruit and nut crops		
Class 1 (grapes, peaches, nectarines)	Tons/acre	2.4
Class 2 (apples, pears)	Tons/acre	2.25
Class 4 (plums, prunes, miscellaneous)	Tons/acre	1.5
Class 5 (walnuts, cherries)	Tons/acre	1.0
Field and row crops		
Class 1 (field and sweet corn)	Tons/acre	4.5
Class 2 (cauliflower, lettuce, broccoli)	Tons/acre	4.0
Class 3 (sorghum, tomatoes, beets, cabbage, squash, brussel sprouts)	Tons/acre	3.0
Class 4 (beans, onions, cucumbers, carrots, peas, peppers, potatoes, garlic, celery, miscellaneous)	Tons/acre	2.0
Class 5 (barley, oats, wheat, milo, asparagus)	Tons/acre	1.5

Source: Adapted from Salvato (1992).

Based on a number of past studies, the quantity of hazardous waste typically represents less than about 0.5 percent of the total waste generated by households. Typically, batteries and electrical items and certain cosmetics accounted for the largest amount.

From a practical standpoint, it would appear that more can be accomplished by identifying and prohibiting disposal of commercial hazardous waste with municipal solid waste. The minimal household hazardous wastes could, with education and municipal cooperation, be disposed of by voluntary actions. These could include periodic community collections and provision of central guarded depositories. Many communities have established ongoing programs for the collection of household hazardous waste.The amount of waste can be expected to decrease as old stockpiles are discarded. Restricting sales and promoting development and substitution of nonhazardous household products would also be indicated. It should also be remembered that a large fraction of the household hazardous waste ends up in the sewer.

TABLE 5-7 Weight of Solid Waste for Given Conditions

Condition of Solid Waste	Weight (lb/yd^3)
Loose solid waste at curb	125–240
As received from compactor truck at sanitary landfill	300–700
Normal compacted solid waste in a sanitary landfill[a]	750–850
Well-compacted solid waste in a sanitary landfill[a]	1000–1250
In compactor truck	300–600
Shredded solid waste, uncompacted	500–600
Shredded solid waste, compacted	1400–1600
Compacted and baled	1600–3200
Apartment house compactor	600–750
In incinerator pit	300–550
Brush and dry leaves, loose and dry	80–120
Leaves, loose and dry	200–260
Leaves, shredded and dry	250–450
Green grass, compacted	500–1100
Green grass, loose and moist	350–500
Yard waste, as collected	350–930
Yard waste, shredded	450–600

Source: Salvato (1992) and Tchobanoglous et al. (1993). Reproduced with permission from Cornell Waste Management Institute, Center for the Environment.

[a] Initial value.

Construction and Demolition Debris

Construction and demolition debris consists of uncontaminated solid waste resulting from the construction, remodeling, repair, and demolition of structures and roads and uncontaminated solid waste consisting of vegetation from land clearing and grubbing, utility line maintenance, and seasonal and storm-related cleanup. Such waste includes, but is not limited to, bricks, concrete and other masonry materials, soil, wood, wall coverings, plaster, drywall, plumbing fixtures, nonasbestos insulation, roofing shingles, asphaltic pavement, glass, plastics that are not sealed in a manner that conceals other wastes, electrical wiring and components containing no hazardous liquids, and metals that are incidental to any of the above (U.S. EPA, 1998c).

Solid waste that is not construction and demolition debris (even if resulting from the construction, remodeling, repair, and demolition of structures, roads, and land clearing) includes, but is not limited to, asbestos waste, garbage, corrugated container board, electrical fixtures containing hazardous liquids such as fluorescent light ballasts or transformers, carpeting, furniture, appliances, tires, drums and containers, and fuel tanks. Specifically excluded from the definition of construction and demolition debris is solid waste (including what otherwise would be construction and demolition debris) resulting from any processing technique, other than that employed at a construction and demolition processing facility, that renders individual waste components unrecognizable, such as pulverizing or shredding.

Some of this material, such as bricks, rocks, wood, and plumbing fixtures, can be recycled. However, care must be taken to ensure (by monitoring each load) that hazardous materials such as those mentioned above are excluded and that fire, odor, and groundwater pollution is prevented. Engineering plans and reports, hydrogeologic report, operation and maintenance reports, and per mits from the regulatory agency are usually required.

Special Wastes Collected Separately

In every community a number of waste materials are collected separately from residential and commercial solid waste. Special wastes include (1) medical wastes, (2) animal wastes, (3) waste oil, and (4) old tires. These wastes are considered in the following discussion.

Medical Wastes—Infectious and Pathological The Solid Waste Disposal Act, commonly referred to as the Resource Conservation and Recovery Act (RCRA), defines medical waste as ''any solid waste which is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals. The term does not include any hazardous waste identified or listed under Subtitle C (mixtures with medical wastes are not excluded) or any household waste as defined in regulations under Code of Federal Regulations, Title 40, Subtitle C (materials found in waste generated by consumers).''

Infectious waste usually comes from a medical care or related facility. It includes all waste materials resulting from the treatment of a patient on isolation (other than patients on reverse or protective isolation), renal dialysis, discarded serums and vaccines, pathogen-contaminated laboratory waste and animal carcasses used in research (including bedding and other waste), and other articles that are potentially infectious such as hypodermic and intravenous needles.

Regulated medical waste under the Act includes the following waste categories: cultures and stock of infectious agents and associated biologicals; human blood and blood products; pathological waste; used sharps (needles, syringes, surgical blades, pointed and broken glass); and contaminated animal carcasses. The EPA is authorized to exclude, if there is no substantial threat to human health or the environment, surgery or autopsy waste, miscellaneous microbiology laboratory waste, dialysis waste, discarded medical equipment, and isolation wastes. Other waste categories may be added if they pose a substantial threat. Potential hazards associated with the handling of infectious waste necessitate certain precautions. Infectious waste needs to be segregated at the source and clearly color (red) coded and marked. The packaging is expected to maintain its integrity during handling, storage, and transportation with consideration of the types of materials packaged. The storage time should be minimal (treated within 24 hr); the packaging moisture proof, puncture resistant, and rodent and insect proof; and the storage places and containers clearly marked with the universal biological hazard symbol and secured. Packaged waste is placed in rigid or semirigid containers and transported in closed leak-proof trucks or dumpsters. It must at all times be kept separate from regular trash and other solid waste. Health care workers and solid waste handlers must be cautious.

Most infectious waste can be treated for disposal by incineration or autoclaving. The residue can be disposed of in an approved landfill. Liquids may be chemically disinfected; pathological wastes may also be buried, if permitted, or cremated; and blood wastes may, under controlled conditions, be discharged to a municipal sanitary sewer provided secondary treatment is employed. Infectious waste may also be rendered innocuous by shredding–disinfection (sodium hypochlorite), thermal inactivation, and gas–vapor treatment. Infectious waste is only one component of medical waste.

In all cases, local, state, and federal regulations should be followed closely. Public concerns and fears associated with the possible spread of the viruses causing acquired immunodeficiency syndrome (AIDS) and hepatitis B, as well as other infections, have accelerated legislative and regulatory action, tighter management practices, and provision of specialized treatment and disposal services. Complete records (medical waste tracking form) must be kept by the generator and hauler of infectious waste to the point of final disposal as part of a four-part manifest system.

Animal Wastes Animal wastes may contain disease organisms causing salmonellosis, leptospirosis, tularemia, foot-and-mouth disease, hog cholera, and other illnesses. (See Zoonoses and Their Spread, Chapter 1.) Manure contaminated with the foot-and-mouth disease virus must be buried in a controlled manner or otherwise properly treated. The excreta from sick animals should be stored 7 to 100 days or as long as is necessary to ensure destruction of the pathogen, depending on temperature and moisture. Dead animals are best disposed of at an incinerator or rendering plant or in a separate area of a sanitary landfill. Large numbers might be buried in a special trench with due consideration to protection of groundwaters and surface waters if approved by the regulatory authority.

Waste Oil Large quantities of waste motor and industrial oil find their way into the environment as a result of accidental spills, oiled roads, oil dumped in sewers and on the land, and oil deposited by motor vehicles. Used oils contain many toxic metals and additives that add to the pollution received by sources of drinking water, aquatic life, and terrestrial organisms. The lead content of oil is of particular concern. It has been estimated that industrial facilities, service stations, and motorists produce 1.2 billion gallons of used oil in the United States each year. Approximately 60 percent is used motor oil. Approximately 60 percent is reprocessed and used for fuel, but air pollution controls are needed. About 25 to 30 percent is rerefined and reused as a lubricant. The remainder is used for road oil, dirt road dust control and stabilization, and other unacceptable uses. Rerefined oil is so classified when it has had physical and chemical impurities removed and, when by itself or blended with new oil or additives, is substantially equivalent or superior to new oil intended for the same purposes, as specified by the American Petroleum Institute.

Used Tires Tire dumps can cause major fires and release many hazardous chemicals, including oil, contributing to air and groundwater pollution. Tires collect rain water in which mosquitoes breed and provide harborage for rats and other vermin. Tires are not suitable for disposal by landfill but may be acceptable if shredded or split, although recycling is preferred and may be required.

ON-SITE HANDLING AND STORAGE

Where solid waste is temporarily stored on the premises, between collections, an adequate number of suitable containers should be provided.

Low-Rise Residential Areas

To a large extent, the type of container used for the collection of residential solid waste will depend on the type of collection service provided, and whether source separtion of wastes is employed (see Table 5-8 below under Solid Waste Collection). The variation in the types of containers used for residential service are illustrated in Figure 5-3.

Low- and Medium-Rise Apartments

Large containers located in enclosed areas are used most commonly for low- and medium-rise apartments. Typical examples are shown in Figure 5-4. In most applications, separate containers are provided for recycbale and commingled nonrecycable materials.

Curbside collection service is common for most low- and medium-rise apartments. Typically, the maintenance staff is responsible for transporting the containers to the street for curbside collection by manual or mechanical means. In many communities, the collector is responsible for transporting containers from a storage location to the collection vehicle. Where large containers are used, the contents of the containers are emptied mechanically using collection vehicles equipped with unloading mechanisms.

High-Rise Apartments

In high-rise apartment buildings (higher than seven stories), the most common methods of handling commingled wastes involve one or more of the follow-

(*a*)

(*b*)

Figure 5-3 Typical containers used for collection of residential solid waste: (*a*) source-separated recyclable materials are placed in three separate containers (one for paper, one for glass, and one for cans and plastics), residual nonrecyclable wastes are placed in separate containers, and yard wastes are place in the street for collection with specialized collection equipment; (*b*) commingled mixed wastes in a single large (90-gal) container.

Figure 5-4 Typical examples of large containers used for low- and medium-rise apartments (note separate containers for recyclable materials).

ing: (1) wastes are picked up by building maintenance personnel from the various floors and taken to the basement or service area; (2) wastes are taken to the basement or service area by tenants; or (3) wastes, usually bagged, are placed by the tenants in a waste chute system used for the collection of commingled waste at a centralized service location. Typically, large storage containers are located in the basements of high-rise apartments. In some locations, enclosed ground-level storage facilities will be provided. In some of the more recent apartment building developments, especially in Europe, underground pneumatic transport systems have been used in conjunction with the individual apartments chutes.

Commercial and Institution

Bulk containers or solid waste bins are recommended where large volumes of solid waste are generated, such as at hotels, restaurants, motels, apartment houses, shopping centers, and commercial places. They can be combined to advantage with compactors in many instances (see Figure 5-5). Containers should be placed on a level, hard, cleanable surface in a lighted, open area. The container and surrounding area must be kept clean, for the reasons previously stated. A concrete platform provided with a drain to an approved sewer with a hot-water faucet at the site to facilitate cleaning is generally satisfactory.

(*a*)

(*b*)

Figure 5-5 Typical containers used for collection of large amounts of waste from commercial establishments: (*a*) open top with lids; (*b*) closed container coupled to stationary compactor.

SOLID WASTE COLLECTION

Collection cost has been estimated to represent about 50 to 70 percent of the total cost of solid waste management, depending on the disposal method. Because the cost of collection represents such a large percentage of the total cost, the design of collection systems must be considered carefully. The type of service provided, the frequency of service, and the equipment used for collection are considered in the following discussion.

Type of Service

The type of collection service provided will depend on the community solid waste management program. Typical examples of the types of collection service provided for the collection of (1) commingled and (2) source-separated and commingled wastes are reported in Table 5-8. It should be noted that numerous other variations in the service provided have been developed to meet local conditions. In addition to routine collection services, presented in Table 5-8, annual or semiannual special collections for appliances, tires, batteries, paints, oils, pesticides, yard wastes, glass and plastic bottles, and ‘‘spring cleaning’’ have proven to be an appreciated community service while at the same time providing environmental protection.

Collection Frequency

The frequency of collection will depend on the quantity of solid waste, time of year, socioeconomic status of the area served, and municipal or contractor responsibility. In residential areas, twice-a-week solid waste collection during warm months of the year and once a week at other times should be the maximum permissible interval. In business districts, solid waste, including garbage from hotels and restaurants, should be collected daily except Sundays (see Figure 5-6). Depending on the type of collection system, the containers used for the on-site storage of solid waste should be either emptied directly into the collection vehicle or hauled away emptied and returned or replaced with a clean container. Solid waste transferred from on-site storage containers will invariably cause spilling, with resultant pollution of the ground and attraction of flies. If other than curb pickup is provided, such as backyard service, the cost of collection will be high. Nevertheless, some property owners are willing to pay for this extra service. Bulky wastes should be collected every three months. Most cities have also instituted ongoing programs for the collection of household hazardous wastes, typically every three months.

Types of Collection Systems

Solid waste collection systems may be classified from several points of view, such as the mode of operation, the equipment used, and the types of wastes

TABLE 5-8 Typical Collection Services for Commingled and Source Separated Solid Waste[a]

Preparation Method for Waste Collected	Type of Service
Commingled wastes	Single collection service of large container for commingled household and yard waste
	Separate collection service for (1) commingled household waste and (2) containerized yard waste
	Separate collection service for (1) commingled household waste and (2) noncontainerized yard waste
Source-separated and commingled waste	Single collection service for a single container with source-separated waste placed in plastic bag along with commingled household and yard wastes
	Separate collection service for (1) source-separated waste placed in a plastic bag and commingled household waste in same container and (2) non-containerized yard wastes
	Single collection service for source-separated and commingled household and yard wastes using a two-compartment container
	Separate collection service for (1) source-separated and commingled household wastes using a two-compartment container and (2) containerized or noncontainerized yard waste
	Separate collection service for (1) source-separated waste and (2) containerized commingled household and yard wastes
	Separate collection service for (1) source-separated waste, (2) commingled household waste, and (3) containerized yard wastes
	Separate collection service for (1) source-separated waste, (2) commingled household waste, and (3) noncontainerized yard wastes

Source: Theisen (2002).

[a]The method of waste preparation for collection is often selected for convenience and efficiency of collection services and subsequent materials processing activities.

collected. Collection systems can be classified, according to their mode of operation, into two categories: (1) hauled container systems and (2) stationary container systems. The individual systems included in each category lend themselves to the same method of engineering and economic analysis (Theisen, 2002). The principal operational features of these two systems are delineated below.

Hauled Container Systems (HCSs) These are collection systems in which the containers used for the storage of wastes are hauled to a materials recovery facility (MRF), transfer station, or disposal site, emptied, and returned to

Figure 5-6 Commercial waste placed on sidewalk in New York City for manual collection at night or in very early morning hours.

either their original location or some other location. There are three main types of vehicles used in hauled container systems: (1) hoist truck, (2) tilt-frame container, and (3) truck tractor trash-trailer (see Figure 5-7). Typical data on the containers and container capacities used with these vehicles are reported in Table 5-9.

Hauled container systems are ideally suited for the removal of wastes from sources where the rate of generation is high because relatively large containers are used (see Table 5-9). The use of large containers eliminates handling time as well as the unsightly accumulations and unsanitary conditions associated with the use of numerous smaller containers. Another advantage of hauled container systems is their flexibility: Containers of many different sizes and shapes are available for the collection of all types of wastes.

***Stationary Container Systems* (*SCSs*)** In the stationary container system, the containers used for the storage of wastes remain at the point of generation, except when they are moved to the curb or other location to be emptied. Stationary container systems may be used for the collection of all types of wastes. The systems vary according to the type and quantity of wastes to be handled as well as the number of generation points. There are two main types: (1) systems in which manually loaded collection vehicles are used (see Figure 5-8) and (2) systems in which mechanically loaded collection vehicles are used (see Figure 5-9).

The major application of manual loading collection vehicles is in the collection of residential source-separated and commingled wastes and litter. Manual loading is used in residential areas where the quantity picked up at each location is small and the loading time is short. In addition, manual methods are used for residential collection because many individual pickup points are inaccessible to mechanized mechanically loaded collection vehicles. Special attention must be given to the design of the collection vehicle intended for use with a single collector. At present, it appears that a side-

(a)

(b)

Figure 5-7 Typical examples of collection vehicles used in hauled container system: (*a*) hoist truck; (*b*) tilt frame; (*c*) trash trailer.

(c)

Figure 5-7 (*Continued*)

loaded compactor, such as the one shown in Figure 5-8*a*, equipped with standup right-hand drive, is best suited for curb and alley collection.

Personnel Requirements

In most hauled container systems, a single collector-driver is used. The collector-driver is responsible for driving the vehicle, loading full containers on to the collection vehicle, emptying the contents of the containers at the disposal site (or transfer point), and redepositing (unloading) the empty containers. In some cases, for safety reasons, both a driver and helper are used. The helper usually is responsible for attaching and detaching any chains or cables used in loading and unloading containers on and off the collection vehicle; the driver is responsible for the operation of the vehicle. A driver and helper should always be used where hazardous wastes are to be handled. Labor requirements for curbside collection with manually and mechanically loaded vehicles with a one-person crew are reported in Table 5-10.

Labor requirements for mechanically loaded stationary container systems are essentially the same as for hauled container systems. Where a helper is used, the driver often assists the helper in bringing loaded containers mounted on rollers to the collection vehicle and returning the empty containers. Occasionally, a driver and two helpers are used where the containers to be emptied must be rolled (transferred) to the collection vehicle from inaccessible

TABLE 5-9 Typical Data on Container Types and Capacities Available for Use with Various Collection Systems

Collection System Vehicle	Container Type	Typical Range of Container Capacities
Hauled container system		
Hoist truck	Used with stationary compactor	6–12 yd^3
Tilt-frame	Open top, also called debris boxes or roll-off	12–50 yd^3
	Used with stationary compactor	15–40 yd^3
	Equipped with self-contained compaction mechanism	20–40 yd^3
Truck-tractor	Open-top trash-trailers	15–40 yd^3
	Enclosed trailer-mounted containers equipped with self-contained compaction mechanism	30–40 yd^3
Stationary container systems (compacting type)		
Compactor, mechanically loaded	Open top and closed top with side loading	1–10 yd^3
	Special containers used for collection of residential wastes from individual residences	90–120 gal
Compactor, mechanically loaded with divided hopper	Special split cart containers used for collection of recyclables and other nonrecyclable commingled waste	90–120 gal
Compactor trailer with mechanical lift assembly on semi-tractor	Special split cart containers used for collection of recyclables and other nonrecyclable commingled waste	90–120 gal
Compactor, manually loaded	Small plastic or galvanized metal containers, disposable paper and plastic bags	20–55 gal
Stationary container systems (noncompacting type)		
Collection vehicle with manually loaded side dump containers	All type of containers used for temporary storage of recyclable materials	32 gal
Collection vehicle with semiautomatic manually loaded side troughs	All type of containers used for temporary storage of recyclable materials	32 gal
Collection vehicle with semiautomatic manually loaded side troughs capable of unloading wheeled containers	All type of containers used for temporary storage of recyclable materials plus wheeled containers	60–120 gal
Collection vehicle with mechanical lift assembly	Special containers used for collection of source separated wastes from individual residences	60–120 gal

Source: Theisen (2002) and Tchobanoglous et al. (1993).

Note: $yd^3 \times 0.7646 = m^3$; $gal \times 0.003785 = m^3$.

(a)

(b)

Figure 5-8 Typical examples of manually loaded collection vehicles used in stationary container system: (*a*) side-loaded right-hand standup drive collection vehicle for commingled solid waste; (*b*) rear-loaded collection vehicle for commingled solid waste; (*c*) side-loading vehicle used for collection of source-separated materials.

(c)

Figure 5-8 (*Continued*)

locations, such as in congested downtown commercial areas. In stationary container systems, where the collection vehicle is loaded manually, the number of collectors varies from one to four, in most cases, depending on the type of service and the collection equipment. While the aforementioned crew sizes are representative of current practices, there are many exceptions. In many cities, multiperson crews are used for curb service as well as for backyard carry service.

Health Issues

The frequency and severity of injuries in the solid waste management industry are very high. The National Safety Council reported that solid waste collection workers have an injury frequency approximately 10 times the national average for all industries, higher than police work and underground mining. Workmen's compensation rates account for about 9 to 10 percent of payroll for all solid waste collectors.

TRANSFER AND TRANSPORT

The urban areas around cities have been spreading, leaving fewer nearby acceptable solid waste disposal sites. The lack of acceptable sites has led to

(*a*)

(*b*)

Figure 5-9 Typical examples of mechanically loaded collection vehicles used in stationary container system: (*a*) side-loading vehicle with dual compartment (courtesy of Heil Environmental Industries; reproduced with permission); (*b*) front-loaded collection vehicle.

TABLE 5-10 Typical Labor Requirements for Curbside Collection with Manually and Mechanically Loaded Collection Vehicle Using One-Person Crew[a]

Average Number of Containers and/or Boxes per Pickup Location	Time (min/location)	
	Manual Pickup	Mechanical Pickup
1 (60–90 gal)	—	0.5–0.6
1 or 2	0.5–0.6	
3 or 4	0.6–0.9	
Unlimited service[b]	1.0–1.2	

Source: Theisen (2002).

[a]Values given are for typical residential area with lot sizes varying from $\frac{1}{4}$ to $\frac{1}{3}$ acre.
[b]Not all residents take advantage of unlimited service each collection day.

the construction of incinerators, resource recovery facilities, or processing facilities in cities or their outskirts or the transportation of wastes longer distances to new landfill disposal sites. However, as the distance from the centers of solid waste generation increases, the cost of direct haul to a site increases. A "distance" is reached (in terms of cost and time) when it becomes less expensive to construct a transfer station or incinerator at or near the center of solid waste generation where wastes from collection vehicles can be transferred to large tractor-trailers for haul to more distant disposal sites. Ideally, the transfer station should be located at the centroid of the collection service area.

Economic Analysis of Transfer Operations

A comparison of direct haul versus the use of a transfer station and haul for various distances is useful in making an economic analysis of potential landfill sites. The transfer station site development, transportation system, and social factors involved in site selection should also be considered in making the comparison.

If the cost of disposal by sanitary landfill is added to the cost comparison, the total relative cost of solid waste transfer, transportation, and disposal by sanitary landfill can be compared to the corresponding cost for incineration, if incineration is an option. The relative cost of incineration with the cost of landfill for various haul distances and a given population is illustrated in Figure 5-10. Based on past experience, a direct-haul distance (one-way) of 25 to 30 miles is about the maximum economical distance, although longer distances are common, where other options are unacceptable or cannot be implemented for a variety of reasons, including cost. A similar comparison in which distance is shown in terms of times of travel to the disposal site is presented in Figure 5-11.

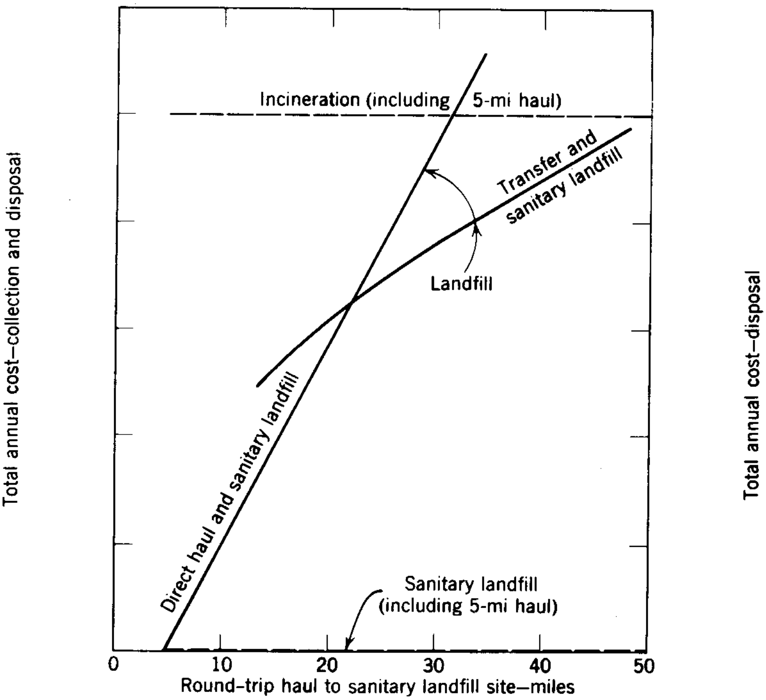


Figure 5-10 Effect of haul distances to site on cost of disposal by sanitary landfill compared to cost of disposal by incineration.

Types of Transfer Stations

Transfer stations are used to accomplish transfer of solid wastes from collection and other small vehicles to larger transport equipment. Depending on the method used to load the transport vehicles, transfer stations, as reported in Table 5-11 may be classified into two general types: (1) direct load and (2) storage load (see Figure 5-12). Combined direct-load and discharge-load transfer stations have also been developed Transfer stations may also be classified with respect to throughput capacity (the amount of material that can be transferred and hauled) as follows: small, less than 100 tons/day; medium, between 100 and 500 tons/day; and large, more than 500 tons/day.

Direct-Load Transfer Stations At direct-load transfer stations, the wastes in the collection vehicles are emptied directly into the vehicle to be used to transport them to a place of final disposition or into facilities used to compact the wastes into transport vehicles (see Figure 5-13) or into waste bales that are transported to the disposal site. In some cases, the wastes may be emptied onto an unloading platform and then pushed into the transfer vehicles, after

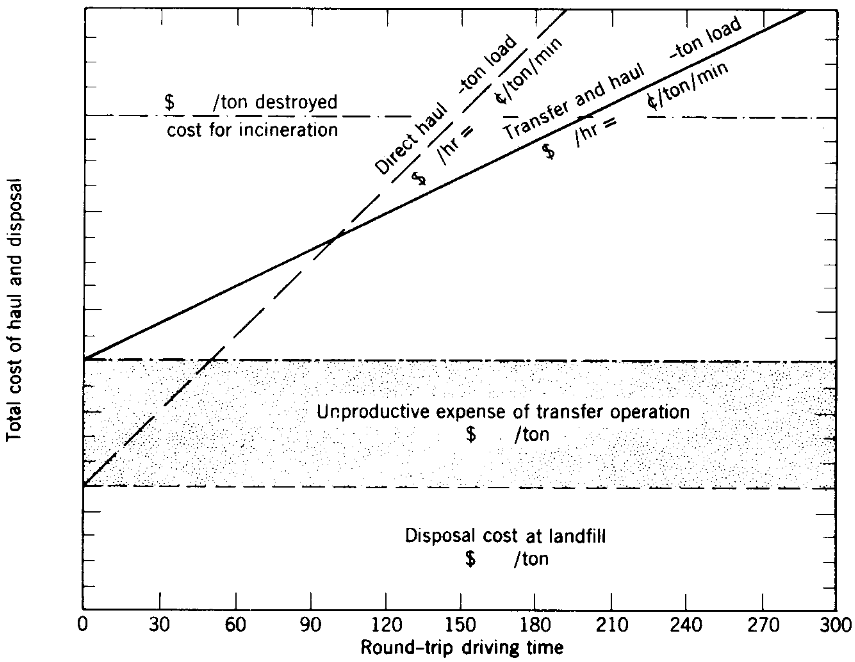


Figure 5-11 Cost comparison–incineration versus transfer and haul to landfill.

recyclable materials have been removed. The volume of waste that can be stored temporarily on the unloading platform is often defined as the *surge capacity* or the *emergency storage capacity* of the station. Small direct-load transfer stations used to serve industrial parks, rural areas, and entrances to landfills are illustrated in Figure 5-14.

Storage-Load Transfer Station In the storage-load transfer station, wastes are emptied directly into a storage pit from which they are loaded into transport vehicles by various types of auxiliary equipment (see Figure 5-1*b*). The difference between a dirtect-load and a storage-load transfer station is that the latter is designed with a capacity to store waste (typically one to three days).

Vehicles for Uncompacted Wastes

Motor vehicles, railroads, and ocean-going vessels are the principal means now used to transport solid wastes. Pneumatic and hydraulic systems have also been used. However, in recent years, because of their simplicity and dependability, open-top semitrailers have found wide acceptance for the hauling of uncompacted wastes from direct-load transfer stations (see Figure 5-15*a*). Another combination that has proven to be very effective for uncom-

TABLE 5-11 Types of Transfer Stations Used for Municipal Solid Waste

Type	Description
	Direct-Load Transfer Stations
Large- and medium-capacity direct-load transfer station without compaction	Wastes to be transported to landfill are loaded directly into large open-top transfer trailers for transport to landfill.
Large- and medium-capacity direct-load transfer stations with compactors	Wastes to be transported to landfill are loaded directly into large compactors and compacted into specially designed transport trailers or into bales, which are then transported to landfill.
Small-capacity direct-load transfer stations	Small-capacity transfer stations are used in remote and rural areas. Small-capacity transfer station are also used at landfills as a convenience for residents who wish to haul wastes directly to landfill.
	Storage-Load Transfer Station
Large-capacity storage-load transfer station without compaction	Wastes to be transported to a landfill are discharged into a storage pit where they are pulverized before being loaded into open trailers. Waste is pulverized to reduce the size of the individual waste constituents to achieve more effective utilization of the transfer trailers.
Medium-capacity storage-load transfer station with processing and compaction facilities	Wastes to be transported to a landfill are discharged into a pit where they are further pulverized before being baled for transport to a landfill.
	Other Types of Transfer Stations
Combined discharge-load and direct-load transfer station	Waste to be transported to a landfill can either be discharged on a platform or discharged directly into a transfer trailer. Wastes discharged onto a platform are typically sorted to recover recyclable materials.
Transfer and transport operations at MRFs	Depending on the type of collection service provided, materials recovery and transfer operations are often combined in one facility. Depending on the operation of the MRF, wastes to be landfilled can be discharged directly into open trailers or into a storage pit to be loaded later into open-top trailers or baled for transport to a landfill.

Source: Adapted from Tchobanoglous et al. (1993).

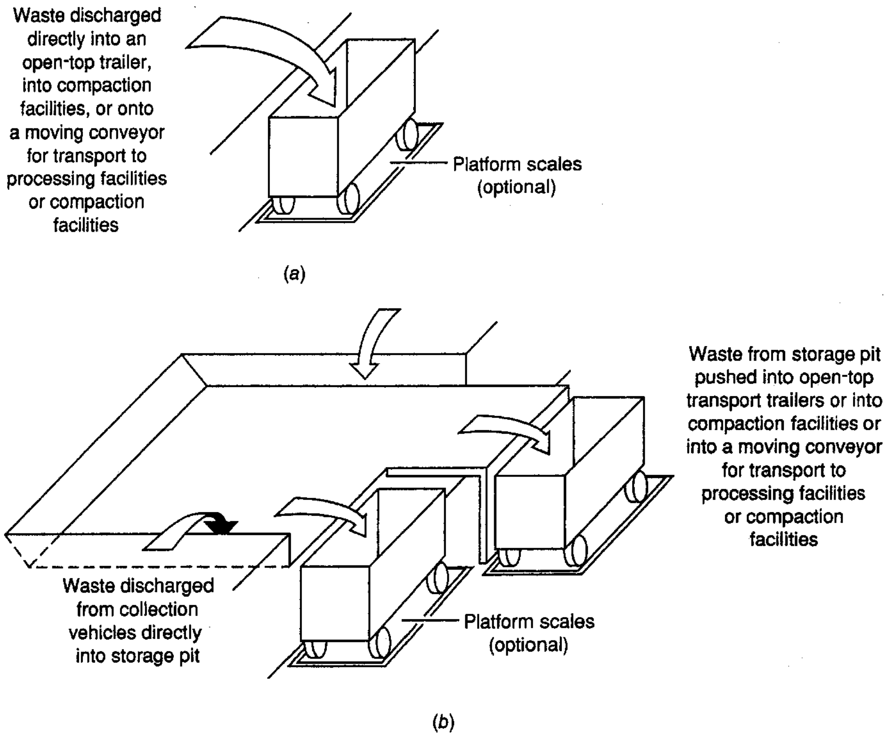


Figure 5-12 Definition sketch for two most common types of transfer stations: (*a*) direct discharge; (*b*) storage-discharge (Tchobaoglous et al., 1993).

pacted wastes is the truck-trailer combination (see Figure 5-15*b*). Transport trailers used for hauling solid waste over great distances are all of monoque construction, where the bed of the trailer also serves as the frame of the trailer. Using monoque construction allows greater waste volumes and weights to be hauled.

Transfer Station Siting Issues

A transfer station, resource recovery facility, or processing facility should be located and designed with the same care as described for an incinerator. Drainage of paved areas and adequate water hydrants for maintenance of cleanliness and fire control are equally important. Other concerns are landscaping, weigh scales, and traffic, odor, dust, litter, and noise control. Rail haul and barging to sea also involve the use of transfer stations. They may include one or a combination of grinding, baling, or compaction to increase densities, thereby improving transportation efficiency.

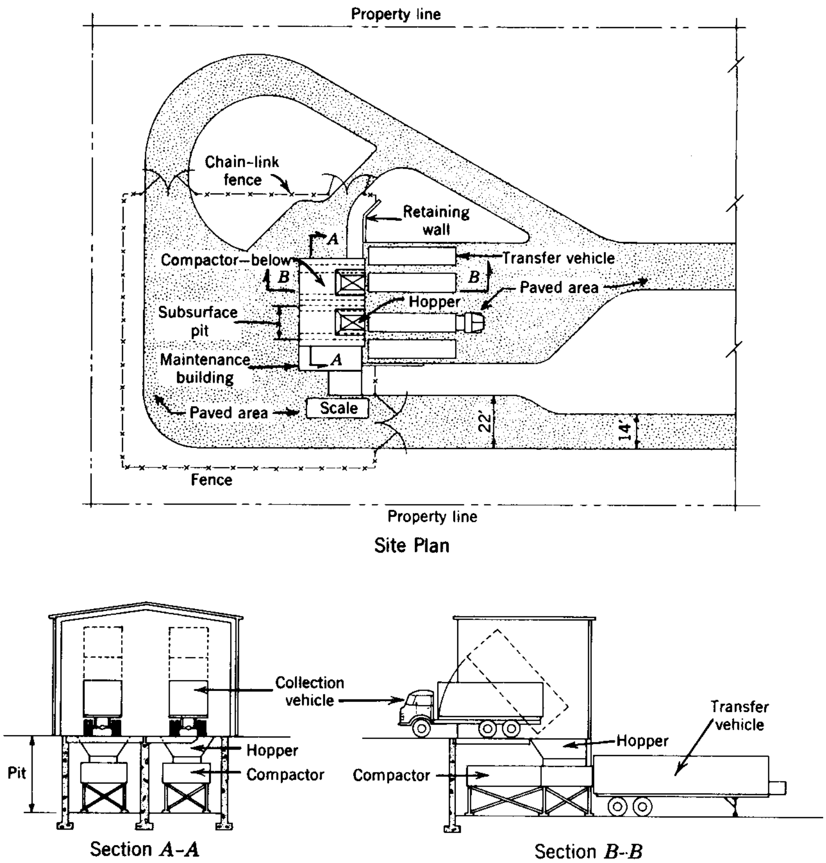


Figure 5-13 Direct-discharge transfer station equipped with stationary compactors. (Courtesy of Malcolm Pirnie, Inc. Reproduced with permission.)

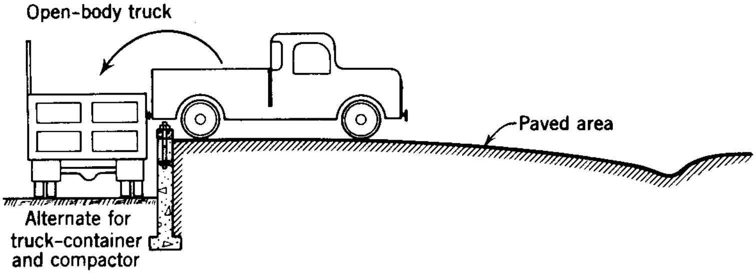
WASTE REDUCTION AND MATERIALS RECOVERY

Proper solid waste management should first prevent and reduce the generation of solid wastes, reduce their hazardous characteristics, and recover and recycle waste to the extent practicable and then dispose of the remaining wastes in a manner that does not endanger public health or the environment. The focus of this section is on waste reduction and the recovery and recycling of materials.

Waste Reduction

The extent to which solid wastes can be reduced, recovered, and recycled should be an integral part of every solid waste management system study,

(a)



(b)

Figure 5-14 Small direct-discharge transfer stations: (*a*) transfer station located in industrial park; (*b*) convenience type located in rural areas at entrance of landfill disposal sites.

whether involving composting, a sanitary landfill, or an incinerator. Composting is also considered a form of recycling. The first step, however, should be waste reduction at the point of generation or product formulation. Industrial material, process, and packaging changes can minimize the waste or substitute a less toxic or objectionable material. The amount of waste can then be reduced and what waste is produced can be recovered, reused, or recycled to the extent feasible, thereby reducing the amount for final disposal. Additional

(a)

(b)

Figure 5-15 Typical examples of transfer trailers used to transport waste over large distances to (*a*) single large trailer with drop bottom and (*b*) tractor trailer combination in process of being unloaded at landfill.

details on source reduction may be found elsewhere (U.S. EPA, 1995c, 1996, 1998b).

There has been considerable interest in a returnable bottle deposit law in some states to reduce highway litter, conserve resources, and reduce the volume of solid wastes for disposal. The bottle law is usually applicable to all types of beverage containers, including glass, metal, and plastic, but not to other types of containers such as food jars, plastic and paper cups, wine and liquor bottles, and the like. The effectiveness of the bottle deposit law has been debated by some considering its limited application, the handling involved, and total cost, tangible and intangible. A substantial number of deposit containers are not returned by the consumer. This results in an unintended income to the supermarket or other retailer and what amounts to an additional cost to the consumer. Other alternatives should be considered. The reduction of *all* types of litter and insults to the landscape, including spillage from uncovered vehicles, elimination of junked cars, debris, and illegal dumps, and education of the public to promote a clean environment such as through Keep America Beautiful, requires greater support. Some returnable bottle laws are being amended to include liquor, wine, and wine cooler bottles and possibly other containers.

Materials Recovery and Recycling

Recovery of materials and energy from solid wastes is not new. Scavengers have salvaged newsprint and cardboard, rags, copper, lead, and iron for years. These materials, together with aluminum, glass, plastics, and wood, are being reclaimed at central collection and processing stations to a greater or lesser extent depending on the available market, tax policies, and public interest. Energy recovery, where feasible, has been an important consideration in which raw solid waste and shredded solid waste, referred to as solid-waste-derived fuel (RDF), is burned to produce steam or electricity.

Recycling can effect savings in landfill space and in energy. One ton of newspapers can save 3.0 to 3.3 yd^3 of landfill space. It is estimated that 95 percent less energy is required to produce aluminum from recycled aluminum than from bauxite. Crushed recycled glass melts at a lower temperature than virgin raw material, thereby conserving energy. Unfortunately, the recycling of glass has essentially ceased because of a glut of material available, the high cost of handling and processing recycled glass, and the cost associated with pollution control.

Resource recovery is not a municipal operation to be entered into just because it seems like the logical or proper thing to do. It is a complex economic and technical system with social and political implications, all of which require competent analysis and evaluation before a commitment is made. Included are the capital and operating costs, market value of reclaimed materials and material quality, potential minimum reliable energy sales, assured quantity of solid wastes, continued need for a sanitary landfill for the disposal of excess and remaining unwanted materials and incinerator residue, and a site location close to the centroid of the generators of solid wastes. Not all concepts are viable. Incentives and monetary support may be required to obtain an acceptable site.

Resource recovery is a partial waste disposal and reclamation process. Materials not recovered may amount to 50 to 70 percent of the original waste by weight, although a resource recovery system can theoretically be used to separate up to 90 percent of the municipal waste stream into possibly marketable components. It has been estimated that under the best conditions only about 50 to 60 percent of the solid waste will be recovered. In 1979, 7 percent was being recycled for materials or energy. In 1990, the national average was estimated to be 11 percent. In the year 2000, the average was about 26 percent. In general, it has been found that the recovery of materials from municipal solid waste is not a paying proposition. Most materials recovery operations are subsidized, in part, by the collection fees or by added montly charges. In most communities, materials recovery facilities are used to help meet mandated diversion (from landfill disposal) requirements.

Processing Technologies for the Recovery of Materials

In the not-so-distant past, solid waste processing and disposal methods have included the open dumping, hog feeding, incineration, grinding and discharge to a sewer, milling, compaction, sanitary landfill, dumping and burial at sea (prohibited in the United States), incineration, reduction, composting, pyrolization, wet oxidation, and anaerobic digestion. Currently, the most commonly accepted processing technologies involve the recovery of materials at materials recovery facilities and composting. Materials recovery facilities are considered below; composting is considered in the following section.

Implementation of Materials Recovery Facilities

Because the EPA has mandated diversion goals, most communities have developed a variety of materials recovery facilities. The purpose of this section is to define the type of materials recovery facilities now in use, to review the principal unit operations and processes used for the recovery of materials, and to highlight the planning issues associated with the implementation of a materials recovery facility. Additional details on materials recovery facilities may be found in U.S. EPA (1991).

Types of Materials Recovery Facilities (MRFs) The separation of household and commercial waste can be done at the source, at the point of collection by collection crews or at centralized *materials recovery facilities* or large integrated *materials recovery/transfer facilities* (MR/TFs). The type of MRF will depend on the type of collection service provided and the degree of source separation the waste has undergone before reaching the MRF. The two general types of MRFs are (1) for source-separated material and (2) for commingled solid waste. The functions of each of theses types of MRFs is reviewed in Table 5-12. As reported in Table 5-12, may different types of MRFs have been developed depending on the specific objective. Further, as reported

TABLE 5-12 Typical Examples of Materials and Functions/Operations of MRFs Used for Processing of Source-Separated Recycable Materials and Commingled Solid Waste

Materials	Function/Operation
	MRFs for Source-Separated Recycable Materials
Mixed paper and cardboard	Manual separation of high-value paper and cardboard or contaminants from commingled paper types; baling of separated materials for shipping; storage of baled materials
	Manual separation of cardboard and mixed paper; baling of separated materials for shipping; storage of baled materials
	Manual separation of old newspaper, old corrugated cardboard, and mixed paper from commingled mixture; baling of separated materials for shipping; storage of baled materials
PETE and HDPE plastics	Manual separation of PETE and HDPE from commingled plastics; baling of separated materials for shipping; storage of baled materials
Mixed plastics	Manual separation of PETE, HDPE, and other plastics from commingled mixed plastics; baling of separated materials for shipping; storage of baled materials
Mixed plastics and glass	Manual separation of PETE, HDPE, and glass by color from commingled mixture; baling of separated materials for shipping; storage of baled materials
Mixed glass	
With sorting	Manual separation of clear, green, and amber glass; storage of separated materials
Without sorting	Storage of separated mixed glass
Aluminum and tin cans	Magnetic separation of tin cans from commingled mixture of aluminum and tin cans; baling of separated materials for shipping; storage of baled materials
Plastic, aluminum cans, tin cans, and glass	Manual or pneumatic separation of polyethylene terepholate (PETE), high-density polyethylene (HDPE), and other plastics; manual separation of glass by color, if separated; magnetic separation of tin cans from commingled mixture of aluminum and tin cans; magnetic separation may occur before or after the separation of plastic; baling of plastic (typically two types), aluminum cans and tin cans, and crushing of glass and shipping; storage of baled and crushed materials

TABLE 5-12 (*Continued*)

Materials	Function/Operation
Yard wastes	Manual separation of plastic bags and other contaminants from commingled yard wastes, grinding of clean yard waste, size separation of waste that has been ground up, storage of oversized waste for shipment to biomass facility, and composting of undersized material
	Manual separation of plastic bags and other contaminants from commingled yard wastes followed by grinding and size separation to produce landscape mulch; storage of mulch and composting of undersized materials
	Grinding of yard waste to produce biomass fuel; storage of ground material
	MRFs for Commingled Solid Waste
Recovery of recyclable materials to meet mandated first-stage diversion goals	Bulky items, cardboard, paper, plastics (PETE, HDPE, and other mixed plastic), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials
Recovery of recyclable materials and further processing of source-separated materials to meet second-stage diversion goals	Bulky items, cardboard, paper, plastics (PETE, HDPE, and other mixed plastic), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials; additional separation of source-separated materials, including paper, cardboard, plastic (PETE, HDPE, other), glass (clear and mixed), aluminum cans, tin cans
Preparation of MSW for use as fuel for combustion	Bulky items, cardboard (depending on market value), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials
Preparation of MSW for use as feedstock for composting	Bulky items, cardboard (depending on market value), plastics (PETE, HDPE, and other mixed plastic), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials
Selective recovery of recyclable materials	Bulky items, office paper, old telephone books, aluminum cans, PETE and HDPE, and ferrous materials; other materials depending on local markets

Source: Adapted from Leverenz et al. (2002).

in Table 5-13, materials recovery facilities can also be classified in terms of size and the degree of mechanization. Small MRFs associated with the further processing of source-separated materials tend to be less highly mechanized.

Methods and Equipment for the Separation and Recovery of Materials Methods and processes used singly and in various combinations to recover and prepare wastes for reuse and/or disposal are summarized in Table 5-14.

TABLE 5-13 Typical Types of Materials Recovery Facilities, Capacity Ranges, and Major Functions and System Components Based on Degree of Mechanization

System Type	Capacity (tons/day)	Major System Components
Materials recovery		
Low	5–20	Processing of source-separated materials only; enclosed building, concrete floors, elevated hand-sorting conveyor, baler (optional), storage for separated and prepared materials for one month, support facilities for workers
Intermediate	20–100	Processing of source-separated commingled materials and mixed paper; enclosed building, concrete floors, elevated hand-sorting conveyor, conveyors, baler, storage for separated and baled materials for two weeks, support facilities for workers, buy-back center
High	>100	Processing of commingled materials or MSW; same facilities as intermediate system plus mechanical bag breakers, magnets, shredders, screens, and storage for baled materials for up to two months
Composting		
Low end system	5–20	Source-separated yard waste feedstock only; grinding equipment, cleared level ground with equipment to form and turn windrows, screening equipment (optional)
High-end system	>20	Feedstock derived from source-separated yard waste or processing of commingled wastes; facilities include enclosed building with concrete floors, in vessel composting reactors; enclosed building for curing of compost product, equipment for bagging and marketing compost product

Source: Leverenz et al. (2002).

Of the methods reported in Table 5-14, manual sorting is by far the most commonly used method for processing waste materials (see Figure 5-16). It is interesting to note that no machine has been developed to date that can match the eye-hand coordination of humans. The particulate grouping of unit processes and operations will depend on the characteristics of the material to be separated.

TABLE 5-14 Typical Methods and Equipment Used for Processing and Recovery of Individual Waste Components from MSW

Processing Options	Description
Manual sorting	Unit operation in which personnel physically remove items from the waste stream. Typical examples include (1) removal of bulky items that would interfere with other processes and (2) sorting material off an elevated conveyor into large bins located below the conveyor.
Size reduction	Unit operation used for the reduction of both commingled MSW and recovered materials. Typical applications include (1) hammermills for shredding commingled MSW, (2) shear shredders for use with commingled MSW and recycled materials such as aluminum, tires, and plastics, and (3) tub grinders used to process yard wastes.
Size separation	Unit operation in which materials are separated by size and shape characteristics, most commonly by the use of screens. Several types of screens are in common use, including (1) reciprocating screens for sizing shredded yard wastes, (2) trommel screens used for preparing commingled MSW prior to shredding, and (3) disc screens used for removing glass from shredded MSW.
Magnetic field separation	Unit operations in which ferrous (magnetic) materials are separated from nonmagnetic materials. A typical application is the separation of ferrous from nonferrous materials (e.g., tin from aluminum cans).
Densification (compaction)	Densification and compaction are unit operations used to increase the density of recovered materials to reduce transportation costs and simplify storage. Typical applications include (1) the use of baling for cardboard, paper, plastics, and aluminum cans and (2) the use of cubing and pelletizing for the production of densified RDF.
Materials handling	Unit operations used for the transport and storage of MSW and recovered materials. Typical applications include (1) conveyors for the transport of MSW and recovered materials, (2) storage bins for recovered materials, and (3) rolling stock such as fork lifts, front-end loaders, and various types of trucks for the movement of MSW and recovered materials.
Automated sorting	Unit operation in which materials are separated by material characteristics. Typical examples include (1) optical sorting of glass by color, (2) X-ray detection of polyvinyl chloride (PVC), and (3) infrared sorting of mixed resins.

Source: Tchobanoglous et al. (1993).

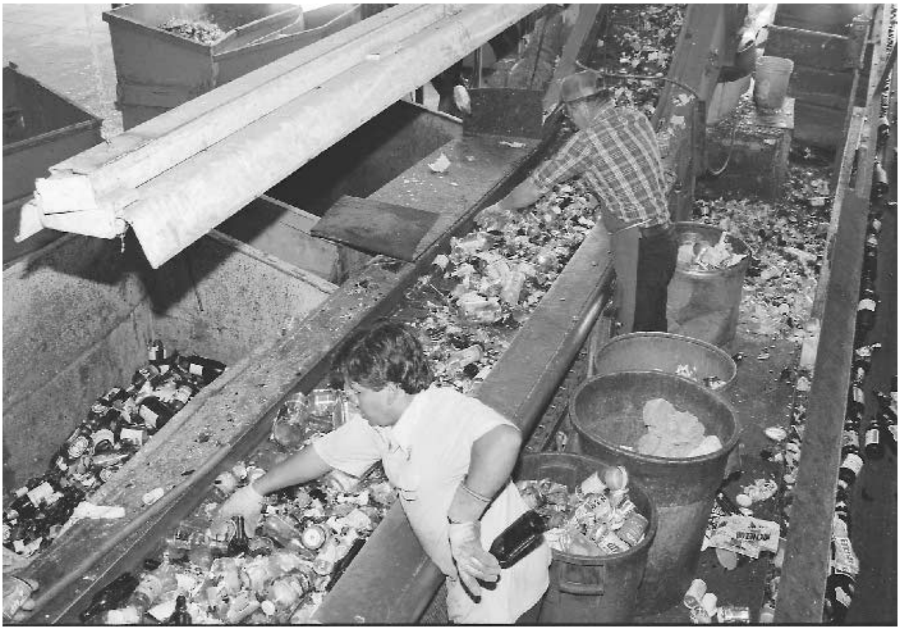


Figure 5-16 Typical sorting line for manual separation of waste components.

MRF Process Flow Diagrams Once a decision has been made on how and what recyclable materials are to be recovered, MRF process flow diagrams must be developed. In developing MRF process flow diagrams, the following factors must be considered: (1) identification of the characteristics of the waste materials to be processed, (2) consideration of the specifications for recovered materials now and in the future, and (3) the available types of equipment and facilities. For example, specific waste materials cannot be separated effectively from commingled MSW unless bulky items such as lumber and white goods and large pieces of cardboard are first removed and the plastic bags in which waste materials are placed are broken open and the contents exposed. The specifications for the recovered material will affect the degree of separation to which the waste material is subjected. Three typical MRF process flow diagrams are presented in Figures 5-17, 5-18, and 5-19 for source-separated recycable material, for mixed paper and cardboard, and commingled solid waste, respectively (Leverenz et al., 2002).

Technical Considerations in the Planning and Design of MRFs

Technical consideration in the planning and design of MRFs involves three basic steps: (1) feasibility analysis, (2) preliminary design, and (3) final design. These planning and design steps are common to all major public works projects such as landfills or wastewater treatment plants. In some cases, the

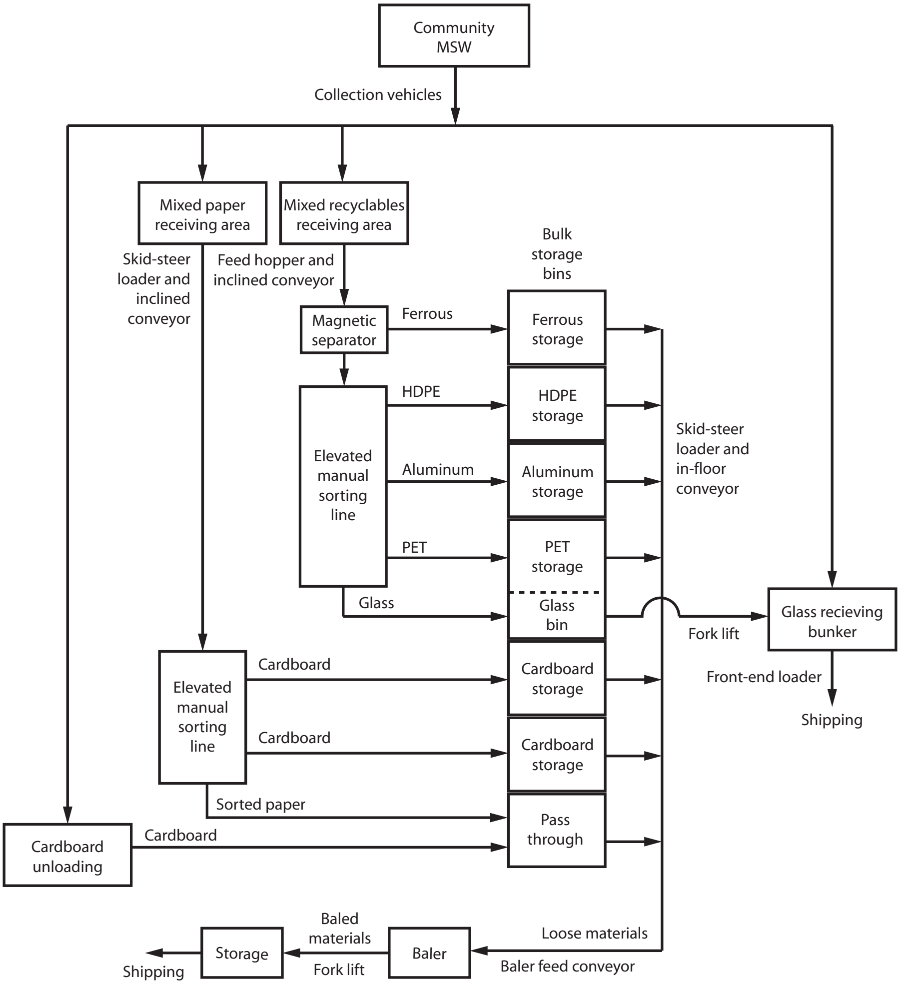


Figure 5-17 Process flow diagram for MRF used to further process source-separated waste (Leverenz et al., 2002).

feasibility analysis has already been accomplished as part of the integrated waste management planning process. These topics are considered further in Table 5-15 (Leverenz et al., 2002).

COMPOSTING

Composting is the controlled decay of organic matter in a warm, moist environment by the action of bacteria, fungi, and other organisms. The organic matter may be in municipal solid waste, sewage sludge, septage, agricultural

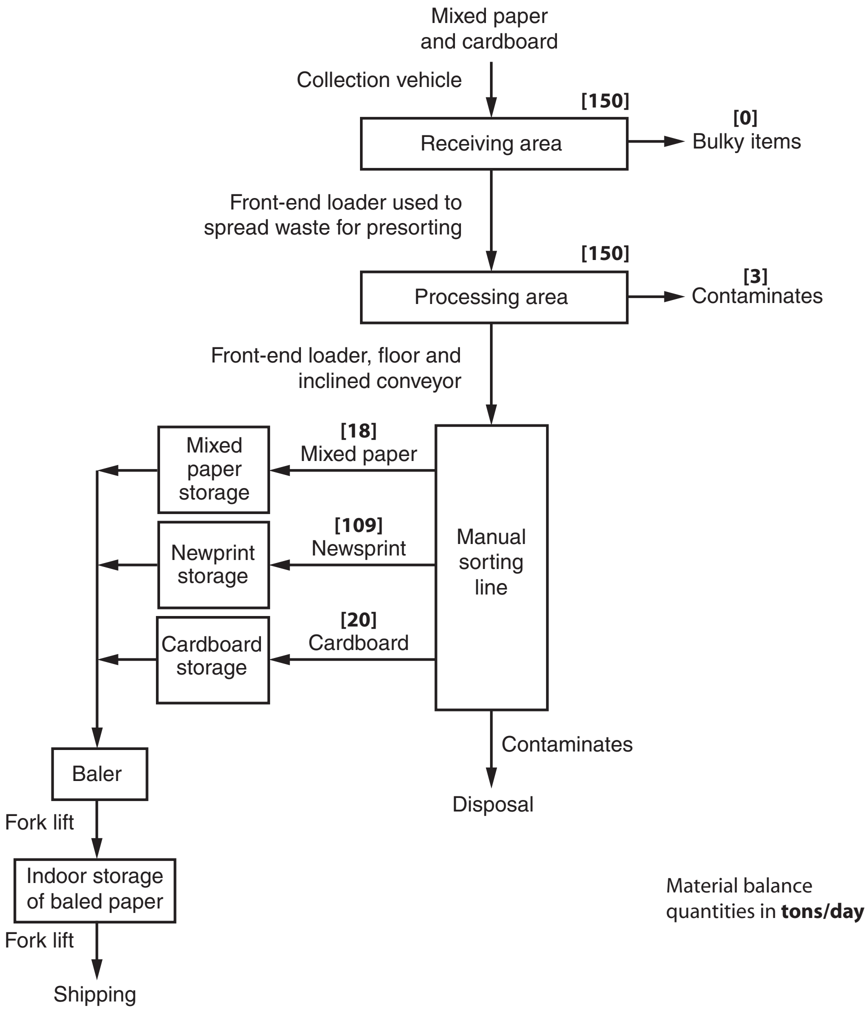


Figure 5-18 Process flow diagram for MRF used to separate mixed paper and cardboard (Leverenz et al., 2002).

waste, manure, leaves and other yard waste, or combinations of these materials and other organic wastes. Composting is becoming an increasingly popular waste management option as communities look for ways to divert portions of the local waste stream from landfills. The principal applications of composting are for (1) yard wastes, (2) the organic fraction of MSW, (3) partially processed commingled MSW, and (4) co-composting the organic fraction of MSW with wastewater sludge. Because of the importance of composting in meeting mandated waste diversion goals, the number of composting facilities has increased significantly over the past 10 years. The uses of com-

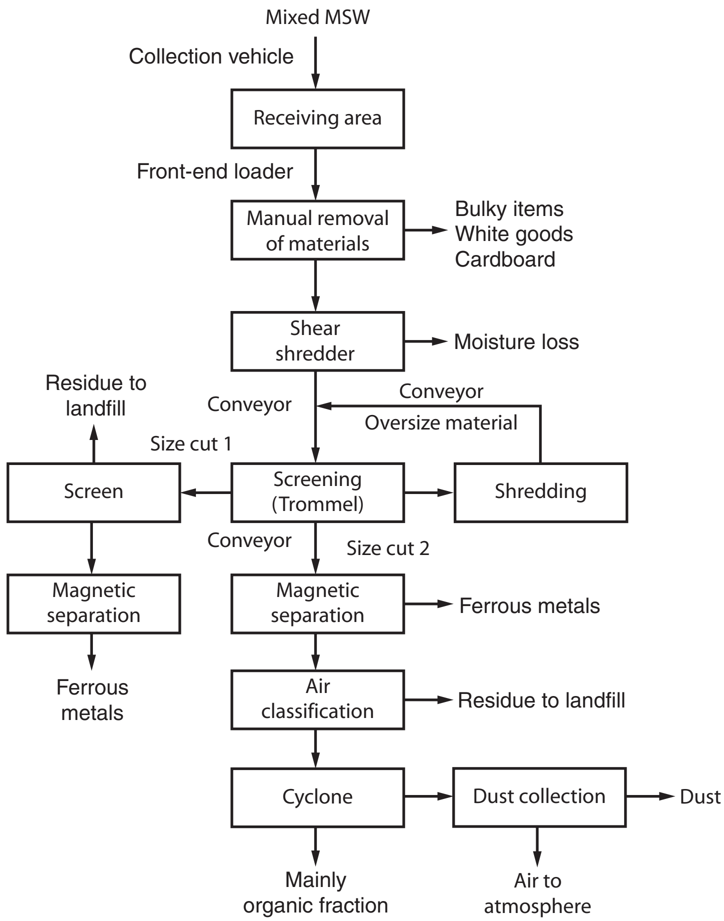


Figure 5-19 Process flow diagram for MRF used to process commingled waste for recovery of recyclable materials (Leverenz et al., 2002).

post and constraints to its use; a description of the compost process; descriptions of some of the more common composting processes, important design and operational considerations, and the implementation of the compost process are considered in the following discussion. Additional details on the compost process may be found in Benedict et al. (1988), Diaz et al. (2002), Haug (1993), and Tchobanoglous et al. (1993).

Uses of Compost and Constraints to Its Use

Compost improves soil moisture retention; it is a good soil conditioner but a poor fertilizer. Compost, depending on the waste source and its composition, may be used as a soil amendment for agricultural soil and landscaping in

TABLE 5-15 Important Technical Considerations in the Planning and Design of MRFs

	Step 1: Feasibility Analysis
Function of MRF	The coordination of the MRF with the integrated waste management plan for the community. A clear explanation of the role and function of the MRF in achieving landfill waste diversion and recycling goals is a key element.
Conceptual design, including types of wastes to be sorted	What type of MRF should be built, which materials will be processed now and in the future, and what should be the design capacity of the MRF. Plan views and renderings of what the final MRF might look like are often prepared.
Siting	While it has been possible to build and operate MRFs in close proximity to both residential and industrial developments, extreme care must be taken in their operation if they are to be environmentally and aesthetically acceptable. Ideally, to minimize the impact of the operation of MRFs, they should be sited in more remote locations where adequate buffer zones surrounding the facility can be maintained. In many communities, MRFs are located at the landfill site.
Economic analysis	Preliminary capital and operating costs are delineated. Estimates of revenues available to finance the MRF (sales of recyclables, avoided tipping fees, subsidies) are evaluated. A sensitivity analysis must be performed to assess the effects of fluctuating prices for recyclables and the impacts of changes in the composition of the waste.
Ownership and operation	Typical ownership and operation options include public ownership, private ownership, or public ownership with contract operation.
Procurement	What approach is to be used in the design and construction of the MRF? Several options exist, including (1) the traditional architect-engineer and contractor process, (2) the turn key contracting process in which design and construction are performed by a single firm, and (3) a full-service contract in which a single contractor designs, builds, and operates the MRF
	Step 2: Preliminary Design
Process flow diagrams	One or more process flow diagrams are developed to define how recyclable materials are to be recovered from MSW (e.g., source separation or separation from commingled MSW). Important factors that must be considered in the development of process flow diagrams include (1) characteristics of the waste materials to be processed, (2) specifications for recovered materials now and in the future, and (3) the available types of equipment and facilities.

TABLE 5-15 (*Continued*)

Materials recovery rates	Prediction of the materials flow to the MRF is necessary to estimate the effectiveness or performance of the recycling program. The performance of a recycling program, the overall component recovery rate, is generally reported as a materials recovery rate or recycling rate, which is the product of three factors: (1) participation factor, (2) composition factor, and (3) source recovery factor. Component capture rates for the recyclable materials most commonly collected in source separation recycling programs must be estimated. Composition factors are measured in waste composition studies. Typical component recovery rates may be found in Leverenz et al. (2002).
Materials balances and loading rates	One of the most critical elements in the design and selection of equipment for MRFs is the preparation of a materials balance analysis to determine the quantities of materials that can be recovered and the appropriate loading rates for the unit operations and processes used in the MRF.
Selection of processing equipment	Factors that should be considered in evaluating processing equipment include: capabilities, reliability, service requirements, efficiency, safety of operation, health hazard, environment impact, and economics.
Facility layout and design	The overall MRF layout includes (1) sizing of the unloading areas for commingled MSW and source-separated materials; (2) sizing of presorting areas where oversize or undesirable materials are removed; (3) placement of conveyor lines, screens, magnets, shredders, and other unit operations; (4) sizing of storage and out-loading areas for recovered materials; and (5) sizing and design of parking areas and traffic flow patterns in and out of the MRF. Many of these layout steps are also common to the layout and design of transfer stations.
Staffing	Depends on type of MRF (i.e., degree of mechanization).
Economic analysis	Refine preliminary cost estimate prepared in feasibility study.
Environmental issues	Important environmental issues include groundwater contamination, dust emissions, noise, vector impacts, odor emissions, vehicular emissions, other environmental emissions.
Health and safety issues	Important health and safety issues are related to worker and public access issues.
	Step 3: Final Design
Preparation of final plans and specifications	Plans and specifications will be used for bid estimates and construction.
Preparation of environmental documents	The necessary environmental documents (e.g., Environmental Impact Report) are prepared.

TABLE 5-15 (*Continued*)

Preparation of detailed cost estimate	A detailed engineers cost estimate is made based on materials take-offs and vendor quotes. The cost estimate will be used for the evaluation of contractor bids if the traditional procurement process is used.
Preparation of procurement documents	A bidding process is used to obtain supplies, equipment, and services related to the construction, operation, and maintenance of the facility.

Source: Leverenz et al. (2002).

municipal parks, golf courses, gardens, and green belts; sod growing; home gardens; and nursery and greenhouse use. Compost may also be used as landfill cover, land reclamation, animal litter, and possibly animal feed. It may also be used as an additive to fertilizer, as a fuel, or in building materials.

The presence of toxic levels of pesticides, heavy metals, and pathogens should be determined and evaluated to ensure the levels are compatible with the intended use of the compost. A typical listing of permissible metal concentrations in compost is presented in Table 5-16. For pathogen reduction purposes, the temperature of the mixture must be maintained at or above 131°F (55°C) for at least three consecutive days.

The total composting time, including curing, is determined by the material, process used, and exposure to the elements. Two weeks to as much as 18

TABLE 5-16 Maximum Allowable Metal Concentrations for Class I and II Compost and Allowable Usage

	Concentration (ppm dry weight)	
Parameter	Class I[a]	Class II[b]
Mercury	10	10
Cadmium	10	25
Nickel	200	200
Lead	250	1000
Chromium, total	1000	1000
Copper	1000	1000
Zinc	1000	2500
Polychlorinated biphenyls (PCBs) total	1	10

Source: New York State (1988).

[a]Must not be used on crops grown for direct human consumption, i.e., crops consumed without processing to minimize pathogens. Can be used on food chain crops and other agricultural and horticultural uses. Must not exceed 10 mm (0.39 in.) particle size.

[b]Must be restricted to use on nonfood chain crops. Must not exceed 25 mm (0.98 in.) particle size.

months may be required for complete stabilization and curing of the compost. Thus, a plant location distant from habitation is recommended as odors may become a problem. Also, because the demand for compost may be seasonal, provision must be made for compost storage.

Composting Process

Composting involves the biological decomposition of organic materials (substrates) under controlled conditions that allow for the development of an end product that is biologically stable and free of viable pathogens and plant seeds and can be applied to land beneficially. The key concepts and objectives contained in the definition of compost are as follows:

- Composting is a biological process (e.g., aerobic anaerobic).
- Composting results in the production of a biologically stable end product.
- The end products free of viable pathogens.
- The end product is free of viable plant seeds.
- The end product can be applied to land beneficially.

To meet the above objectives, the composting process, as illustrated in Figure 5-20, usually involves the following three basic steps

- Preprocessing (e.g., size reduction, seeding, nutrient addition, and addition of bulking agent),

Figure 5-20 Overview of windrow composting operation.

- Decomposition and stabilization of organic material (two-stage process comprised of a first-stage high-rate phase followed by second-stage curing phase), and
- Postprocessing (e.g., grinding, screening, bagging, and marketing of compost product).

Composting of mixed solid waste should be preceded by a separation and recycling program, including glass, plastic, and metal separation; then usually shredding or grinding; and a program for the periodic collection of household hazardous waste. Industrial and other hazardous waste must be excluded.

The two-stage decomposition and stabilization of organic solid waste to a compost process can be described by the following reaction:

$$\left.\begin{array}{r}\text{Proteins}\\ \text{Amino acids}\\ \text{Lipids}\\ \text{Carbohydrates}\\ \text{Cellulose}\\ \text{Lignin}\\ \text{Ash}\end{array}\right\} \begin{array}{l} + O_2 + \text{nutrients} + \text{bacteria} \rightarrow \\ \text{compost} + \text{new cells} + CO_2 \\ + H_2O + NO_3^- + SO_4^{2-} + \text{heat}\end{array} \qquad (5\text{-}1)$$

(principal components comprising the organic fraction of MSW) — (principally cellulose, lignin, and ash)

As shown by the above reaction, essentially all of the organic matter with the exception of celluose and lignin are converted during the compost process. It should be noted that in time both the cellulose and lignin will undergo further biological decompostion, primarily thorugh the action of fungi and actinomycetes.

Postprocessing will typically include screening and nutient and other amendment additions, depending on the application. Many municipalities make the compost available to the residents for a nominal price.

Composting Technologies

The three composting methods used most commonly in the United States are (1) windrow, (2) aerated static pile, and (3) in-vessel methods. It should be noted that over the past 100 years more than 50 individual compost processes have been developed. The more important of these processes based on function and/or the type of reactor used for the process are summarized in Table 5-17. Some of the processes are described below.

Although many process variations are in use, odor control is a major concern in all processes. Aeration and controlled enclosed processing facilities can be used to minimize the problem. Provision must also be made for vector control, leachate collection, and the prevention of groundwater and surface-

TABLE 5-17 Municipal Composting Systems Grouped by Function or Reactor Configuration

Function or Configuration	Commercial Process
Heaps and windrows, natural aeration, batch operation	Indore/Bangalore
	Artsiely
	Baden-Baden (hazemag)
	Buhler
	Disposals Associates
	Dorr-Oliver
	Spohn
	Tollemache
	Vuilafvoer Maatschappij (VAM)
Cells with natural or forced aeration, batch operation	Beccari
	Biotank (Degremont)
	Boggiano-Pico
	Kirkconnel (Dumfriesshire)
	Metro-Waste
	Prat (Sofranie)
	Spohn
	Verdier
	Westinghouse/Naturizer
Horizontal rotating and inclined drums, continuous operation	Dano Biostabilizer
	Dun Fix
	Fermascreen (batch)
	Head Wrightson
	Vickers Seerdrum
Vertical flow reactors, continuous operation, agitated bed, natural or forced aeration	Earp-Thomas
	Fairfield-Hardy
	Frazer-Eweson
	Jersey (John Thompson)
	Multibacto
	Nusoil
	Snell
	Triga
Agitated bed	Fairfield-Hardy

Source: Tchobanoglous et al. (2002).

water pollution. The stabilized and cured compost may be ground but is usually screened before sale. Storage space is required.

Windrow Composting In the windrow process, the sludge–amendment mixture to be composted is placed in long piles (see Figure 5-20). The windrows are 3 to 6 ft high (1–2 m) and 6 to 15 ft wide (2–5 m) at the base. The windrow process is conducted normally in uncovered pads and relies on natural ventilation with frequent mechanical mixing of the piles to maintain aerobic conditions. The windrow process can be accelerated if the compost is turned over every four or five days, until the temperature drops from about 150 or 140°F (66 or 60°C) to about 100°F (38°C) or less. Under typical operating conditions, the windrows are turned every other day. The turning is accomplished with specialized equipment (see Figure 5-21) and serves to aerate the pile and allow moisture to escape. To meet the EPA pathogen reduction requirements, the windrows have to be turned five times in 15 days, maintaining a temperature of 55°C. The complete compost process may require two to six months.

Because anaerobic conditions can develop within the windrow between turnings, putrescible compounds can be formed that can cause offensive odors, especially when the windrows are turned. In many locations, negative aeration is provided to limit the formation of odorous compounds. Where air is provided mechanically, the process is known as aerated windrow composting (Benedict et al., 1998). Odors will result if the compost is not kept aerobic. It may be necessary to enclose the operation and provide fans and collectors of the odorous air, forcing it through a scrubber or other treatment device for discharge up a stack to the atmosphere.

Aerated Static Pile Composting In the aerated static pile process, the material to be composted is placed in a pile and oxygen is provided by mechanical aeration systems. Most states require paved surfaces for the pile

Figure 5-21 View of machine used to aerate compost placed in windrows.

construction areas to permit capture and control runoff and allow operation during wet weather. The most common aeration system involves the use of a grid of subsurface piping (see Figure 5-22). Aeration piping often consists of flexible plastic drainage tubing assembled on the composting pad. Because the drainage-type aeration piping is inexpensive, it is often used only once. Before constructing the static pile, a layer of wood chips is placed over the aeration pipes or grid to provide uniform air distribution. The static pile is then built up to 8 to 12 ft (2.6–3.9 m) using a front-end loader. A cover layer of screened or unscreened compost is placed over the sludge to be composted. Typically, oxygen is provided by pulling air through the pile with an exhaust fan. Air that has passed through the compost pile is vented to the atmosphere though a compost filter for odor control.

In-Vessel Composting Systems In-vessel composting is accomplished inside an enclosed container or vessel. Every imaginable type of vessel has been used as a reactor in these systems, including vertical towers, horizontal rectangular and circular tanks, and circular rotating tanks. In-vessel composting systems can be divided into two major categories: plug flow and dynamic (agitated bed). In plug flow systems, the relationship between particles in the composting mass stays the same throughout the process, and the system op-

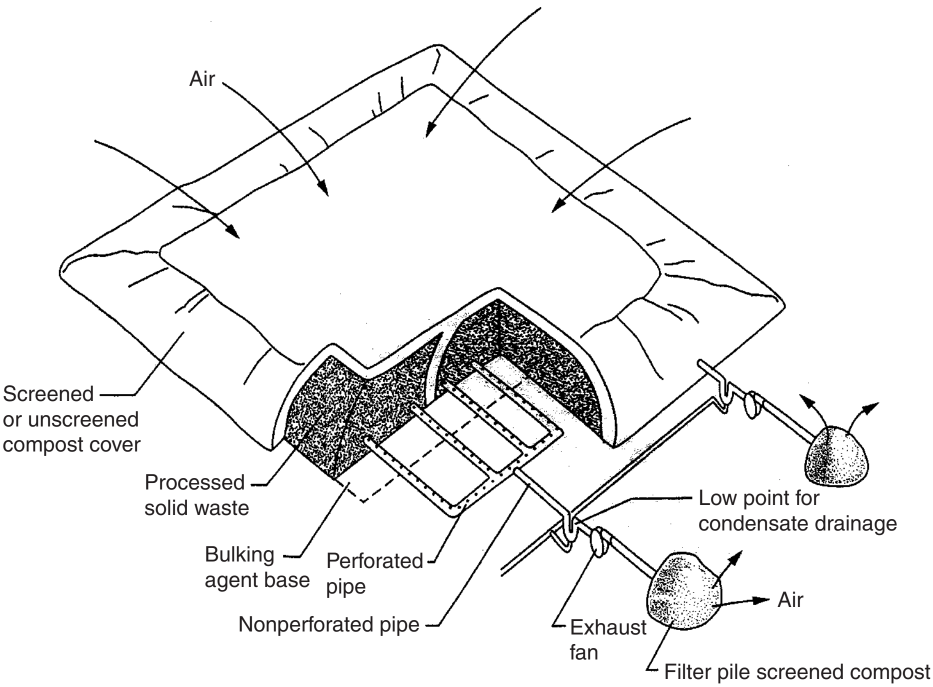


Figure 5-22 Schematic of static aerated compost pile.

erates on the basis of a first-in, first-out principle. In a dynamic system, the composting material is mixed mechanically during the processing.

Mechanical systems are designed to minimize odors and process time by controlling environmental conditions such as air flow, temperature, and oxygen concentration. The popularity of in-vessel composting systems has increased in recent years. Reasons cited for this increased use are process and odor control, faster throughput, lower labor costs, and smaller area requirements. The detention time for in-vessel systems varies from 1 to 2 weeks, but virtually all systems employ a 4- to 12-week curing period after the active composting period.

Other Composting Technologies *Naturizer* composting uses sorting, grinding and mixing, primary and secondary composting including three grinding operations, aeration, and screening. Digested sewage sludge, raw-sewage sludge, water, or segregated wet garbage is added at the first grinding for dust and moisture control. The total operation takes place in one building in about six days.

The *Dano* composting (stabilizer) plant consists of sorting, crushing, biostabilization 3 to 5 days in a revolving drum to which air and moisture are added, grinding, air separation of nonorganics, and final composting in open windrows. Temperatures of 140°F (60°C) are reached in the drum. Composting can be completed in 14 days by turning the windrows after the fourth, eighth, and twelfth days. Longer periods are required if the windrows are not kept small, turned, and mixed frequently and if grinding is not thorough. In a more recent version, the drum treatment is for 8 hr followed by screening, final composting in covered aerated piles for about three weeks, and then three weeks of aging in static piles.

The *Fairfield–Hardy* process handles garbage and trash and sewage sludge. The steps in the process are (1) sorting—manual and mechanical to separate salvageable materials; (2) coarse shredding; (3) pulping; (4) sewage sludge addition, if desired; (5) dewatering to about 50 percent moisture; (6) three- to five-day digestion with mixing and forced air aeration, temperature ranges from 140 to 170°F (60–76°C); (7) air curing in covered windrows; and (8) pelletizing, drying, and bagging. Compost from the digester is reported to have heat values of 4000 Btu/lb and, when pelletized and dried, 6450 Btu/lb.

The *Bangalore* process is used primarily in India. Layers of unshredded solid waste and night soil are placed in a shallow trench; the top is covered with soil. The duration of the treatment is 120 to 150 days.

Compost Process Design and Operational Considerations

The principal design considerations associated with the aerobic biological decomposition of prepared solid wastes are presented in Table 5-18. It can be concluded from this table that the preparation of a composting process is

TABLE 5-18 Important Design Considerations for Aerobic Composting Process

Item	Comment
Particle size	For optimum results, the size of solid wastes should be between 25 and 75 mm (1 and 3 in).
Carbon to nitrogen (C/N) ratio	Initial C/N ratios (by mass) between 25 and 50 are optimum for aerobic composting. At lower ratios ammonia is given off. Biological activity is also impeded at lower ratios. At higher ratios, nitrogen may be a limiting nutrient.
Blending and seeding	Composting time can be reduced by seeding with partially decomposed solid wastes to the extent of about 1–5% by weight. Sewage sludge can also be added to prepared solid wastes. Where sludge is added, the final moisture content is the controlling variable.
Moisture content	Moisture content should be in the range between 50 and 60% during the composting process. The optimum value appears to be about 55%.
Mixing/turning	To prevent drying, caking, and air channeling, material in the process of being composted should be mixed or turned on a regular schedule or as required. Frequency of mixing or turning will depend on the type of composting operation.
Temperature	For best results, temperature should be maintained between 122 and 131°F (50 and 55°C) for the first few days and between 131 and 140°F (55 and 60°C) for the remainder of the active composting period. If temperature goes beyond 151°F (66°C), biological activity is reduced significantly.
Control of pathogen	If properly conducted, it is possible to kill all the pathogens, weeds, and seeds during the composting process. To do this, the temperature must be maintained between 140 and 158°F (60 and 70°C) for 24 hr.
Air requirements	The theoretical quantity of oxygen required can be estimated using the stiochiometrc equation for the conversion of organic matter. Air with at least 50% of the initial oxygen concentration remaining should reach all parts of the composting material for optimum results, especially in mechanical systems.
pH control	To achieve an optimum aerobic decomposition, pH should remain at 7–7.5 range. To minimize the loss of nitrogen in the form of ammonia gas, pH should not rise above about 8.5.
Degree of decomposition	The degree of decomposition can be estimated by measuring the reduction in the organic matter present using the chemical oxygen demand (COD) test. Another measurement that has been used to determine the degree of decomposition is the use of respiratory quotient (RQ)
Land requirement	The land requirements for a plant with a capacity of 50 tons/day will be 1.5–2.0 acres. The land area required for larger plant will be less.

Source: Tchobanoglous et al. (2002).

Note: $1.8 \times °C + 32 = °F$.

not a simple task, especially if optimum results are to be achieved. For this reason, most of the commercial composting operations that have been developed are highly mechanized and are carried out in specially designed facilities. Because of their importance, pathogen and odor control are considerd further below. Additional details on the design and operation of compost processes may be found in Haug (1980) and Diaz et al. (2002):

Pathogen Control Pathogenic organisms and weed seeds exposed to the higher temperatures for the times indicated in Table 5-19 will be destroyed. However, because of the nature of solid waste, the processes used, and the range in temperature within compost clumps or zones and between the outside and inside of a mass of compost, the required lethal temperatures cannot be ensured. The EPA requires 131°F (55°C) for three days to obtain pathogen destruction before compost land spreading, but this temperature does not kill all pathogens. The World Health Organization (WHO) recommends that the compost attain a temperature of at least 140°F (60°C). It has been found that

TABLE 5-19 Temperature and Time of Exposure Required for Destruction of Some Common Pathogens and Parasites

Organism	Observations
Salmonella typhosa	No growth beyond 46°C; death within 30 min. at 55–60°C and within 20 min. at 60°C; destroyed in a short time in compost environment.
Salmonella sp.	Death within 1 hr at 55°C and within 15–20 min. at 60°C.
Shigella sp.	Death within 1 hr at 55°C.
Escherichia coli	Most die within 1 hr at 55°C and within 15–20 min. at 60°C.
Entamoeba histolytica cysts	Death within a few min. at 45°C and within a few sec at 55°C.
Taenia saginata	Death within a few min. at 55°C.
Trichinella spiralis larvae	Quickly killed at 55°C; instantly killed at 60°C.
Brucella abortus or *Br. suis*	Death within 3 min. at 62–63°C and within 1 hr at 55°C.
Micrococcus pyogenes var. *aureus*	Death within 10 min. at 50°C.
Streptococcus pyogenes	Death within 10 min. at 54°C.
Mycobacterium tuberculosis var. *hominis*	Death within 15–20 minutes at 66°C or after momentary heating at 67°C.
Corynebacterium diphteria	Death within 45 min. at 55°C.
Necator americanus	Death within 50 min. at 45 C.
Ascaris lumbricoides eggs	Death in less than 1 hr at temperatures over 50°C.

Source: Tchobanoglous et al. (1993).

Note: 1.8 × (°C) + 32 = °F.

salmonella repopulation is possible in a soil amendment from composted sludge. Microbial activity is greatest when mean municipal compost temperature is 114 to 140°F (40–60°C), using aeration to control the temperature to achieve the highest composting rates. Temperatures above 140°F (60°C) tend to slow down the process as many organisms die off at and above this temperature.

Control of Odor The majority of the odor problems in aerobic composting processes are associated with the development of anaerobic conditions within the compost pile. In many large-scale aerobic composting systems, it is common to find pieces of magazines or books, plastics (especially plastic films), or similar materials in the organic material being composted. These materials normally cannot be decomposed in a relatively short time in a compost pile. Furthermore, because sufficient oxygen is often not available in the center of such materials, anaerobic conditions can develop. Under anaerobic conditions, organic acids will be produced, many of which are extremely odorous. To minimize the potential odor problems, it is important to reduce the particle size, remove plastics and other nonbiodegradable materials from the organic material to be composted, or use source-separated and uncontaminated feedstocks.

Issues in the Implementation of Composting Facilities

The principal issues associated with the use of the compost process are related to (1) the production of odors, (2) the presence of pathogens, (3) the presence of heavy metals, and (4) definition of what constitutes an acceptable compost. The blowing of papers and plastic materials is also a problem in windrow composting. Unless the questions related to these issues are resolved, composting may not be a viable technology in the future.

Production of Odors Without proper control of the composting process, the production of odors can become a problem, especially in windrow composting. It is fair to say that every existing composting facility has had an odor event and in some cases numerous events. As a consequence, facility siting, process design, and biological odor management are of critical importance.

Facility Siting Important issues in siting as related to the production and movement of odors include proper attention to local microclimates as they affect the dissipation of odors, distance to odor receptors, the use of adequate buffer zones, and the use of split facilities (use of different locations for composting and maturation operations).

Proper Process Design and Operation Proper process design and operation are critical in minimizing the potential for the production of odors. If composting operations are to be successful, special attention must be devoted to the following items: preprocessing, aeration requirements, temperature control, and turning (mixing) requirements. The facilities used to prepare the waste materials for the composting process must be capable of mixing any required additives, such as nutrients, seed (if used), and moisture with the waste material to be composted completely and effectively. The aeration equipment must be sized to meet peak oxygen demand requirements with an adequate margin of safety. In the static pile method of composting, the aeration equipment must also be sized properly to provide the volume of air required for cooling of the composting material. The composting facilities must be instrumented adequately to provide for positive and effective temperature control. The equipment used to turn and mix the compost to provide oxygen and to control the temperature must be effective in mixing all portions of the composting mass. Unmixed compost will undergo anaerobic decomposition leading to the production of odors. Because all of the operations cited above are critical to the operation of an odor-free composting facility, standby equipment should be available.

Biological Odor Management Because occasional odor events are impossible to eliminate, special attention must be devoted to the factors that may affect biological production of odors. Causes of odors in composting operations include low carbon-to-nitrogen (C/N) ratios, poor temperature control, excessive moisture, and poor mixing For example, in composting operations where the compost is not turned and the temperature is not controlled, the compost in the center of the composting pile can become pyrolyzed. When subsequently moved, the odors released from the pyrolyzed compost have been *extremely severe*. In enclosed facilities, odor control facilities such as packed towers, spray towers, activated-carbon contactors, biological filters, and compost filters have been used for odor management. In some cases, odor-masking agents and enzymes have been used for the temporary control of odors.

Public Health Issues If the composting operation is not conducted properly, the potential exists for pathogenic organisms to survive the composting process. The absence of pathogenic organisms is critical if the product is to be marketed for use in applications where the public may be exposed to the compost. Although pathogen control can be achieved easily with proper operation of the composting process, not all composting operations are instrumented sufficiently to produce pathogen-free compost reliably. In general, most pathogenic organisms found in MSW and other organic material to be composted will be destroyed at the temperatures and exposure times used in controlled composting operations (typically 55°C for 15–20 days). Temperatures required for the control of various pathogens were given previously in Table 5-19.

Health Hazard

Exposure of workers to dust at a sewage sludge and other composting site might cause nasal, ear, and skin infections, burning eyes, skin irritation, and other symptoms, pointing to the need for worker protection safeguards.

Other concerns are possible leachate contamination of groundwater and surface water, toxic chemicals remaining in the finished compost, insect and rodent breeding, noise, and survival of pathogens, including molds and other parasite spores and eggs. Pathogens may be spread by leachate, air, insects, rodents, and poor housekeeping and personal hygiene. Tests for pathogens, and the toxic level of chemicals and metals listed in Table 5-16 should be made periodically. Precautions are indicated in view of the potential hazards. Workers should be advised of the infectious and hazardous materials likely to be present in the solid waste handled and the personal hygiene precautions to be taken and be provided with proper equipment, protective gear, and housing. Their health should be monitored. All solid waste should be inspected before acceptance to ensure that it does not contain hazardous wastes. A dressing room, including lockers, toilet, lavatory, and shower facilities, is needed. Equipment cabs should have air conditioning, including dust filters.

Heavy-Metal Toxicity A concern that may affect all composting operations, but especially those where mechanical shredders are used, involves the possibility of heavy-metal toxicity. When metals in solid wastes are shredded, metal dust particles are generated by the action of the shredder. In turn, these metal particles may become attached to the materials in the light fraction. Ultimately, after composting, these metals would be applied to the soil. While many of them would have no adverse effects, metals such as cadmium (because of its toxicity) are of concern. In general, the heavy-metal content of compost produced from the organic fraction of MSW is significantly lower than the concentrations found in wastewater treatment plant sludges. The metal content of source separated-wastes is especially low. The co-composting of wastewater treatment plant sludges and the organic fraction of MSW is one way to reduce the metal concentrations in the sludge.

Product Quality Product quality for compost material can be defined in terms of the nutrient content, organic content, pH, texture, particle size distribution, moisture content, moisture-holding capacity, presence of foreign matter, concentration of salts, residual odor, degree of stabilization or maturity, presence of pathogenic organisms, and concentration of heavy metals. Unfortunately, at this time, there is no agreement on the appropriate values for these parameters. The lack of agreement on appropriate values for these parameters has been and continues to be a major impediment to the development of a uniform compost product from location to location. For compost materials to have wide acceptance, public health issues must be resolved in a satisfactory manner.

Cost The cost of composting should reflect the total cost of the operation less the savings effected. The cost of the operation would include the cost of the site, site preparation, compost concrete or asphalt platform, worker housing and facilities, utilities, equipment (grinder, bucket loader, and composting drum and aeration facilities if part of the process), power, separation and recycling preparation, and disposal of noncompostable materials as well as leachate collection, treatment and disposal, odor control, final screening, bagging, and maintenance. Savings would include reduced landfill disposal cost, income from sale of salvaged material, and sale of stabilized compost. Under favorable conditions, the total net cost of composting might be less compared to other methods. The size of the operation, labor costs, process used, sustained market for recovered materials, need for an enclosure, and other factors will determine the net cost.

A comprehensive market analysis should be made in the planning stage. The cost of an indoor system is much higher than an outdoor system. The operation of an outdoor system is significantly affected by the ambient temperature and precipitation. The indoor system makes possible better temperature, leachate, odor, and operation control as well as better public relations. Composting is not a profit-making operation.

SANITARY LANDFILL PLANNING, DESIGN, AND OPERATION

A sanitary landfill is a controlled method of solid waste disposal. The site must be geologically, hydrologically, and environmentally suitable. *It is not an open dump*. The nuisance conditions associated with an open dump, such as smoke, odor, unsightliness, and insect and rodent and seagull and other bird problems, are not present in a properly designed, operated, and maintained sanitary landfill. Professional planning and engineering supervision is required. A well-designed and operated landfill must prevent groundwater pollution, provide for gas (methane) venting or recovery, have a leachate collection and treatment system, provide gas and leachate monitoring wells, and be located above the 100-year flood level. A typical cross section through a modern landfill is shown in Figure 5-23. The EPA and states have detailed regulations governing landfill siting, design, construction, operation, gas and water monitoring, landscape plan, closure monitoring, and maintenance for 30 years. The purpose of this section is to identify and discuss important issues in the implementation of landfills, including planning, design and operation, and landfill closure.

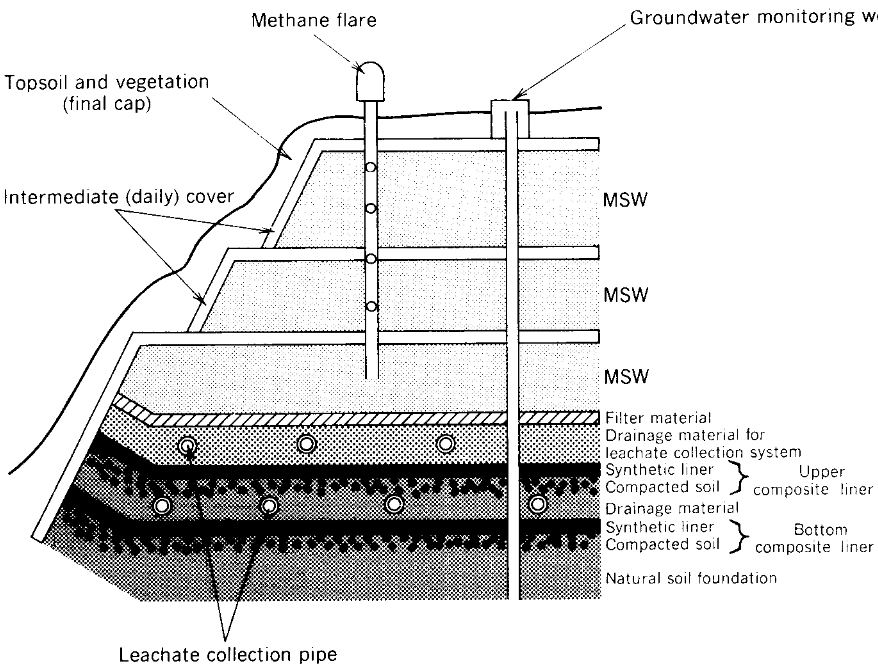


Figure 5-23 Schematic diagram of configuration of selected engineering features at MSW landfills.

Sanitary Landfill Planning

Key elements in the planning and implementation of a landfill include (1) legal requirements, (2) intermunicipal cooperation, (3) social and political factors, and (4) long-term planning issues. Landfill design considerations are considered in the section following the description of the types of landfills.

Legal Requirements State environmental protection agency regulations and local sanitary codes or laws usually build on federal regulatory requirements. A new solid waste disposal location may not be established until the site, design, and method of proposed operation, including waste reduction, resource recovery, and recycling, have been approved by the agency having jurisdiction. The agency should be authorized to approve a new solid waste disposal area and require such plans, reports, specifications, and other necessary data to determine whether the site is suitable and the proposed method of operation feasible. Intermunicipal planning and operation on a multimunicipal, multicounty, or multiregional basis should be given very serious consideration before a new solid waste disposal site is acquired. Larger landfills usually are more efficient and result in lower unit costs.

The principal federal requirements for municipal solid waste landfills are contained in Subtitle D of the Resource Conservation and Recovery Act (RCRA) and in EPA Regulations on Criteria for Classification of Solid Waste Disposal Facilities and Practices (*Code of Federal Regulations,* Title 40, Parts 257 and 258). The final version of Part 258—Criteria for Municipal Solid Waste Landfills (MSWLFs)—was signed on September 11, 1991. The subparts of Part 258 deal with the following areas:

Subpart A	General
Subpart B	Location restrictions
Subpart C	Operating criteria
Subpart D	Design criteria
Subpart E	Groundwater monitoring and corrective action
Subpart F	Closure and postclosure care
Subpart G	Financial assurance

In addition, many state environmental protection agencies have parallel regulatory programs that deal specifically with their unique geologic and soil conditions and environmental and public policy issues.

Intermunicipal Cooperation—Advantages County or regional areawide planning and administration for solid waste collection, treatment, and disposal can help overcome some of the seemingly insurmountable obstacles to satisfactory solution of the problem. Some of the advantages of county or regional areawide solid waste management are the following:

1. It makes possible comprehensive study of the total area generating the solid wastes and consideration of an areawide solution of common problems on short-term and long-term bases. A comprehensive study can also help overcome the mutual distrust that often hampers joint operations among adjoining municipalities.
2. There is usually no more objection to one large site operation than to a single town, village, or city operation. Coordinated effort can therefore be directed at overcoming the objections to one site and operation, rather than to each of several town, village, and city sites.
3. The unit cost for the disposal of a large volume of solid waste is less. Duplication of engineering, overhead, equipment, labor, and supervision is eliminated.
4. Better operation is possible in an areawide service, as adequate funds for proper supervision, equipment, and maintenance can be more easily provided.
5. More sites can be considered. Some municipalities would have to resort to a more costly method because suitable landfill sites may not be available within the municipality.

6. County or regional financing for solid waste disposal often costs less, as a lower interest rate can usually be obtained on bonds because of the broader tax base.
7. A county agency or a joint municipal survey committee, followed by a county or regional planning agency, and then an operating department, district, or private contractor, is a good overall approach because it makes possible careful study of the problem and helps overcome interjurisdictional resistance.

Social and Political Factors An important aspect of solid waste disposal site selection, in addition to the factors mentioned below, is the evaluation of public reaction and education of the public so that understanding and acceptance are developed. A long-term program of public information is needed. Equally important are the climate for political cooperation, cost comparison of alternative solutions, available revenue, aesthetic expectations of the people, organized community support, and similar factors. Films and slides that explain proper sanitary landfill operations are available from state and federal agencies and equipment manufacturers. Sites having good operations can be visited to obtain first-hand information and show the beneficial uses to which a completed site can be put.

Long-Term Planning and Design Issues Local officials can make their task easier by planning ahead together on a county or regional basis for 20 to 40 years in the future and by acquiring adequate sites at least 5 years prior to anticipated needs and use. The availability of federal and state funds for planning, collection, recycling, treatment, and disposal of solid waste on an areawide basis such as a county or region should be explored. The planning will require compliance with public health, environmental, planning, and zoning requirements, both state and local; and an engineering analysis of alternative sites. Also required are population projections, volume and characteristics of all types of solid wastes to be handled, cost of land and site preparation, expected life of the site, haul distances from the sources of solid waste to the site, cost of equipment, cost of operation, cost of closure and maintenance, and possible use and value of the finished site.

Consideration must also be given to the climate of the region, including precipitation and prevailing winds; geology, soils, hydrology, flood levels, and topography; and the need for liners, leachate collection and treatment [National Pollutant Discharge Elimination System (NPDES) permit], and methane gas control. Location and drainage to prevent surface-water and groundwater pollution, groundwater monitoring (at least one well up gradient and three wells down gradient), access roads to major highways, location of airports and wetlands, and availability of suitable cover material are other considerations. *Public information and involvement should be an integral and continuing part of the planning process leading to a decision*. The reader is referred to Chapter 2 for a discussion of the broad aspects of community and facility planning and environmental impact analysis.

Once a decision is made, it should be made common knowledge and plans developed to show how it is proposed to reclaim, improve, and reuse the site upon completion. Public education should include a series of talks, slides, news releases, question-and-answer presentations, and inspection of good operations. To aid in the planning process, some general guidelines for landfill design, construction, and operation are presented in Table 5-20. Artist's renderings and architectural models are very helpful in explaining construction methods and final land use. Landscape architects can make a contribution in converting the sanitary landfill to a community asset, such as parks, playgrounds with picnic areas, nature trails, bicycle and jogging paths, and hills with scenic observation sites. Unfilled land sites or islands could be set aside for permanent buildings.

Sanitary Landfill Methods

There are many methods of operating a sanitary landfill. The most common are the trench, area, ramp, and valley fill methods, as illustrated in Figure 5-24. These landfill methods are described below. With the regulatory requirements for constructed liner and leachate collection and removal systems now imposed by the EPA as set forth in RCRA, a defined operational area and well-designed operational plan are essential and must be closely followed to ensure an efficient and environmentally sound operation.

Trench Method The trench method (see Figure 5-24*a*) is used primarily on level ground, although it is also suitable for moderately sloping ground. In this method, trenches are constructed by making a shallow excavation and using the excavated material to form a ramp above the original ground. Solid waste is then methodically placed within the excavated area, compacted, and covered at the end of each day with previously excavated material. Because of the need to install landfill control measures (e.g., liners), a number of trenches are typically excavated at one time. Trenches are made 20 to 25 ft wide and at least twice as wide as any compacting equipment used. The depth of fill is determined by the established finished grade and depth to groundwater or rock. If trenches can be made deeper, more efficient use is made of the available land area.

Area or Ramp Method On fairly flat and rolling terrain, area method (see Figure 5-24*b*) can be utilized by using the existing natural slope of the land. The width and length of the fill slope are dependent on the nature of the terrain, the volume of solid waste delivered daily to the site, and the approximate number of trucks that will be unloading at the site at one time. Side slopes are 20 to 30 percent; width of fill strips and surface grades are controlled during operation by means of line poles and grade stakes. The working

TABLE 5-20 Some General Sanitary Landfill Design, Construction, and Operation Guidelines

Benchmark—Survey benchmark measured from U.S. Geological Survey benchmark established on-site and landfill cells referenced to it; a benchmark for each 25 acres of landfill.

Bottom liners—As specified by the regulatory agency and as indicated by the hydrogeological survey. See Figure 5-27.

Distance from any surface water—Based on soil attenuation, drainage, natural and man-made barriers, but not less than 100 ft, preferably 200 ft or more.

Equipment—Adequate numbers, type, and sizes; properly maintained and available.

Equipment shelter—Available for routine maintenance and repair.

Flood plains—No solid waste management facility permitted unless provisions made to prevent hazard.

Gas control—Prevent hazard to health, safety, and property; provide vents, barriers, collection, monitoring. Gas monitoring is required, also for volatile organic chemical and toxic emissions. See Figures 5-32 to 5-35.

Leachate—Not to drain or discharge into surface waters, except pursuant to State Pollutant Discharge Elimination System, and shall not contravene groundwater quality standards. Leachate collection system maintained.

Limits of fill—No closer than 100 ft from boundary lines of property. Restrictions primarily on proximity to water supply aquifers, wellhead areas, wetlands, floodplains, and surface waters.

Monitoring wells—Four or more at new or modified facility; at least three located down gradient for a small site. Regulatory agency may require wells at existing facility. Off-site wells may be used. Wells must reflect groundwater flow and quality under the landfill site.

- Water monitoring may be required. Safe Drinking Water Act MCLs are used to determine pollution and evaluate pollution travel.
- Baseline water quality and annual seasonal data are required at a new site and some existing sites.

Plans and construction—Engineering plans and specifications as required and approved by regulatory agency. Construction under supervision of project engineer who certifies construction is in accordance with approved plans and specifications.

Site—A hydrogeological survey of the site and surrounding land, soil borings, permeability, and groundwater levels. Check with Federal Aviation Administration.

Termination—Prevent contravention of surface water, groundwater, and air quality standards and gas migration, odors, vectors, and adverse environmental or health effects. At least 2 ft final cover, including an impervious barrier and gas-venting layer, along with an upper grass cover crop; 4% slope to minimize infiltration, prevent ponding and a surface water drainage system.

Vertical separation—five-foot separation between bottom liner and high groundwater. If natural soil is equivalent to 10 ft of soil with coefficients of permeability less than 5×10^{-6} cm/sec, separation may be reduced if a double-liner system is provided; 10-ft vertical separation required to bedrock.

Access—Permitted when attendant on duty; controlled by fencing, signs, or other means.

TABLE 5-20 (*Continued*)

Compaction and cover—Solid waste spread in 2-ft or less layers and promptly compacted. Working face minimal.

- Ten feet of maximum lift height.
- At least 6 in. daily cover at end of each day, or more often.
- At least 12 in. intermediate cover if solid waste not deposited within 30 days.
- Surface water drainage control during operation.
- Final cover when additional lift is not applied within 1 year; when final elevation is reached and within 90 days; when a landfill is terminated. Capped as required by regulatory agency. See Figure 5-37.

Hazardous wastes—No industrial or commercial solid waste or septage, or other materials producing hazardous waste, without specific permit authorization. No bulk liquids or 55-gal drums filled with liquids.

Litter and papers—Confined by fencing or suitable means. Vehicles confining papers and litter to be admitted.

Maintenance—Cover material and drainage control designed and maintained to prevent ponding and erosion, and to minimize infiltration, based on a 25-year storm and from a 24-hour, 25-year storm. Prepare a landscape plan.

- Grass or ground cover established within 4 months and maintained.
- Soil cover integrity, slopes, cover vegetation, drainage, groundwater and gas monitoring, and structures maintained for a period of 30 years or longer.
- Leachate collection and removal system, inspection manholes, and lift stations maintained operational as long as necessary.
- Liner leakage monitored and reported to regulatory agency.
- Establish a trust fund, surety bond, insurance, etc., to ensure long-term maintenance.

Noise—Shall not cause excessive sound levels beyond property lines in residential areas. Level 7 a.m.–10 p.m.: rural 60 dBA, suburban 65 dBA, urban 70 dBA. Level 10 p.m.–7 a.m., rural 50 dBA, suburban 55 dBA, urban 60 dBA.

On-site roads—Maintained passable and safe.

Open burning—Prohibited except under permit.

Personnel shelter—Adequately heated and lighted; includes safe drinking water, sanitary toilet and shower facilities, telephone or radio communications.

Reports—As required in permit.

Safety—Safety hazards minimized.

Salvaging—Controlled, if permitted.

Small loads—Separate facility (convenience station) at the site for use of local residents and small trucks.

Solid waste disposal—Confined to an area effectively maintained, operated, and controlled. No industrial, commercial solid waste, no sludge or septage unless specifically approved. Inspection for hazardous waste required.

Supervision—Operation supervised by a certified operator, including dumping sequence, compaction, cover, surface drainage.

Vectors, dust, and odors—Controlled to prevent nuisance or hazard to health, safety, or property.

Weigh station—For weight measurement, fees, and waste inspection.

Source: Salvato (1992).

Note: See also applicable federal and state regulations.

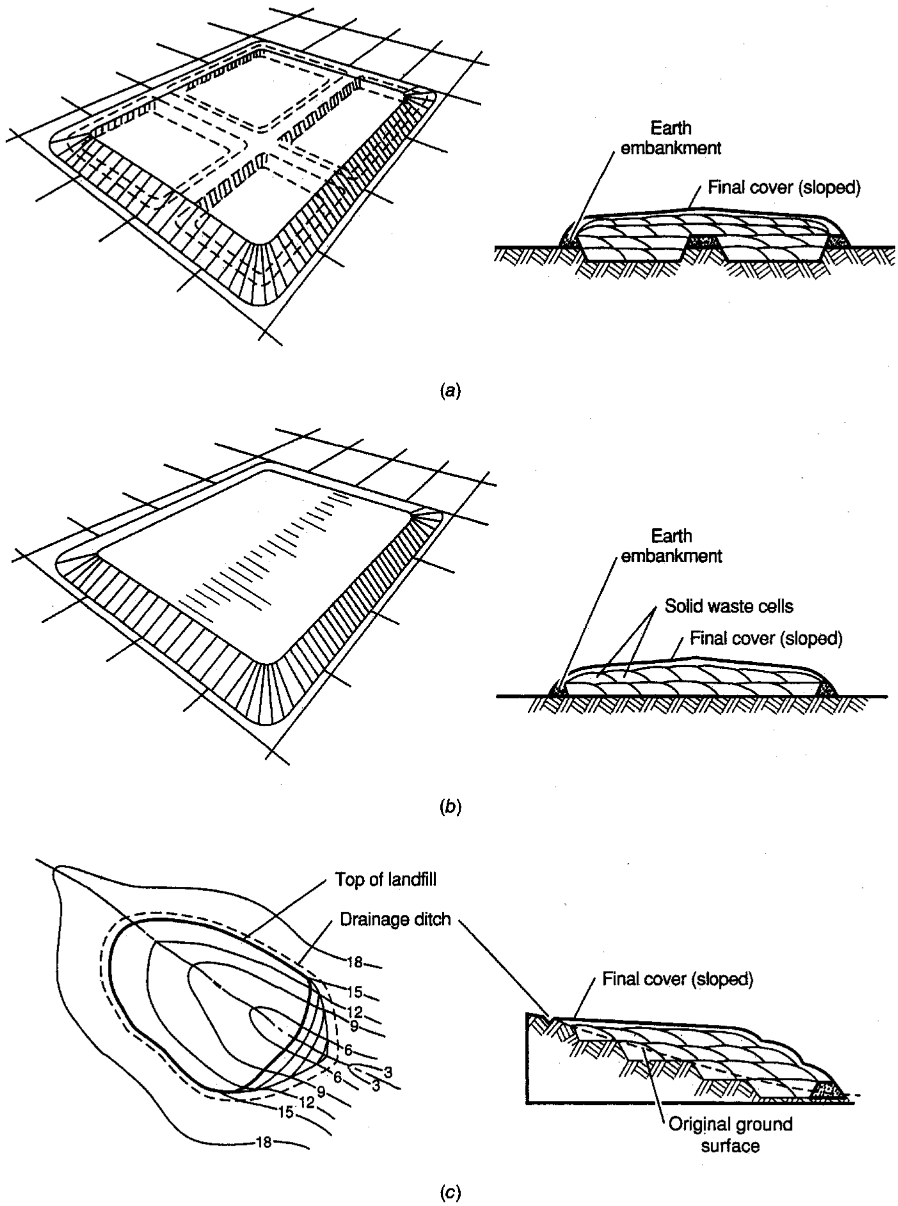


Figure 5-24 Schematic view of different types of landfills: (*a*) trench, (*b*) area; (*c*) canyon or ravine (Tchobanoglous et al., 1993).

face should be kept as small as practical to take advantage of truck compaction, restrict dumping to a limited area, and avoid scattering of debris. In the area method, cover material is hauled in from a nearby stockpile or other source. The base of the landfill is established by the previously determined elevation of bedrock, groundwater, and bottom liners and leachate collection and removal systems.

Valley or Ravine Area Method In valleys and ravines, the ravine method (see Figure 5-24*c*) is usually the best method of operation. The development of a large ravine landfill site is illustrated in Figure 5-25. In those areas where the ravine is deep, the solid waste should be placed in ‘‘lifts’’ from the bottom up with a depth of 8 to 10 ft. Cover material is obtained from the sides of the ravine. It is not always desirable to extend the first lift the entire length of the ravine. It may be desirable to construct the first layer for a relatively short distance from the head of the ravine across its width. The length of this initial lift should be determined so that a one-year settlement can take place before the next lift is placed, although this is not essential if operation can be controlled carefully. Succeeding lifts are constructed by trucking solid waste over the first lift to the head of the ravine. When the final grade has

Figure 5-25 Development of large ravine landfill site. Equipment is compacting subbase of landfill in preparation for placement of geomembrane liner.

been reached (with allowance for settlement), the lower lift can be extended and the process repeated. The bottom landfill liner and leachate collection and removal system must be designed carefully to ensure that slope stability of the liner system and the waste placed is adequately maintained.

General Landfill Design Issues

The general planning process described above is followed by specific site selection and preparation. Site preparation requires that an engineering survey be made and a map drawn at a scale of not less than 200 ft to the inch with contours at 2-ft intervals, showing the boundaries of the property; location of lakes, streams, springs, marine waters, and structures within 1000 ft; adjoining ownership; and topography. Also required are soil borings, including *in situ* hydraulic conductivity determinations, designs for liners and leachate collection systems, groundwater levels, up-gradient and down-gradient monitoring wells, water quality samples, prevailing winds, and drainage plans.

Location The site location directly affects the total solid waste collection and disposal cost. If the site is remotely situated, the cost of hauling to the site may become high and the total cost excessive. It has been established that the normal, economical hauling distance to a solid waste disposal site is 10 to 15 miles, although this will vary depending on the volume of solid waste, site availability, and other factors. Actually, a suitable site and the hauling time and route are more important than the hauling distance. The disposal site may be as far as 40 to 80 miles away if a transfer station is used. Rail haul and barging introduce other possibilities. The cost of transferring the solid waste per ton is used to compare solid waste collection and disposal costs and make an economic analysis. Open excavations left by surface mining operations may be considered for solid waste disposal as a means of reclaiming land and restoring it to productive use.

Accessibility Another important consideration in site selection is accessibility. A disposal area should be located near major highways to facilitate use of existing arterial roads and lessen the hauling time to the site. Highway wheel load and bridge capacity and underpass and bridge clearances must also be investigated. It is not good practice to locate a landfill in an area where collection vehicles must constantly travel through residential streets to reach the site. The disposal area itself should normally be located at least 500 ft from habitation, although lesser distances have been successfully used to fill in low areas and improve land adjacent to residential areas for parks, playgrounds, or other desirable uses. Where possible, a temporary attractive screen should be erected to conceal the operation. To allow vehicular traffic to utilize the site throughout the year, it is necessary to provide good access roads to the site so that trucks can move freely in and out of the site during all weather conditions and seasons of the year. Poorly constructed and maintained roads to a site can create conditions that cause traffic tie-ups and time loss for the collection vehicles.

Land Area (Volume) Required The volume needed for solid waste disposal is a function of population served, per-capita solid waste contribution, resource recovery and recycling, density and depth of the solid waste in place, number of lifts, total amount of earth cover used, and time in use, adjusted for nonhazardous commercial and industrial wastes. Because of the high start-up costs associated with a modern landfill, the capacity of a proposed landfill should be sufficient for a 20- to 40-year period (see Figure 5-25). Further, because the population in an area will not usually remain constant, it is essential that population projections and development be taken into account. These factors plus the probable nonhazardous solid waste contributions by commercial establishments, industry, and agriculture must be considered in planning for needed land. A density of compacted fill of 800 to 1000 lb/yd^3 is readily achieved with proper operation; 600 lb/yd^3 or less is poor; 1200 lb/yd^3 or more is very good.

Leachate Generation, Control, and Treatment

The best solution to the potential leachate problem is to prevent its development. Landfill leachate generation cannot in practice be entirely avoided, particularly during operation, except possibly in some arid climates. However, a tight soil cap and/or liner on completion can greatly minimize the possibility; however, a leachate-free landfill may not be *entirely* desirable, as discussed below. Leachate control measures for groundwater and surface-water quality protection must be incorporated in the site design and monitoring started before operation (see Figure 5-26). A water balance for the landfill disposal facility should be established to serve as a basis for the design of leachate control and surface runoff systems, taking into consideration heavy rainfall, landfill, cap construction, in addition to runoff, infiltration, and evapotranspiration.

Leachate from existing community sanitary landfills and from industrial waste storage and disposal sites can be expected to contain organic and inorganic chemicals characteristic of the contributing community and industrial wastes. Household hazardous wastes may include small amounts of cleaning solvents, paints and paint thinners, oils, pesticides, and drugs if not restricted or their sale prohibited. The EPA and others have reported that hazardous wastes probably represent less than 0.5 percent of the total waste generated by households. A knowledge of the industry and its production will provide a starting point in the selection of parameters to be analyzed in characterizing the leachate from an existing site.

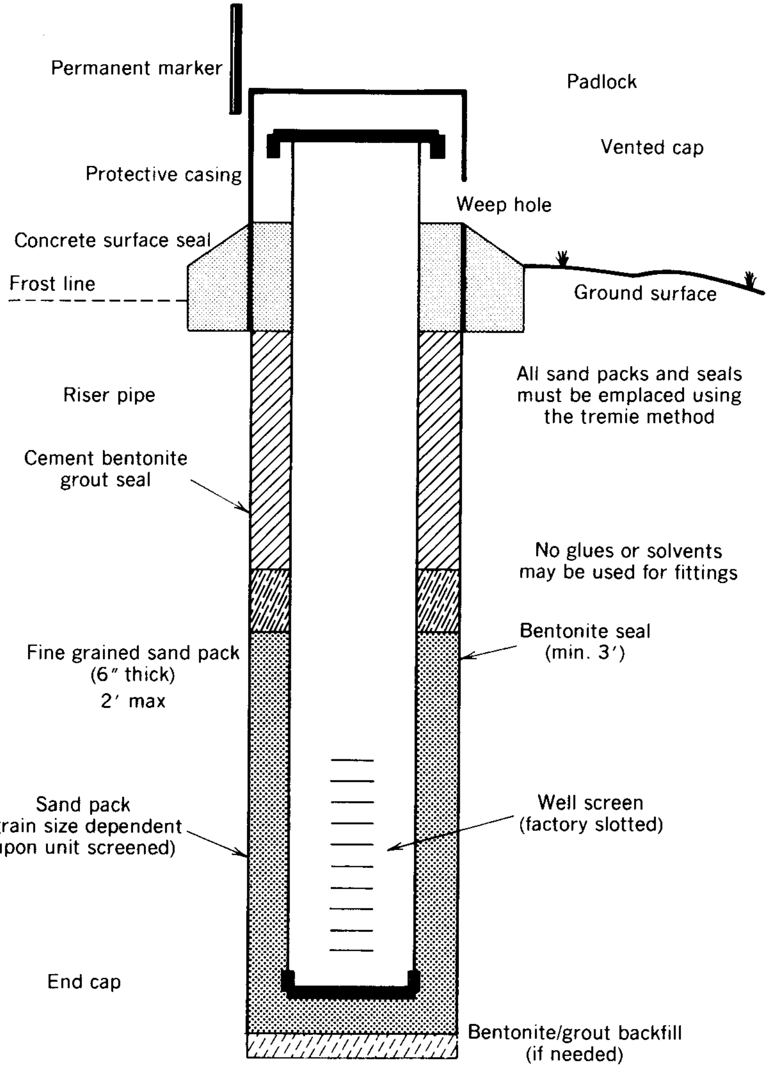


Figure 5-26 Typical monitoring well diagram (New York State, 1990a).

Leachate Generation The precipitation less runoff, transpiration, and evaporation will determine the amount of infiltration. Infiltration and percolation will, in the long term, after field capacity has been reached, determine the amount of leachate, if any, produced, assuming groundwater and lateral flow are excluded. A major factor is a cover material that is carefully graded, which ideally permits only limited infiltration and percolation to support vegetative cover and solid waste decomposition, with optimal runoff but without erosion to prevent significant leachate production. The soil cover should have a low permeability with low swell and shrink tendency upon wetting and drying. Runoff depends on rainfall intensity and duration, permeability of the cover soil, surface slope (4 percent, not greater than 30 percent for side slopes), condition of the soil and its moisture content, and the amount and type of vegetative cover. Evapotranspiration during the growing season for grasses and grains may be 20 to 50 in.

Leachate Control It should be noted that if all infiltration is excluded and the solid waste kept dry, biodegradation by bacteria, fungi, and other organisms will cease and the solid waste will be preserved in its original state. Bacterial activity will generally cease when the moisture content drops below 14 to 16 percent. The maintenance of an optimal amount of moisture in the fill, as in controlled composting (an aerobic process), is necessary for biodegradation (an anaerobic process in a landfill), methane production, final stabilization, and possible future recycling of the solid waste or reuse of the site.

The objective in the design of landfill liners is to minimize or eliminate the infiltration of leachate into the subsurface soils below the landfill so as to eliminate the potential for the groundwater contamination. A number of liner designs have been developed to minimize the movement of leachate into the subsurface below the landfill. One of the many types of liner designs that have been proposed is illustrated in Figure 5-27. In the multilayer landfill liner design illustrated in Figure 5-27, each of the various layers has a specific function. For example, in Figure 5-27, two composite liners are used as a barrier to the movement of leachate and landfill gas. The drainage layer is to collect any leachate that may be generated within the landfill. The final soil layer is used to protect the drainage and barrier layers. The placement of a geomembrane liner in an area-type landfill is illustrated in Figure 5-28. A modification of the liner design shown in Figure 5-27 is shown in Figure 5-29. The liner system shown in Figure 5-29 is for a monofill (e.g., a landfill for a single waste component such as glass). Composite liner designs employing a geomembrane and clay layer provide more protection and are hydraulically more effective than either type of liner alone.

If leachate migration is or may become a problem at an old or existing landfill, and depending on the local situation and an engineering evaluation, several options may be considered. These include a cap on the surface consisting of clay or a liner regraded with topsoil seeded to grass to effectively shed precipitation, cutoff walls or dams keyed into an impermeable stratum to isolate the fill, pressure treatment and sealing of the bottom and sides of the fill, surface-water drains up-gradient and around the landfill area, curtain drains or wells to intercept and drain away the contributing groundwater flow, collection and recirculation of leachate with treatment of any excess, or, in special cases and if warranted, the material in the landfill can be excavated, treated, recycled, and/or disposed of at a controlled site. The excavation of

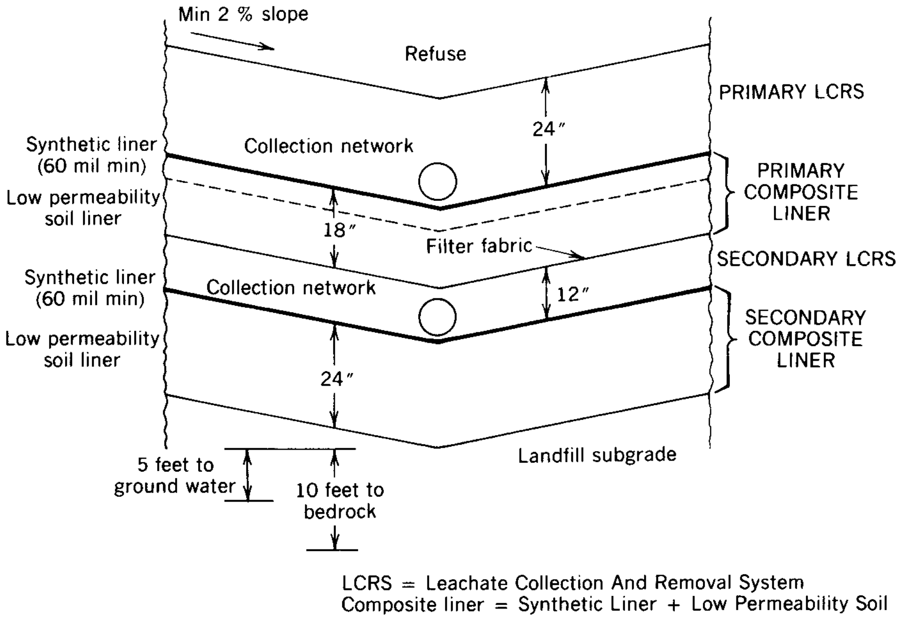


Figure 5-27 Double-bottom composite liner system (New York State, 1990a).

an existing landfill may, however, introduce other problems if hazardous wastes are involved and hence must be carefully evaluated in advance.

Leachate Recirculation Waste biodegradation and stabilization of the biodegradable organic matter in a landfill can be accelerated by leachate recirculation. Controlled leachate recirculation, including nutrient addition to maintain optimum moisture and pH, can enhance anaerobic microbial activity, break down organics as shown by reduced total organic carbon (TOC) and chemical oxygen demand (COD, convert solid waste organics to methane and carbon dioxide, and precipitate heavy metals. Complete biological stabilization can be achieved in four to five years. Heating of recirculated leachate to 86°F (30°C) has been found to accelerate the stabilization process.

A landfill designed for leachate recirculation should, as a minimum, incorporate a conservatively designed liner system and an effectively maintained leachate collection, removal, and recirculation distribution system, in addition to a gas collection and venting system (see Figure 5-30). A double-liner system with leak detection monitoring wells would enable the landfill owner and regulatory agency to monitor the liner system performance. The leachate collection and removal system should be designed to be accessible for routine maintenance and cleaning in view of the potential for biological film clogging. Recirculation would increase the strength of the recirculated leachate and

Figure 5-28 Placement of geomembrane liner in area-type landfill.

accelerate fill stabilization. Establishment of early gradual recirculation and an active anaerobic biomass is important as each cell is closed. A final site closure utilizing a relatively impermeable crowned cap and surface-water drainage system should be implemented for final site closure.

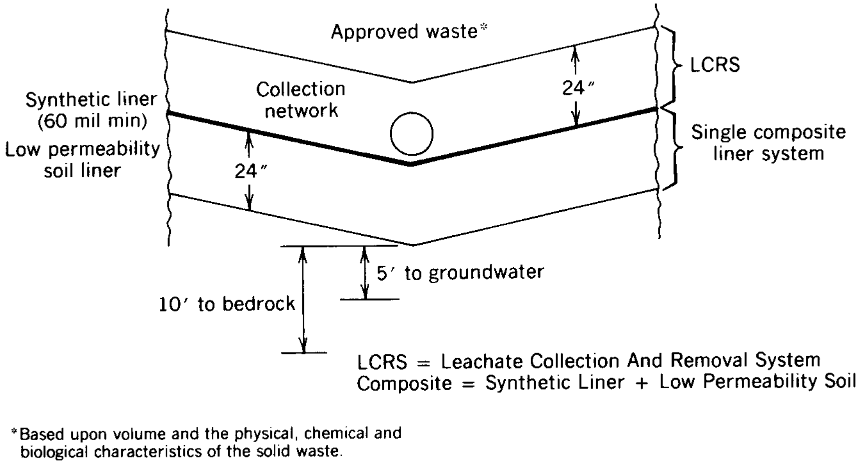


Figure 5-29 Industrial/commercial and ash monofill waste landfill liner configuration (New York State, 1990a).

Leachate Treatment Leachates containing a significant fraction of biologically refractory high-molecular-weight organic compounds (i.e., those in excess of 50,000) are best treated by physicochemical methods, such as lime addition followed by settling. Leachates containing primarily low-molecular-weight organic compounds are best treated by biological methods, such as activated sludge. Combinations of these methods may be required to achieve permit requirements and stream discharge standards. In the final analysis, the treatment required will depend on the composition of the fill material, leachate

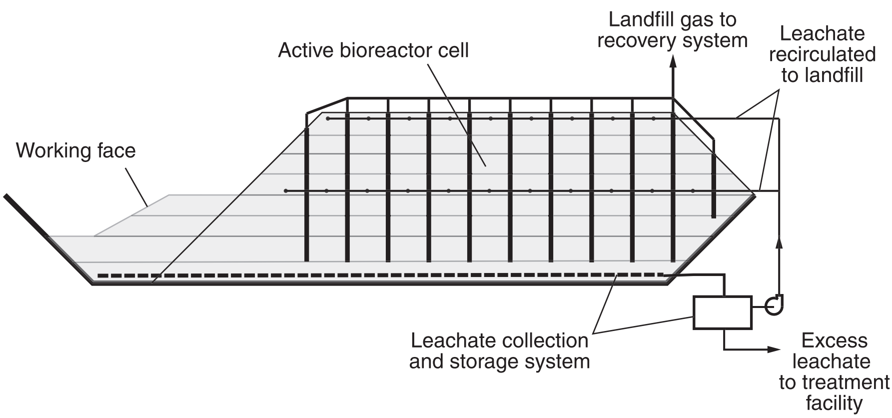


Figure 5-30 Schematic diagram for landfill with leachate recirculation (O'Leary and Tchobanoglous, 2002).

volume and characteristics, and the water pollution control standards to be met.

Landfill Gas Generation, Control, and Recovery and Utilization

Gases found in landfills include ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), hydrogen sulfide (H_2S), methane (CH_4), nitrogen (N_2), and oxygen (O_2). The typical percentage distribution of the gases found in the landfill is reported in Table 5-21. As shown in Table 5-21, methane and carbon dioxide are the principal gases produced from the anaerobic decomposition of the biodegradable organic waste components in MSW. In addition, a number of trace gases will also be found in landfill gas. The type and concentration of the trace gases will depend to a large extent on the past history of the landfill. Issues related to the generation, control of migration, and utilization of landfill gas are considered in the following discussion.

Generation of the Principal Landfill Gases The generation of principal landfill gases is thought to occur in five more or less sequential phases, as illustrated in Figure 5-31. Each of these phases is described briefly below; additional details may be found in Tchobanoglous et al. (1993).

Phase I. Initial Adjustment Phase I is the *initial adjustment phase,* in which the organic biodegradable components in municipal solid waste

TABLE 5-21 Typical Constituents in Landfill Gas

Component	Percent (dry volume basis)
Methane	45–60
Carbon dioxide	40–60
Nitrogen	2–5
Oxygen	0.1–1.0
Sulfides, disulfides, mercaptans, etc.	0–1.0
Ammonia	0.1–1.0
Hydrogen	0–0.2
Carbon monoxide	0–0.2
Trace constituents	0.01–0.6
Characteristic	**Value**
Temperature, °F	100–120
Specific gravity	1.02–1.06
Moisture content	Saturated
High heating value, Btu/sft^3 [a]	475–550

Source: Tchobanoglous et al. (1983).

[a] sft^3 = standard cubic foot.

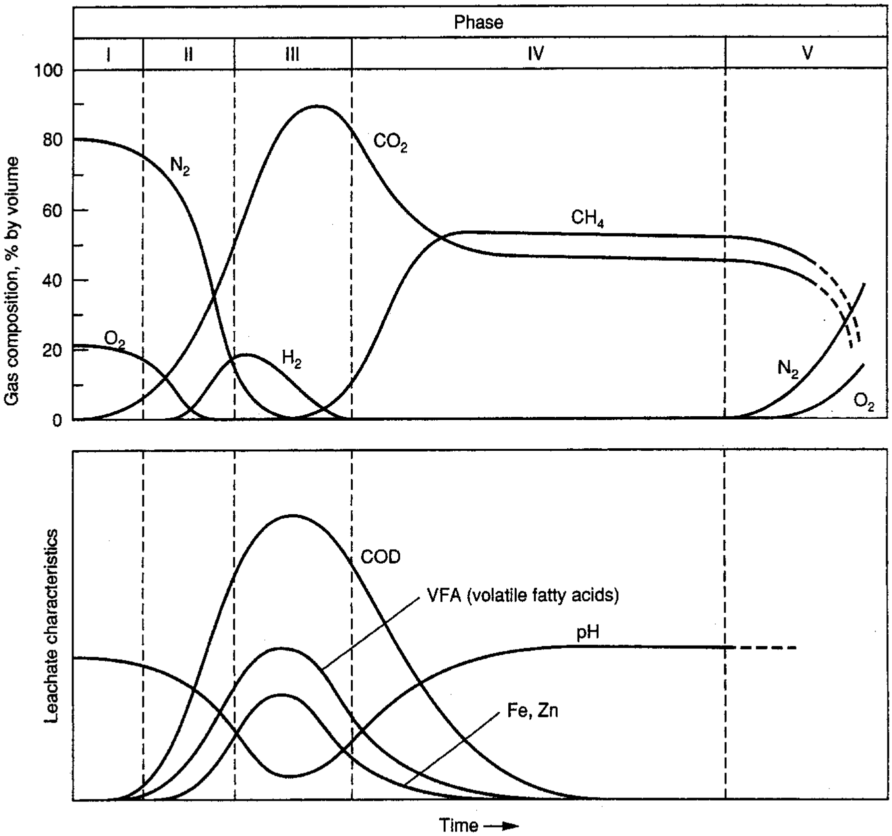


Figure 5-31 Generalized phases in generation of landfill gases (I—initial adjustment, II—transition phase; III—acid phase; IV—methane fermentation; V—maturation phase) (Tchobanoglous et al., 1993).

begin to undergo bacterial decomposition soon after they are placed in a landfill. In phase I, biological decomposition occurs under aerobic conditions because a certain amount of air is trapped within the landfill.

Phase II. Transition Phase In phase II, identified as the *transition phase*, oxygen is depleted and anaerobic conditions begin to develop.

Phase III. Acid Phase In phase III, the bacterial activity initiated in phase II is accelerated with the production of significant amounts of organic acids and lesser amounts of hydrogen gas. The first step in the three-step process involves the enzyme-mediated transformation (hydrolysis) of higher molecular mass compounds (e.g., lipids, organic polymers, and proteins) into compounds suitable for use by microorganisms as a source of energy and cell carbon. The second step in the process (acidogenesis) involves the bacterial conversion of the compounds resulting from the first step into lower molecular weight intermediate compounds, as typified by acetic acid (CH_3COOH) and small concentrations of fulvic and other more complex organic acids. Carbon dioxide (CO_2) is the principal gas generated during phase III.

Phase IV. Methane Fermentation Phase In phase IV, a second group of microorganisms that convert the acetic acid and hydrogen gas formed by the acid formers in the acid phase to methane (CH_4) and CO_2 becomes more predominant. Because the acids and the hydrogen gas produced by the acid formers have been converted to CH_4 and CO_2 in phase IV, the pH within the landfill will rise to more neutral values in the range of 6.8 to 8.

Phase V. Maturation Phase Phase V occurs after the readily available biodegradable organic material has been converted to CH_4 and CO_2 in phase IV. As moisture continues to migrate through the waste, portions of the biodegradable material that were previously unavailable will be converted.

Control of Landfill Gas Migration When methane is present in the air in concentrations between 5 and 15 percent, it is explosive. Because only limited amounts of oxygen are present in a landfill when methane concentrations reach this critical level, there is little danger that the landfill will explode. However, methane mixtures in the explosive range can be formed if landfill gas migrates off site and is mixed with air. The lateral migration of methane and other gases can be controlled by impermeable cutoff walls or barriers (see Figure 5-32) or by the provision of a ventilation system such as gravel-filled trenches around the perimeter of the landfill (see Figure 5-33). Gravel-packed perforated pipe wells or collectors may also be used to collect and diffuse the gas to the atmosphere, if not recovered. To be effective, the system must be carefully designed, constructed, and maintained.

Cutoff walls or barriers should extend from the ground surface down to a gas-impermeable layer such as clay, rock, or groundwater. Clay soils must be water saturated to be effective. Perforated pipes have been shown to be of limited effectiveness and are not recommended for the reduction of gas pressure when used alone. Gravel-filled trenches may permit migration of gases across the trench, especially when covered by snow or ice; vertical perforated pipes reduce somewhat the effect of snow or ice. Gravel-filled trenches require removal of leachate or water from the trench bottom and are susceptible to plugging by biomass buildup. Gravel-filled trenches in combination with an impermeable barrier provide good protection against gas migration when keyed to a gas-impermeable strata below the landfill. Induced exhaust wells or trenches with perforated pipes and pump or blower are reported to be very effective. Where enclosed structures are constructed over or in close proximity to a landfill, it is necessary to have these places continuously monitored. A combustible gas detection system to provide early warning (light and alarm) can alert personnel. The monitors comprising the detection system can also

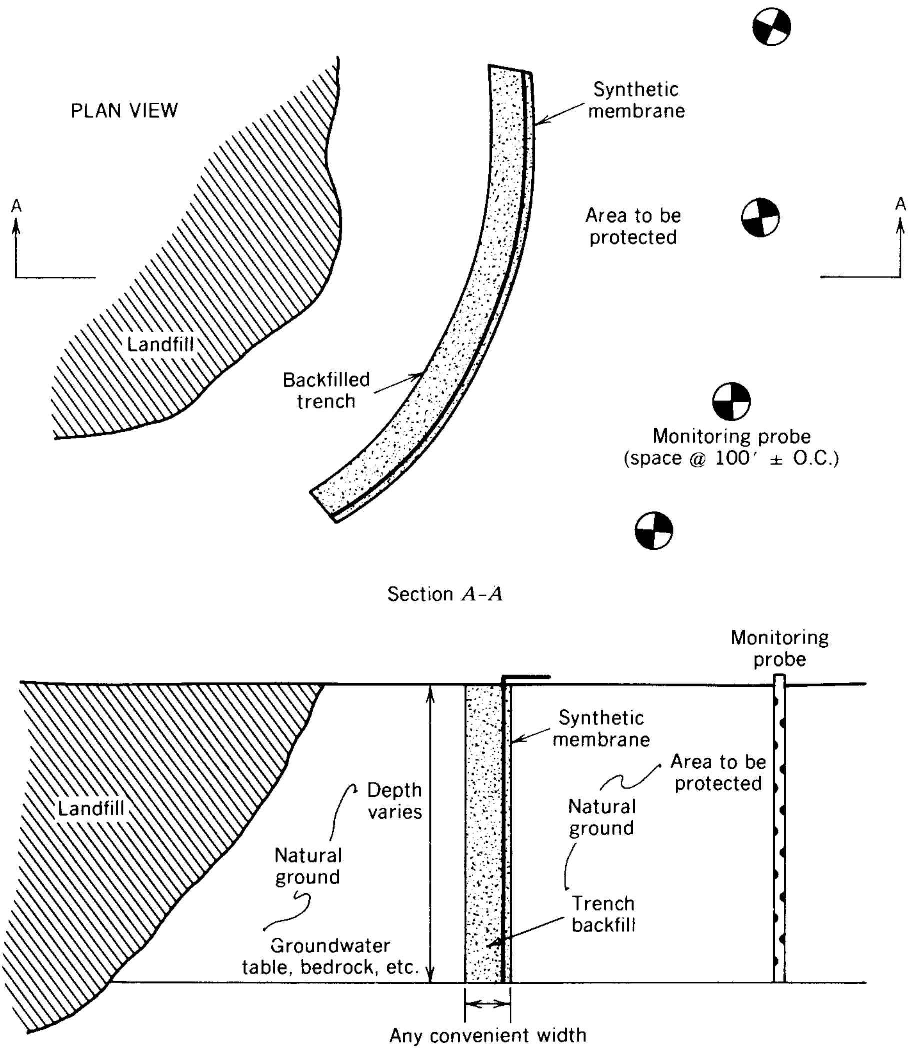


Figure 5-32 Typical passive gas control synthetic membrane.

activate ventilation fans at preset low methane levels. Soil and cement bentonite trenches or cutoff walls have also been used to prevent lateral gas migration.

Methane Recovery and Utilization Methane is produced in a landfill when anaerobic methane-producing bacteria are active. The condition shown in Figure 5-31 may be reached in six months to five years depending on the landfill. Acidic conditions inhibit growth of methane-producing bacteria; alkaline conditions have the opposite effect. Methane production is quite variable de-

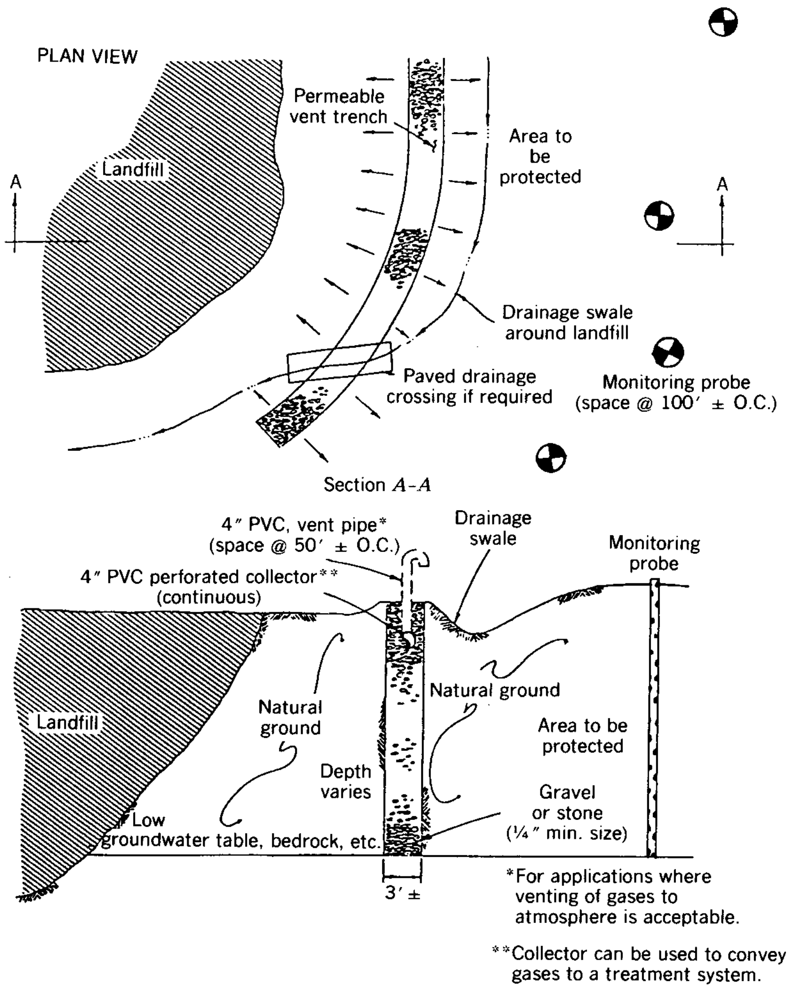


Figure 5-33 Passive gas control using permeable trench (SCS, 1980).

pending on the amount and type of decomposable material in the landfill, moisture content, temperature, and resulting rate of microbial decomposition under anaerobic conditions.

Methane is odorless, has a heat value of about 500 Btu/ft^3 compared to 1000 Btu for commercial gas, has a specific gravity less than air, and is nearly insoluble in water. The gases from landfills, after anaerobic conditions have been established, are quite variable, ranging from 50 to 60 percent methane and 40 to 50 percent carbon dioxide. Included are small amounts of nitrogen, oxygen, water, mercaptans (very odorous), and hydrocarbons. Hydrogen sulfide may also be released if large amounts of sulfates are in the landfill. Vinyl chloride, benzene, and other toxics in trace amounts may also be produced by the action of bacteria on chlorinated solvents deposited in the fill. The presence of oxygen and nitrogen with methane gas would indicate the entrance of air into the landfill due to methane being withdrawn too rapidly. If methane extraction is not controlled to reduce or eliminate the entrance of oxygen and nitrogen, the production of methane will slow down or stop.

In the early stages the landfill gases are primarily carbon dioxide with some methane. The carbon dioxide is heavier than air and can dissolve in water to form carbonic acid, which is corrosive to minerals with which it comes into contact. Mercaptans, carbon dioxide, and water are usually extracted to upgrade the methane to pipeline quality. Removal of carbon dioxide may improve Btu content to 900 or 1000 Btu/ft^3. Methane as it comes from a landfill is often very corrosive. Deep landfills, 30 ft or deeper, and 30 acres or more in area with a good cover are better methane producers. Actually, gas will be generated as long as biodegradable material remains and is primarily dependent on precipitation, infiltration, and moisture content. Gas can be extracted using plastic tube wells in each cell with perforations or well screens toward the bottom connected to a controlled vacuum pump (see Figure 5-34) or a series of covered horizontal gravel trenches connected to a pipe collection system (see Figure 5-35). The extracted gas may be used for heating and generating electricity.

Management of Surface Waters

The runoff from the drainage area tributary to the solid waste disposal site must be determined by hydraulic analysis to ensure that the surface-water drainage system, such as ditches, dikes, berms, or culverts, is properly designed and that flows are diverted to prevent flooding, erosion, infiltration, and surface-water and groundwater pollution, both during operation and on completion. The design basis should be the maximum 25-year 24-hr precipitation. The topography and soil cover should be examined carefully to ensure that there will be no obstruction of natural drainage channels. Obstructions could create flooding conditions and excessive infiltration during heavy rains and snow melt. Uncontrolled flooding conditions can also erode the cover material.

A *completed* landfill for residential solid waste that is properly capped should, ideally, not present any serious hazard of groundwater pollution, *provided surface water (and groundwater) and most of the precipitation are drained, transpired, and evaporated off the landfill and the landfill site*. Two different types of landfill covers are presented in Figures 5-36 and 5-37. The major source of water for leachate production would then be precipitation–infiltration during operation, before the final cap is put in place. Precipitation–infiltration can be minimized by the temporary use of impervious geomembrane sheets over the completed landfill. A small amount of infiltration is desirable to support biological decomposition of the solid waste, as noted above. It becomes essential, therefore, that the solid waste working face be

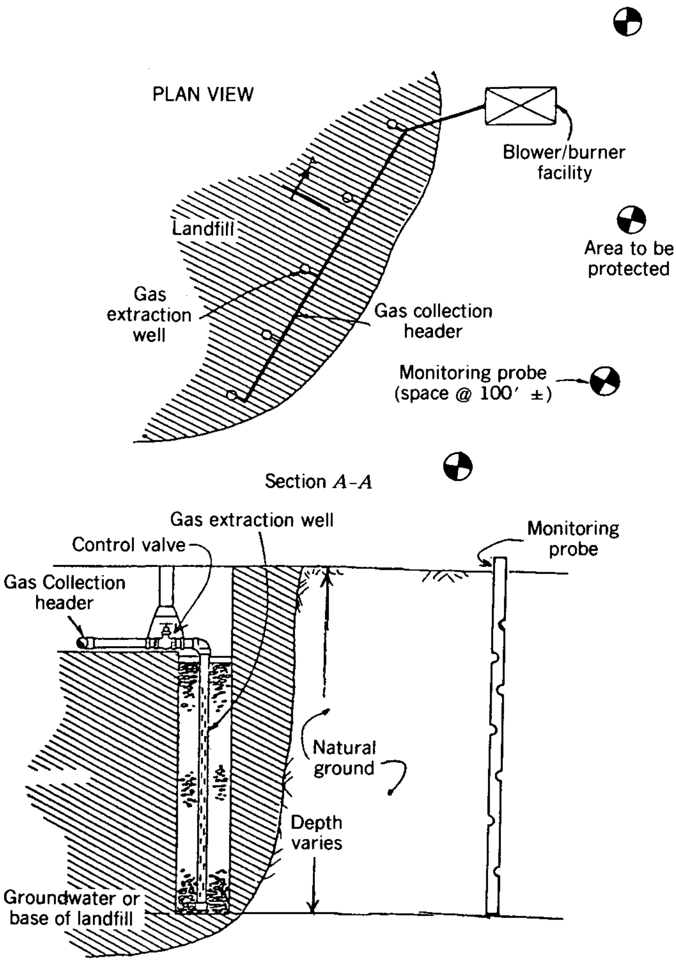


Figure 5-34 Typical gas extraction system (U.S. EPA, 1985).

kept at a minimum, that the final cover be placed and graded promptly, and that a surface-water drainage system be installed as soon as possible.

Cover Material The site should preferably provide adequate and suitable cover material. The most suitable soil for cover material is one that is easily worked and yet minimizes infiltration; however, this is not always available. It is good practice to stockpile topsoil for final cover and other soil for cold-weather operation and access road maintenance. Shredded (milled) solid waste in a landfill does not cause odors, rodent or insect breeding, or unsightliness, and it may not require daily earth cover. However, precipitation will

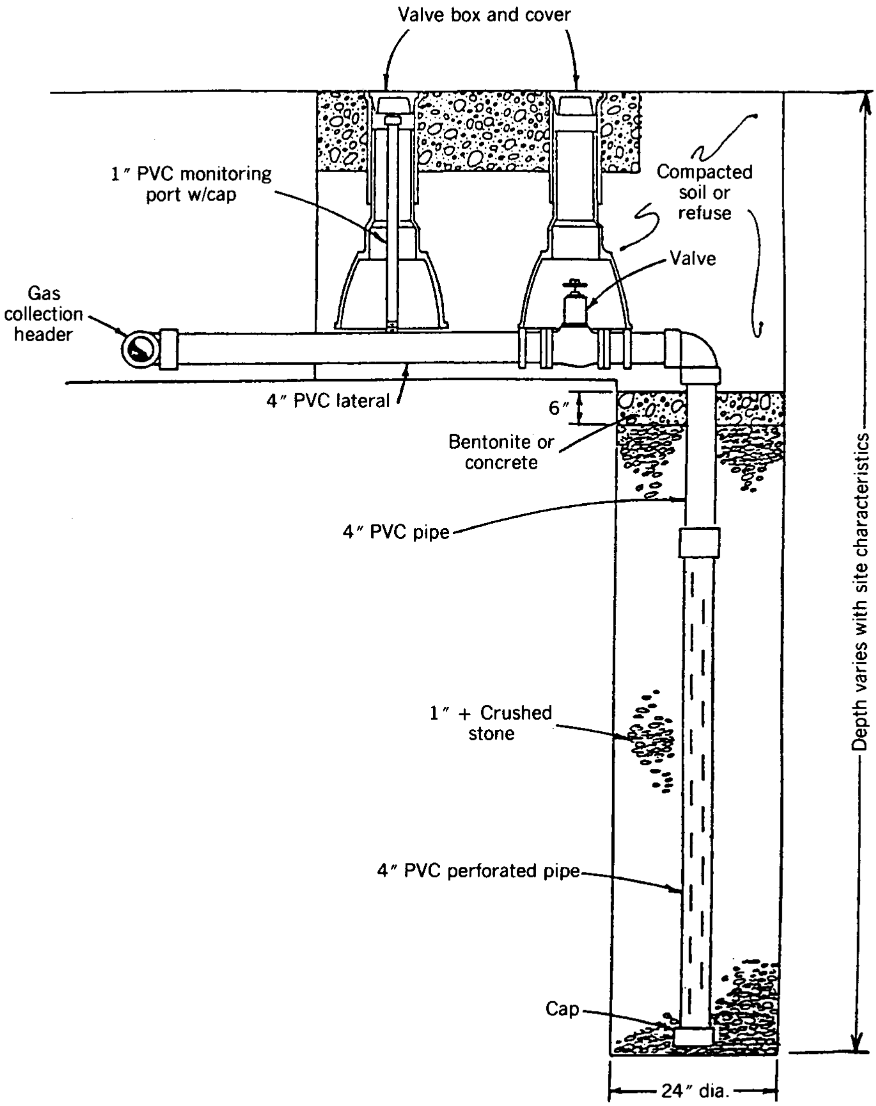


Figure 5-35 Typical gas extraction well (U.S. EPA, 1985).

be readily absorbed and leachate produced unless the waste is covered with a low-permeability soil that is well graded to shed water.

The control of leachate and methane and the role played by the final earth cover, including the importance of proper grading of the landfill final cover (4 percent slope) to minimize infiltration, promote runoff, and prevent erosion, have been previously discussed. A final cover to minimize infiltration of pre-

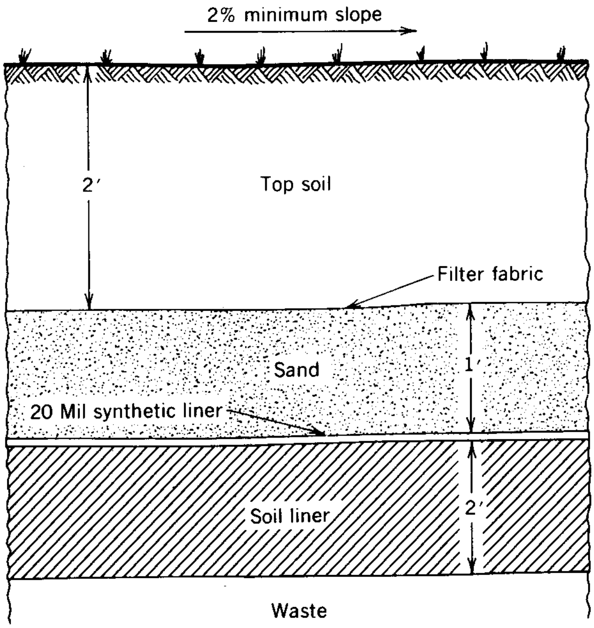


Figure 5-36 Typical multiplayer landfill cap. Minimum of 4 percent surface slope is usually preferred (U.S. EPA, 1985).

cipitation, support vegetation, and encourage evapotranspiration is recommended. The vegetation, such as seeded grass (hydroseeded for rapid cover), will prevent wind and water erosion and contribute to transpiration and evaporation. The final slope should be maintained at 1 : 30. A tight cover or membrane cap requires provision for effective gas collection and release.

Landfill Vegetation Four feet or more earth cover is recommended if the area is to be landscaped, but the amount of cover depends on the plants to be grown. Native grasses may require 2 ft of topsoil, and large trees with deep tap roots may require 8 to 12 ft. The carbon dioxide and methane gases generated in a landfill may interfere with vegetation root growth, if not prevented or adequately diffused. The gases can be collected and disposed of through specially designed sand or gravel trenches or a porous pipe gas-venting system. Oxygen penetration to the roots is necessary. Carbon dioxide as low or lower than 10 percent in the root zone can be toxic to roots; methane-utilizing bacteria deplete the oxygen. Precautions to help maintain a healthy vegetation cover include selecting a tolerant species and seeking professional advice, avoiding areas of high gas concentrations, excluding gas from root zone (use built-up mounds for planting or line with membrane or clay soil barrier and vent trench and plant in suitable backfill soil), avoiding heavily compacted soil (loosen first if necessary and supplement soil fertility

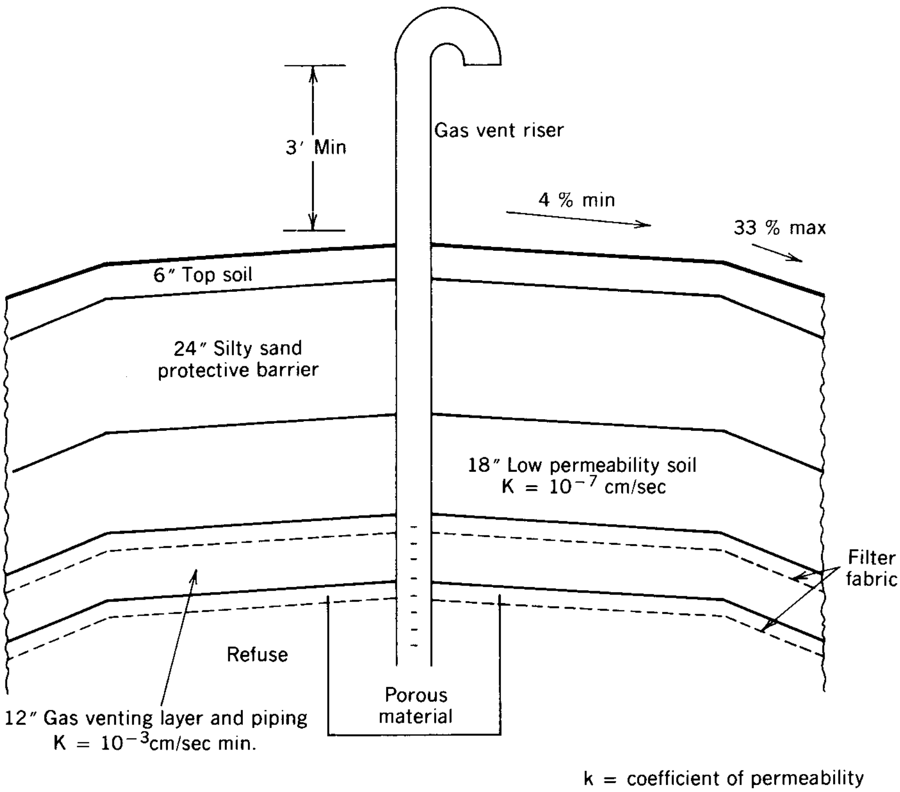


Figure 5-37 Final cover with passive gas vent. (Courtesy of New York State.)

and improve its physical condition following good nursery practice), using smaller plant stock, and providing adequate irrigation (see Figure 5-38).

Landfill Mining

The excavation and recycling of a landfill waste appears to be feasible where there has been adequate moisture to permit decomposition and stabilization of the waste. In locations where rainfall averages 60 in./year or more, a portion of the decomposed waste is generally suitable for recycling or for use as cover material for a new landfill at the same location excavated. On the other hand, in arid regions where the rainfall averages 10 to 20 in./year or less, the waste placed in landfills is often well preserved after more than 20 years. Other factors such as landfill design, type of cover material, waste composition, and age of the landfill must be evaluated and regulatory approval obtained.

A thorough hydrogeological investigation of an old landfill site is necessary before considering its excavation (mining), recycling, and possible reuse. The

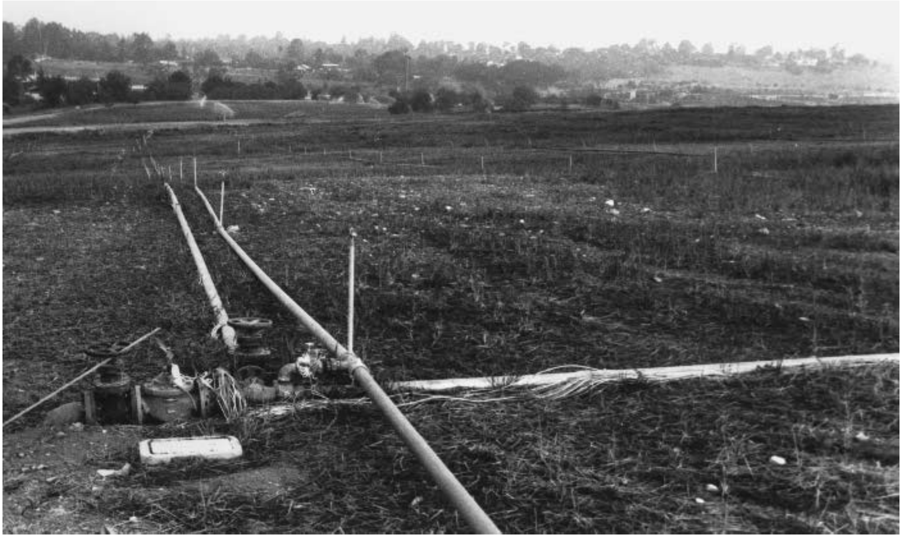


Figure 5-38 Completed landfill with irrigation system.

up-gradient and down-gradient groundwater levels and quality, the depth and type of soil beneath the fill, the thickness of the fill and its composition, including the possible presence of hazardous wastes, are among the conditions to be investigated. Numerous tests are necessary as landfill waste is not homogeneous. If reuse of the excavated site as a municipal landfill site is proposed, preliminary discussions with the regulatory agency are essential.

Landfill Facilities and Equipment for Disposal by Sanitary Landfill

In addition to the control of leachate and landfill gases, a number of other facilities and operating equipment are required for the effective implementation of a sanitary landfill. Personnel requirements are discussed in the following section.

Fire Protection The availability of fire protection facilities at a site should also be considered as fire may break out at the site without warning. Protective measures may be a fire hydrant near the site with portable pipe or fire hose, a watercourse from which water can be readily pumped, a tank truck, or an earth stockpile. The best way to control deep fires is to separate the burning solid waste and dig a fire break around the burning solid waste using a bulldozer. The solid waste is then spread out so it can be thoroughly wetted down or smothered with earth. Limiting the solid waste cells to about 200 tons, with a depth of 8 ft and 2 ft of compacted earth between cells (cells 20 $\times$ 85 ft assuming 1 yd^3 of compacted solid waste weighs 800 lb), will minimize the spread of underground fires. The daily 6-in. cover will also minimize the start and spread of underground fires. Fires are a rare occurrence at a properly compacted and operated sanitary landfill.

Weigh Station It is desirable to construct a weigh station at the entrance to the site. Vehicles can be weighed upon entering and, if necessary, billed for use of the site. Scales are required to determine tonnage received, unit operation costs, relation of weight of solid waste to volume of in-place solid waste, area work loads, personnel, collection rates, organization of collection crews, and need for redirection of collection practices. However, the cost involved in construction of a weigh station cannot be always justified for a small sanitary landfill handling less than 20 to 50 tons/day. Nevertheless, estimates of volume and/or weights received should be made and records kept on a daily or weekly basis to help evaluate collection schedules, site capacity, usage, and so on. At the very least, an annual evaluation is essential.

Equipment Requirements To attain proper site development and ensure proper utilization of the land area, it is necessary to have sufficient proper equipment available at all times at the site (see Figure 5-39). One piece of solid waste compaction and earth-moving equipment is needed for approximately each 80 loads per day received at the solid waste site. The type of equipment should be suitable for the method of operation and the prevailing soil conditions. Additional standby equipment should be available for emergencies, breakdowns, and equipment maintenance. Typical equipment requirements are summarized in Table 5-22.

Tractors Tractor types include the crawler, rubber-tired, and steel-wheeled types equipped with bulldozer blade, bullclam, or front-end loader. The crawler tractor with a front-end bucket attachment is an all-purpose piece of equipment (see Figure 5-40). It may be used to excavate trenches, place and compact solid waste, transport cover material, and level and compact the completed portion of the landfill. Some types can also be used to load cover material into trucks for transportation and deposition near the open face. The steel-wheeled compactor is a common piece of equipment at landfills.

A bulldozer blade on a crawler tractor is good for landfills where hauling of cover material is not necessary. It is well suited for the area method landfill in which cover material is taken from nearby hillsides. It can also be used for trench method operation where the trench has been dug with some other type of equipment. A bulldozer is normally used in conjunction with some other type of earth-moving equipment, such as a scraper, where earth is hauled in from a nearby source.

The life of a tractor is figured at about 10,000 hr. Contractors usually depreciate their equipment over a 5-year period. On a landfill, if it is assumed that the equipment would be used 1000 hr a year, the life of the equipment could be 10 years. After 10 years, operation and maintenance costs can be

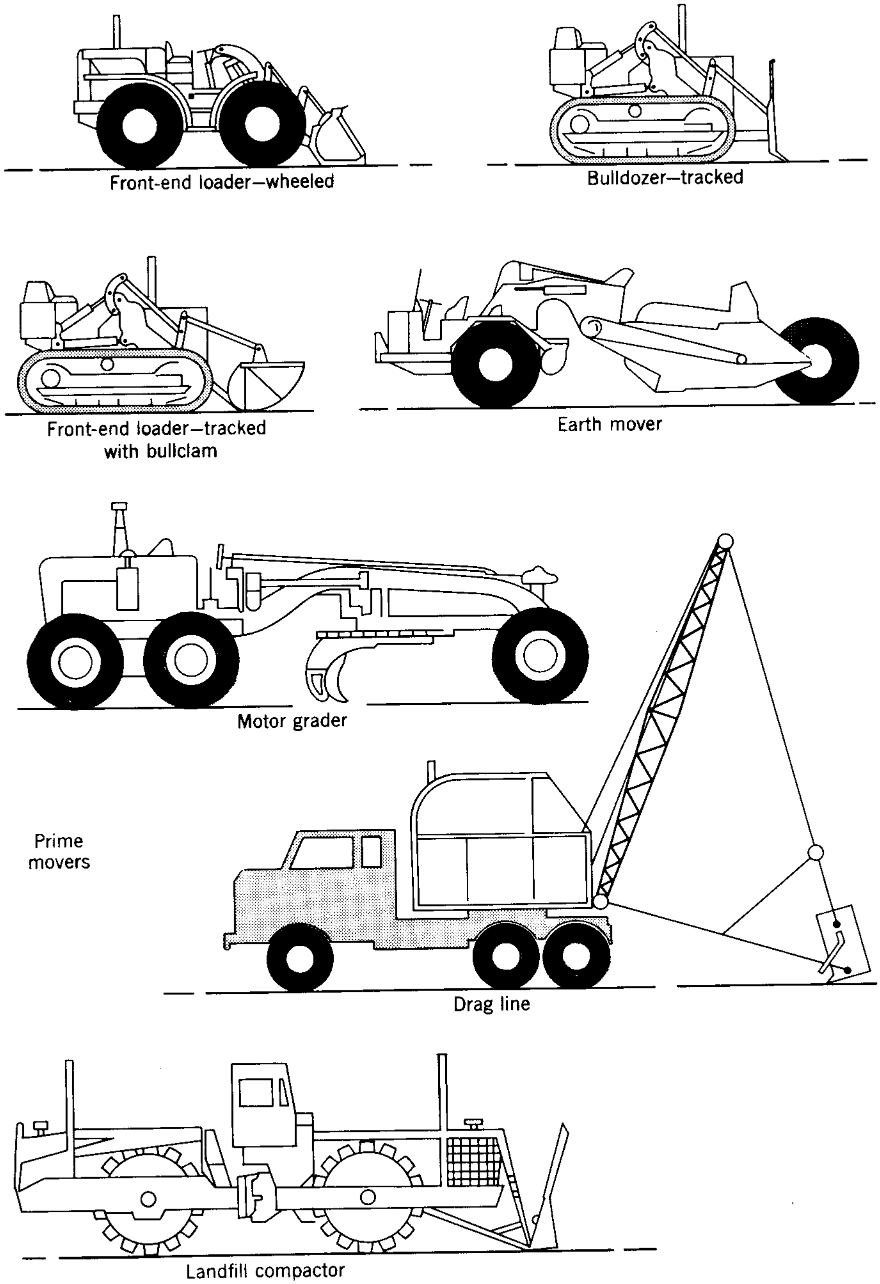


Figure 5-39 Typical equipment used for operation of sanitary landfill.

TABLE 5-22 Typical Minimum Landfill Equipment Requirements

	Daily	Equipment			
Service Population	Tonnage	Number	Type	Size (lb)	Accessory
0–15,000	0–50	1	Tractor, crawler, or rubber-tired	10,000–30,000	Dozer blade, landfill blade, front-end loader (1–2 yd^3)
15,000–50,000	50–150	1	Tractor, crawler, or rubber-tired	30,000–60,000	Dozer blade, landfill blade, front-end loader (2–4 yd) multipurpose bucket
		1 each	Scraper or dragline, water truck		
50,000–100,000	150–300	1–2	Tractor, crawler, or rubber-tired	30,000 or more	Dozer blade, landfill blade, front-end loader (2–5 yd), multipurpose bucket
		1 each	Scraper or dragline, water truck		
100,000 or more	300 or more	2 or more	Tractor, crawler, or rubber-tired	45,000 or more	Dozer blade, landfill blade, front-end loader, multipurpose bucket
		1 each	Scraper, dragline, steel-wheeled compactor, road grader, water truck		

Source: Adapted from Brunner and Keller (1972).

(*a*)

(*b*)

Figure 5-40 Common types of crawler tractors used at sanitary landfills: (*a*) tractor with dozer blade (wheeled compactor with trash blade also shown); (*b*) tractor with trash blade.

expected to approach or exceed the annual cost of new equipment. Lesser life is also reported. Equipment maintenance and operator competence will largely determine equipment life.

The size and type of machine needed at the sanitary landfill are dependent on the amount of solid waste to be handled, availability of cover material, compaction to be achieved, and other factors (Brunner and Keller, 1972). A rule that has been used is that a community with a population of less than 10,000 requires a $1\frac{1}{8}$-yd^3 bucket on a suitable tractor. Communities with a population between 10,000 and 30,000 should have a $2\frac{1}{4}$-yd^3 bucket, and populations of 30,000 to 50,000 should have at least a 3-yd^3 bucket. Larger populations will require a combination of earth-moving and compaction equipment depending on the site and method of operation. A heavy tractor (D-8) can handle up to 200 tons of solid waste per day, although 100 to 200 tons per day per piece of equipment is a better average operating capacity. Tire fill foam and special tire chains minimize tire puncture and other damage on rubber-tired equipment.

Many small rural towns have earth-moving equipment that they use for highway maintenance and construction. For example, a rubber-tired loader with special tires can be used on a landfill that is open two days a week. On the other three days the landfill can be closed (with fencing and locked gate), and the earth-moving equipment can be used on regular road construction work and maintenance. The people and contract users of the site should be informed of the part-time nature of the operation to receive their full cooperation. The public officials responsible for the operation should establish a definite schedule for the assignment of the equipment to the landfill site to ensure the operation is always under control and maintained as a sanitary landfill.

Other Equipment The dragline is suitable for digging trenches, stockpiling cover material, and placing cover material over compacted solid waste. An additional piece of equipment is necessary to spread and compact the solid waste and cover material. Although not commonly used, the backhoe is suitable for digging trenches on fairly level ground, and the power shovel is suitable for loading trucks with cover material.

In large operations, earth movers can be used for the short haul of cover material to the site when adequate cover is not readily available nearby. Dump trucks may also be needed where cover material must be hauled in from some distance. Other useful equipment is a grader, a sheepsfoot roller, and a water tank truck equipped with a sprinkler to keep down dust or a power sprayer to wet down the solid waste to obtain better compaction.

Equipment Shelter An equipment shelter at the site will protect equipment from the weather and possible vandalism. The shelter can also be used to store fire protection equipment and other needed materials and for routine equipment maintenance and repair. Operators of sanitary landfills have found a shelter to be of great value during the winter months since there is much less difficulty in starting motorized equipment. However, the shelter location must be on solid ground, not subject to gas migration from the landfill.

Landfill Operation and Supervision

Operational issues for modern landfills include operational control, personnel and operation, salvaging policy, area policing, insect and rodent control, maintenance, and operational policies (see also Table 5-20).

Operation Control The direction of operation of a sanitary landfill should be with the prevailing wind to prevent the wind from blowing solid waste back toward the collection vehicle and over the completed portion of the landfill. To prevent excessive wind scattering of solid waste throughout the area, snow fencing or some other means of containing papers should be provided. The fencing can be utilized in the active area and then moved as the operation progresses. In some instances, the entire area is fenced. Other sites have natural barriers around the landfill, such as is the case in heavily wooded areas. It is desirable to design the operation so that the work area is screened from the public line of sight. Noise levels between 7 a.m. and 10 p.m. are generally required to be kept below 60 dBA in rural areas, 65 in suburban areas, and 70 in urban areas beyond property lines.

Large items such as refrigerators, ranges, and other ‘‘white goods’’ and tires should be recycled. Brush and yard wastes are preferably composted. Other bulky items not recyclable should be placed in a separate area of the landfill for periodic burial. Prior compression or shredding of bulky objects will improve compaction of the fill, reduce land volume requirements, and allow more uniform settlement. Consideration should always be given to resource recovery and recycling where possible. Tires are usually not acceptable in landfills but may be if chipped or properly cut.

Drivers of small trucks and private vehicles carrying rubbish and other solid wastes interfere with the operation of a landfill. To accommodate these individuals on weekends and avoid traffic and unloading problems during the week, it is good practice to provide a special unloading area (convenience station) adjacent to the landfill entrance. A satellite transfer station is also an alternative, in conjunction with a regional landfill.

Personnel and Operation Proper full-time supervision is necessary to control dumping, compaction, and covering. Adequate personnel are needed for proper operation. Depending on the size of the community, there should be a minimum of one man at a site and six men per 1000 yd^3 dumped per day that the site is open. The supervisor should erect signs for direction of traffic to the proper area for disposal. It is essential that the supervisor be present at all hours of operation to ensure that the landfill is progressing according to plan. Days and hours of operation should be posted at the entrance to the landfill. A locked gate should be provided at the entrance to keep people out when closed. It is also advisable to inform the public of the days and hours of operation.

Solid waste treatment and disposal facilities represent very large investments. They have the potential for grave air, water, and land pollution and contain complex equipment and controls. Proper operation meets regulatory agency permit conditions and requires continuous, competent operational control. The training and certification of operators of resource recovery facilities, landfills, incinerators, and hazardous waste sites are provided by various state and private organizations.

In supervising an operation, the length of the open face should be controlled since too large an open face will require considerably more cover material at the end of a day's operation. Too small an open face will not permit sufficient area for the unloading of the expected number of collection vehicles that will be present at one time. After vehicles have deposited the solid waste at the top or, preferably, at the base of the ramp as directed, the solid waste should be spread and compacted from the bottom up into a 12- to 18-in. layer (24 in. maximum) with a tractor. Three to five passes should give a compaction of 1000 to 1250 lb/yd^3. *Passing over the waste should be done continually throughout the day* to ensure good compaction and vermin and fire control. If solid waste is allowed to pile up without spreading and compaction for most of the day, proper compaction will not be achieved, resulting in uneven settlement and extra maintenance of the site after the fill is completed. At the end of each day, the solid waste should be covered with at least 6 in. of earth or a suitable foam. For final cover of solid waste, at least 2 ft of earth is required.

No Burning or Salvaging Air pollution standards and sanitary codes generally prohibit any open burning. Limited controlled burning might be permitted in some emergency cases (for uncontaminated wood and stumps), but special permission would be required from the air pollution control agency, health department, and local fire chief. Arrangements for fire control, complete burning in one day, control over material to be burned (no rubber tires or the like), and restrictions for air pollution control would also be required. Salvaging at sanitary landfills is not recommended since, as usually practiced, it interferes with the operation. It will slow down the entire operation and thus result in time loss. Salvaging can also result in fires and unsightly stockpiles of the salvage material in the area.

Area Policing Since wind will blow papers and other solid waste around the area as the trucks are unloading, it will be necessary to clean up the area and access road at the end of each day. One of the advantages of portable snow fencing is that it will usually confine the papers near the open face, thereby make the policing job easier and less time consuming. At many sanitary landfills, dust will be a problem during dry periods of the year. A truck-mounted water sprinkler can keep down the dust and can also be used to wet down dry solid waste to improve compaction. The bulldozer operator should be protected by a dust mask, special cab, or similar device.

Insect and Rodent Control An insect and rodent control program is not usually required at a properly designed and operated landfill. However, from time to time, certain unforeseen conditions may develop that will make control necessary. For this reason, prior arrangement should be made to take care of such emergencies until the proper operating corrections can be made. Prompt covering of solid waste is necessary. See Chapter 10.

Maintenance Once a sanitary landfill, or a lift of a landfill, is completed or partially completed, it will be necessary to maintain the surface to take care of differential settlement. Settlement will vary, ranging up to approximately 20 to 30 percent, depending on the compaction, depth, and character of solid waste. Ninety percent of the settlement can be expected in the first 5 years. Settlement maintenance is required for perhaps 20 or 30 years. Maintenance of the cover is necessary to prevent excessive precipitation and surface-water infiltration, erosion, ponding, and excessive cracking, allowing insects and rodents to enter the fill and multiply.

It is necessary to maintain proper surface-water drainage to reduce precipitation–infiltration and minimize percolation of contaminated leachate through the fill to the groundwater table or the surface. A final 4 percent grade, with culverts and lined ditches as needed, is essential. The formation of water pockets is objectionable since this will promote surface-water infiltration. Vehicular traffic over these puddles will wash away the final earth cover over the solid waste and cause trucks to bog down. The maintenance of access roads to the site is also necessary to prevent dust and the formation of potholes, which will slow down vehicles using the site. Finally, provision must be made for groundwater, surface-water and gas monitoring, and control. The landfill surface should be properly capped, graded, and planted with suitable tolerant vegetation as previously noted.

Summary of Recommended Operating Practices

1. The sanitary landfill should be planned as an engineering project, to be constructed, operated, and maintained by qualified personnel under technical direction, without causing air, land, or water pollution, safety or health hazards, or nuisance conditions. Surveying benchmarks should be established and maintained to guide fill progression and site closure. Careful supervision must be given to landfill bottom separation and soil compaction, construction of primary and secondary composite liners, synthetic liner placement and seals, and leachate drainage and collection system. Construction of the landfill cap requires similar supervision.

2. The face of the working fill should be kept as narrow as is consistent with the proper operation of trucks and equipment in order to keep the area of exposed waste material to a minimum.
3. All solid waste should be spread as dumped and compacted into 12- to 18-in.-thick layers as it is hauled in. Operate tractor up- and down-slope (3:1) of fill to get good compaction—three to five passes.
4. All exposed solid waste should be covered with 6 in. of earth at the end of each day's operation.
5. The final earth covering for the surface and side slopes should minimize infiltration, be compacted, and be maintained at a depth of at least 24 in. See state regulations.
6. The final level of the fill should provide a 4 percent slope to allow for adequate drainage. Side slopes should be as gentle as possible to prevent erosion. The top of the fill and slopes should be promptly seeded. Drainage ditches and culverts are usually necessary to carry away surface water without causing erosion.
7. The depth of solid waste should usually not exceed an average depth of 8 to 10 ft after compaction. In a landfill where successive lifts are placed on top of the preceding one, special attention should be given to obtain good compaction and proper surface water drainage. A settlement period of preferably one year should be allowed before the next lift is placed.
8. Control of dust, wind-blown paper, and access roads should be maintained. Portable fencing and prompt policing of the area each day after solid waste is dumped are necessary. If possible, design the operation so that it is not visible from nearby highways or residential areas.
9. Salvaging, if permitted by the operator of the solid waste disposal area, should be conducted in such a manner as not to create a nuisance or interfere with operation. Salvaging is not recommended at the site.
10. A separate area or trench may be desirable for the disposal of such objects as tree stumps, large limbs, if not shredded and recycled, and nonrecyclable miscellaneous materials.
11. Where necessary, provision should be made for the disposal, under controlled conditions, of small dead animals and septic tank wastes. These should be covered immediately. The disposal of sewage sludge, industrial or agricultural wastes, and toxic, explosive, or flammable materials should not be permitted unless study and investigation show that the inclusion of these wastes will not cause a hazard, nuisance, or groundwater or air pollution. See appropriate regulatory agency for details.
12. An annual or more frequent inspection maintenance program should be established for completed portions of the landfill to ensure prompt repair of cracks, erosion, and depressions.
13. Sufficient equipment and personnel should be provided for the spreading, compacting, and covering of solid waste. Daily records should be

kept, including type and amount of solid wastes received. *At least annually,* an evaluation should be made of the weight of solid waste received and volume of solid waste in place as a check on compaction and rate at which the site is being used.

14. Sufficient standby equipment should be readily available in case there is a breakdown of the equipment in use.
15. The breeding of rats, flies, and other vermin; release of smoke and odors; pollution of surface waters and groundwaters; and causes of fire hazards are prevented by proper operation, thorough compaction of solid waste in 12- to 18-in. layers, daily covering with earth, proper surface-water and groundwater drainage, and good supervision.
16. Leachate and gas-monitoring wells should be sampled periodically to detect significant changes. This should include methane concentrations in on-site or other nearby buildings.

Site Closure or Conversion

If a disposal site is to be closed, the users, including contractors, should be notified and an alternate site designated. A rat-poisoning (baiting) program should be started at least two weeks before the proposed closing of a site that has not been operated as a sanitary landfill and continued until the site has been completely closed. The site should be closed off and made inaccessible; it should be covered with at least 2 ft of compacted earth on the top and all exposed sides or as required by the regulatory agency, graded to shed water, seeded to grass, and then posted to prohibit further dumping. Side slopes should be no greater than 3 : 1 to reduce erosion and maintenance. Steps must be taken to prevent contravention of surface-water and groundwater standards, gas migration, or adverse health or environmental hazards. If the site is adjacent to a stream, the solid waste must be moved an appropriate distance back from the high-water level to allow for the construction of an adequate and substantially protected earth dike. Legal closure requirements may be quite onerous if groundwater pollution is suspected or if enclosed structures are in a vicinity that might be affected by methane migration. This is discussed further below.

Where adequate land is available and the site is suitable as determined by an engineering and hydrogeological analysis, it may be possible to convert the landfill into a properly designed, constructed, operated, and maintained sanitary landfill. Conversion of a *suitable* existing site can overcome the problems associated with the selection of a new site.

Landfill Closure Requirements The state regulatory agency closure requirements must be followed.

Use of Completed Landfill A sanitary landfill plan should provide for landscaping and a specific use for the area after completion. Final grades for a sanitary landfill should be established in advance to meet the needs of the proposed future use. For example, the use of the site as a golf course can tolerate rolling terrain while a park, playground, or storage lot would be best with a flat graded surface. Other uses of completed landfills include toboggan and ski runs for children, nature areas, bicycle and hiking paths, open areas, and airport runway extensions. In planning for the use of such an area, permanent buildings or habitable dwellings should not be constructed close to or over the fill since gas production beneath the ground may migrate into sewers, utility conduits, and basements or through floor slabs and sump drains of such dwellings or buildings, reaching explosive levels. Some open structures that would not require excavation, such as grandstands and open equipment shelters, can be built on a sanitary landfill with little resulting hazard. Buildings constructed on sanitary landfills can be expected to settle unevenly unless special foundation structures such as pilings are provided; however, special provisions must be made to monitor and dissipate gas production. When the final land use is known beforehand, selected undisturbed ground islands or earth-fill building sites are usually provided to avoid these problems, but gas monitoring is still necessary.

INCINERATION

The incineration of solid waste involves the conversion of solid wastes into gaseous, liquid, and solid conversion products with the concurrent or subsequent release of heat energy. Incineration is typically implemented to reduce the volume of solid waste and, to the extent possible, recover energy. A properly designed and controlled incinerator is satisfactory for burning combustible municipal solid waste and chemical, infectious, and pathological wastes. In general, incineration is not generally recommended for small towns, villages, apartment buildings, schools, institutions, camps, and hotels unless good design and supervision can be ensured and cost is not a factor. Further, a landfill is a necessary adjunct for the disposal of incinerator residue and unrecycled solid waste. The purpose of this section is to review (1) the basic operations involved in the incineration of solid waste, (2) briefly the principal combustion products and residues formed during combustion, (3) the types of incinerators that are used for solid waste, (4) factors that must be controlled in the incineration process, (5) residuals management, (6) site selection, plant layout, and building design, and (7) issues in the implementation of incineration facilities.

Description of Operation of MSW Incinerator

The basic operations involved in the combustion of commingled MSW are identified in Figure 5-41. The operation begins with the unloading of solid

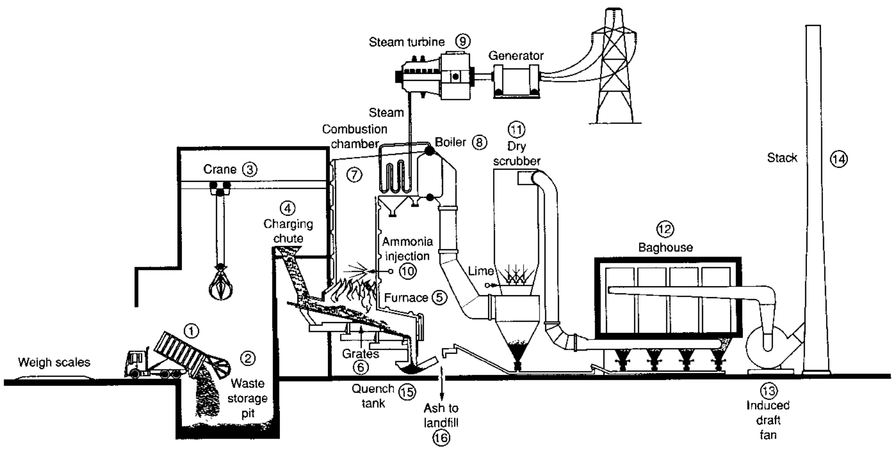


Figure 5-41 Definition sketch for operation of modern mass-burn incinerator.

wastes from collection trucks (1) into a storage pit (2). The length of the unloading platform and storage bin is a function of the size of the facility and the number of trucks that must unload simultaneously. The depth and width of the storage bin are determined by both the rate at which waste loads are received and the rate of burning. The capacity of the storage pit is usually equal to the volume of waste for two to four days. The overhead crane (3) is used to batch load wastes into the feed (charging) chute (4), which directs the wastes to the furnace (5). The crane operator can select the mix of wastes to achieve a fairly even moisture content in the charge. Large or noncombustible items are also removed from the wastes. Solid wastes from the feed (charging) chute fall onto the grates (6), where they are mass fired. Several different types of mechanical grates are commonly used. Typical physical and chemical characteristics of incinerator solid waste are reported in Table 5-23.

Air may be introduced from the bottom of the grates (under-fire air) by means of a forced-draft fan or above the grates (over-fire air) to control burning rates and furnace temperature. Because most organic wastes are thermally unstable, various gases are driven off in the combustion process taking place in the furnace. These gases and small organic particles rise into the combustion chamber (7) and burn at temperatures in excess of 1600°F. Heat is recovered from the hot gases using water-filled tubes in the walls of the combustion chamber and with a boiler (8) that produces steam that is converted to electricity by a turbine generator (9). When 30 percent or less of the solid waste is rubbish or when the solid waste contains more than 50 percent moisture, additional supplemental fuel will be needed.

Air pollution control equipment is required on all new incinerators. Air pollution control equipment may include ammonia injection for NO_x (nitrogen oxides) control (10), a dry scrubber for SO and acid gas control (11), and a bag house (fabric filter) for particulate removal (12). To secure adequate air

TABLE 5-23 Physical and Chemical Characteristics of Incinerator Solid Waste[a]

Constituents	Percent by Weight (as received)
Proximate analysis	
Moisture	15–35
Volatile matter	50–65
Fixed carbon	3–9
Noncombustibles	15–25
Ultimate analysis	
Moisture	15–35
Carbon	15–30
Oxygen	12–24
Hydrogen	2–5
Nitrogen	0.2–1.0
Sulfur	0.02–0.1
Noncombustibles	15–25
Higher heating value (Btu/lb as received)	
Without recycling	3000–6000
With recycling	3000–5000

Source: DeMarco et al. (1969) and Tchobanoglous et al. (1993).

[a]Principally residential–commercial waste.

flows to provide for head losses through air pollution control equipment, as well as to supply air to the combustor itself, an induced-draft fan (13) may be needed. The end products of combustion are hot combustion gases and ash. The cleaned gases are discharged to the stack (14) for atmospheric dispersion. Ashes and unburned materials from the grates fall into a residue hopper (15) located below the grates where they are quenched with water. Fly ash from the dry scrubber and the bag house is mixed with the furnace ash and conveyed to ash treatment facilities (16). Details on incinerator design, air pollution control equipment, and ash treatment and disposal may be found in Tchobanoglous and Kreith (2002) and Tchobanoglous et al. (1993).

In addition to the above operational aspects, complex instrumentation, including transmission to a central control panel, is necessary to properly operate a modern incinerator. Included are temperature indicators, air and water flows, pressure indicators, alarms, waste feed cutoffs when combustion and emission regulations are violated, and other indicators and controls that may be required by the regulatory authority.

Combustion Products and Residues

Municipal solid waste burned in incinerators will result in the production of combustion gases, particulates, and bottom and fly ash. The characteristics of these products will depend on the types of wastes burned and the incinerator design, operating temperature, residence time, and controls.

Combustion Essentials The three essentials for combustion, as outlined above, are (1) time, (2) temperature, and (3) turbulence, including sufficient oxygen. There must be sufficient time to drive out the moisture, the temperature must be raised to the ignition point, and there must be sufficient turbulence to ensure mixing of the gases formed with enough air to burn completely the volatile combustible matter and suspended particulates. The combustion process involves first, drying, volatilization, and ignition of the solid waste and, second, combustion of unburned furnace gases, elimination of odors, and combustion of carbon suspended in the gases. The second step requires a high temperature, at least 1500 to 1800°F (816–982°C) sufficient air, and mixing of the gas stream to maintain turbulence until burning is completed. The temperature in the furnace may range from 2100 to 2500°F (1149–1371°C) if not controlled. A combustion temperature of 2500°F (1371°C) is normal for steam generation and energy recovery.

When the gases leave the combustion chamber, the temperature should be between 1500°F and 1800°F (816 and 982°C), and the gas entering the stack should be 1000°F (538°C) or less. The minimum temperature for burning carbonaceous wastes to avoid release of smoke is 1500°F (816°C). A temperature of less than 1500°F will also permit the release of dioxins and furans. The exit temperature will have to be lowered to 200°F (93°C) for wool or cotton filters, 450 to 500°F (232–260°C) for glass fiber filters before the gas is filtered, or 600°F (316°C) or less if electrical precipitators are used. At a temperature of 1200 to 2000°F (649–1093°C) or higher, depending on temperature and residence time, oxides of nitrogen are formed that contribute to air pollution. Hospital wastes require incineration at a temperature of 1800 to 2000°F (982–1093°C) to ensure degradation of organic compounds. Inorganic agents are not destroyed.

Gaseous Combustion Products The principal elements of solid wastes are carbon, hydrogen, oxygen, nitrogen, and sulfur. Under ideal conditions, the gaseous products derived from the combustion of municipal solid wastes would include carbon dioxide (CO_2), water (H_2O, flue gas), oxygen (O_2), nitrogen (N_2) , and small amounts of sulfur dioxide (SO_2). Because many different reaction sequences are possible, depending on the exact nature of the wastes and the operating characteristics of the combustion reactor, the gaseous emissions from combustion may include sulfur and nitrogen oxides and smaller amounts of hydrogen chloride, mercury, lead, arsenic, cadmium, dioxins and furans, and organic compounds. The amounts and concentrations going up the stack are determined also by the combustion effectiveness and the efficiency of air pollution control equipment.

The basic reactions for the oxidation (combustion) of the carbon, hydrogen, and sulfur contained in the organic fraction of MSW are as follows:

$$\underset{(12)}{C} + \underset{(32)}{O_2} \rightarrow CO_2 \quad \text{(for carbonA)} \tag{5-2}$$

$$\underset{(4)}{2H_2} + \underset{(32)}{O_2} \rightarrow 2H_2O \quad \text{(for hydrogen)} \tag{5-3}$$

$$\underset{(32.1)}{S} + \underset{(32)}{O_2} \rightarrow SO_2 \quad \text{(for sulfur)} \tag{5-4}$$

If it is assumed that dry air contains 23.15 percent oxygen by weight, then the amount of air required for the oxidation of 1 lb of carbon would be equal to 11.52 lb [(32/12)(1/0.2315)]. The corresponding amounts for hydrogen and sulfur are 34.56 and 4.31 lb, respectively. Thermal processing systems are often categorized on the basis of their air requirements. Combustion with exactly the amount of oxygen (or air) needed for complete combustion is known as *stoichiometric combustion*. Combustion with oxygen in excess of the stoichiometric requirements is termed *excess air combustion*.

Combustion Residues The principal solid residues are (1) bottom ash, (2) fly ash, and (3) noncombusted organic and inorganic materials. The residue after burning (bottom and fly ash) is about 25 percent of the original weight (10–15 percent by volume), 5 percent where intensive recycling is practiced. Other residuals associated with the incineration of solid waste may include scrubber sludge and wastewater treatment plant sludge, both of which will tend to concentrate contaminants. It is essential, therefore, that the fly ash, bottom ash, and scrubber and wastewater sludge be analyzed for contaminants likely to be present and evaluated for their significance. The disposal method and facility should be tailored to ensure protection of the public health and the environment.

Types of Incinerators

A variety of incinerator types have been used for the combustion of solid waste, including (1) mass-fired combustors, (2) refuse-derived fuel- (RDF) fired combustors, (3) modular combustion units, and (4) on-site commercial and industrial incinerators.

Mass-Fired Combustors In a mass-fired combustor, minimal processing is given to solid waste before it is placed in the hopper used to feed the combustor. The crane operator in charge of loading the charging hopper can manually reject obviously unsuitable items. However, it must be assumed that anything in the MSW stream may ultimately enter the combustor, including bulky oversize noncombustible objects (e.g., broken tricycles) and even potentially hazardous wastes deliberately or inadvertently delivered to the system. For these reasons, the combustor must be designed to handle these objectionable wastes without damage to equipment or injury to operational personnel. The energy content of mass-fired waste can be extremely variable, dependent on the climate, season, and source of waste. In spite of these potential disadvantages, mass-fired combustors have become the technology of choice for most existing and planned incineration facilities (Tchobanoglous et al., 1993).

A typical mass-burn incinerator schematic showing steam and electricity production is illustrated in Figure 5-42. Types of furnaces used are the rectangular refractory lined (Figure 5-43), the rotary kiln (Figure 5-44), and the rectangular furnace with waterwalls (Figure 5-45). In the rectangular furnace, two or more grates are arranged in tiers. The rotary kiln furnace incorporates a drying grate ahead of a rotary drum or kiln where burning is completed. Waterwall furnaces substitute water-cooled tubes for the exposed furnace walls and arches. Other types of furnaces are also available. All furnaces should be designed for continuous feed. Reciprocating or moving and traveling grates are the most common. Mass-burn incinerators usually burn raw solid wastes in a refractory-lined rotary kiln after drying and combustion, with underfire and overfire air and a tube boiler to generate steam, hot water, or electricity. A diagram of a modern mass-burn facility is shown in Figure 5-46. In a cogeneration incinerator, steam and electricity are produced.

Modern furnace walls are usually lined with tile or have waterwalls. With tile refractories, repairs can be readily made without the need for expensive and time-consuming rebuilding of entire solid brick walls found in old plants. Special plastic or precast refractories can be used for major or minor repairs. Waterwalls in a furnace actually consist of water-cooled tubes that also serve

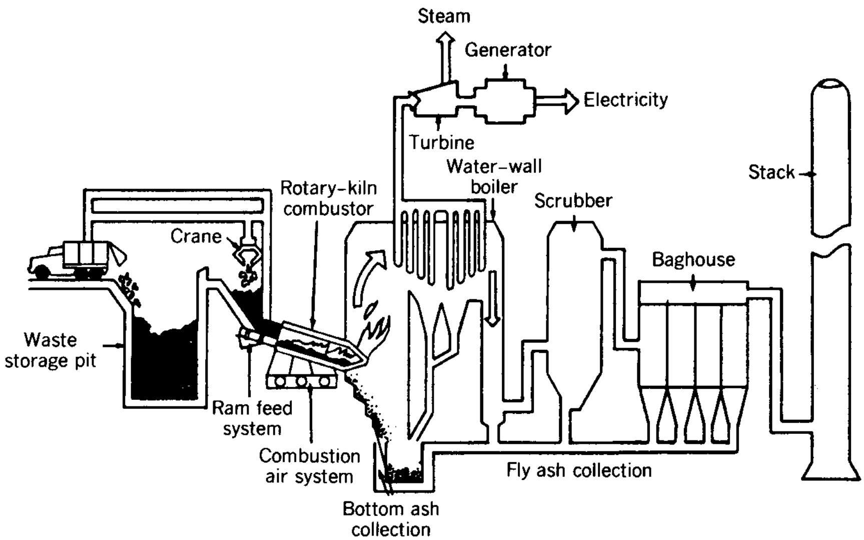


Figure 5-42 Schematic of typical mass-burn municipal waste combustion facility with energy production facilities (U.S. EPA, 1989).

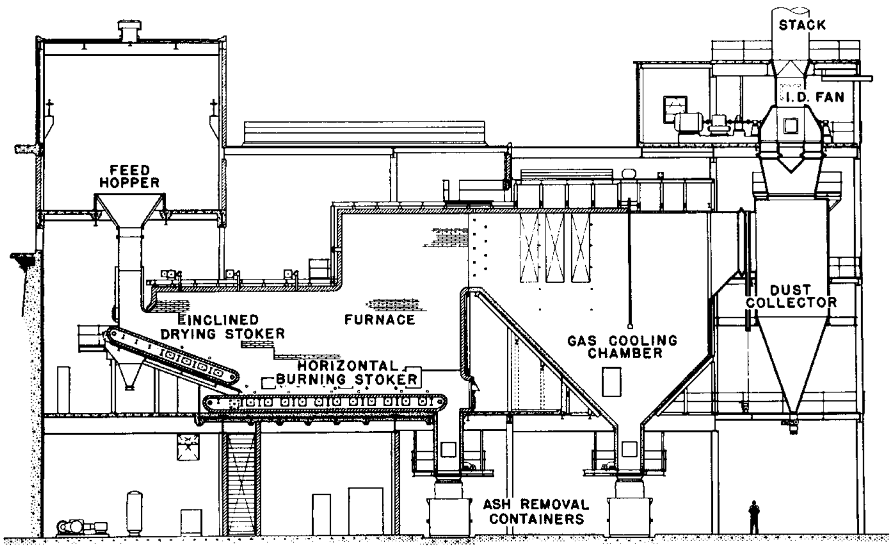


Figure 5-43 Modern continuous-feed, refractory-lined incinerator with traveling-grate stokers (rectangular type) (Corey, 1969).

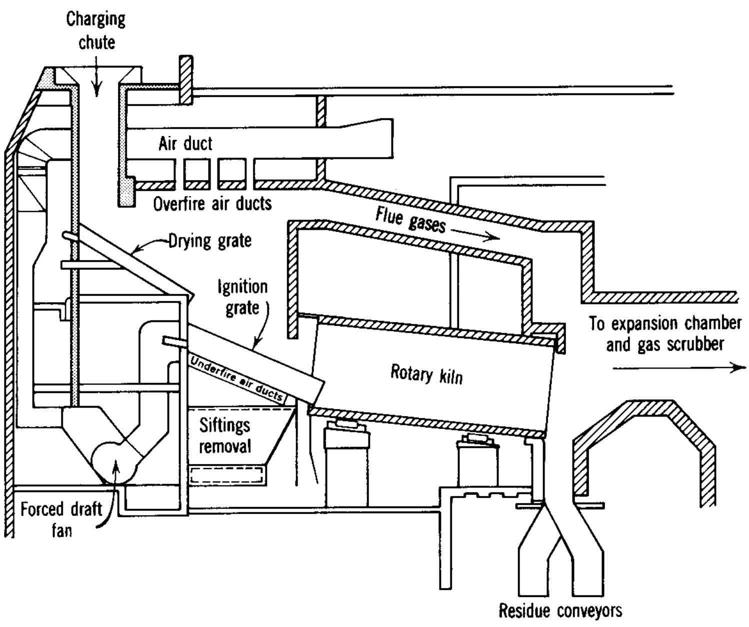


Figure 5-44 Rotary kiln furnace (DeMarco et al., 1969).

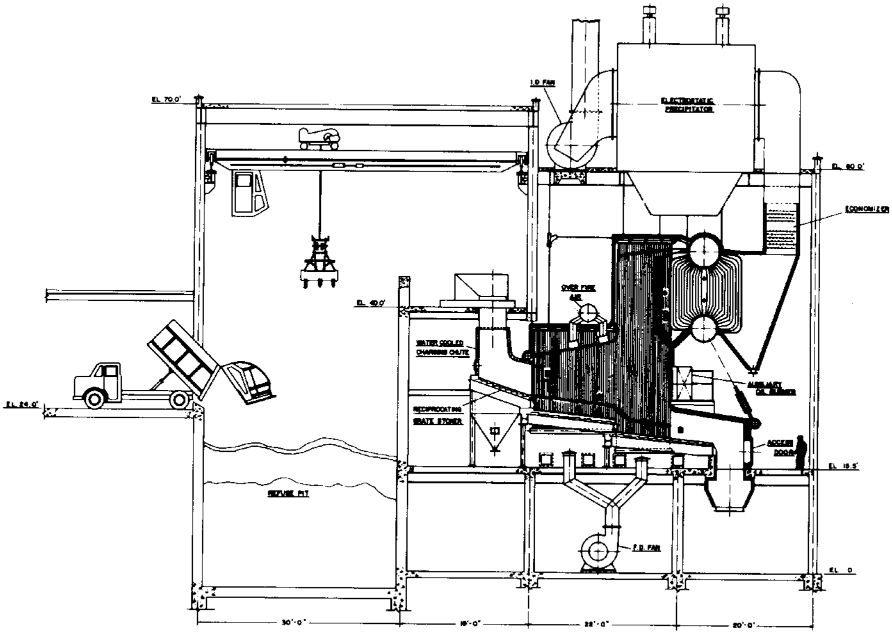


Figure 5-45 Continuous-feed incinerator with rocking-grate stoker and waterwalls (Corey, 1969).

as heat exchangers, thereby reducing the outlet gas temperature and simplifying dust collection. The tubes also cover and protect exposed furnace walls and arches. Less air is required: 100 to 200 percent excess air for refractory walls compared to less than 80 percent for waterwalls. External pitting of the water-cooled tubes may occur if the water temperature drops below 300°F (149°C) due to condensation of the corrosive gases. Internal tube corrosion must also be prevented by recirculation of conditioned water.

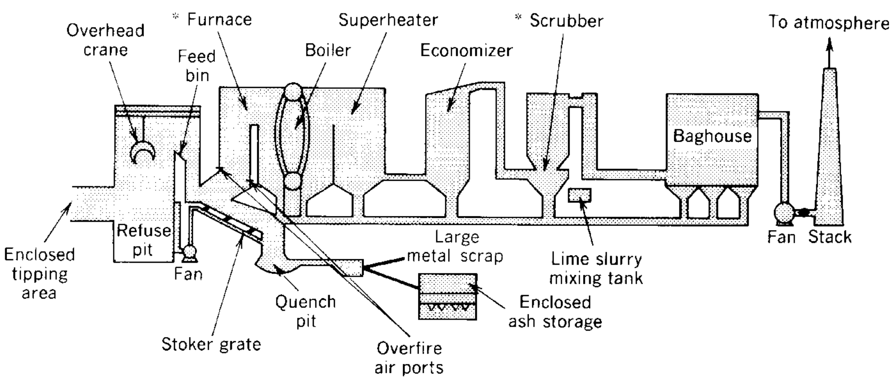


Figure 5-46 Diagram of modern mass burn facility (U.S. EPA, 1987a).

RDF-Fired Combustors Compared to the uncontrolled nature of unprocessed commingled MSW, RDF can be produced from the organic fraction of MSW (see Chapter 12) with fair consistency to meet specifications for energy content, moisture, and ash content. The RDF can be produced in shredded or fluff form or as densified pellets or cubes. Densified RDF (d-RDF) is more costly to produce but easier to transport and store. Either form can be burned by itself or mixed with coal and combusted in a waterwall furnace (see Figure 5-13) equipped with a traveling gate for ash management.

Because of the higher energy content of RDF compared to unprocessed MSW, RDF combustion systems can be physically smaller than comparatively rated mass-fired systems. However, more space will be required if the front-end processing system needed to prepare the RDF is to be located adjacent to the combustor. A RDF-fired system can also be controlled more effectively than a mass-fired system because of the more homogeneous nature of RDF, allowing for better combustion control and better performance of air pollution control devices. Additionally, a properly designed system for the preprocessing of MSW can effect the removal of significant portions of metals, plastics, and other materials that may contribute to harmful air emissions (Tchobanoglous et al., 1993).

Modular Combustion Units Modular combustion units are available for capacities of less than 700 lb/hr to 250 tons/day and include a secondary combustion chamber. These units may be used for the batch incineration of municipal, hospital, commercial, and industrial wastes. Volume reduction of 80 to 90 percent and energy recovery of about 55 percent are claimed. Emission control (scrubber and/ or baghouse) is needed and skilled operation is required.

On-Site Commercial and Industrial Incinerators When possible, a large municipal incinerator should be used in preference to a small on-site incinerator. Better operation at lower cost with less air pollution can usually be expected. Based on past experience, conventional mass-fired incinerators generally are not economically feasible for communities with a population of less than 50,000 to 100,000, but modular controlled air units incorporating heat recovery are suitable for smaller volumes of waste. However, on-site incinerators are used in hospitals, schools, and commercial and industrial establishments. Their continued use is being severely limited by air pollution control requirements. Many of the units now in use need to be replaced or redesigned to meet modern air pollution control standards. The controlled-air incinerator with a waste-heat boiler for energy recovery can overcome many, if not all, of the deficiencies.

Incinerator Capacity and Stack Heights Incinerators are rated in terms of tons of burnable or incinerable waste per day. For example, an incinerator having a furnace capacity of 600 tons/day can theoretically handle 600 tons in 24 hr with three-shift operation, 400 tons in 16 hr with two-shift operation, and 200 tons in 8 hr with one-shift operation. Hence, if 400 tons of incinerable wastes collected per day are to be incinerated in 8 hr, an incinerator with a rated capacity of 1200 tons per day will be required plus a 15 percent downtime allowance for repairs. In determining design capacity, consideration must also be given to daily and seasonal variations, which will range from 85 to 115 percent of the median.

High stacks (chimneys) 150 to 200 ft above ground level are usually constructed to provide natural draft and air supply for combustion. Stack heights of 300 to 600 ft are not uncommon. Discharge of gases at these heights also facilitates dilution and dispersal of the gases. In some designs, short stacks are used for aesthetic reasons, and the equivalent effective stack height is obtained by induced draft. Meteorological conditions, topography, adjacent land use, air pollution standards, and effective stack height should govern.

Control of the Incineration Process

The poor image that incineration has in the eyes of many people is due largely to the failure to control the operation, with resultant destruction of the equipment and air pollution. A properly designed and operated incinerator requires control instrumentation for (1) temperature, (2) draft pressures, (3) smoke emission, (4) weights of solid wastes coming in and leaving the plant, and (5) air pollution control equipment. Competent well-trained operators are also essential.

Temperature Temperature monitoring is necessary for control purposes to monitor the incoming air and gases leaving the combustion chamber at the settling chamber outlet, the cooling chamber outlet, the dust collector inlet and outlet, and the stack temperature. Furnace temperature can be controlled by adjusting the amount of overfire or underfire air. The temperature of the gases leaving the furnace is reduced by spraying with water (causes a white stack plume unless the flue gas is reheated before discharge), dilution with cool air (high equipment cost to handle large volumes of diluted gases), or passing through heat exchangers (ready market for heat, steam, electricity, or high-temperature water needed). Gas scrubbers using water sprays can be used to cool effluent gas so that an induced-draft fan can be used to reduce the chimney height; large particulates can also be removed.

Draft Pressure Draft pressure measurements are needed to control the induced-draft fan and the stack draft. Measurements should be made at the underfire air duct, overfire air duct, stoker compartment, sidewall air duct, sidewall low-furnace outlet, dust collector inlet and outlet, and induced fan inlet. Control of underfire air can provide more complete combustion with less fly-ash carryover up the stack.

Smoke Density The smoke emission can be controlled by continuous measurement of the particulate density in the exhaust gas. A photoelectric pickup of light across the gas duct is used, preferably located between the particulate collector and the induced fan duct.

Weigh Station Platform scales to weigh and record the incoming solid waste and outgoing incinerator residue, fly ash, siftings, and other materials are generally required.

Instrumentation Devices should include those to keep record of overfire and underfire air flow rates; temperature and pressure in the furnace, along gas passages, in the particulate collectors, and in the stack; electrical power and water use; and grate speed.

Odor Odor control requires complete combustion of hydrocarbons, that is, excess air and a retention time of 1 sec at 1500°F (816°C) [above 1400°F (760°C) at the exit of the furnace]. Adequate dilution of gases leaving the stack by an effective stack height (actual stack height plus plume rise) is another possible method for odor control, but its effectiveness is related to meteorological conditions and persistence of the odors. Wet scrubbers can also be used to absorb odors while removing particulates.

Gaseous Emissions The principal gaseous emissions from the combustion of mixed wastes are: carbon dioxide, water vapor, sulfur oxides, nitrogen oxides, carbon monoxide, and hydrogen chloride. Hydrogen chloride and other acids can cause corrosion of air pollution control equipment. A lime spray dry scrubber followed by a baghouse (fabric) filter is effective in greatly reducing sulfur dioxide and hydrogen chloride gases, metals, dioxins, furans, and organic emissions, as well as fly ash. There is some evidence that the lower the temperature of flue gases [below about 300°F (149°C)] entering the pollution control devices, the greater the amount of phenols, benzenes, dioxins, and other organics condensed and collected on the particulates. Typical gaseous emission guidelines are presented in Table 5-24.

Particulate Emissions These can be controlled by settling chambers, wetted baffle spray system, cyclones, wet scrubbers, electrostatic precipitators, and fabric filters. Their efficiencies and other details are discussed in Chapter 6. Apparently, only wet scrubbers, electrostatic precipitators, and bag filters can meet air pollution code requirements. Cyclones in combination with other devices might approach the standard. Typical particulate emission guidelines are presented in Table 5-24.

TABLE 5-24 Some Municipal Solid Waste Incineration Emission Design and Operation Guidelines

Control	Guidelines
Particulate emissions	Not greater than 0.010 grains[a] per dry standard cubic foot of exhaust (stack) gas, corrected to 7% oxygen; not greater than 0.015 grains at startup; existing, small to midsize units, up to 0.030 grains
Carbon monoxide	Outlet concentration not greater than 50 ppm on an 8-hr average; 4-hr average and 100 ppm maximum proposed
Hydrogen chloride emissions	A running 8-hr average emission of not greater than 10% by weight of uncontrolled emissions reduced by not less than 90%, or less than 50 ppm stack concentration (25 ppm proposed); flue gas at control device outlet not greater than 300°F (149°C); RCRA requires, for hazardous waste, 99% HCl removal, unless less than 4 lb/hr
Sulfur dioxide	Not greater than 30 ppm or not less than 70% reduction, 24-hr daily average
Nitrogen oxides	Best available technology to limit emissions, additional requirements in nonattainment areas
Furnace design—operating temperature and residence time	Residence time for flue gas of at least 1 sec at no less than 1800°F (982°C) in combustion zone or a furnace design to provide a residence time for flue gas and a temperature which, in combination, are shown to be equivalent; auxiliary burner required; combustion index[b] of 99.9% for 8-hr average or 99.5% based on 7-day average; minimum furnace temperature of 1500°F (816°C) after last overfire air injection and 10% plume opacity, 15 min average; auxiliary burners to maintain furnace temperature.
Stack testing (at startup and at 18-month interval)	Within specified periods for carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, oxygen, hydrogen chloride, and trace contaminants including arsenic, beryllium, cadmium, chromium, copper, zinc, lead, mercury[c], nickel; polychlorinated dibenzo-*p*-dioxins, polychlorinated dibenzofurans, benzo-*a*-pyrene, total aromatic hydrocarbons, formaldehyde, and polychlorinated biphenyls; also particulates
Continuous emission monitoring	Instrumentation for continuously monitoring emissions and operation parameters, including oxygen, plume opacity, sulfur dioxide, hydrogen chloride, nitrogen oxides, carbon monoxide, carbon dioxide, temperatures, and combustion index[b]; file is kept of measurements and operation parameters, including steam pressure and flow, auxiliary fuel used, operation controls of electrostatic precipitators, fabric filters, gaseous contaminant emission control devices.

TABLE 5-24 (*Continued*)

Control	Guidelines
Dioxin or furan emissions[d]	Minimize to approach 0.2 ng/dry m^3 corrected to 7% oxygen, but not in excess of 2.0 ng/dry $m^{3\,e}$
Startup shutdown	Plan of practices and procedures to avoid unacceptable or excess emissions
Operator certification	Operator training program; operation directed at all times by certified operator
Noise	Not greater than 60 dBA between 7 a.m. and 10 p.m. in rural area, 65 dBA suburban, and 70 dBA urban; between 10 p.m. and 7 a.m., 50 dBA rural, 55 dBA suburban, and 70 dBA urban
Opacity	No emissions having average opacity of 10% or greater for any consecutive 6-min period, but may exceed 20% in 60-min period
Operating records	As specified, retained at least 3 years; plan prepared for proper operation and maintenance prior to operation

Source: Salvato (1992).

Note: Plants and animals around incinerators can cumulate pollutants (contaminants) and serve as biological monitors for airborne metal and organic pollutants. Additional guidelines (and regulations) are being developed. See the Clean Air Act of 1990 and state regulations.

[a] 1 grain = 0.064 g ≤ 180 mg/dry m^3 (RCRA).

[b] Cl = $CO_2 \times 100/CO_2 + CO$; CO_2 and CO in the exhaust gas, ppm by volume (dry) = combustion Index at 7% oxygen (≤99.80% 8-hr average). Continuous monitoring is required.

[c] Mercury and mercury compounds in flue gas exist as a gas. They are not captured by fabric filters or electrostatic precipitators and hence may escape out of the stack. Mercury release should not exceed 0.002 lb Hg/ton of solid waste. Wet scrubbers remove mercury by condensing, but sludge requires treatment.

[d] RCRA requires 99.9999% destruction and removal efficiency.

[e] Approximately equivalent to 70 nanograms per normal cubic meter (ng/Nm^3) (EPA). One nanogram = one billionth of a gram. A limit of 30 ng/m^3 has been proposed.

Residue Management

Incinerator ash and fly ash leaving the furnace (collected by scrubber, baghouse, electrostatic precipitator) may contain various concentrations of hazardous pollutants. These may require treatment and disposal so as not to endanger the public health or the environment. Concentrations of pollutants in incinerator bottom ash and fly ash will be determined by the characteristics of the waste burned, plant design, operation, efficiency of air cleaning devices, and other factors. It should also be noted that the EPA does not consider ash from an incinerator burning residential solid waste a hazardous waste, even though it may contain some metals.

To minimize the potential for the release of leachate from incinerator ash, there is a trend toward stabilization of the ash by cementing, vitrification, or asphalting. Recycling of ash into a useful material is the preferred solution.

Prevention of hazardous leachate is the goal. Up to 30 percent ash, by weight, can be used as an additive to cement for building materials and solidification in ceramics or glass. Incinerator bottom ash can be mixed with fly ash and lime from a dry scrubber. When properly moistened, the resultant ash–lime mixture will form a pozzolanic-like cement in which the metals are immobilized and cannot leach out under normal conditions. It can be used as a road base or for similar purposes.

It is recommended that bottom and fly ash, if not reused, be disposed of in a properly designed and constructed sanitary landfill with a double liner or a dedicated monofill. Bottom ash alone or bottom ash combined with fly ash may be disposed of in a sanitary landfill with a single liner. Control of dioxin, cadmium, and lead in ash is the major concern. The preferred landfill design would have two liners with groundwater monitoring and leachate collection above and between the liners, or the equivalent, to prevent the migration of hazardous leachate into groundwater.

Site Selection, Plant Layout, and Building Design

It is extremely important that a careful investigation be made of the social, physical, and economic factors involved when incineration is proposed. Some of the major factors are the following:

1. Public acceptance in relation to the surrounding land use and precautions to be taken in location and design to offset public objections should be considerations. A location near the wastewater treatment plant, for example, may meet with less objection. Heat utilization for sludge drying or burning and use of treated wastewater for cooling are possibilities.
2. Site suitability in reference to foundation requirements, prevailing winds, topography, surface water and groundwater, floods, adjacent land uses, and availability of utilities should be considered. A location central to the source of wastes for minimum haul distance and smooth movement of traffic in and out of the site and readily accessible to major highways without interrupting traffic are important considerations.
3. Plant layout should be arranged to facilitate tasks to be performed and provide for adequate space, one-way traffic, parking, paving, drainage, and equipment maintenance and storage.
4. Building design should be attractive and provide adequate toilets, showers, locker room, and lunchroom. A control room, administrative offices, weighmaster office, maintenance and repair shops, and laboratory should be included. Adequate lighting contributes to attractiveness, cleanliness, and operating efficiency. Good landscaping will promote public acceptance.

5. Also to be evaluated are the availability and cost of providing electric power, water supply, sanitary sewers, and pretreatment required before plant wastewater can be discharged to the sewer and availability of storm sewers, telephone, and fuels.
6. The proposed method and cost of handling bulky and nonincinerable wastes should be taken into consideration when incineration is proposed. Also to be determined are the location and size of the sanitary landfill and its ability to receive incinerator residue as well as the bulky and nonincinerable solid wastes that are not recycled.
7. The incinerator design should provide for resource and energy recovery to the extent feasible.

The reader is referred to Chapter 2 for the broad aspects of community and facility planning and environmental impact analysis.

Issues in the Implementation of Incineration Facilities

The principal issues associated with the use of the incineration facilities for the transformation of MSW are related to (1) siting, (2) management of emissions, (3) public health, and (4) economics. Unless the questions related to these issues are resolved, implementation of solid waste incineration facilities will continue to be an uphill battle. These subjects are introduced briefly below.

Siting As with the siting of MRFs, discussed previously, it has been possible to build and operate combustion facilities in close proximity to both residential and industrial developments; however, extreme care must be taken in their operation if they are to be environmentally and aesthetically acceptable. Ideally, to minimize the impact of the operation of combustion facilities, they should be sited in more remote locations where adequate buffer zones surrounding the facility can be maintained. In many communities, combustion facilities are located in remote locations or at the landfill site.

Management of Emissions The operation of incineration facilities, as noted previously, results in the production of a variety of emissions, including (1) gaseous and particulate emissions, many of which are thought to have serious health impacts; (2) solid residuals, including bottom ash, fly ash, and scrubber product; and (3) liquid emissions, which can result from one or more of the following sources: wastewater from the ash removal facilities; effluent from wet scrubbers; wastewater from pump seals, cleaning, flushing, and general housekeeping activities; wastewater from treatment systems used to produce high-quality boiler water; and cooling tower blowdown. The demonstrated ability to control these emissions from an incineration facility effectively is of fundamental importance in the siting of incineration facilities. The proper design of control systems for these emissions is a critical part of the design of incineration facilities. In some cases, the cost and complexity of the environmental control system(s) are equivalent to or even greater than those of the combustion facilities.

Public Health Issues Emissions from a modern, properly designed and operated incineration facility are considered to be of little, if any, health significance but are perceived by some to be a serious hazard. The evidence is not conclusive as emissions are widely dispersed and their effects are difficult to evaluate. Nevertheless, pollution controls to prevent accidental emissions must be ensured. Sensitive individuals who have been exposed to high concentrations of dioxin have developed chloracne, a persistent skin dermatitis, and suffered liver and other disorders. Birth defects and cancer have not been demonstrated. Additional studies are needed to better identify and measure the effects of air pollutants inhaled and the effects of fallout. The significance of the types and amounts of pollutants and their persistence in the environment remain to be clarified.

Economics The economics of incineration must be evaluated carefully to choose between competing systems. The least expensive operation for a particular community would be determined by comparing the total annual cost, including operating costs and fixed charges on the capital outlay, for each method. It will generally be found that, for large cities, three-shift operation will be the least expensive. The two- or one-shift operation will be somewhat cheaper for the smaller community. The relative cost of maintenance, however, will be higher and the efficiency poor because of startup and shutdown of the furnace, with accompanying refractory brick spalling due to differential expansion and air pollution from fly ash. The best way to compare alternatives is by the use of life-cycle costing, which accounts for operating and maintenance costs over the lifetime of the system. The solid waste industry has developed a standardized approach to life-cycle costing through the use of the pro forma income statement.

HAZARDOUS WASTES

The identification and management of hazardous waste have become a major environmental undertaking and are the subject of a number of textbooks and numerous reference books. The purpose here is to introduce the subject of hazardous waste management. Topics to be considered include (1) definition of hazardous waste, (2) a review of pertinent legislation, (3) the generation of hazardous wastes, and (4) an introduction to hazardous waste management. Additional details may be found in LaGrega et al. (2001).

Definition of Hazardous Waste

Under the RCRA of 1976, the term *hazardous waste* means a solid waste, or combination of solid wastes, that, because of its quantity, concentration, or physical, chemical, or infectious characteristics, may

1. cause or significantly contribute to an increase in mortality or an increase in serious irreversible or incapacitating reversible illness or
2. pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of or otherwise managed.

Hazardous wastes include chemical, biological, flammable, explosive, and radioactive substances. They may be in a solid, liquid, sludge, or gaseous (contained) state and are further defined in various federal acts designed to protect the public health and welfare, including land, air, and water resources.

A waste is regarded as hazardous if it is lethal, nondegradable, and persistent in the environment, can be magnified biologically (as in food chains), or otherwise causes or tends to cause detrimental cumulative effects. The EPA lists four characteristics of hazardous wastes:

1. *Ignitability*—wastes that pose a fire hazard during routine management. Fires not only present immediate dangers of heat and smoke but also can spread harmful particles (and gases) over wide areas.
2. *Corrosivity*—wastes requiring special containers because of their ability to corrode standard materials or requiring segregation from other wastes because of their ability to dissolve toxic contaminants.
3. *Reactivity* (or explosiveness)—wastes that, during routine management, tend to react spontaneously, react vigorously with air or water, are unstable to shock or heat, generate toxic gases, or explode.
4. *Toxicity*—wastes that, when improperly managed, may release toxicants in sufficient quantities to pose a substantial hazard to human health or the environment. Toxic wastes are harmful or fatal when ingested or absorbed. When toxic wastes are disposed of on land, contaminated liquid may drain (leach) from the waste and pollute groundwater. Toxicity is identified through a laboratory procedure called the toxicity characteristics leaching procedure, which replaces the extraction procedure leach test. Organic chemicals, metals, and pesticides regulated under the toxicity rule are reported in Table 5-25.

Not included in RCRA hazardous waste regulations are domestic sewage, irrigation waters or industrial discharges permitted under the federal Water Pollution Control Act, certain nuclear materials as defined by the Atomic Energy Act, household wastes (including toxic and hazardous waste), certain

TABLE 5-25 Organic Chemicals, Metals, and Pesticides Regulated Under RCRA Toxicity Characteristic Rule[a]

New Constituents	Regulatory Levels[b] (mg/l)	Old EP Constituents	Regulatory Levels[c] (mg/l)
Benzene	0.50	Arsenic	5.0
Carbon tetrachloride	0.50	Barium	100.0
Chlordane	0.03	Cadmium	1.0
Chlorobenzene	100.0	Chromium	5.0
Chloroform	6.0	Lead	5.0
m-Cresol	200.0[d]	Mercury	0.2
o-Cresol	200.0	Selenium	1.0
p-Cresol	200.0	Silver	5.0
1,4-Dichlorobenzene	7.5	Endrin	0.02
1,2-Dichloroethane	0.50	Lindane	0.4
1,1-Dichloroethylene	0.70	Methoxychlor	10.0
2,4-Dinitrotoluene	0.13[e]	Toxaphene	0.5
Heptachlor (and its hydroxide)	0.008	2,4-Dichlorophenoxycetic acid	10.0
Hexachloro-1,3-butadiene	0.5	2,4,5-Trichlorophenoxy propionic acid	1.0
Hexachlorobenzene	0.13[e]		
Hexachloroethane	3.0		
Methyl ethyl ketone	200.0		
Nitrobenzene	2.0		
Pentachlorophenol	100.0[f]		
Pyridine	5.0[e]		
Tetrachloroethylene	0.7		
Trichloroethylene	0.5		
2,4,5-Trichlorophenol	400.0		
2,4,6-Trichlorophenol	2.0		
Vinyl chloride	0.20		

Source: U.S. EPA (1990).

[a] Based on the Toxicity Characteristics Leaching Procedure (TCLP)

[b] Added in 1990.

[c] Based on old Extraction Procedure (EP) leach test

[d] If o-, m-, and p-Cresol concentrations cannot be differentiated, the total cresol concentration is used. The regulatory level for total cresol is 200.0 mg/L.

[e] Quantification limit is greater than the calculated regulatory level. The quantification limit, therefore, becomes the regulatory level.

[f] The agency will propose a new regulatory level for this constituent, based on the latest toxicity information.

mining wastes, agricultural wastes (excluding some pesticides), and small-quantity wastes from businesses generating fewer than 220 lb of hazardous waste per month.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended in 1986, defines hazardous substances as used in the Clean Air Act and the Clean Water Act (federal Water Pollution Control Act). The Department of Transportation, the Food and Drug Administration, the Occupational Safety and Health Administration, and the Consumer Product Safety Commission also define toxic or hazardous substance exposure.

Legislation

The RCRA of 1976, as amended, expands the purposes of the Solid Waste Disposal Act of 1965. It promotes resource recovery and conservation and mandates government (federal and state) control of hazardous waste from its point of generation to its point of ultimate disposal, including a manifest identification and permitting system. Legislation was prompted by the serious dangers associated with the improper handling and disposal of hazardous waste. The most common problems associated with the disposal of hazardous waste, in addition to public opposition, are groundwater pollution from lagoons, landfills, dumps, sludge disposal, other land disposal systems, spills, and unauthorized dumping.

1984 RCRA Ammendments In 1984, the RCRA was amended to require double liners or the equivalent and leachate collection systems at hazardous waste surface impoundments and landfills. Variances from groundwater monitoring to characterize the water quality before, during, and after operation are not allowed. The Act as amended in 1984 applies to generators producing as little as 220 lb (100 kg) of hazardous waste in a calendar month, which must be sent to a state or federal approved facility.

The RCRA as amended also prohibits land disposal of certain classes of untreated hazardous wastes beyond specified dates unless it can be demonstrated to the EPA that there will be no migration of hazardous constituents from the land disposal unit for as long as the wastes remain hazardous. Land disposal includes landfill, surface impoundment (treatment and surface storage), waste pile, injection well, land treatment facility, salt dome or salt bed formation, and underground mine or cave.

It should be noted that domestic wastewater, any mixture of domestic wastewater and any other waste that passes through a sewer system to a publicly operated treatment works (POTW) for treatment, and industrial wastewater discharges that are point-source discharges subject to NPDES permits are not considered to be solid or hazardous wastes. The POTW is then responsible to ensure that discharges to its sewers or plant do not contravene its NPDES permit or interfere with plant operation or sludge management.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 CERCLA (Superfund) regulates leachate and other releases of hazardous substances from inactive and abandoned hazardous waste sites or from sites operating prior to November 1980. Businesses that produce between 220 and 2000 lb of hazardous wastes in a calendar month are also regulated.

Most of the existing hazardous waste sites were created by the petroleum and chemical industries. Some municipal landfills received mixed solid waste, including toxic and hazardous commercial and industrial waste, in addition to small quantities of household cleaners, solvents, and pesticides. The result was pollution of the soil, groundwater, and surface water due to the infiltration and percolation of rain and snow melt, dissolution, and migration in the waste. In addition, toxic gases could be released from evaporating liquids, sublimating solids, and chemical reactions. CERCLA comes into play when hazardous waste sites are identified and classified.

The federal government can require the "person" who generated or transported the waste or owned or operated the disposal site to clean up the site. If a responsible person cannot be found, the federal government can perform the cleanup using a special fund (Superfund) established mainly by a tax on chemical production. Under such circumstances, states are required to contribute 10 percent of the cost of the cleanup. The federal and state governments may recover the cost, if the responsible person can be found.

Toxic Substances Control Act of 1976 The Toxic Substances Control Act (TSCA) of 1976 regulates the production, use, and disposal of chemical substances that may present an unreasonable risk of injury to health or environment. Manufacturers must give notice of plans to produce a new chemical or market a significant new use for an old chemical; they may be required to provide and keep records and reports.

Other Laws Other laws controlling hazardous substances are:

Clean Air Act (EPA)—regulates the emission of hazardous air pollutants.

Clean Water Act (EPA)—regulates the discharge of hazardous pollutants into the nation's waters.

Marine Protection, Research, and Sanctuaries Act (EPA)—regulates waste disposal at sea.

Occupational Safety and Health Act (OSHA)—regulates hazards in the workplace, including worker exposure to hazardous substances.

Hazardous Materials Transportation Act (Department of Transportation)—regulates the transportation of hazardous materials.

Atomic Energy Act (Nuclear Regulatory Commission)—regulates nuclear energy production and nuclear waste disposal.

Surface Mining Control and Reclamation Act (Department of the Interior)—regulates the environmental aspects of mining (particularly coal) and reclamation.

Priority Toxic Pollutants and Hazardous Wastes

Twenty-four toxic substances have been identified by the EPA, the Consumer Products Safety Commission (CPSC), the Food and Drug Administration (FDA), and the Occupational Safety and Health Administration (OSHA) for *joint* attack. The National Institute for Occupational Safety and Health (NIOSH) is also concerned with the control of toxic substances. The substances include acrylonitrile, arsenic, asbestos, benzene, beryllium, cadmium, chlorinated solvents (trichloroethylene, perchloroethylene, methylchloroform, and chloroform), chlorofluorocarbons, chromates, coke oven emissions, diethylstilbestrol (DES), dibromochloropropane (DBCP), ethylene dibromide, ethylene oxide, lead, mercury and mercury compounds, nitrosamines, ozone, polybrominated biphenyls (PBBs), polychlorinated biphenyls (PCBs), radiation, sulfur dioxide, vinyl chloride and polyvinyl chloride, and toxic waste disposals that may enter the food chain. Initially, the EPA listed 129 specific toxic pollutants, as reported in Table 5-26, for priority action.

Although legislation is very important, control also requires consideration of the social, political, and economic impacts of hazardous materials, in addition to health and environmental factors. Continual surveillance of spills and existing and abandoned waste sites for the present and for as long as the waste remains hazardous will be necessary.

Generation of Hazardous Waste

The major generators of hazardous waste among 15 industries studied by the EPA are as follows, more or less in order of the quantities produced:

- primary metals,
- organic chemicals,
- electroplating,
- inorganic chemicals,
- textiles,
- petroleum refining, and
- rubber and plastics.

Examples of hazardous waste types generated by businesses and industries are given in Table 5-27. Hazardous wastes that are characterized as ignitable,

TABLE 5-26 Original 129 Priority Toxic Pollutants Identified by Council on Environmental Quality

Pollutant	Characteristics	Sources	Remarks
Pesticides: Generally chlorinated hydrocarbons	Readily assimilated by aquatic animals, fat soluble, concentrated through food chain (biomagnified), persistent in soil and sediments	Direct application to farmland and forestland, runoff from lawns and gardens, urban runoff, discharge in industrial wastewater	Several chlorinated hydrocarbon pesticides already restricted by EPA; aldrin, dieldrin, DDT, DDD, endrin, heptachlor, lindane, chlordane
Polychlorinated biphenyls (PCBs): used in electrical capacitors and transformers, paints, plastics, insecticides, other industrial products	Readily assimilated by aquatic animals, fat soluble, subject to biomagnification, persistent, chemically similar to chlorinated hydrocarbons	Municipal and industrial waste discharges disposed of in dumps and landfills	TSCA ban on production after June 1, 1979 but will persist in sediments; restrictions on many freshwater fisheries as result of PCB pollution (e.g., lower Hudson, upper Housatonic, parts of Lake Michigan)
Metals: antimony, arsenic, beryllium, cadmium, copper, lead, mercury, nickel, selenium, silver, thallium, zinc	Nonbiodegradable, persistent in sediments, toxic in solution, subject to biomagnification	Industrial discharges, mining activity, urban runoff, erosion of metal-rich soil, certain agricultural uses (e.g., mercury as fungicide)	
Asbestos	May cause cancer when inhaled, aquatic toxicity not well understood	Manufacture and use as retardant, roofing material, brake lining, etc.; runoff from mining	
Cyanide	Variably persistent, inhibits oxygen metabolism	Wide variety of industrial uses	
Halogenated aliphatics: used in fire extinguishers, refrigerants, propellants, pesticides, solvents for oils and greases and dry cleaning	Largest single class of "priority toxics," can cause damage to central nervous system and liver, not very persistent	Produced by chlorination of water, vaporization during use	Large-volume industrial chemicals, widely dispersed, but less threat to environment than persistent chemicals

Ethers: Used mainly as solvents for polymer plastics	Potent carcinogen, aquatic toxicity and fate not well understood	Escape during production and use	Though some are volatile, ethers have been identified in some natural waters
Phthalate esters: Used chiefly in production of polyvinyl chloride and thermoplastics as plasticizers	Common aquatic pollutant, moderately toxic but teratogenic and mutagenic properties in low concentrations; aquatic invertebrates are particularly sensitive to toxic effects; persistent and can be biomagnified	Waste disposal vaporization during use (in nonplastics)	
Monocyclic aromatics (excluding phenols, cresols, and phthalates): used in manufacture of other chemicals, explosives, dyes, and pigments and in solvents, fungicides, and herbicides	Central nervous system depressant; can damage liver and kidneys	Enters environment during production and byproduct production states by direct volatilization; wastewater	
Phenols: large-volume industrial compounds used chiefly as chemical intermediates in production of synthetic polymers, dyestuffs, pigments, pesticides, and herbicides	Toxicity increases with degree of chlorination of phenolic molecule; very low concentrations can taint fish flesh and impart objectionable odor and taste to drinking water; difficult to remove from water by conventional treatment; carcinogenic in mice	Occur naturally in fossil fuels, wastewater from coking ovens, oil refineries, tar distillation plants, herbicide manufacturing, and plastic manufacturing; can all contain phenolic compounds	

TABLE 5-26 (*Continued*)

Pollutant	Characteristics	Sources	Remarks
Polycyclic aromatic hydrocarbons: used as dyestuffs, chemical intermediates, pesticides, herbicides, motor fuels, and oils	Carcinogenic in animals and indirectly linked to cancer in humans; most work done on air pollution; more is needed on aquatic toxicity of these compounds; not persistent and are biodegradable though bioaccumulation can occur	Fossil fuels (use, spills, and production), incomplete combustion of hydrocarbons	
Nitrosamines: used in production of organic chemicals and rubber; patents exist on processes using these compounds	Tests on laboratory animals have shown nitrosamines to be some of most potent carcinogens	Production and use can occur spontaneously in food cooking operations	

Source: Council on Environmental Quality (1978).

TABLE 5-27 Examples of Hazardous Waste Generated by Business and Industries

Waste Generators	Waste Type
Chemical manufacturers	Strong acids and bases, spent solvents, reactive wastes
Vehicle maintenance shops	Heavy-metal paint wastes, ignitable wastes, used lead acid batteries, spent solvents
Printing industry	Heavy-metal solutions, waste inks, spent solvents, spent electroplating wastes, ink sludges containing heavy metals
Leather products manufacturing	Waste toluene and benzene
Paper industry	Paint wastes containing heavy metals, ignitable solvents, strong acids and bases
Construction industry	Ignitable paint wastes, spent solvents, strong acids and bases
Cleaning agents and cosmetics manufacturing	Heavy-metal dusts, ignitable wastes, flammable solvents, strong acids and bases
Furniture and wood manufacturing and refinishing	Ignitable wastes, spent solvents
Metal manufacturing	Paint wastes containing heavy metals, strong acids and bases, cyanide wastes, sludges containing heavy metals

Source: U.S. EPA (1986).

corrosive, explosive, or toxic should be removed from industrial wastes prior to discharge to a municipal sewer. Many toxic wastes upset biological wastewater treatment processes and are transferred to the effluent and sludge, adding to the disposal problem.

Hazardous Waste Management

Hazardous waste management is a major health and environmental challenge. The ultimate *goal* should be "zero discharge." However, until that goal is approached, the elements of hazardous waste management that must be dealt with include (1) source reduction at the point of generation; (2) recycling both on- and off-site; (3) transportation to processing and/or disposal facilities; (4) treatment and processing to reduce or eliminate toxicity, to reduce the volume, and to immobilize contaminants; and (5) secure long-term storage and disposal. Each of these subjects is considered briefly in the following discussion. Details on hazardous waste management may be found on the EPA website and in LaGrega et al. (2001).

Hazardous Waste Reduction In plant waste, reduction measures can be most effective in reducing the air, liquid, and solid waste contaminants generated, and hence the treatment needed to meet disposal standards, with resultant cost savings. In addition, treatment can result in the recovery of valuable materials that can offset, in whole or in part, the cost of treatment. However, treatment to recover valuable materials may result in the production of other hazardous wastes, which in turn would require treatment and disposal.

Hazardous Waste Recycling Often it may not be possible to reduce the volume or toxicity of some hazardous wastes. However, it may be possible to reuse the waste material in other processes within the same facility or other related facilities. Hazardous wastes that may be recycled either directly or after processing include water, solvents, spent oils, and selected solids. To enhance the recycling of waste materials at other facilities, waste exchange clearinghouses have been developed to facilitate such exchanges. Information that is required for waste exchange programs includes company ID code, category (acid, solvent, cutting fluid, etc.), primary usable constituents, contaminants, physical state, quantity, packaging, and geographic location (LaGrega et al., 2001).

Hazardous Waste Transportation The transportation of hazardous wastes always introduces the possibility of accidental spills. Should this happen, the transporter is required to immediately notify the appropriate authorities (state police, environmental protection agency) and take whatever action is necessary to protect the public health and the environment. Information and advice on what to do and on the characteristics of the chemicals involved (see manifest) in an emergency is available 24 hr a day, 365 days a year, from the Chemical Emergency Center (CHEMTREC) operated by the Chemical Manufacturers Association. Their telephone number is 800-424-9300.

In case of fire or other emergency at a facility having hazardous materials, information concerning the site, materials, and precautions to be taken can be immediately obtained by response personnel from the National Oceanic and Atmospheric Administration (NOAA). A Computer-Aided Management Emergency Operations (CAMEO) system has been developed to facilitate immediate communication. More information is available from NOAA at 206-526-6317. Information availability is required by the Superfund Amendments and Reauthorization Act (SARA).

Hazardous Waste Processing Technologies The principal objectives of hazardous waste treatment are (1) toxicity reduction, (2) conversion to forms that can subsequently be processed by other technologies, (3) total elimination (e.g., complete destruction), (4) volume reduction, and (5) immobilization. Treatment technologies used to process hazardous wastes may be classified as (1) biological methods, (2) physicochemical processes, (3) stabilization and solidification, and (4) thermal destruction. The principal processes comprised by these technologies are reported in Table 5-28. Additional details on treatment methods for hazardous waste may be found in Dawson and Mercer (1986), U.S. EPA (1985, 1986, 1987b), and LaGrega et al. (2001),

Long-Term Storage of Hazardous Wastes So-called secure land burial and deep-well disposal under carefully controlled conditions, *where permitted*, are a last resort. In general, these types of disposal are strongly discouraged as they simply transfer the problem to another environmental media and must be monitored for the life of the hazardous waste. Some hazardous wastes, both solid and liquid, may be temporarily stored in clay, asphalt, concrete, soil cement, or (sodium) bentonite–soil lined basins, or in polymeric membrane lined basins, pending a decision on the best methods for treatment and disposal. Membrane linings are made of special rubber, polyethylene, polyolefin, polychloroprene, and polyvinyl chloride. All are usually suitable for wastewater and biodegradable industrial wastes. However, solvents, strong acids and caustics, and brines could damage clay or soil-based linings. Benzene and toluene, for example, are not contained by a clay liner, but when mixed with a small proportion of water and placed in a landfill, clay remains a good barrier. These chemicals, including pesticides, are best destroyed by controlled incineration. Petroleum-based organic wastes could damage some polymeric membranes and asphaltic materials. Carbon tetrachloride and xylene cause soil dehydration and possible cracking of clay soil. Clay liners must be carefully constructed with concern for lift thickness, soil moisture, type and weight of roller and number of passes, soil texture, and dry density to achieve the required permeability.

In view of the many limitations, *wastes and lining materials should be tested for effectiveness and compatibility before use*. In any case, all liners should be carefully placed on well-compacted subbases and, in addition, all basins storing hazardous wastes should incorporate a groundwater monitoring and surveillance system, including a leachate collection system and peripheral well monitoring. Two layers of linings with intermediate collection systems to collect possible leachate percolation and a groundwater monitoring system are required by the EPA. It can be assumed that all liners, cutoff walls, or other containments will eventually leak to some degree. Storage should be considered a temporary expedient. In all cases, strict compliance with approved design and construction specifications, and continuous professional inspection during construction must be ensured.

Monitoring of the air, surface water, and groundwater for as long as the waste remains a threat to the public health and the environment is an essential component of any site. Surface-water runoff and groundwater would be monitored for organic and inorganic chemicals. The air would be monitored for odors, volatile organics, and indicated toxic chemicals.

TABLE 5-28 Typical Treatment Methods for Hazardous Wastes

Method	Typical Processes	Description
Biological methods	(1) Suspended growth processes (aerobic, anoxic, and anaerobic); (2) attached growth processes (aerobic, anoxic, and anaerobic); (3) combined suspended and attached growth processes (aerobic, anoxic, and anaerobic)	Biological processes are used to treat (1) liquids (contaminated groundwater, industrial process wastewaters, and landfill leachate); (2) slurries (sludges and contaminated soils with clean or contaminated water); (3) solids (contaminated soils); and (4) vapors (from other treatment processes).
Physicochemical processes	(1) Carbon adsorption; (2) chemical oxidation; (3) gas stripping; (4) steam stripping; (5) membrane separation; (6) supercritical fluids extraction and supercritical water oxidation	Granular activated carbon adsorption is used for the sorption of organic compounds from liquids. Powdered activated carbon is typically used in conjunction with the activated sludge treatment process. Chemical oxidation is used to detoxify a wide array of organic compounds. Stripping processes are used to remove volatile and semivolatile organics from industrial process waters. Membrane separation is used to remove contaminants from a variety of process waters and liquids. Supercritical fluids extraction and supercritical water oxidation are used to remove organics from water, sediments, and soil.
Stabilization and solidification	(1) Cement-based solidification; (2) pozzolan-based aggregate; (3) thermoplastic; (4) organic polymers	Stabilization and solidification processes are used for the (1) treatment of industrial wastes; (2) treatment of a variety of wastes, including incinerator bottom and fly ash, before placement in a secure landfill; and (3) treatment of large quantities of contaminated soil. These processes are all used to immobilize hazardous waste contaminants.
Thermal methods	(1) Vapor, liquid, and solid combustion; (2) catalytic volatile organic chemical (VOC) combustion; (3) fluidized-bed incinerators; (4) pyrolysis reactors	Thermal processes are used to destroy organic fraction of hazardous waste contaminants found in all types of waste streams, including gases and vapors, liquids, slurries, and solids.
Land disposal	(1) Municipal landfills; (2) monofill landfills; (3) land farming; (4) impoundment and storage facilities; (5) deep-well injection	The objective of land disposal is to ensure that wastes placed in such facilities do not migrate off-site. In land framing the objective is to bring about natural and biological decay of hazardous waste materials. The problem with deep-well injection is that the final location of the injected wastes is unknown.

Source: Adapted in part from LaGrega et al. (2001).

Basic Control Principles for Hazardous Waste Management As with most air, water, solid waste, and other pollution control activities, certain general and basic control principles can also be applied, as appropriate, to hazardous wastes. These include the following:

1. Elimination and reduction of waste at the source by prevention of leakage, segregation of hazardous waste, product reformulation, process or materials change, good housekeeping practices, and inventory control.
2. Recovery, reuse, and recycling of wastes, including return to the manufacturer, energy recovery, and waste exchange among compatible industries.
3. Concentration of waste by treatment—centrifugation, coagulation, sedimentation, filtration, flotation, surface impoundment, distillation, reverse osmosis, precipitation, solidification, encapsulation, evaporation, electrodialysis, absorption, or blending.
4. Thermal decomposition—controlled high-temperature incineration and proper disposal of residue, also ocean incineration. Incinerators used include refractory lined, fixed hearth (controlled air), rotary kiln, cement kiln furnace, and fluidized bed.
5. Chemical treatment—chemical oxidation, precipitation, reduction, neutralization, chlorination, pyrolysis, detoxification, ion exchange, absorption, or chemical dechlorination processes.
6. Burial in a secure landfill; storage or containment with proper monitoring and surveillance (may be banned by the EPA or state).
7. Biological degradation; activated sludge, lagoon, or other biological treatment.
8. Stabilization, solidification, or encapsulation; also in-place vitrification on-site.
9. Deep-well, mine, and ocean disposal under controlled conditions and if permitted; possibly composting and microwave decomposition. Ocean disposal of sludge has been banned effective December 31, 1991, but this prohibition is being reevaluated.

The methods available are not always completely effective and must be tailored to specific contaminants.

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6 Air Pollution and Noise Control

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AIR POLLUTION AND NOISE CONTROLS

Air pollution is the presence of solids, liquids, or gases in the outdoor air in amounts that are injurious or detrimental to humans, animal, plants, or property or that unreasonably interfere with the comfortable enjoyment of life and property. Air pollution inside dwellings or places of assembly is discussed under Indoor Air Quality in Chapter 11. The composition of clean air is shown in Table 6-1. The effects of air pollution are influenced by the type and quantity of pollutants and their possible interactions* as well as wind speed and direction, typography, sunlight, precipitation, vertical change in air temperature, photochemical reactions, height at which pollutant is released, and susceptibility of the individual and materials to specific contaminants—singularly and in combination. Air pollution is not a new or recent phenomenon. It has been recognized as a source of discomfort for centuries as smoke, dust, and obnoxious odors.

The solution of any air pollution problem must avoid transferring the pollutant removed to another medium, without adequate treatment. See environmental engineering multimedia considerations in Chapter 2 and Figure 2-1.

Health Effects

Humans are dependent on air. We breathe about 35 lb of air per day as compared with the consumption of 3 to 5 lb of water and $1\frac{1}{2}$ lb (dry) of food. Pollution in the air may place an undue burden on the respiratory system and contribute to increased morbidity and mortality, especially among susceptible

*Synergism, antagonism, additive.

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0–471-41813-7

TABLE 6-1 Composition of Clean, Dry Air Near Sea Level

Component	Percent by Volume	Content (ppm)
Nitrogen	78.09	780,900
Oxygen	20.94	209,400
Argon	0.93	9,300
Carbon dioxide	0.0318	318[a]
Neon	0.0018	18
Helium	0.00052	5.2
Krypton	0.0001	1
Xenon	0.000008	0.08
Nitrous oxide	0.000025	0.25[b]
Hydrogen	0.00005	0.5
Methane	0.00015	1.5[c]
Nitrogen dioxide	0.0000001	0.001
Ozone	0.000002	0.02
Sulfur dioxide	0.00000002	0.0002
Carbon monoxide	0.00001	0.1
Ammonia	0.000001	0.01

Sources: Cleaning Our Environment—The Chemical Basis for Action, American Chemical Society, 1969, p. 4 (copyright 1969 by the American Chemical Society; reprinted with permission); with C. E. Junge, *Air Chemistry and Radioactivity,* Academic, New York, 1963, p. 3; A. C. Stern (ed.), *Air Pollution,* Vol. 1, 2nd ed., Academic, New York, 1968, p. 27; E. Robinson and R. C. Robbins, *Sources, Abundance, and Fate of Gaseous Atmospheric Pollutants,* prepared for American Petroleum Institute by Stanford Research Institute, Menlo Park, CA, 1968.

Note: The concentrations of some of these gases may differ with time and place, and the data for some are open to question. Single values for concentrations, instead of ranges of concentrations, are given to indicate order of magnitude, not specific and universally accepted concentrations.

[a] 352 ppm in 1989; 369 ppm in 2000, Mauna Loa, Hawaii.

[b] 0.304 ppm in 1985; 0.314 ppm in 1999 based on Advanced Global Atmospheric Gases Experiment (AGAGE), Cape Grim, Tasmania, Australia monitoring sites.

[c] 1.7 ppm in 1990; 1.73–1.84 ppm in 1999 based on AGAGE values from Cape Grim, Tasmania, Australia and Mace Head, Ireland monitoring sites.

individuals in the general population. Particulates greater than 3 μm in diameter are likely to collect in the lung lobar bronchi; smaller particulates (less than 3 μm) end up in the alveoli, the thoracic or lower regions of the respiratory tract, where more harm can be done. Health effects are discussed under Illnesses Associated with Air Pollution—Lung Diseases in Chapter 1.

Some well-known air pollution episodes are given in Table 6-2. The illnesses were characterized by cough and sore throat; irritation of the eyes, nose, throat, and respiratory tract; and stress on the heart. The weather conditions were typically fog, temperature inversion, and nondispersing wind. The precise levels at which specific pollutants become a health hazard are difficult to establish by existing surveillance systems, but they probably are well in excess of levels currently found in the ambient air. Meteorological

TABLE 6-2 Some Major Air Pollution Episodes

Location	Excess Deaths	Illnesses	Causative Agents
Meuse Valley, Belgium			
December 1930	63	6000	Probably SO_2 and oxidation products with particulates from industry—steel and zinc.
Donora, Pennsylvania			
October 1948	20	7000	Not proven; particulates and oxides of sulfur high; probably from industry—steel and zinc; temperature inversion
Poza Rica, Mexico			
1950	22	320	H_2S escape from a pipeline
London, England			
December 1952	4000	Increased	Not proven; particulates and oxides of sulfur high; probably from household coal-burning; fog
January 1956	1000	—	—
December 1957	750	—	—
January 1959	200–250	—	—
December 1962	700	—	—
December 1967	800–1000	—	—
New York, New York			
November 1953	165	—	Increased pollution
October 1957	130	—	Increased pollution
January–February 1963	200–400	—	SO_2 unusually high (1.5 ppm maximum)
November 1966	152168	—	Increased pollution and inversion
New Orleans, Louisana			
October 1955	2	350	Unknown
1958	—	150	Believed related to smouldering city dump
Seveso and Meda, Italy[a]			
July 1976	Unknown, long-term	200+	Dioxin, an accidental contaminant formed in the manufacture of 2,4,5-T and hexachlorophene—a bactericide

Bhopal, India			
December 1985	2000–5000	8000 disabled, 200,000 injured	Leak of methyl isocyanate from pesticide factory
Chernobyl, Soviet Union[b]			
April 1986	31 on site, more than 300 total	130,000 evacuated; 6000 workers	Nuclear power plant accidental release, explosion and fire

[a] A reactor overheated, the safety valve opened, and $4\frac{1}{2}$ lb of dioxin discharged for 30 min to the atmosphere. About 50 persons were hospitalized, 450 children had a skin disease, 200 families (735 persons) were evacuated, and 40,000 contaminated animals were killed. (*Conserv. News,* December 1, 1976, pp. 8–9; Associated Press, Seveso, Italy, July 10, 1977.) Contaminated soil and vegetation over 272 acres was stripped and incinerated. By July 1977, many homes were cleaned and 500 persons were ready to be admitted. No major illnesses or effects reported other than chloracine (dermatitis) and increased stress-related cardiovascular mortality. [P. Bertazzi et al., *Am. J. Epidemiol.,* **129,** 1187 (1989).]

[b] Excess fallout-related cancer cases over the lifetime of the populations of Europe and the Soviet Union are estimated at 800,000–950,000. (R. H. Nussbaum, Comments on "Health Effects from Radiation," *Environ. Sci. Technol.,* July 1988.) The actual risk is not likely to be known. Excess lifetime cancer deaths are estimated at 17,000. (T. G. Davis, "Chernobyl: The Aftermath," *J. Environ. Health,* March/April 1989, pp. 185–186.) Perhaps 150,000 people suffered some sort of thyroid illness, of which 60,000 were children, 13,000 very seriously. An estimated 6000 workers became ill. (F. X. Clines, "A New Arena for Soviet Nationalism: Chernobyl," *New York Times,* December 30, 1990, p. 1.) The United Nations International Atomic Energy Agency concluded in May 1991 that the major harm was that due to anxiety and stress rather than physical illness. ("Ten Years after Chernobyl," *Ann. Med.,* April 1996.) Thyroid cancers increased dramatically in Belarus, Ukraine, and Bryansk regions of Russia. [Radioactive Contamination of Wood and Its Products," *J. Environ. Radioactivity,* **55**(2), 179–86 (2001).] Contamination of timber and subsequent distribution of irradiated products such as furniture and lumber will likely lead to increase in radiation exposure.

factors, sample site, frequency and measurement methods, including their accuracy and precision, all enter into data interpretation. Nevertheless, standards to protect the public health are necessary and have been established. (See Tables 6-5 through 6-7 later in the chapter.)

It should be noted that whereas smoking is a major contributor to respiratory disease in the smoker, air pollution, climate, age, sex, and socioeconomic conditions affect the incidence of respiratory disease in the general population. Occupational exposure may also be a significant contributor in some instances. However, the effects may be minimized by engineering and individual controls. Where engineering controls are not adequate, respirators can provide good protection if adapted to the type and concentration of airborne contaminants, provided they are properly fitted, maintained, and actually used. However, respirators should never be considered an equivalent alternate to engineering controls. They should only be used after a thorough review of engineering controls has determined that process modifications and engineering controls are absolutely infeasible or where the risk to human health associated with the failure of an engineering control is excessive.

Economic Effects

Pollutants in the air cause damage to property, equipment, and facilities, in addition to increased medical costs, lost wages, and crop damage. Sulfur and formaldehyde pollution attack copper roofs and zinc coatings; steel corrodes two to four times faster in urban and industrial areas due to moisture, chloride, sulfate, and ammonium pollution. The usual electrical equipment contacts become unreliable unless serviced frequently; clothing fabric, rubber, plastics, and leather are weakened; lead-based paints, banned in home construction but still in use in certain industrial applications, are degraded by hydrogen sulfide and oil-based paints by sulfur dioxide; and building surfaces and materials (especially carbonate rock by sulfur dioxide) and works of art are corroded and deteriorate. In addition, particulates (including smoke) in polluted air cause erosion, accelerate corrosion, and soil clothes, buildings, cars, and other property, making more frequent cleaning and use of indoor air-filtering equipment necessary. Ozone reduces the useful life of rubber and other elastomers, attacks some paints, discolors dyes, and damages textiles. See also Measurement of Materials' Degradation, this chapter.

The U.S. Environmental Protection Agency (EPA) is required to periodically assess the cost and benefit of the Clean Air Act (CAA). These reviews have been both retrospective and prospective. In a retrospective review of the cost and benefit of the CAA between 1970 and 1990, a mean monetized benefit of $22.2 trillion (in 1990 dollars) was estimated. The cost of compliance in the same period was estimated at $0.5 Trillion. Specific benefits included in these estimates were Agriculture; net surplus due to ozone reduction, $23 billion; IQ (intelligence quotient, lost IQ points + children with IQ $<$ 70 points), $399 billions; chronic bronchitis, $3.3 trillion; and reduced mortality due to particulate matter reduction, \$16.6 billion. All of these values are mean values and have varying ranges based on the uncertainty associated with estimating each parameter. For example, the 5th percentile ''low'' benefit associated with the period of 1970 to 1990 was \$5.6 trillion while the 95th percentile ''high'' benefit was \$49.4 trillion. The costs associated with complying with the CAA are more easily monetized and have much less variability because they are primarily associated with pollution control equipment design, purchase, and maintenance. Other control costs include policy development, regulatory enforcement, and regulatory pollution monitoring, all of which are eventually borne by shareholders, customers, and taxpayers.[1] The daily personal cost of air pollution can be tallied by over-the-counter medicines to treat the medical symptoms of air pollution as well as lost work days and decreased productivity and quality of life.[2]

Effects on Plants

It has been suggested that plants be used as indicators of harmful contaminants because of their greater sensitivity to certain specific contaminants. Hydrogen fluoride, sulfur dioxide, smog, ozone, and ethylene are among the compounds that can harm plants. Urban smog is likely to contain carbon monoxide, soot, dust, and ozone from the reaction of sunlight on nitrogen oxides, hydrocarbons, and other volatile organic compounds. Assessment of damage shows that the loss can be significant, although other factors such as soil fertility, temperature, light, and humidity also affect production. Ozone has been indicated in forest decline and in damage to a variety of other agriculture products.[3] Among the plants that have been affected are truck garden crops (New Jersey), orange trees (Florida), orchids (California), and various ornamental flowers, shade trees, evergreen forests, alfalfa, grains, tobacco, citrus, lettuce (Los Angeles), and many others. In Czechoslovakia more than 300 mi^2 of evergreen forests was reported severely damaged by sulfur dioxide fumes.[4] Smog such as the type found in Los Angeles is the product of a photochemical reaction involving nitrogen oxides, hydrocarbons and oxygen. Where local topography and meteorology inhibit dispersion, smog can accumulate to unhealthy concentrations. Photochemical smog has also been reported in New York, Japan, Mexico City, Madrid, the United Kingdom, and other congested areas with high motor vehicle traffic. The brown clouds associated with smog are due to excess NO_x, which preferentially absorbs light from the blue-green spectrum. The remaining colors result in the brownish color associated with smog that can reduce visibility and is aesthetically displeasing.[5]

Injury to plants due to ozone shows up as flecks, stipple and bleaching, tip burns on conifers, and growth suppression. Peroxyacyl nitrate* (PAN)

* Also cause of eye irritation.

injury is apparent by glazing, silvering, or bronzing on the underside of the leaf. Sulfur dioxide injury shows up as bleached and necrotic areas between the veins, growth suppression, and reduction in yield. Hydrogen fluoride injury is evidenced by plant leaf tip and margin burn, chlorosis, dwarfing, abrupt growth cessation, and lowered yield.[6] See also Acid Rain (Acidic Precipitation), this chapter.

Effects on Animals

Fluorides have caused crippling skeletal damage to cattle in areas where fluorides absorbed by the vegetation are ingested. Animal laboratory studies show deleterious effects from exposure to low levels of ozone, photochemical oxidants, and PAN. Lead and arsenic have also been implicated in the poisoning of sheep, horses, and cattle. All of the canaries and about 50 percent of the animals exposed to hydrogen sulfide in the Poza Rica, Mexico, incident (see Table 6-2) were reported to have died. Morbidity and mortality studies are ongoing to determine actual impacts of air pollutants on animals.

Aesthetic, Climatic, and Related Effects

Insofar as the general public is concerned, smoke, dust, and haze, which are easily seen, cause the greatest concern. Reduced visibility not only obscures the view but is also an accident hazard to air, land, and water transportation. Soiling of statuary, clothing, buildings, and other property increases municipal and individual costs and aggravates the public to the point of demanding action on the part of public officials and industry. Correction of the air pollution usually results in increased product cost to the consumer, but failure to correct pollution is usually more costly.

Air pollution, both natural and man made, affects the climate. Dust and other particulate matter in the air provide nuclei around which condensation takes place, forming droplets and thereby playing a role in snowfall and rainfall patterns. Haze, dust, smoke, and soot reduce the amount of solar radiation reaching the surface of the earth. Aerosol emissions from jet planes also intercept some of the sun's rays.

Certain malodorous gases interfere with the enjoyment of life and property. In some instances, individuals are seriously affected. The gases involved include hydrogen sulfide, sulfur dioxide, aldehydes, phenols, polysulfides, and some olefins. Air pollution control equipment such as thermal oxidizers and carbon absorbers are available to eliminate or control these objectionable compounds.

Effect of Carbon Dioxide and Other Gases on Global Warming Solar energy, as light in the form of short-wavelength radiation, that reaches the earth is absorbed and reradiated back to the atmosphere as long-wavelength infrared radiation or heat energy. (Ultraviolet radiation has little effect on earth warming.) However, carbon dioxide, methane, chlorofluorocarbons (CFCs), clouds and atmospheric water vapor, and nitrous oxides tend to trap the reradiated heat, causing a reflection of that heat back to the earth and a warming of the lower atmosphere, oceans, and the earth's surface—known as the greenhouse effect. According to the EPA, carbon dioxide constitutes 49 percent of the greenhouse effect, as compared to methane 18 percent, CFCs 14 percent, nitrous oxides 6 percent, and other gases 13 percent.[7] Still other estimates place the relative contributions as carbon dioxide 57 percent, CFCs 25 percent, methane 12 percent, and nitrous oxide 6 percent.[8] The relative contributions will always be flux depending on the concentration in the atmosphere and because all greenhouse gases are not equal in their warming potential. Certain man-made compounds are far more effective greenhouse gases than other naturally occurring compounds. Nitrous oxide, both man made and naturally occurring, is 310 times more effective than carbon dioxide. Hydrofluorocarbon (HFC) 23, a man-made refrigerant, is 11,700 times more effective than carbon dioxide.[9]

Industrial, power plant, and automobile emissions and the burning of fossil fuels and forests contribute carbon dioxide and other gases to the atmosphere. This is in addition to the carbon dioxide naturally released during respiration and decomposition. Methane is produced by the decay of organic matter in wetlands, rice paddies, ruminant animals and termites, forest fires and wood burning, landfills, and gas drilling and releases. Chlorofluorocarbon sources include refrigerants, solvents, and plastic foam manufacture. Sources of nitrogen oxides include burning coal and other fossil fuel, fertilizer breakdown, and soil bacteria reactions. Other gases involved to a lesser extent are carbon monoxide and sulfur dioxide.

The warming effect of the gases in the lower atmosphere is offset to some extent by the cooling effect of the haze, dust, smoke, soot, and dust from volcanic eruptions that intercept and reduce the solar radiation reaching the earth. However, evaporation from the warmed oceans and other bodies of water and land surfaces due to greenhouse warming would be increased, as would vegetation transpiration, causing further cooling. The increased evaporation would also cause an increase in precipitation in some areas. In addition, the oceans, rain, and growing forests and other vegetation during photosynthesis altogether remove or absorb significant quantities of carbon dioxide. These processes that remove carbon dioxide from the environment are often referred to as carbon dioxide "sinks." Tropical rain forests are a major carbon dioxide sink, and their destruction both adds carbon dioxde to the atmosphere and removes a carbon repository.

There seems to be agreement that the destruction of tropical rain forests should be brought under control and that a massive global reforestation program is desirable. However, the planting of even a billion trees a year for 10 years is estimated to absorb only about 1 to 3 percent of the carbon dioxide produced by human activity in the United States. Federal analysts have reached similar conclusions. They estimated that planting 20 billion trees per year could capture up to 67 percent of the nation's annual emissions of carbon dioxide under the best of conditions. Although trees take in carbon dioxide and return oxygen to the air, storing the carbon in the wood, fully mature trees neither store nor emit carbon. Eventually, annual tree growth roughly equals the loss and decay of branches and leaves.[10] But there are many other ecological and aesthetic reasons to save the tropical forests.

Ultimately, large reductions in oil and coal burning are needed to substantially reduce carbon dioxide emissions. Energy conservation and greater use of renewable resources such as hydroelectric power, solar energy, wind power, geothermal energy, wave energy, and biomass energy, where possible, can all reduce the net increase of global warming gases; however, they are not without their own technical and feasibility issues. Nuclear power generation is essentially carbon dioxide emission free, but political as well as safety concerns have prevented wider adoption of the technology in the United States. The result has been the expansion of fossil-fueled power plants. The release of carbon dioxide will expand for many years to come if alternate sources of energy are not developed.

New-generation nuclear reactors such as pebble bed systems offer the possibility of intrinsic safety and even decentralized power systems. Recent research has shown that if the full production process is considered when comparing nuclear to coal-fueled power systems, the actual damage to human health has been far greater historically with coal power production than with nuclear production. These analyses consider the total product cycle from raw-material extraction to power delivery. When the dangers of fuel extraction and processing are factored into the risk associated with coal power production, the nuclear options appear safer.[11]

In addition to temperature rise, the probable net projected effects of increased greenhouse gases include changes in rain, snow, and wind patterns that affect agriculture, overall precipitation, humidity, soil moisture, and storm frequency. The growing season would be lengthened. Melting polar ice would raise ocean levels.

In spite of many uncertainties, according to *Climate Change 2001: The Science Basis,*[12] it appears that the carbon dioxide level and global warming are increasing. However, many scientists believe that the facts (and assumptions) do not adequately support the predictions.[13,14] An astrophysicist with the Harvard Smithsonian Centre for Astrophysics commented that the "best current science offers little justification for rapid cuts in carbon dioxide." She believes "human-made global warming is relatively minor and will be slow to develop."[15] In any case, there is agreement on the need to maintain and improve environmental quality and conserve natural resources.

Effect of Ozone and Chlorofluorocarbons Another global factor is the ozone layer in the upper atmosphere (stratosphere), about 8 to 30 miles above the earth's surface. It helps shield the earth by filtering out or absorbing harmful UV solar radiation. Ozone is formed naturally by the action of sunlight on the oxygen molecule. When released in the lower atmosphere (troposphere), CFCs and halons (a compound consisting of bromine, chlorine, and carbon) migrate upward to the stratosphere through the mixing force of wind, where they remain chemically stable as long as 400 years. When exposed to UV solar radiation, CFCs release chlorine atoms and certain other gases that react with ozone in the stratosphere, reducing the total amount of ozone available to intercept destructive UV radiation. The chlorine in one CFC molecule is believed to destroy tens of thousands of ozone molecules. Bromine is more than 40 times as destructive as chlorine. Nitrous oxide also contributes to ozone depletion.[16] Chemical fertilizers, soil bacteria, burning forests, and fossil fuels are sources of nitrous oxide.

The destruction of ozone by CFCs, halons, and other compounds permits more of the solar radiation to reach the earth, which could cause an increase in skin cancer, eye cataracts, and changes in climate and animal and plant life. This additional solar radiation could also overexpose and kill phytoplankton, a major source of food for fish, seals, penguins, and whales. Subsequent phytoplankton reduction, including algae, would result in less uptake of carbon dioxide. This would cause an increase in the atmospheric carbon dioxide level and contribute to the earth's warming and a reduction in aquatic life and our food supply, as previously noted.

Chlorofluorocarbons remain in the stratosphere for 75 to 110 years.[17] Because of the potential health and environmental effects, steps have been taken to phase out products containing CFCs and halons throughout the world. The product sources include refrigerants (dichlorodifluoromethane, or freon), industrial solvents, volatile paints, plants manufacturing plastic foams, and aerosol spray cans containing CFC propellant. The CFCs are no longer used as blowing agents in the manufacture of food service disposables.[18] Bromine[19] from halons used primarily in fire extinguishers and from chemicals used to make fire retardants, soil fumigants, and agricultural products also destroy ozone by reacting with chlorine synergistically in the absence of oxygen and sunlight. Methyl chloroform and carbon tetrachloride contribute to the problem. Existing refrigerating systems using CFCs that are scrapped remain future sources of CFC release if not contained, recycled, or otherwise controlled. Suggested alternatives to CFCs include hydrochlorofluorocarbons (HCFCs),[20] which although not as harmful as CFCs, should nevertheless be recycled. A global attack was started in 1987—the Montreal Protocol on Substances That Deplete the Ozone Layer was signed by 32 countries, with a goal to reduce the 1986 level of use of CFCs and halons by 50 percent.[21] In May 1989, representatives of the European Economic Community (EEC) and 81 other countries, including the United States and Canada, agreed to phase out all CFC use by the year 2000, if possible, as well as the use of halons, carbon tetrachloride, and methyl chloroform.[22] In June 1990, environment ministers from 93 nations met in London and agreed to phase out the production and use of CFCs and related chemicals, including halons and carbon tetrachloride, by the end of the century and methyl chloroform by 2005. The HCFCs are to be phased out between 2000 and 2040.

Ozone is also formed in the lower atmosphere (troposphere), which extends upward for about 8 miles. There, nitrogen oxides, gasoline vapors, and other hydrocarbon emissions from refineries, motor vehicles, solvents, and the like react with sunlight and heat. However, the EPA believes that ozone in the lower atmosphere near the ground level does not replace ozone lost from the upper levels.[23] Ozone at ground level causes lung dysfunction and irritation of the mucous membranes of the eyes, nose, and throat as well as tree and crop damage. Under stable conditions, ozone interactions cause smog and deterioration of exterior paints, rubber, synthetic fibers, and plastics.

***Acid Rain* (*Acidic Precipitation*)** Releases of nitrogen and sulfur oxides and carbon dioxide, as well as other pollutants, are carried into the atmosphere, where they interact with sunlight and vapor and may be deposited as "acid rain" many miles from the source. The term includes rain, snow, sleet, fog, mist, and clouds containing sulfuric acid, nitric acid, and carbonic acid as well as direct dry deposition. Large regional emissions and then deposition over a limited area exacerbate the acid rain problem, such as in the northeast United States and eastern Canada. The Southeast, Midwest, West, Rocky Mountain states, western Europe, Scandinavia, and eastern Europe are also affected. In New York and the Northeast, 60 to 70 percent of the reported acidity is due to sulfuric acid, 30 to 40 percent to nitric acid. The relative proportion of each is indicative of the probable preponderant pollutant sources.[24] Major sources of sulfur dioxide, nitrogen oxides, and carbon dioxide are coal- and oil-burning power plants, refineries, and copper and other metal smelters. Principal sources of nitrogen oxide emissions[25] are electric utility and industrial boilers and motor vehicles. Nitrogen oxides from motor vehicle and high-temperature combustion not only contribute to photochemical smog but to changes in the atmosphere, and they return to earth in acid form mixed with precipitation.

High stacks permit the discharge of pollutants into the upper air stream that are then carried great distances by prevailing winds, usually from west to east in the United States. Natural sources of sulfur dioxide, such as active volcanoes, the oceans, and anaerobic emissions from decaying plants, fertilizers, and domestic animals, contribute to the problem. However, the risk to the public health and welfare is complex and very difficult to quantify.[26] There does not appear to be any significant threat to the public health,[27] although this is debatable. About half of all atmospheric sulfur worldwide is reported to come from natural sources.[28] The main contributor to *natural* acidity is carbon dioxide. The natural acidity of precipitation may vary from pH 5.4 to 5.7* (with the lower pH in the northeast United States according to the National Acid Deposition Program of 1978 to 1984) and may be as low as 4.0 to 4.6 or lower. While a forest canopy may reduce acidity and ammonia, particulates in the air may, in part, neutralize the acid.

*Lemon juice has a pH of 2, vinegar 3, pure rain 5.6, distilled water 7, and baking soda 8.2.

As previously noted, acidic precipitation contributes to deterioration of buildings, monuments and statues, roofing materials, and automobiles. It is also believed to adversely affect trees (mainly conifers at high altitudes), possibly crops and other vegetation. Ozone at ground level is also reported to be a major cause of forest decline.[29] Acidic precipitation may be temporarily beneficial to some vegetation.[30] However, a second stage of acid rain can kill nitrogen-fixing microorganisms and cause decreased production, and then death, as acidity penetrates the soil profile and root system. Calcium and magnesium, necessary for tree growth, are leached from the soil. Aluminum in the soil also becomes available for vegetative uptake. The calcium and magnesium/aluminum ratio is decreased, impairing tree and root growth as the toxic aluminum accumulates in the roots. Susceptibility to insects and stresses due to cold, drought, and heat increase.[31] Forest management, climate, soil nutrients, and geology may also play a role.

Acid rain also adversely affects lakes and streams, where the pH may be reduced to less than 5.0, with resultant reduced fish production. The decomposition of organic deposits contributes to lake acidity. Acidification and demineralization of soils cause higher input of toxic aluminum and other metals to lakes and streams. The condition is more apparent in a lake or groundwater when its buffering capacity and that of the surrounding soil (alkalinity and calcium) are reduced or exhausted. This leads to the release of toxic metals to water supply sources, particularly to shallow well-water supplies. There could also be accumulation in fish, as for example increased levels of mercury, aluminum, cadmium, and zinc of 10 to 100 times the normal range.

Control measures should start with coal desulfurization at mining sites and source reduction, such as at high-sulfur oil- and coal-burning plants, and with nitrogen oxides from motor vehicles. Further reduction can be achieved by flue gas desulfurization and the use of scrubbers and other emission control devices. The use of alternative, low-sulfur fuels, as well as hydroelectric, nuclear, and solar power, should also be considered. The application of lime or limestone to lakes and their watersheds is only a temporary measure, a long-term solution must be found.

Acid rain is only one aspect of air pollution. Other toxic stack emissions requiring control include hazardous air pollutants (HAPs) such as lead, mercury, cadmium, zinc, vanadium, arsenic, copper, selenium, and organic pollutants. These must be eliminated or reduced to innocuous levels.

SOURCES AND TYPES OF AIR POLLUTION

The sources of air pollution may be man made, such as the internal combustion engine, or natural, such as plants (pollens). The pollutants may be in the form of particulates, aerosols, and gases or microorganisms. Included are pesticides, odors, and radioactive particles carried in the air.

Particulates range from less than 0.01 to 1000 μm* in size; generally they are smaller than 50 μm. Smoke is generally less than 0.1 μm size soot or carbon particles. Those below 10 μm can penetrate the lower respiratory tract; particles less than 3 μm reach the tissues in the deep parts of the lung. Particles over 10 μm are removed by the hairs at front of nose. Included are dust and inorganic, organic, fibrous, and nonfibrous particles. Aerosols are usually particles 50 μm to less than 0.01 μm in size; although generally they are less than 1 μm in diameter. Gases include organic gases such as hydrocarbons, aldehydes, and ketones and inorganic gases (oxides of nitrogen and sulfur, carbon monoxide, hydrogen sulfide, ammonia, and chlorine).

Man-made Sources

Air pollution in the United States is the result of industrialization and mechanization. The major sources and pollutants are shown in Table 6-3. It can be seen that carbon monoxide is the principal pollutant by weight and that the motor vehicle is the major contributor, followed by industrial processes and stationary fuel combustion. However, in terms of hazard, it is not the tons of pollutant that is important but the toxicity or harm that can be done by the particular pollutant released. Lead has shown the most dramatic reduction, due to the use of nonleaded gasoline.

Agricultural spraying of pesticides, orchard-heating devices, exhaust from various commercial processes, rubber from tires, mists from spray-type cooling towers, and the use of cleaning solvents and household chemicals add to the pollution load. Toxic pollutant emissions and their fate in the environment need further study.

Particulates, gases, and vapors that find their way into the air without being vented through a stack are referred to as fugitive emissions. They include uncontrolled releases from industrial processes, street dust, and dust from construction and farm cultivation. These need to be controlled at the source on an individual basis.

Wood stoves contribute significantly to air pollution. This type of pollution is a potential health threat to children with asthma and elderly people with chronic lung problems. Wood stove use may have to be limited. Stoves are being redesigned to keep the air pollution at acceptable levels.

Natural Sources

Discussions of air pollution frequently overlook the natural sources. These include dust, plant and tree pollens, arboreal emissions, bacteria and spores,

*A micron (μm) is 1/1000 of a millimeter, or 1/25,000 of an inch. Particles of 10 μm and larger in size can be seen with the naked eye.

TABLE 6-3 Air Pollution According to Source and Type of Pollutant: United States, Selected Years 1970–1998

Year	All Sources	On-Road Transportation	Nonroad Engines and Vehicles	Stationary Fuel Combustion	Industrial Processes	Waste Disposal and Recycling	Other
Carbon Monoxide (Millions of Short Tons)							
1970	129.4	88.0	12.0	4.6	9.8	7.1	7.9
1975	116.8	83.1	13.1	4.5	7.5	3.2	5.3
1980	117.4	78.0	14.5	7.3	7.0	2.3	8.3
1985	117.0	77.4	16.0	8.5	5.2	1.9	8.0
1987	108.4	71.2	14.5	7.0	4.9	1.9	8.9
1988	118.7	71.1	17.3	7.4	5.2	1.8	16.0
1989	106.4	66.1	17.8	7.4	5.2	1.7	8.2
1990	98.5	57.8	18.2	5.5	4.7	1.1	11.2
1991	100.9	62.1	18.6	5.9	4.6	1.1	8.7
1992	97.6	59.9	19.0	6.2	4.5	1.1	7.0
1993	98.2	60.2	19.4	5.6	4.6	1.2	7.1
1994	102.6	61.8	19.8	5.5	4.6	1.2	9.7
1995	93.4	54.1	20.2	5.9	4.6	1.2	7.3
1996	95.5	53.3	20.2	6.1	3.5	1.1	11.2
1997	94.4	51.7	20.3	5.4	3.6	1.1	12.2
1998	89.5	50.4	19.9	5.4	3.6	1.2	9.0
Nitrogen Oxides (Millions of Short Tons)							
1970	20.9	7.4	1.9	10.1	0.8	0.4	0.3
1975	22.6	8.6	2.6	10.5	0.5	0.2	0.2
1980	24.4	8.6	3.5	11.3	0.6	0.1	0.2
1985	23.2	8.1	3.9	10.0	0.8	0.1	0.3

1988	24.1	7.7	4.4	10.5	0.8	0.1	0.7
1989	23.9	7.7	4.5	10.5	0.8	0.1	0.3
1990	24.0	7.1	4.8	10.9	0.8	0.1	0.4
1991	24.2	7.5	4.9	10.8	0.7	0.1	0.3
1992	24.6	7.6	4.9	10.9	0.8	0.1	0.3
1993	25.0	7.8	4.9	11.1	0.7	0.1	0.2
1994	25.4	8.1	5.0	11.0	0.8	0.1	0.4
1995	24.9	7.8	5.1	10.8	0.8	0.1	0.3
1996	24.7	7.8	5.2	10.4	0.7	0.1	0.5
1997	24.8	7.9	5.3	10.4	0.8	0.1	0.4
1998	24.5	7.8	5.3	10.2	0.8	0.1	0.3
Volatile Organic Compounds (VOCs) (Millions of Short Tons)							
1970	31.0	13.0	1.9	0.7	3.2	2.0	10.2
1975	26.1	10.5	2.1	0.7	3.3	1.0	8.5
1980	26.3	9.0	2.3	1.0	3.5	0.8	9.7
1985	24.4	9.4	2.4	1.6	2.0	1.0	8.0
1988	24.3	8.3	2.6	1.4	2.1	1.0	9.0
1989	22.5	7.2	2.6	1.4	2.1	0.9	8.4
1990	20.9	6.3	2.5	1.0	1.8	1.0	8.3
1991	21.1	6.5	2.6	1.1	1.9	1.0	8.1
1992	20.7	6.1	2.6	1.1	1.9	1.0	8.0
1993	20.9	6.1	2.6	1.0	1.9	1.0	8.2
1994	21.5	6.4	2.7	1.0	1.9	1.0	8.5
1995	20.8	5.7	2.7	1.1	1.9	1.1	8.4
1996	18.7	5.5	2.7	1.0	1.4	0.4	7.7
1997	18.9	5.3	2.6	0.9	1.4	0.4	8.2
1998	17.9	5.3	2.5	0.9	1.4	0.4	7.4

TABLE 6-3 **(*Continued*)**

Year	All Sources	On-Road Transportation	Nonroad Engines and Vehicles	Stationary Fuel Combustion	Industrial Processes	Waste Disposal and Recycling	Other
			Sulfur Dioxide (Millions of Short Tons)				
1970	31.2	0.4	0.1	23.5	7.1	[a]	0.1
1975	28.0	0.5	0.1	22.7	4.7	[a]	[a]
1980	25.9	0.5	0.2	21.4	3.8	[a]	[a]
1985	23.7	0.5	0.6	20.0	2.4	[a]	[a]
1988	23.1	0.6	0.7	19.8	2.0	[a]	[a]
1989	23.3	0.6	0.8	19.9	2.0	[a]	[a]
1990	23.7	0.5	0.9	20.3	1.9	[a]	[a]
1991	23.0	0.6	0.9	19.8	1.7	[a]	[a]
1992	22.8	0.6	1.0	19.5	1.7	[a]	[a]
1993	22.5	0.5	1.0	19.2	1.6	0.1	[a]
1994	21.9	0.3	1.0	18.9	1.6	0.1	[a]
1995	19.2	0.3	1.0	16.2	1.6	[a]	[a]
1996	19.1	0.3	1.0	16.3	1.4	[a]	[a]
1997	19.6	0.3	1.0	16.7	1.5	[a]	[a]
1998	19.6	0.3	1.1	16.7	1.5	[a]	[a]
			PM_{10} (Millions of Short Tons)				
1988	61.1	0.4	0.5	1.4	0.9	0.3	57.7
1989	53.1	0.4	0.5	1.4	0.9	0.3	49.7
1990	30.0	0.3	0.5	1.2	0.9	0.3	26.7
1991	29.6	0.3	0.5	1.1	0.9	0.3	26.4
1992	29.5	0.3	0.5	1.2	0.9	0.3	26.3
1993	28.0	0.3	0.5	1.1	0.8	0.3	25.0
1994	30.9	0.3	0.5	1.1	0.8	0.3	27.9
1995	27.1	0.3	0.5	1.2	0.8	0.3	24.0

1990	30.0	0.3	0.5	1.2	0.9	0.3	26.7
1991	29.6	0.3	0.5	1.1	0.9	0.3	26.4
1992	29.5	0.3	0.5	1.2	0.9	0.3	26.3
1993	28.0	0.3	0.5	1.1	0.8	0.3	25.0
1994	30.9	0.3	0.5	1.1	0.8	0.3	27.9
1995	27.1	0.3	0.5	1.2	0.8	0.3	24.0
1996	33.0	0.3	0.5	1.2	0.6	0.3	30.2
1997	34.2	0.3	0.5	1.1	0.6	0.3	31.5
1998	34.7	0.3	0.5	1.1	0.6	0.3	32.0
			$PM_{2.5}$ (Millions of Short Tons)				
1990	8.0	0.3	0.4	0.9	0.5	0.2	5.6
1991	7.7	0.3	0.4	0.9	0.5	0.2	5.4
1992	7.6	0.3	0.4	0.9	0.5	0.2	5.2
1993	7.3	0.3	0.4	0.9	0.4	0.3	5.1
1994	8.0	0.3	0.4	0.8	0.5	0.3	5.7
1995	7.2	0.2	0.4	0.9	0.5	0.2	4.9
1996	8.2	0.2	0.4	0.9	0.3	0.2	6.1
1997	8.5	0.2	0.4	0.8	0.4	0.2	6.5
1998	8.4	0.2	0.4	0.8	0.4	0.2	6.4
			Lead (Thusands of Short Tons)				
1970	220.9	172.0	9.7	10.6	26.4	2.2	[b]
1975	159.7	130.2	6.1	10.3	11.4	1.6	[b]
1980	74.2	60.5	4.2	4.3	3.9	1.2	[b]
1985	22.9	18.1	0.9	0.5	2.5	0.9	[b]
1988	7.1	2.6	0.9	0.5	2.3	0.8	[b]
1989	5.5	1.0	0.8	0.5	2.4	0.8	[b]

TABLE 6-3 (*Continued*)

Year	All Sources	On-Road Transportation	Nonroad Engines and Vehicles	Stationary Fuel Combustion	Industrial Processes	Waste Disposal and Recycling	Other
1990	5.0	0.4	0.8	0.5	2.5	0.8	[b]
1991	4.2	[a]	0.6	0.5	2.3	0.8	[b]
1992	3.8	[a]	0.6	0.5	1.9	0.8	[b]
1993	3.9	[a]	0.5	0.5	2.0	0.8	[b]
1994	4.0	[a]	0.5	0.5	2.2	0.8	[b]
1995	3.9	[a]	0.5	0.5	2.3	0.6	[b]
1996	3.9	[a]	0.5	0.5	2.3	0.6	[b]
1997	4.0	[a]	0.5	0.5	2.3	0.6	[b]
1998	4.0	[a]	0.5	0.5	2.3	0.6	[b]

Sources: Office of Air Quality Planning and Standards, *National Air Pollutant Emission Estimates, 1900–1998,* EPA 454/R-00-002, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 2000.

Note: Data are calculated emissions estimates, PM_{10}, $PM_{2.5}$ = particulate matter, particles less than 10 and 2.5 μm in diameter.

[a]Emissions less than 0.05 million short tons per year (less than 0.05 thousand short tons per year in the case of lead emissions).

[b]No emissions calculated.

gases and dusts from forest and grass fires, ocean sprays and fog, esters and terpenes from vegetation, ozone and nitrogen dioxide from lightning, ash and gases (SO_2, HCl, HF, H_2S) from volcanoes, natural radioactivity, and microorganisms such as bacteria, spores, molds, or fungi from plant decay. Most of these are beyond control or of limited significance.

Ozone is found in the stratosphere at an altitude beginning at 7 to 10 miles. The principal natural sources of ozone in the lower atmosphere are lightning discharges and, in small amount, reactions involving volatile organic compounds released by forests and other vegetation. Ozone is also formed naturally in the upper atmosphere by a photochemical reaction with UV solar radiation.

Types of Air Pollutants

The types of air pollutants are related to the original material used for combustion or processing, the impurities it contains, the actual emissions, and reactions in the atmosphere. See Table 6-3. A *primary pollutant* is one that is found in the atmosphere in the same form as it exists when emitted from the stack; sulfur dioxide, nitrogen dioxide, and hydrocarbons are examples. A *secondary pollutant* is one that is formed in the atmosphere as a result of reactions such as hydrolysis, oxidation, and photochemistry; photochemical smog is an example.

Most combustible materials are composed of hydrocarbons. If the combustion of gasoline, oil, or coal, for example, is inefficient, unburned hydrocarbons, smoke, carbon monoxide, and, to a lesser degree, aldehydes and organic acids are released.

The use of automobile catalytic converters to control carbon monoxide and hydrocarbon emissions causes some increase in sulfates and sulfuric acid emissions, but this is considered to be of minor significance. The elimination of lead from gasoline has, in some cases, led to the substitution of manganese for antiknock purposes with the consequent release of manganese compounds, which are also potentially toxic.

Impurities in combustible hydrocarbons (coal and oil), such as sulfur, combine with oxygen to produce SO_2 when burned. The SO_2 subsequently may form sulfuric acid and other sulfates in the atmosphere. Oxides of nitrogen, from high-temperature combustion in electric utility and industrial boilers and motor vehicles [above 1200°F (649°C)], are released mostly as NO_2 and NO. The source of nitrogen is principally the air used in combustion. Some fuels contain substantial amounts of nitrogen, and these also react to form NO_2 and NO. Fluorides and other fuel impurities may be carried out with the hot stack gases. (The role of sulfur and nitrogen oxides in acid rain is discussed earlier in this chapter.)

Photochemical oxidants* are produced in the lower atmosphere (troposphere) as a result of the reaction of oxides of nitrogen and volatile organics

*Including ozone, PANs, formaldehydes, and peroxides. Nitrogen dioxide colors air reddish-brown.

in the presence of solar radiation, as previously noted. Ozone may contribute to smog, respiratory problems, and damage to crops and forests (as previously stated).

Of the sources noted above, industrial processes are the principal source of volatile organics (hydrocarbons), with transportation the next largest contributor. Stationary fuel combustion plants and motor vehicles are the major sources of nitrogen oxides. Ozone, the principal component of modern smog, is the photochemical oxidant actually measured, which is about 90 percent of the total (ref. 24, p. 9). Ozone and other photochemical products formed are usually found at some distance from the source of the precursor compounds.

SAMPLING AND MEASUREMENT

State and local government agencies participate in the EPA national air quality monitoring system. The EPA focuses on the National Ambient Air Quality Standards—airborne particulate matter, sulfur dioxide, ozone, and lead—in over 4000 locations across the United States.[32]

Air-sampling devices are used to detect and measure smoke, particulates, acid deposition, and gaseous contaminants. The equipment selected and used and its siting are determined by the problem being studied and the purpose to be served. Representative samples free from external contamination must be collected and readings or analyses standardized to obtain valid data. Supporting meteorological and other environmental information is needed to properly interpret the data collected. Continuous sampling equipment should be selected with great care. The accuracy and precision of equipment needs to be demonstrated to ensure that it will perform the assigned task with a minimum of calibration and maintenance. Reliable instruments are available for the monitoring of ambient air parameters, such as those listed in Table 6-4. Other instruments such as for *opacity,* hydrocarbons, and sulfur are also available.

A continuous air quality monitoring system for the measurement of selected gaseous air pollutants, particulates, and meteorological conditions over a large geographical area can make possible immediate intelligence and reaction when ambient air quality levels or emissions increase beyond established standards. In the system, each monitoring station sends data to a data reception center, say every hour, via telephone lines or other communication network. The collected data are processed by computer and visually displayed for indicated action. Field operators who can perform weekly maintenance and calibration checks and a trained central technical staff to coordinate and scrutinize the overall daily monitoring system operation and data validation are essential for the production of usable and valid "real-time" data.[33]

The air monitoring data can be used to measure ambient air quality and its compliance with state and national standards; detect major local source air quality violations; provide immediate information for a statewide air pollution

TABLE 6-4 Measurement Methods for Ambient Air Quality Parameters

Pollutant	Measurement Methods
SO_2	Ultraviolet pulsed fluorescence, flame photometry, coulometric; dilution or permeation tube calibrators
CO	Nondispersive infrared tank gas and dilution calibration, gas filter correlation
O_3	Gas-phase chemiluminescence ultraviolet (UV) spectrometry; ozone UV generators and UV spectrometer or gas-phase titration (GPT) calibrators
NO_2	Chemiluminescence; permeation or GPT calibration
Lead	High-volume sampler and atomic absorption analysis
PM_{10}[a]	Tapered-element oscillating microbalance, automated beta gauge
$PM_{2.5}$	Twenty-four-hour filter sampling
TSPs[b]	High-volume sampler and weight determination
Sulfates, nitrates	High-volume sampler and chemical analysis—deposit dissolved and analyzed colorimetrically
Hydrocarbons	Flame ionization and gas chromatography[c]; calibration with methane tank gas
Asbestos and other fibrous aerosols	Induced oscillation/optical scattering, microscope, and electron microscope
Biologic aerosols	Impaction (Petri dish), incubated 24 hr and microbial colonies counted

[a] 10 μm or small particle.

[b] Total suspended particulates. type, size, and composition are important.

[c] Not generally required to measure these if O_3 is measured

episode alert warning system; provide long-term air quality data to meet public and private sector data needs, such as for environmental planning and environmental impact analysis; determine long-term air pollution concentrations and trends in a state; and provide air quality information to the public.

A continuous air quality monitoring system requires use of continuously operating analyzers of a design that measures ambient concentrations of specified air pollutants in accordance with EPA ‘‘reference methods’’ or ‘‘equivalent methods.’’[34] The EPA designates air pollution analyzers after reviewing extensive test data submitted by the manufacturers for their instrumentation. Only analyzers designated as reference or equivalent methods may be used in ambient air monitoring networks to define air quality. This is necessary to ensure correct measurements and operation, thereby promoting uniformity and comparability of data used to define national ambient air quality.

The EPA has specified[35] a detailed ambient monitoring program for use by states, local government, and industry. Included in the program are formal data quality assurance programs, monitoring network design, probe (air intake) siting, methodology, and data reporting requirements. The EPA has specified a daily uniform air pollution index known as the pollutant standard index (or PSI) for public use in comparing air quality. The PSI values are discussed and summarized later in Table 6-7.

Types of analyzers used to measure national ambient air quality parameters are summarized in Table 6-4. Continuous analyzers utilizing "gas-phase" measurements with electronic designs, rather than "wet chemistry" measurements, are preferred as they are more accurate and reliable. However, inasmuch as not all regulatory agencies, particularly those at a local level, have the resources or need for sophisticated equipment, other devices are also mentioned below.

Particulate Sampling—Ambient Air

Measurements needing much more development are in the area of particulates, where inhalable particles sizing (less than 10–3 μm), identification, metals, sulfates, and nitrates are important. Particulates can also be collected and tested for their mutagenic properties. Of all the particulate ambient air sampling devices, the high-volume sampler is the one most commonly used in the United States, although alternate continuous monitoring devices are increasingly being used. Other devices also have application for the collection of different-sized particulates.

High-volume (*Hi-vol*) *samplers* pass a measured high rate of (40–60 cfm) through a special filter paper (or fiberglass), usually for a 24-hr period. The filter is weighed before and after exposure, and the change in weight is a measure of the suspended particulate matter in (PM) in micrometers per square meter of air filtered. The particulates can be analyzed for weight, particle size (usually between 50 and 0.1 μm), and composition (such as benzene solubles, nitrates, lead, and sulfates), and radioactivity. Particle size selective inlets can be put on hi-volume samplers, and samples can be separated into two parts using impactor principles, those in the particle size ranging above and below 2 to 3 μm. There is more interest in measuring 10-μm or smaller particles (PM_{10}) since they penetrate deeper into the respiratory tract and are more likely to cause adverse health effects.

High-volume sampling is the EPA reference method. Air flow measurement is very important. An orifice with a manometer is recommended for flow measurement.

Sedimentation and settling devices include fallout or dustfall jars, settling chambers or boxes, Petri dishes, coated metal sheets or trays, and gum-paper stands for the collection of particulates that settle out. Vertically mounted adhesive papers or cylinders coated with petroleum jelly can indicate the directional origin of contaminants. Dustfall is usually reported as milligrams per centimeter squared per month. Particulates can also be measured for radioactivity.

The *automatic* (*tape*) *smoke sampler* collects suspended material on a filter tape that is automatically exposed for predetermined intervals over an extended period of time. The opacity of the deposits or spots on the tape to the transmission or reflectance of light from a standard source is a measure of the air pollution. This instrument provides a continuous electrical output that can be telemetered to give immediate data on particulates. Thus, the data are available without the delay of waiting for laboratory analysis of the high-volume filter. The equipment is used primarily to indicate the dirtiness of the atmosphere and does not directly measure the particulate total suspended particulate (TSP) ambient air quality standard.

Inertial or centrifugal collection equipment operates on the cyclone collection principle. Large particles above 1 μm in diameter are collected, although the equipment is most efficient for the collection of particles larger than 10 μm.

Impingers separate particles by causing the gas stream to make sudden changes in direction in passing through the equipment. The wet impinger is used for the collection of small particles, the dry impinger for the larger particles. In the dry impinger, a special surface is provided on which the particles collide and adhere.

In the *cascade impactor,* the velocities of the gas stream vary, making possible the sorting and collection of different-sized particles on special microscopic slides. Particulates in the range of 0.7 to 50 μm are collected.

Electrostatic precipitator-type sampling devices operate on the ionization principle using a platinum electrode. Particles less than 1 μm in size collect on an electrode of opposite charge and are then removed for examination. Combustible gases, if present, can affect results.

Nuclei counters measure the number of condensation nuclei in the atmosphere. They are a useful reference for weather commentators. A sample of air is drawn through the instrument, raised to 100 percent relative humidity, and expanded adiabatically, with resultant condensation on the nuclei present. The droplets formed scatter light in proportion to the number of water droplets, which are counted by a photomultiplier tube. Concentrations of condensation nuclei may range from 10 to 10,000,000 particles/cm^3.[36] Condensation nuclei are believed to result from a combination of natural and man-made causes, including air pollution. A particle count above 50,000 is said to be characteristic of an urban area.

Pollen samplers generally use petroleum-jelly-coated slides placed on a covered stand in a suitable area. The slides are usually exposed for 24 hr, and the pollen grains are counted with the aid of a microscope. The counts are reported as grains per centimeter squared. See Chapter 10 for ragweed control and sampling.

Gas Sampling

Gas sampling requires separation of the gas or gases being sampled from other gases present. The temperature and pressure conditions under which a sample is collected must be accurately noted. The pressure of a gas mixture is the sum of the individual gas pressures, as each gas has its own pressure.

The volumes of individual gases at the same pressure in a mixture are also additive. *Concentrations of gases when reported in terms of ppm and ppb are by volume rather than by weight.** Proper sampling and interpretation of results require competency and experience, knowledge concerning the conditions under which the samples are collected, and an understanding of the limitations of the testing procedures. Automated and manual instruments and equipment for gas sampling and analysis include the following.

Pulsed Fluorescent Analyzer[37] This instrument measures sulfur dioxide by means of absorption of UV light. Pulsating UV light is focused through a narrow-bandpass filter that reduces the outgoing light to a narrow wavelength band of 230 to 190 nm and directs it into the fluorescent chamber. Ambient air containing SO_2 flows continuously through this chamber where the UV light excites the SO_2 molecules, which in turn emit their characteristic decay radiation. This radiation, specific for SO_2, passes through a second filter and onto a sensitive photomultiplier tube. This incoming light energy is transformed electronically into an output voltage that is directly proportional to the concentration of SO_2 in the sample air. The World Health Organization (WHO) Global Environmental Monitoring System determinations use the following methods: acidimetric titration or hydrogen peroxide, the colormetric pararosaniline or West-Gaeke, the amperometric or coulometric, and the conductimetric.

Atomic Spectrometry In atomic spectrometry a sample solution is atomized into a flame that produces a characteristic and measurable spectrum of light wavelengths. *Gas chromatography* separates compounds that can be volatilized, while *liquid chromatography* separates compounds that are not volatile. *Mass spectrometry* identifies a separated pure component by its characteristic mass spectrum. Sampling analytical methods for the examination of toxic and hazardous organic materials include gas chromatography with flame ionization detector, gas chromatography–mass spectrometry, gas chromatography–photoionization detector, and electron capture. Calibration is accomplished through laboratory standards and certified permeation tubes.

Some continuous monitoring instruments for atmospheric measurement of pollution are quite elaborate and costly. The simplest readily available instrument should be selected that meets the required sensitivity and specificity. Power requirements, service, maintenance, calibration frequency, and time required to collect and transmit information are important considerations.

Nitrogen Oxide Chemiluminescence Analyzer[37] Nitric oxide (NO) is measured by the gas-phase chemiluminescent reaction between nitric oxide and ozone. This technique is also used to determine nitrogen dioxide (NO_2) by

*In either metric (SI) or customary (U.S.) units.

catalytically reducing NO_2 in the sample air to a quantitative amount of NO. Sample air is drawn through a capillary into a chamber held at 25 in. Hg vacuum. Ozone produced by electrical discharge in oxygen is also introduced into the chamber.

The luminescence resulting from the reaction between NO and ozone is detected by a temperature-stabilized photomultiplier tube and wavelength filter. An automatic valving system periodically diverts the sample air through a heated activated-carbon catalyst bed to convert NO_2 to NO before it enters the reaction chamber. The sample measured from the converter is called NO_x. Since it contains the original NO plus NO produced from the NO_2 conversion, the differences between the sequential NO_x and NO readings are reported as NO_x. Primary dynamic calibrations are performed with gas-phase titration using ozone and nitric oxide standards and with NO_2 permeation tubes.

Ozone Chemiluminescence Analyzer[37] Ozone is measured by the gas-phase chemiluminescence technique, which utilizes the reaction between ethylene and ozone (O_3). Sample air is drawn into a mixing chamber at a flow rate of 1 l/min where it is mixed with ethylene gas and introduced at a flow rate of 25 cc/min. The luminescence resulting from the reaction of the ethylene with ambient ozone in the air supply is detected by a temperature-stabilized photomultiplier tube. This signal is then amplified and monitored by telemetry and on-site recorders. These ozone instruments contain provision for weekly zero and span checks. Primary dynamic calibrations are periodically performed that require standardization against a known, artificially generated ozone atmosphere. Ozone is also measured by UV light instrumentation.

Carbon Monoxide Infrared (IR) Analyzer[37] This method utilizes dual-beam photometers with detection accomplished by means of parallel absorption chambers or cells that are separated by a movable diaphragm. The IR energy passes into each chamber—one containing the sample with CO, the other containing the reference gas. The reference gas heats up more than the ambient air sample with CO since CO absorbs more of the IR energy. This results in higher temperature and, hence, the volume–pressure in the reference chamber that is transmitted to the separating diaphragm designed to provide an electrical output to measure the CO concentration. However, it is necessary to remove water vapor interference as the humidity in ambient air absorbed by IR energy can introduce a significant error in CO readings. In one instrument (the EPA reference method), the interference due to water vapor is eliminated by first passing one portion of the ambient air sample through a catalytic converter where CO is converted to CO_2 prior to entry into the reference chamber. The other half of the air sample containing CO passes directly into the sample chamber. This procedure cancels out the effect of moisture since both gas streams are identical except for the presence of CO.[37] Carbon monoxide is also measured by gas-phase correlation.

Smoke and Soiling Measurement

Historically, smoke and/or opacity was measured by The *Ringelmann smoke chart*.[38] This consists of five* rectangular grids produced by black lines of definite width and spacing on a white background. When held at a distance, about 50 ft from the observer, the grids appear to give shades of gray between white and black. The grid shadings are compared with the pollution source (stack), and the grid number closest to the shade of the pollution source is recorded. About 30 observations are made in 15 min, and a weighted average is computed of the recorded Ringelmann numbers. The chart is used to determine whether smoke emissions are within the standards established by law; the applicable law is referenced to the chart. The system cannot be applied to dusts, mists, and fumes. Inspectors need training in making smoke readings. A reading of zero would correspond to all white; a reading of 5 would correspond to all black.

The Ringelmann chart has been replaced by a determination of the *percent opacity* of a particular emission as seen by a trained observer.† For example, a Ringelmann reading of 1 would correspond to an opacity of about 20 percent.

Tape Sampler—Soiling Soiling can be indicated as RUDS (reflectance units of dirt shade). One RUDS is defined as an optical reflectance of 0.01 caused by 10,000 ft of air passing through 0.786 in.^{2} (1-in.-diameter circle) of filter paper. A vacuum pump draws the air to be sampled through the filter tape. The particles collected soil a spot on the tape. The tape is advanced automatically after a 2-hr period; the air flow rate used is 0.455 cfm. A filter is used with the light source that admits light with a wavelength of approximately 400 nm to measure the light reference, which information can be sent to a monitor. The sampling time period and air flow rate were chosen to conform with ASTM (American Society for Testing and Materials) standards.

***Tape Sampler—Coefficient of Haze* (*COH*)** The tape sampler can be designed to measure light transmittance rather than reflectance. This will produce soiling measurements expressed as COH, an index of contaminant concentration, which is the EPA preferred method. The method is similar to that outlined above except the photocell is under the tape. White light is used. It is necessary to automatically rezero the instrument near each spot to compensate for tape thickness variation. The compensation is performed by solid-state electronics.

The automated filter tape air sampler can also be used to monitor some gases. Special filter tapes are used to measure hydrogen sulfide, fluorides, and

*Reduced to four grids or charts in the United States. The width or thickness of lines and their spacing in each grid or chart vary. A handy reduction of the Ringelmann smoke chart is the Power's Micro-Ringelmann available from Power, 33 West 42nd Street, New York, NY 10036.
†See U.S. EPA Method 9, Appendix A, 40 CFR 60, 2001.

other gases. The spots produced by the gaseous pollutant are chemically treated and evaluated using the reflectance or transmission method.

Many of these measures of smoke and or opacity have been moved back to the source (smoke stack) where more enforceable standards can be applied. Industrial operation permits can require the installation of electronic opacity monitors. These monitors measure either the transmission of light from a source to a sensor across the stack (extinction) or the variability of light transmission across the stack (scintillation). Inspectors may request operation records and maintenance logs during facility inspection.

Stack Sampling

The collection of stack samples, such as fly ash and dust emissions, requires special filters of known weight and a measure of the volume of gases sampled. The sample must be collected at the same velocity at which the gases normally pass through the stack. The gain in weight divided by the volume of gases sampled corrected to 0°C (or 21°C) temperature and 760 mm Hg gives a measure of the dust and fly ash going out of the stack, usually as grains per cubic foot. When a series of samples is to be collected or measurements made, a ‘‘sampling train’’ is put together. It may consist of a sampling nozzle, several impingers, a freeze-out train, a weighed paper filter, dry gas meter, thermometers, and pump.

A common piece of equipment for boiler and incinerator stack sampling is the Orsat apparatus. By passing a sample of the stack gas through each of three different solutions, the percent carbon dioxide, carbon monoxide, and oxygen constituents in the flue gas are measured. The remainder of the gas in the mixture is usually assumed to be nitrogen. Special methods are used to test for other gases and metals.

Tracer materials may be placed in a stack to indicate the effect of a pollution source on the surrounding area. The tracer may be a fluorescent material, a dye, a compound that can be made radioactive, a special substance or chemical, or a characteristic odor-producing material. The tracer technique can be used in reverse—that is, to detect the source of a particular pollutant, provided there are no interfering sources.

Measurement of Materials’ Degradation

The direct effects of air pollution can be observed by exposing various materials to the air at selected monitoring stations. The degradation of materials is measured for a selected period on a scale of 1 to 10, with 1.0 representing the least degradation and 10.0 the worst, as related to the sample showing the least degradation. Materials exposed and conditions measured include steel corrosion, dyed fabric (nonspecific) for color fading, dyed fabric (NO_x sensitive), dyed fabric (ozone sensitive), dyed fabric (fabric soiling), dyed fabric (SO_2 sensitive), silver tarnishing, nylon deterioration, rubber cracking (crack depth), leather deterioration, copper pitting, and others. The samples are exposed for a selected period, such as rubber, 7 days at a time; silver, 30 days at a time; nylon, 30 or 90 days at a time; cotton, 90 days at a time; steel, 90 days and 1 year at a time; and zinc, 1 year at a time. Shrubs, trees, and other plants sensitive to certain contaminants or pollutants can also be used to monitor the effects of air pollution.

ENVIRONMENTAL FACTORS

The behavior of pollutants released to the atmosphere is subject to diverse and complex environmental factors associated with meteorology and topography. Meteorology involves the physics, chemistry, and dynamics of the atmosphere and includes many direct effects of the atmosphere on the earth's surface, ocean, and life. Topography refers to both the natural and man-made features of the earth's surface. The pollutants can be either accumulated or diluted, depending on the nature and degree of the physical processes of transport, dispersion, and removal and the chemical changes taking place. Because of the complexities of pollutant behavior in the atmosphere, it is important to distinguish between the activity of short-range primary pollutants (total suspended solids, sulfur dioxide), to which micrometeorology applies, and long-range secondary pollutants (ozone, acid rain), to which regional meteorology applies.

Within the scope of this text, the intention is not to provide a complete technical understanding of all the meteorological and topographical factors involved but to provide an insight into the relationships to air pollution of the more important processes.

Meteorology

The meteorological elements that have the most direct and significant effects on the distribution of air pollutants are wind speed and direction, solar radiation, stability, and precipitation. Therefore, it is important to have a continuing baseline of meteorological data, including these elements, to interpret and anticipate probable effects of air pollution emissions. Data on temperature, humidity, wind speed and direction, and precipitation are generally available through official government weather agencies. The National Weather Service (formerly U.S. Weather Bureau), Asheville, North Carolina, is a major source of information. Other potential sources of information are local airports, stations of the state fire weather service, military installations, public utilities and industrial complexes, and colleges and universities.

Wind Wind is the motion of the air relative to the earth's surface. Although it is three dimensional in its movement, generally only the horizontal components are denoted when used because the vertical component is very much smaller than the horizontal. This motion derives from the unequal heating of the earth's surface and the adjacent air, which in turn gives rise to a horizontal variation in temperature and pressure. The variation in pressure (pressure gradient) constitutes an imbalance in forces so that air motion from high toward low pressure is generated.

The uneven heating of the surface occurs over various magnitudes of space, resulting in different magnitudes of organized air motions (circulations) in the atmosphere. Briefly, in descending order of importance, these are

1. the primary or general (global) circulation associated with the large-scale hemispheric motions between the tropical and polar regions,
2. the secondary circulation associated with the relatively large-scale motions of migrating pressure systems (highs and lows) developed by the unequal distribution of large land and water masses, and
3. the tertiary circulation (local) associated with small-scale variations in heating, such as valley winds and land and sea breezes.

For a particular area, the total effect of these various circulations establishes the hourly, daily, and seasonal variations in wind speed and direction. With respect to a known source or distribution of sources of pollutants, the frequency distribution of wind direction will indicate toward which areas the pollutants will be most frequently transported. It is customary to present long-term wind data at a given location graphically in the form of a "wind rose," an example of which is shown in Figure 6-1.

The concentration resulting from a continuous emission of a pollutant is inversely proportional to wind speed. The higher the wind speed, the greater the separation of the particles or molecules of the pollutant as they are emitted, and vice versa. This is shown graphically in Figure 6-2*a*. Wind speed, therefore, is an indicator of the degree of dispersion of the pollutant and contributes to the determination of the area most adversely affected by an emission. Although an area may be located in the most frequently occurring downwind direction from a source, the wind speeds associated with this direction may be quite high so that resulting pollutant concentrations will be low as compared to another direction occurring less frequently but with lower wind speeds.

Smaller in scale than the tertiary circulation mentioned above, there is a scale of air motion that is extremely significant in the dispersion of pollutants. This is referred to as the micrometeorological scale and consists of the very short term, on the order of seconds and minutes, fluctuations in speed and direction. As opposed to the "organized" circulations discussed above, these air motions are rapid and random and constitute the wind characteristic called "turbulence." The turbulent nature of the wind is readily evident upon watching the rapid movements of a wind vane. These air motions provide the most effective mechanism for the dispersion or dilution of a cloud or plume of pollutants. The turbulent fluctuations occur in both the horizontal and vertical

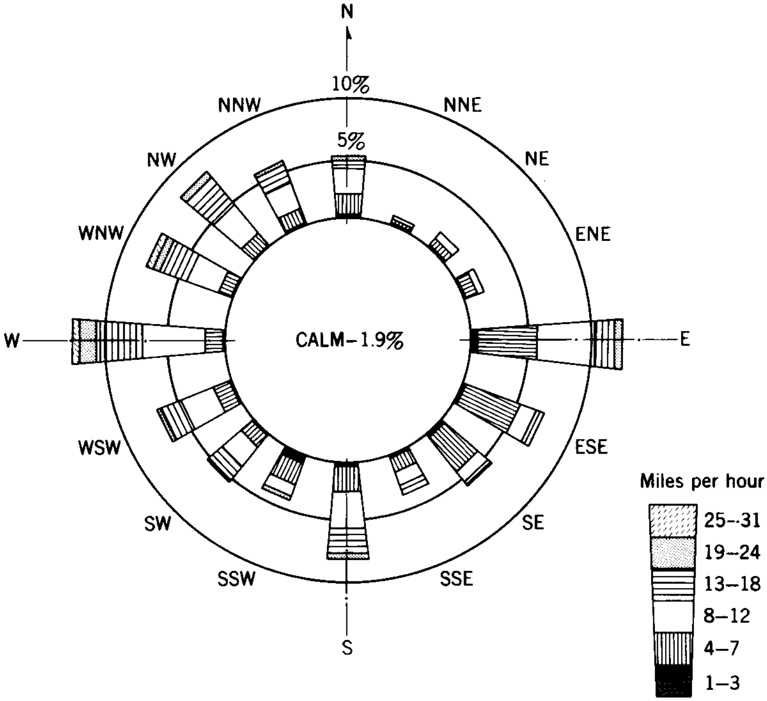

Figure 6-1 Example of wind rose for a designated period of time, by month, season, or year. The positions of the spokes show the direction from which the wind was blowing. The total length of the spoke is the percentage of time, for the reporting period, that the wind was blowing from that direction. The length of the segments into which each spoke is divided is the percentage of time the wind was blowing from that direction at the indicated speed in miles per hour. Horizontal wind speed and direction can vary with height.

directions. The dispersive effect of fluctuations in horizontal wind direction is shown graphically in Figure 6-2*b*.

Turbulent motions are induced in the air flow in two ways: by thermal convective currents resulting from heating from below (thermal turbulence) and by disturbances or eddies resulting from the passage of air over irregular, rough ground surfaces (mechanical turbulence).

It may be generally expected that turbulent motion and, in turn, the dispersive ability of the atmosphere would be greatly enhanced during a period of good solar heating and over relatively rough terrain.

Another characteristic of the wind that should be noted is that wind speed generally increases with height in the lower levels. This is due to the decrease with height of the "frictional drag" effect of the underlying ground surface features.

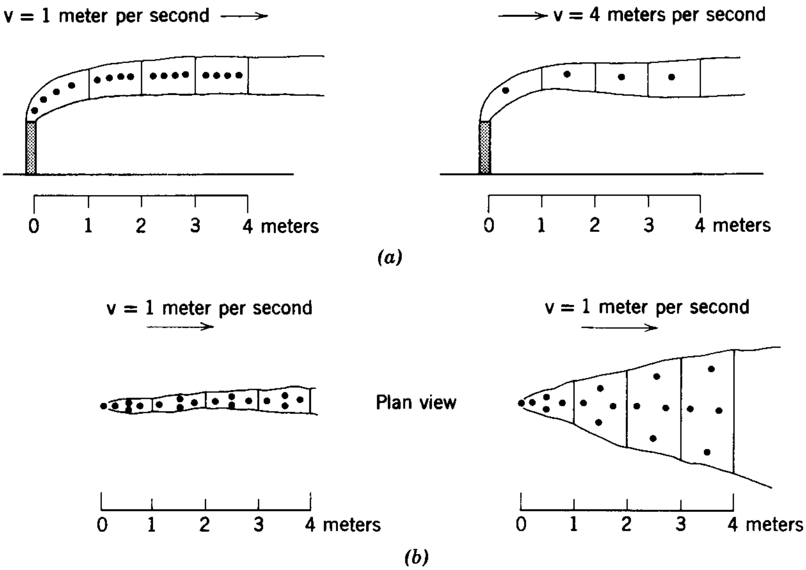

Figure 6-2 (*a*) Effect of wind speed on pollutant concentration from constant source; (*b*). Effect of variability of wind direction on pollutant concentration from constant source (continuous emission of 4 units/sec).

Stability and Instability The stability of the atmosphere is its ability to enhance or suppress vertical air motions. Under unstable conditions the air motion is enhanced, and under stable conditions the air motion is suppressed. The conditions are determined by the vertical distribution of temperature.

In vertical motion, parcels of air are displaced. Due to the decrease of pressure with height, a parcel displaced upward will encounter decreased pressure and expand. If this expansion process is relatively rapid or over a large area so that there is little or no exchange of heat with the surrounding air or by a change of state of water vapor, the process is dry adiabatic and the parcel of air will be cooled. Likewise, if the displacement is downward so that an increase in pressure and compression is experienced, the parcel of air will be heated.

The rate of cooling of a mass of warm dry air in a dry environment with height is the *dry adiabatic process lapse rate* and is approximately −5.4°F/1000 ft (−1°C/100 m). The normal lapse rate (cooling) on the average is −3.5°F/1000 ft (−0.65°C/100 m). This relationship holds true in the troposphere up to about 10 km (6 miles). Temperature increases above this level in the stratosphere.

The *prevailing* or *environmental lapse rate* is the decrease of temperature with height that may exist at any particular time and place. It can be shown that if the decrease of temperature with height is greater than −5.4°F/1000 ft, parcels displaced upward will attain temperatures higher than their surroundings. Air parcels displaced downward will attain lower temperatures than their surroundings. The displaced parcels will tend to continue in the direction of displacement. Under these conditions, the vertical motions are enhanced and the layer of air is defined as "unstable."

Furthermore, if the decrease of temperature with height is less than −5.4°F/1000 ft, it can be shown that air parcels displaced upward attain temperatures lower than their surroundings and will tend to return to their original positions. Air parcels displaced downward attain higher temperatures than their surroundings and also tend to return to their original position. Under these conditions, vertical motions are suppressed and the layer of air is defined as "stable."

Finally, if the decrease of temperature with height is equal to −5.4°F/1000 ft, displaced air parcels attain temperatures equal to their surroundings and tend to remain at their position of displacement. This is called "neutral stability."

Inversions Up to this point, the prevailing temperature distribution in the vertical has been referred to as a "lapse rate," which indicates a decrease of temperature with height. However, under certain meteorological conditions, the distribution can be such that the temperature increases with height within a layer of air. This is called an "inversion" and constitutes an extremely stable condition.

There are three types of inversions that develop in the atmosphere: radiational (surface), subsidence (aloft), and frontal (aloft).

Radiational inversion is a phenomenon that develops at night under conditions of relatively clear skies and very light winds. The earth's surface cools by reradiating the heat absorbed during the day. In turn, the adjacent air is also cooled from below so that within the surface layer of air there is an increase of temperature with height.

Subsidence inversion develops in high-pressure systems (generally associated with fair weather) within a layer of air aloft when the air layer sinks to replace air that has spread out at the surface. Upon descent, the air heats adiabatically, attaining temperatures greater than the air below.

A condition of particular significance is the subsidence inversion that develops with a stagnating high-pressure system. Under these conditions, the pressure gradient becomes progressively weaker so that the winds become very light, resulting in a great reduction in the horizontal transport and dispersion of pollutants. At the same time, the subsidence inversion aloft continuously descends, acting as a barrier (lid) to the vertical dispersion of the pollutants. These conditions can persist for several days so that the resulting accumulation of pollutants can cause a serious health hazard.

Frontal inversion forms when air masses of different temperature characteristics meet and interact so that warm air overruns cold air.

There are many and varied effects of stability conditions and inversions on the transport and dispersion of pollutants in the atmosphere. In general, enhanced vertical motions under unstable conditions increase the turbulent motions, thereby enhancing the dispersion of the pollutants. Obviously, the stable conditions have the opposite effect.

For stack emissions in inversions—depending on the elevation of emission with respect to the distribution of stability in the lower layers of air—behavior of the plumes can be affected in many different ways. Pollutants emitted within the layer of a surface-based (radiational) inversion by low stacks can develop very high and hazardous concentrations at the surface level. On the other hand, when pollutants are emitted from stacks at a level aloft within the surface inversion, the stability of the air tends to maintain the pollutant at this level, preventing it from reaching the surface. However, after sunrise and continued radiation from the sun resulting in heating of the earth's surface and adjacent air, the inversion is "burned off." Once this condition is reached, the lower layer of air becomes unstable and all of the pollutant that has accumulated at the level aloft is rapidly dispersed downward to the surface. This behavior is called "fumigation" and can result in very high concentrations during the period. See Figure 6-3.

Precipitation Precipitation constitutes an effective cleansing process of pollutants in the atmosphere in three ways: the washing out or scavenging of large particles by falling raindrops or snowflakes (washout), accumulation of small particles in the formation of raindrops or snowflakes in clouds (rainout), and removal of gaseous pollutants by dissolution and absorption.

The most effective and prevalent process is the washout of large particles, particularly in the lower layer of the atmosphere, where most of the pollutants are released. The efficiencies of the various processes depend on complex relationships between properties of the pollutants and the characteristics of the precipitation.

Topography

The topographic features of a region include both the natural (e.g., valleys, oceans, rivers, lakes, foliages) and man-made (e.g., cities, bridges, roads, canals) elements distributed within the region. These elements, per se, have little direct effect on pollutants in the atmosphere. The prime significance of topography is its effects on the meteorological elements. As stated previously, the variation in the distribution of land and water masses gives rise to various types of circulations. Of particular significance are the local or small-scale circulations that develop. These circulations can contribute either favorably or unfavorably to the transport and dispersion of the pollutants.

Along a coastline during periods of weak pressure gradient, intense heating of the land surface, as opposed to the lesser heating of the contiguous water surface, develops a temperature and pressure differential that generates an onshore air circulation. This circulation can extend to a considerable distance inland. At times during stagnating high-pressure systems, when the transport and dispersion of pollutants have been greatly reduced, this short-period af-

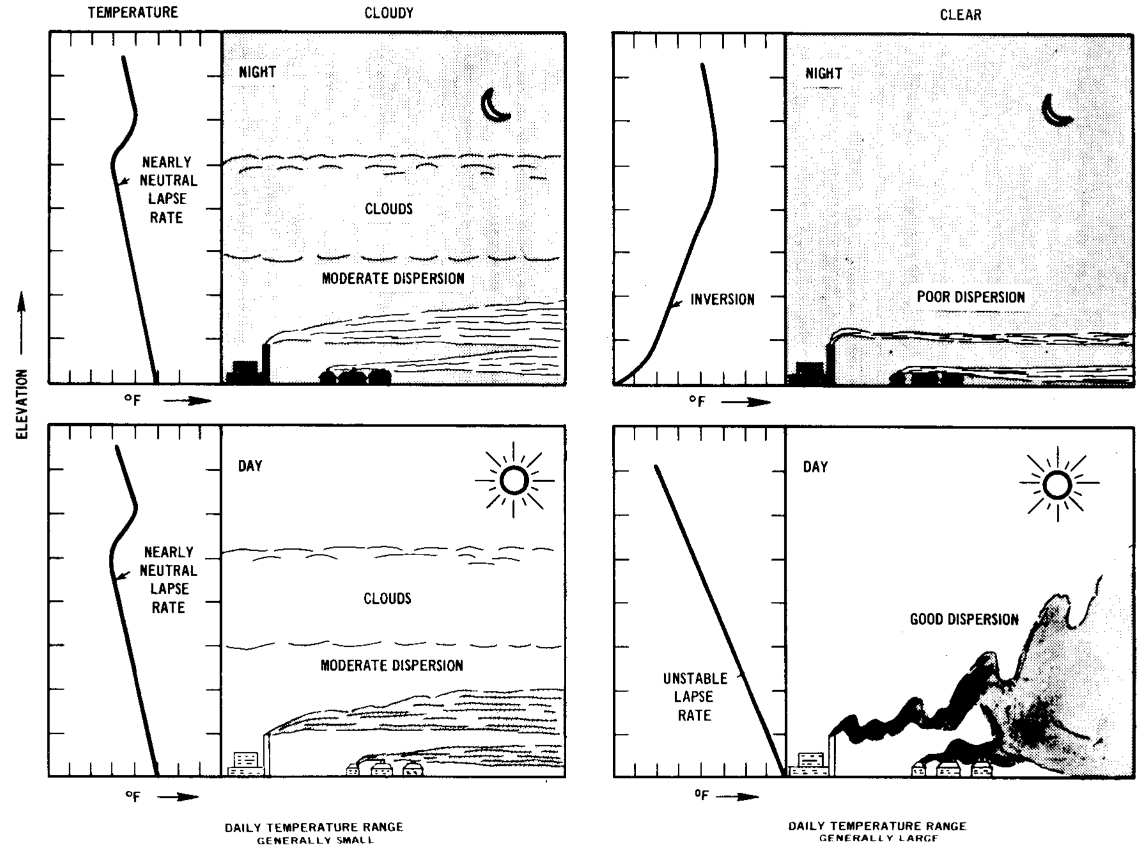

Figure 6-3 Diurnal and nocturnal variation of vertical mixing. (*Source:* M. I. Weisburd, *Field Operation and Enforcement Manual for Air Pollution,* Vol. 1: *Organization and Basic Procedures,* U.S. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, NC, 1972, p. 1.24.)

ternoon increase in airflow may well prevent the critical accumulation of pollutants.

In valley regions, particularly in the winter, intense *surface inversions* are developed by the drainage down the slopes of air cooled by the radiationally cooled valley wall surfaces. Bottom valley areas that are significantly populated and industrialized can be subject to critical accumulation of pollutants during these periods.

The increased roughness of the surface created by the widespread distribution of buildings throughout a city can significantly enhance the turbulence of the airflow over the city, thereby improving the dispersion of the pollutants emitted. But at the same time the concrete, stone, and brick buildings and asphalt streets of the city act as a heat reservoir for the radiation received from the sun during the day. This, plus the added heat from nighttime space heating during the cool months of the year, creates a temperature and pressure differential between the city and the surrounding rural area so that a local circulation inward to the city is developed. The circulation tends to concentrate the pollutants in the city. This phenomenon called the ‘‘urban heat island effect.’’

Areas on the windward side of mountain ranges can expect added precipitation due to the forced rising, expansion, and cooling of the moving air mass with resultant release of available moisture. This increased precipitation serves to increase the removal of the pollutants.

It is apparent, then, that topographical features can have many and diverse effects in the meteorological elements and the behavior of pollutants in the atmosphere.

AIR POLLUTION SURVEYS

An air pollution survey of a region having common topographical and meteorological characteristics is a necessary first step before a meaningful air resources management plan and program can be established. The survey includes an inventory of source emissions and a contaminant and meteorological sampling network, supplemented by study of basic demographic, economic, land-use, and social factors.

Inventory

The inventory includes the location, height, exit velocity, and temperature of emission sources and identification of the processes involved; the air pollution control devices installed and their effectiveness; and the pounds or tons of specific air pollutants emitted per day, week, month, and year, together with daily and seasonal variations in production. Inventories of area sources (e.g., home heating, small dry cleaners) can be done simply through fuel use and solvent sales data. The emissions are calculated from emission tables or by material balance. An estimate can then be made of the total pollution burden on the atmospheric resources of any given air basin.[39] Tables have been developed to assist in the calculation of the amounts and types of contaminants released; they can also be used to check on information received through personal visits, questionnaires, telephone calls, government reports, and technical and scientific literature.[40] Additional sources of information are the complaint files of the health department, municipal and private agencies, published information, university studies, state and local chamber of commerce reports and files, and results of traffic surveys as well the Census of Housing local fuel and gasoline sales. Much of this material is now available electronically via the internet. Data about concentration of primary pollutants for example is available via the Aerometric Information Retrieval System (AIRS) at www.epa.gov/airs.

Air Sampling

Air and meteorological sampling equipment located in the survey area will vary, depending on a number of factors such as land area, topography, population densities, industrial complexes, and manpower and budget availability. A minimum number of stations is necessary to obtain meaningful data.

Specific sampling sites for a comprehensive survey or for monitoring are selected on the basis of objective, scope, and budgetary limitations; accessibility for year-round operation, availability of reliable electrical power, amount and type of equipment available, program duration, and personnel available to operate stations; meteorology of the area, topography, adjacent obstructions, and vertical and horizontal distribution of equipment; and sampler operator problems, space requirements, protection of equipment and site, possible hazards, and public attitude toward the program.[41] The EPA can provide monitoring and siting guidance.[42,43] Careful attention must also be given to the elimination of sampling bias and variables as related to size of sample, rate of sampling, collection and equipment limitations, and analytical limitations.

Basic Studies and Analyses

Basic studies include population densities and projections; land-use analysis; mapping; and economic studies and proposals, including industrialization, transportation systems, community institutions, environmental health and engineering considerations, relationship to federal, state, and local planning, and related factors. Liaison with other planning agencies can be helpful in obtaining needed information that may already be available. See Chapter 2.

When all the data from the emission inventory, air sampling, and basic studies are collected, analyzed, and evaluated, a report is usually prepared. The analysis step should include calculations to show how the pollutants released to the atmosphere are dispersed and their possible effects under existing conditions and with future development.

Mathematical models could be developed, or commercially available modeling packages could be utilized, based on certain assumptions and the data collected, to estimate the pollution levels that might result under various emission, topographical, and meteorological conditions. A data bank and a system for the collection and retrieval of information would generally be indicated. The approximate cost to achieve selected levels of air quality (for health, aesthetic, plant, and animal considerations) and the possible effect on industrial expansion, transportation modes and systems, availability and cost of fuel, and community goals and objectives should be determined. See also (a) Planning and Zoning and (b) Air Quality Modeling, this chapter.

The report would recommend air quality objectives based on EPA standards for areas in the region studied based on existing and proposed land uses. This will require consultation and coordination with state and local planning agencies.[44]

Short- and long-term objectives and priorities should be established to achieve the desired air quality. Recommendations to reduce air pollution might include control of pollutant emissions and limits in designated areas and under hazardous weather conditions and predictions; time schedules for starting control actions; control of fuel composition; requirement of plans for new or altered emission sources and approval of construction for compliance with emission standards; denial of certain plan approvals and prohibition of activities, or requirement of certain types of control devices; and performance standards to be met by existing and new structures and facilities.

The report is then formally submitted to the regulatory agency, board, or commission for further action. It would generally include recommendations for needed laws, rules, and regulations and administrative organization and staffing for the control of existing and new sources of air pollution.

AMBIENT AIR QUALITY STANDARDS*

Topographic, meteorological, and land-use characteristics of areas within an air region will vary. The social and economic development of an area will result in different degrees of air pollution and demands for air quality. Because of this, it is practical and reasonable to establish different levels of air purity

* "Ambient air" means that portion of the atmosphere, external to buildings, to which the general public has access.

for certain areas within a region. However, any standards adopted must ensure, at a very minimum, no adverse effects on human health.*

Federal Standards

The federal Air Quality Act of 1967 (Public Law 90-148) was amended in 1970, 1974, 1977, 1990, and 1997 and is now know as the Clean Air Act (CAA). The original act was passed in 1955. Emissions from stationary sources and motor vehicles are regulated under the act. Stationary sources must obtain permits that specify the amount and type of allowable emissions from the air quality regulatory agency. Modifications to an existing facility are subject to the provisions of the Act. The Act requires that the administrator of the EPA develop and issue to the states criteria of air quality for the protection of public health and welfare and further specifies that such criteria shall reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on health and welfare that may be expected from the presence of an air contaminant, or combination of contaminants, in varying quantities.

The Act requires the administrator to designate interstate or intrastate air quality control regions throughout the country as considered necessary to ensure adequate implementation of air quality standards. These regions are to be designated on the basis of meteorological, social, and political factors, which suggests that a group of communities should be treated as a unit.

The federal Clean Air Act, as amended, requires that the administrator of the EPA promulgate national ambient air quality standards (NAAQSs) for sulfur oxides, particulate matter, carbon monoxide, photochemical oxidants, hydrocarbons, and nitrogen oxides. These standards are included in Table 6-5.

The Act requires each state to adopt

*In the United States national primary and secondary ambient air quality standards were promulgated effective April 30, 1971. *Primary* ambient air quality standards are those that, in the judgment of the EPA administrator, based on the air quality criteria and allowing an adequate margin of safety, are required to protect the public health. *Secondary* ambient air quality standards are those that, in the judgment of the administrator, based on the air quality criteria, are required to protect the public welfare from any known or anticipated adverse effects associated with the presence of air pollutants in the ambient air (on soil, water, vegetation, materials, animals, weather, visibility, personal comfort, and well-being).

In England (Ministry of Housing and Local Government 1966B), the standard states, in part: "No emission discharged in such amount or manner as to constitute a demonstrable health hazard in either the short or long term can be tolerated. Emissions, in terms of both concentration and mass rate of emission, must be reduced to the lowest practicable amount."

In the Soviet Union, the goal is protection from any agent in the atmosphere that can be demonstrated to produce physiological effect, even if the effect cannot be shown to be harmful.

TABLE 6-5 National Ambient Air Quality Standards (NAAQS) in Effect in 1988

	Primary (Health Related), Standard Level		Secondary (Welfare Related)	
Pollutant	Averaging Time	Concentration[a]	Averaging Time	Concentration
PM_{10}	Annual arithmetic mean[b]	50 $\mu g/m^3$	Same as primary	
	24 hr[b]	150 $\mu g/m^3$	Same as primary	
$PM_{2.5}$	Annual arithmetic mean	15 $\mu g/m^3$	Same as primary	
	24 hr	65 $\mu g/m^3$	Same as primary	
SO_2	Annual arithmetic mean	0.03 ppm (80 $\mu g/m^3$)	3 hr[c]	1300 $\mu g/m^3$ (0.50 ppm)
	24 hr[c]	0.14 ppm (365 $\mu g/m^3$)		
CO	8 hr[c]	9 ppm (10 mg/m^3)	No secondary standard	
	1 hr[c]	35 ppm (40 mg/m^3)	No secondary standard	
NO_2	Annual arithmetic mean	0.053 ppm (100 $\mu g/m^3$)	Same as primary	
O_3	1 hr	0.12 ppm (235 $\mu g/m^3$)	Same as primary	
	Maximum daily 8-hr average[d]	0.08 ppm (157 $\mu g/m^3$)	Same as primary	
Pb	Maximum quarterly average	1.5 $\mu g/m^3$	Same as primary	

Source: National Ambient Air Quality Standards (*NAAQS*) *2002,* U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards Technical Support Division, Research Triangle Park, NC, March 2002. Available: www.epa.gov/airs/criteria.html.

[a] Parenthetical value is an approximately equivalent concentration.

[b] TSP was the indicator pollutant for the original particulate matter (PM) standards. This standard has been repolaced with the new PM_{10} standard and it is no longer in effect. New PM standards were promulgated in 1987 using PM_{10} (particles less than 10μm in diameter) as the new indicator pollutant. The annual standard is attained when the expected annual arithmetic mean concentration is less than or equal to 50 $\mu g/m^3$; the 24-hr standard is attained when the expected number of days per calendar year above 150 $\mu g/m^3$ is equal to or less than 1; as determined in accordance with Appendix K of the PM *NAAQS*.

[c] Not to be exceeded more than once per year.

[d] The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than 1, as determimed in accordance with Appendix H of the Ozone NAAQS.

a plan which provides for the implementation, maintenance, and enforcement of such national ambient air quality standards within each air quality control region (or portion thereof) within the State. [Title I, Sec. 110 (a)(1)]

States are expected to attain the national primary ambient air quality standards after approval by the administrator of the state plan. Both primary and secondary federal standards apply nationwide; however, state standards may be more stringent, except for motor vehicle emission standards, which are prescribed by law (California is exempt).

The 1977 amendments to the Clean Air Act allow each state to classify clean air areas as class I, where air quality has to remain virtually unchanged; class II, where moderate industrial growth would be allowed; or class III, where more intensive industrial activity would be permitted.

Class I areas *shall* include international parks, national wilderness areas exceeding 5000 acres, national memorial parks exceeding 5000 acres, and national parks exceeding 6000 acres. This classification and designation was made by Congress.

The EPA has expanded its concerns beyond the conventional air pollutants, because of government agency and public concern and accidental toxic chemical releases, to include the regulation of some 188 chemicals and chemical categories that may be classified as hazardous air pollutants.* Chemicals may fall into an acutely hazardous category depending on their dermal, oral, and inhalation effects, which are based on the dose or concentration that will kill one-half of a group of test animals (LD_{50} or LC_{50}). A dermal dose less than 50 ppm, an oral dose less than 25 ppm, and an inhalation dose less than 0.5 mg/l for up to 8 hrs would qualify the chemical as an acutely hazardous air pollutant.[45] Some hazardous pollutants that should be given attention are listed in Table 6-6.

Air quality issues also arise from federal legislation, especially the Resource Conservation and Recovery Act (RCRA), Comprehensive Environ-

TABLE 6-6 Some Hazardous Air Pollutants

Acrylontrile	Ethylene oxide
Arsenic	Formaldehyde
Benzene	Methylene chloride
1,3-Butadiene	Nickel
Cadmium	Perchloroethylene
Carbon tetrachloride	Polycyclic organic matter
Chloroform	Radionuclides
Chromium	Trichloroethylene
Ethylene dichloride	Glycol ethers

* See the Clean Air Act of 1990.

mental Response, Compensation, and Liability Act (CERCLA or Superfund), and the Emergency Planning and Community Right-to-Know Act, also called Superfund Amendments and Reauthorization Act Title III (SARA Title III). Of these, SARA Title III has the most dramatic and far-reaching impact on industry regarding the control of toxic chemicals in air. In addition, the EPA has proposed standards limiting emissions of volatile organic pollutants from process vents and equipment leaks at new and existing hazardous waste transfer, storage, treatment, and disposal facilities. These regulations will impose additional air monitoring and emission control responsibilities on RCRA-permitted facilities. Current air quality aspects of RCRA apply to hazardous waste incinerators and land treatment and disposal facilities as well as to remedial action to clean designated sites.

Clean Air Act of 1990

The Clean Air Act amendments of 1990 have added significantly to potential ambient air quality improvement. Some of the major features follow.

Title I deals with the attainment of ambient air quality standards. The EPA may establish geographical boundaries and grade nonattainment areas that exceed standards for carbon monoxide, ozone, and particulate matter. States must reduce overall emissions, and the EPA can impose sanctions (loss of funds for highways and construction) against states and cities for noncompliance.

Title II deals with mobile sources of air pollution. Stricter tailpipe emission limits are established for oxides of nitrogen, hydrocarbons, and carbon monoxide. Cleaner fuel and vehicles will be required in certain cities having ozone, smog, or carbon monoxide problems.

Title III deals with the reduction and regulation of 188 toxic air emissions from commercial and industrial sources and municipal incinerators. The "maximum achievable control technology" will be required at existing, new, or modified sources.

Title IV deals with the control of acid deposition, commonly referred to as acid rain, primarily from plants burning fossil fuels. Reductions in sulfur dioxide emissions will be required on an EPA-phased-time basis, taking into consideration location of sources and existing emissions. Emissions of nitrogen oxides are to be reduced, and standards are to be issued by the EPA. Continuous monitoring of sulfur dioxide, nitrogen oxides, and opacity will be required. Utilities may save, buy, or sell pollution emission allowances.

Title V deals with the development and requirement of a permit system by the EPA similar to the National Pollutant Discharge Elimination System used under the Clean Water Act. All sources of toxic air pollutants will be required to obtain an operating permit valid for up to five years. The permit will list the compliance requirements; the program will be administered by the states.

Title VI deals with the phasing out of ozone-depleting chemicals, including CFCs, halons, HCFCs, carbon tetrachloride, and methyl chloroform. Under the law, CFCs, halons, and carbon tetrachloride are to be phased out by the year 2000. Methyl chloroform is to be phased out in 2002 and HCFCs by 2030. Recycling of refrigerants from motor vehicle air-conditioning units is required. The Act requires that assistance be provided to developing countries.

Title VII deals with enforcement. Corporations and corporate officials are subject to civil and criminal liabilities. The EPA may issue administrative penalties of up to $200,000 and field citations up to $5000. Also, private citizens or groups may take action against violators.

Title VIII deals with the study of visibility impairment, regulation of air pollution from outer continental shelf activities, monitoring of carbon dioxide emissions by utilities, and grants for air pollution planning and control programs.

Title IX requires that the EPA conduct a research program that includes sampling, measurement, monitoring, analysis, and modeling of air pollution.

Title X requires that the EPA ensure, to the extent possible, that 10 percent of research funding be made available to disadvantaged business concerns.

Title XI authorizes a training and benefits program for workers who become unemployed because of the Act.

Clean Air Act Amendments of 1997

In 1997, the EPA proposed more restrictive NAAQSs for ozone and particulate matter. A new standard for particulate matter was drafted that regulated particulates less than 2.5 μm in diameter. These fine particulates are implicated in respiratory distress because of their ability to penetrate deep into the lungs. The proposed ozone standard reduced the permissible concentration to an 8-hr average of 0.080 ppm. This is in contrast to the previous 12-hr 0.120-ppm standard. The EPA estimated these standards would affect 125 million people including 35 million children in the United States. The proposed rules were challenged in court in 1997 and remained in litigation until the Supreme Court of the United States and subsequently the District of Columbia Circuit Court sided with the EPA in 2002. The standards will should have a significant effect on the number of communities that will have to address ground-level ozone issues. Mobile sources of $PM_{2.5}$, such as heavy-duty diesel trucks, may also be significantly affected by these amendments.

Pollutant Standards Index (PSI)

The pollutant standards index is a uniform method recommended* to classify and report urban air quality. Five criteria pollutants are judged for the amount

*Recommendation of task force consisting of the Council on Environmental Quality, the EPA, Department of Commerce, National Oceanic and Atmospheric Administration, and the National Bureau of Standards.

and adverse effects on human health, as shown in Table 6-7. On that basis, the air quality evaluated is designated as presenting "hazardous conditions" if the PSI is greater than 300; "very unhealthful conditions" if the PSI is between 200 and 300; "unhealthful conditions" if the PSI is between 100 and 200; "moderate" if the PSI is 50 to 100; and "good" if the PSI is between 0 and 50. The PSI for one day rises above 100, that is, to the "Alert" level or higher, when any one of the five criteria pollutants reaches a level that may be judged to have adverse effects on human health.

CONTROLS

Air pollution involves a source such as a power-generating plant burning heavy fuel oil; a production byproduct or waste such as particulates, vapors, or gases; release of pollutants into the atmosphere, such as smoke or sulfur dioxide; transmission by airflows; and receptors who are affected, such as people, animals, plants, structures, and clothing. Controls can be applied at one or more points between the source and the receptor, starting preferably at the source. The application of control procedures and devices is more effective when supported by public information, raw-material or production and process revision, and installation of proper air-cleaning equipment. Regulatory persuasion and, if necessary, legal action would follow.

Source Control

Processes that are sources of air pollution include chemical reaction, evaporation, crushing and grinding, drying and baking, and combinations of these operations.

For stationary combustion installations, such as fossil-fuel-fired electric generating stations and plants generating steam for space heating or processes, the amounts and types of pollutants can be kept to a minimum using a fuel with less air pollution potential. Some examples of the types and amounts of contaminants from different types of fuels are given in Table 6-8. As can be seen, sulfur dioxide is a major pollutant in all fuels. Its removal for health and environmental (acid rain) reasons has a high priority.

Processes can also be designed and modified to reduce waste and the pollutants produced at the source. This has been a fundamental step in the reduction of industrial wastewater pollution and can certainly be applied to air pollution control.

The internal combustion engine is a major producer of air pollutants. A change from gasoline to another fuel or a major improvement in the efficiency of the gasoline engine would attack that problem at the source. Inspection of cars and light trucks for compliance with exhaust emissions standards can significantly reduce hydrocarbon and carbon monoxide levels in the ambient air. Heavy-duty gasoline trucks also add a large percentage of carbon mon-

TABLE 6-7 Comparison of PSI Values with Pollutant Concentrations and Health Effects

		Pollutant Levels							
Index Value	Air Quality Level	$PM_{2.5}$, 24 hr ($\mu g/m^3$)	SO_2, 24 hr (ppm)	CO, 8 hr (ppm)	O_3, 8 hr (ppm)	NO_2, 1 hr (ppm)	Health Effect Descriptor	General Health Effects	Cautionary Statements
500	Significant harm	500	1.004	50.4	—	2.04	Hazardous	Premature death of ill and elderly. Healthy people will experience adverse symptoms that affect their normal activity.	All persons should remain indoors, keeping windows and doors closed. All persons should minimize physical exertion and avoid traffic.
400	Emergency	350	0.804	40.4	—	1.64	Hazardous	Premature onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons.	Elderly and persons with existing diseases should stay indoors and avoid physical exertion. General populations should avoid outdoor activity.
300	Warning	250	0.604	30.4	0.374[a]	1.24	Very unhealthful	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population.	Elderly and persons with existing heart or lung disease should stay indoors and reduce physical activity.
200	Alert	150.4	0.304	15.4	0.124	0.65	Unhealthful	Mild aggravation of symptoms in susceptible persons, with irritation symptoms in the healthy population.	Persons with existing heart or respiratory ailments should reduce physical exertion and outdoor activity.
100	Moderate	40.4	0.144	9.4	0.084	[b]	Moderate		
50	Good	15.4	0.034[c]	4.4	0.064	[b]			

Source: Guideline for Public Reporting of Daily Air Quality—Pollutant Standards Index (PSI), EPA 454/R-99-010, U.S. Enironmental Protection Agency, Office of Air Quality Planning and Standards (OAQPS), Research Triangle Park, NC, 1999, Table 7, p. 13.

[a] When 8-hr O_2 concentrations exceed 0.374 ppm, air quality index (AQI) values of 301 or higher must be calculated with 1-hr O_3 concentrations.

[b] NO_2 has no short-term NAAQS and can generate an AQI only above AQI value of 200.

[c] Annual primary National Ambient Air Quality Standards (NAAQS); see Table 6-5.

TABLE 6-8 Uncontrolled Contaminant Emissions (lb/10⁶ Btu of Fuel)[a]

Contaminant	Bituminous Coal[b]	Anthracite Coal	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas
Solids	0.39 (A)[c]	0.39 (A)	0.112	0.085	0.018
SO_2	1.52 (S)[d]	1.52 (S)	1.046 (S)	1.120 (S)	0.006
NO_2	0.82	0.70	0.439	0.365	0.200
Organics, volatile organic carbon	0.003	0.003	0.020	0.021	0.020
Organic acids	1.150	0.595	0.714	0.765	0.003
Aldehydes	<0.001	<0.001	0.007	0.014	0.005
NH_3	0.078	0.040	0.047	0.050	0.020
CO	0.023	0.023	0.001	0.014	0.004

Source: From E. W. Davis, Division of Air Resources, New York State Department of Environmental Conservation, Albany, NY, personal communication, 1990. An extensive collection of emission factors is available from the EPA AP-42 at http://www.epa.gov/ttn/chief/ap42/index.html.

[a] Typical fuel values:
Bituminous coal = 25.629 m $\times$ 10^6 Btu/ton
Anthracite coal = 25.721 m $\times$ 10^6 Btu/ton
Residual fuel oil = 149.7 m $\times$ 10^6 Btu/10^6 gal
Distillate fuel oil = 138.7 m $\times$ 10^6 Btu/10^6 gal
Natural gas = 1029 Btu/ft^3

[b] Utility.

[c] Contaminant emission in pounds = 0.0630 $\times$ (A), where (A) is ash content in percent.

[d] Contaminant emission in pounds = 1.407 $\times$ (S), where (S) is sulfur content in percent.

oxide and hydrocarbons; however, their reduction will require phasing out old trucks and catalytic converter installation on new trucks. Reducing the lead content of gasoline and capturing gasoline evaporation during handling from filling stations, petroleum storage tanks, auto tanks, and carburetors are other means of source control. Improved mass transit, use of bus lanes, reduced travel by personal car, better traffic control for faster vehicle travel, and less stop-and-go are other means to reduce emissions.

Significant air pollution control can be achieved by process and material changes, recovery and recycling of waste materials, or product recovery, as by collection of combustion product particles of value.

Proper design of basic equipment, provision of adequate solid waste collection service, elimination of open burning, and the upgrading or elimination of inefficient apartment house, municipal, institutional, and commercial incinerators also attack the problem at the source.

Proper operation and maintenance of production facilities and equipment will often not only reduce air pollution but also save money. For example, air–fuel ratios can determine the amount of unburned fuel going up the stack, combustion temperature can affect the strain placed on equipment when operated beyond rated capacity, and the competency of supervision can determine the quantity and type of pollutants released and the quality of the product.

Emission Control Equipment

Municipal waste incinerators can emit hazardous levels of dioxins and other organic chemicals, metals, and acid gases if not regulated. In view of this, the EPA is requiring strict controls on air emissions from such facilities.[46] In addition to dioxins, the organics include furans, chlorobenzenes, chlorophenols, formaldehyde, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls. The metals are arsenic, beryllium, cadmium, chromium, lead, and mercury. The EPA believes that proper incinerator combustion, acid gas scrubber, and particulate removal can achieve 99 percent or greater reduction of dioxins and furans, 95 percent or greater reduction of organics, 90 percent or greater reduction of hydrogen chloride, and 97 to 99 percent reduction of metals.

Emission control equipment is designed to remove or reduce particulates, aerosols (solids and liquid forms), and gaseous byproducts from various sources and, in some instances, emissions resulting from inefficient design and operation.

The operating principles of aerosol collection equipment include

1. inertial entrapment by altering the direction and velocity of the effluent;
2. increasing the size of the particles through conglomeration or liquid mist entrainment to subject the particles to inertial and gravitational forces within the operational range of the control device;
3. impingement of particles on impact surfaces, baffles, or filters; and
4. precipitation of contaminants in electrical fields or by thermal convection.[47]

The collection of gases and vapors is based on the particular physical and chemical properties of the gases to be controlled.

Particulate Collectors and Separators

Some of the more common collectors and separators are identified below. These have application in mechanical operations for dust control such as in pulverizing, grinding, blending, woodworking, and handling flour as well as at power stations, incinerators, cement plants, heavy metallurgical operations, and other dusty operations. In general, collector efficiencies increase with particle size and from a low efficiency with baffled settling chambers, increasing with cyclones, electrostatic precipitators, spray towers, scrubbers, and baghouses, depending also on design, operation, and combinations of collectors used.

Settling chambers cause velocity reduction, usually to slower than 10 fps, and the settling of particles larger than 40 μm in diameter in trays that can be removed for cleaning. Special designs can intercept particles as small as 10 μm.

Cyclones impose a downward spiraling movement on the tangentially directed incoming dust-laden gas, causing separation of particles by centrifugal force and collection at the bottom of the cone. Particle sizes collected range from 5 to 200 μm at gas flows of 30 to 25,000 ft^3/min. Removal efficiency below 10 μm particle size is low. Cyclones can be placed in series or combined with other devices to increase removal efficiency. See Figures 6-4 and 6-5.

Sonic collectors can be used to facilitate separation of liquid or solid particles in settling chambers or cyclones. High-frequency sound pressure waves cause particles to vigorously vibrate, collide, and coalesce. Collectors can be designed to remove particles smaller than 10 μm.

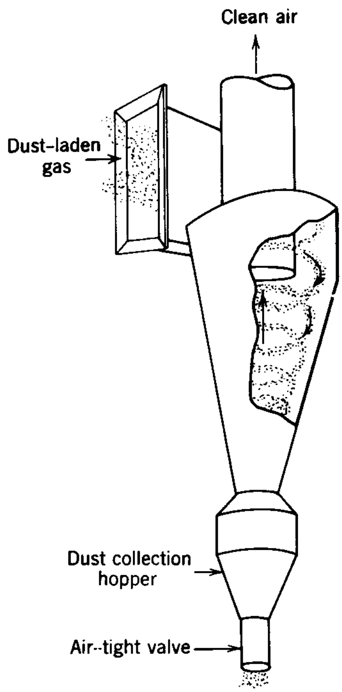

Figure 6-4 Flow of dust through cyclone. (Adapted from *Air Pollution Control Field Operations Manual,* PHS Pub. No. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

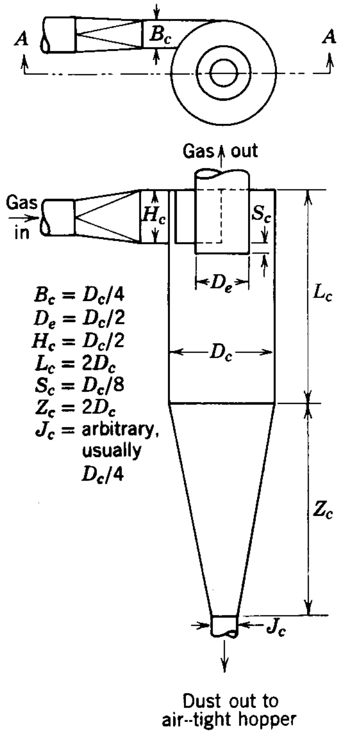

Figure 6-5 Diagram of cyclone separator. (*Source: Air Pollution Control Field Operations Manual,* PHS Pub. No. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

Filters are of two general types: the baghouse and cloth screen. The filter medium governs the temperature of the gas to be filtered, particle size removed, capacity and loading, and durability of the filter. Filter operating temperatures vary from about 200°F (93°C) for wool or cotton to 450 to 500°F (232–260°C) for glass fiber.

A *baghouse filter* is shown in Figure 6-6. The tubular bags are 5 to 18 in. in diameter and from 2 to 30 ft in length. The dust-laden gas stream to be filtered passes through the bags where the particles build up on the inside and, in so doing, increase the filtering efficiency. Periodic shaking of the bags (tubes) causes the collected dust to fall off and restore the filtering capacity. The baghouse filter has particular application in cement plants, heavy metallurgical operations, and other dusty operations. Efficiencies exceeding 99 percent and particle removal below 10 μm in size are reported, depending on the major form and buildup. Baghouses are usually supplemented by scrubber systems.

Cloth-screen filters are used in the smaller grinding, tumbling, and abrasive cleaning operations. Dust-laden air passes through one or more cloth screens

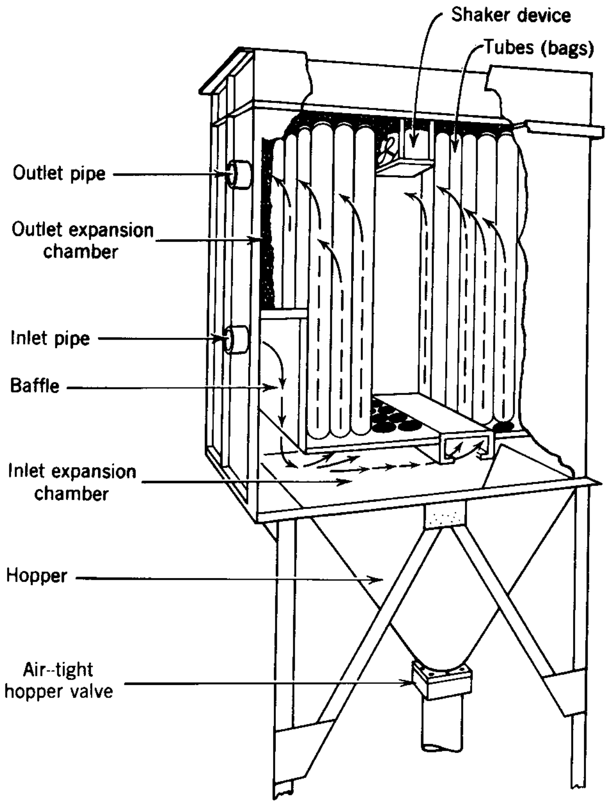

Figure 6-6 Simplified diagram of a baghouse. (*Source: Air Pollution Control Field Operations Manual,* PHS Pub. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

in series. The screens are replaced as needed. Other types of filters use packed fibers, filter beds, granules, and oil baths.

Electrostatic precipitators have application in power plants, cement plants, and incinerators as well as in metallurgical, refining, and heavy chemical industries for the collection of fumes, dusts, and acid mists. Particles, in passing through a high-voltage electrical field, are charged and then attracted to a plate of the opposite charge where they collect. The accumulated material falls into a hopper when vibrated. See Figure 6-7.

The gases treated may be cold or at a temperature as high as 1100°F (593°C), but 600°F (316°C) or less is more common, typically 280 to 300°F (138–149°C). Precipitators are efficient for the collection of particles less than 0.5 μm in size; hence, cyclones and settling chambers, which are better for the removal of larger particles, are sometimes used ahead of precipitators. Single-stage units operate at voltages of 25,000 V or higher; two-stage units

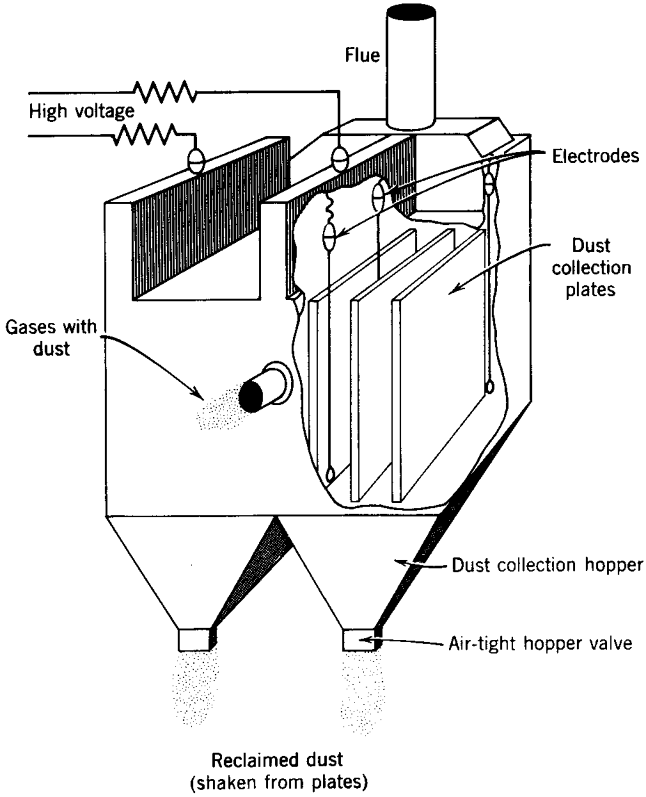

Figure 6-7 Diagram of plate-type electrostatic precipitator used to collect catalyst dust. (Adapted from *Air Pollution Control Field Operations Manual,* PHS Pub. 937, Department of Health, Education and Welfare, Washington, DC, 1962.)

(used in air conditioning) operate at 12,000 V in the first or ionizing unit and at 6000 V in the second collection unit.

Electrostatic precipitators are commonly used at large power stations and incinerators to remove particulates from flue gases. Particulate removal of at least 98 to 99 percent can be achieved. They are considered one of the most effective devices for this purpose. Flue gases may be cooled by water spray, air cooling, or passage through a boiler.

Scrubbers are of different types, selected for specific applications. They include spray towers, ejector venturis, venturi scrubbers, and packed-bed, plate, moving-bed, centrifugal, impingement, and entrainment types. See Figures 6-8 and 6-9.

Wet collectors are generally used to remove gases such as hydrogen chloride, nitrous oxides, and sulfur dioxide and particles that form as a dust, fog, or mist. A high-pressure liquid spray is applied to the gas passing through the washer, filter, venturi, or other device. In so doing, the gas is cooled and

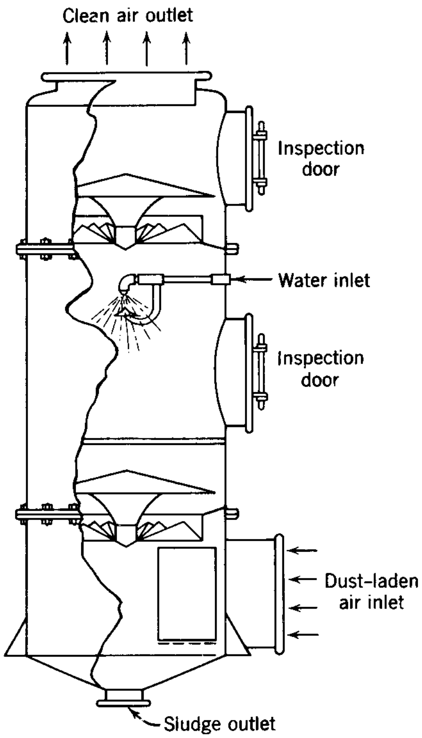

Figure 6-8 Centrifugal wash collector. (*Source: Air Pollution Control Field Operations Manual,* Department of Health, Education, and Welfare, Washington, DC, 1962.)

cleaned. Although water is usually used as the spray, a caustic may be added if the gas stream is acidic. Where the spray water is recirculated, corrosion of the scrubber, fan, and pump impeller can be a serious problem. Particle size collected may range from 40 μm to as low as 1 μm with efficiency as high as 98 to 99 percent, depending on the collector design. Required removal efficiencies for hydrogen chloride, sulfur dioxide, and hydrogen fluoride can usually be met.

Controls for sulfur dioxide emissions include wet and dry flue gas desulfurization and fuel switching and physically cleaning coal. Nitrogen oxide emissions can be controlled by special burners or by catalytic or selective noncatalytic reduction. A "duct injection" technology (dry scrubber) is being emphasized by the Department of Energy (DOE) to reduce sulfur dioxide emissions from existing coal-fired power plants: "Lime is sprayed into existing ductwork located just after the combustion chamber. Fly ash in the exhaust stream reacts with the small pieces of lime, then with sulfur oxides and is finally captured by a filter fabric" (ref. 48, pp. 45–46).

For every ton of sulfur removed, 3 to 6 tons of sludge from wet scrubbers will require safe disposal.

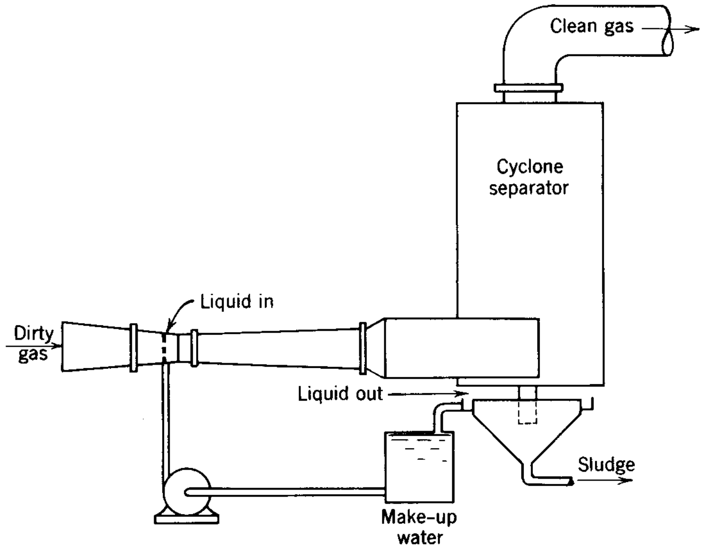

Figure 6-9 Venturi scrubber. (*Source: Air Pollution Control Field Operations Manual,* PHS Pub. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

Gaseous Collectors and Treatment Devices

The release of gases and vapors to the atmosphere can be controlled by combustion, condensation, absorption, and adsorption. Combustion devices include thermal afterburners, catalytic afterburners, furnaces, and flares.

Thermal afterburners are used to complete the combustion of unburned fuel, such as smoke and particulate matter, and to burn gaseous hydrocarbons and odorous combustible gases. Apartment house and commercial incinerators and meat-packing plant smokehouses are examples of smoke and particulate emitters. Rendering, packing house, refinery, and paint and varnish operations; fish processing; and coffee roasting are examples of odor-producing operations. Afterburners usually operate at around 1200°F (649°C) but may range from 900 to 1600°F (482–871°C) depending on the ignition temperature of the contaminant to be burned.

Catalytic afterburners may be used for the burning of lean mixtures of combustible gaseous air contaminants. They are also used to reduce nitrous oxides, with ammonia injection.

Condensers are best used to remove vapors by condensation, generally prior to passage to other air pollution control equipment, thus reducing the load on this equipment. Condensers are of the surface and contact types. In the surface condenser, the vapor comes into contact with a horizontal cool surface and condenses to form liquid droplets with a pure saturated vapor or, more commonly, a film. In the contact condenser, the coolant, vapors, and condensate are all in intimate direct contact.

Adsorbers are of the fixed-bed stationary or rotating type, in horizontal or vertical cylinders, usually with activated-carbon beds or supported screens, through which the gas stream passes. In adsorption, the molecules of a fluid such as a gas, liquid, or dissolved substance to be treated are brought into contact with the adsorbent, such as activated carbon, aluminas, silicates, char, or gels that collect the contaminant in the pores or capillaries. The material adsorbed is called the adsorbate. In some cases, the adsorbent, such as activated carbon, is regenerated by superheated steam at about 650°F (343°C); the contaminant is condensed and collected for proper disposal. In other cases, the adsorbent and adsorbate are separated from the fluid and discarded. Solid adsorbents have very large surface-to-volume ratios and different adsorptive abilities, depending on the particular adsorbate. The life of an activated-carbon adsorption bed is reduced if particulate matter is not first removed.

In *absorption*, the gaseous emission to be treated is passed through a packed tower, spray or plate tower, and venturi absorbers, where it comes in contact with a liquid absorbing medium or spray that selectively dissolves or reacts with the air contaminants to be removed. For example, oxides of nitrogen can be absorbed by water; hydrogen fluoride, by water or an alkaline water solution. Absorption is generally also used to control emissions of sulfur dioxide, hydrogen sulfide, hydrogen chloride, chlorine, and some hydrocarbons. Lime injection controls acid gas emissions from incinerators.

Vapor conservation equipment is used to prevent vapors escaping from the storage of volatile organic compounds such as gasoline. A storage tank with a sealed floating roof cover or a vapor recovery system connected to a storage tank is used. Vapors that can be condensed are returned to the storage tank.

Dilution by Stack Height

Since wind speed increases with height in the lower layer of the atmosphere, the release of pollutants through a tall stack enhances the transport and diffusion of the material. The elevated plume is rapidly transported and diffused downwind. This generally occurs at a rate faster than that of the diffusion toward the ground. The resulting downwind distribution of pollutant concentrations at the ground level is such that concentrations are virtually zero at the base of the stack, increase to a maximum at some downwind distance, and then decrease to negligible concentrations thereafter. This distribution and the difference due to stack height are shown schematically in Figure 6-10. This applies to uncomplicated weather and level terrain. Obviously, if the plume is transported to hill areas, the surfaces will be closer to the center of the plume and hence will experience higher concentrations.

Meteorological conditions will determine the type of diffusion the pollutant plume will follow. See Figure 6-3. With heavy atmospheric turbulence associated with an unstable lapse rate, the plume will "loop" as it travels downwind. With lesser turbulence associated with a neutral lapse rate, the plume will form a series of extended, overlapping cones called "coning." With stable air conditions and little turbulence associated with an inversion, the plume

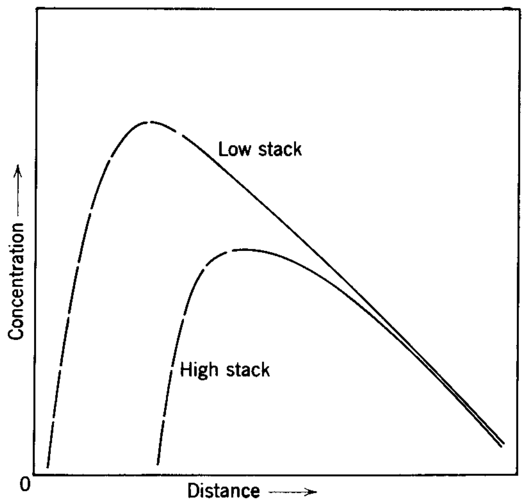

Figure 6-10 Variation of ground-level pollutant concentration with downwind distance. (The distance may be hundreds of miles.)

will "fan" out gradually. With the discharge of a plume below an inversion, the plume will be dispersed rapidly downward to the ground surface, causing "fumigation." With the discharge of a plume within the inversion layer, the plume will spread out horizontally as it moves downwind with little dispersion toward the ground. Erratic weather conditions can cause high concentrations of pollutants at ground level if the plume is transported to the ground.

It has been general practice to use high stacks for the emission of large quantities of pollutants, such as in fossil-fueled power production, to reduce the relatively close-in ground-level effects of the pollutants. Stacks of 250 to 350 ft in height are not unusual, and some are as high as 800 to 1250 ft. It should be recognized, however, that there is a practical limit to height beyond which cost becomes excessive and the additional dilution obtained is not significant. There may also be legal permitting restrictions on the maximum stack height.

Although local conditions are improved where a tall stack is used, adverse environmental effects continue to be associated with the distant (long-range) transport of pollutants. For example, the pollutants contribute to acid rain, heavy-metal particle deposition, and toxic metal dissolution from surrounding or downwind soils and rocks into surface and groundwaters, which adversely affect the flora and fauna hundreds or more miles away (as previously noted). Therefore, emphasis should be placed on reduction of emission concentrations, rather than on dispersion from a tall stack, to improve ambient air quality. The EPA is also considering requiring pollution control devices on tall stacks and limiting tall stacks for emission dispersion by requiring removal instead.

Planning and Zoning

The implementation of planning and zoning controls requires professional analysis and the cooperation of the state and regional planning agencies and the local county, city, village, and town units of government.

The local economic, social, and political factors may limit what can realistically be achieved in many instances. For example, a combination of factors, including planning and zoning means, should be considered in locating a new plant. These means could include plant siting downwind from residential, work, and recreational areas, with consideration given to climate and meteorological factors, frequency of inversions, topography, air movement, stack height, and adjacent land uses. Additional factors are distance separation, open-space buffers, designation of industrial areas, traffic and transportation control, and possible regulation of plant raw materials and processes. All these controls must recognize the present and future land use and especially the air quality needed for health and comfort, regardless of the land ownership.

The maintenance of air quality that meets established criteria requires regulation of the location, density, and/or type of plants and plant emissions that could cause contravention of air quality standards. This calls for local and regional land-use control and cooperation to ensure that the permitted construction of plants would incorporate practices and control equipment that would not emit pollution that could adversely influence the air quality of the community in the airshed. See Tables 6-6 and 6-7 and Ambient Air Quality Standards, this chapter.

Monitoring of the air at carefully selected locations would continually inform and alert the regulatory agency of the need for additional source control and enforcement of emission standards. Conceivably, under certain unusually adverse weather conditions, a plant may have to take previously planned emergency actions to reduce or practically eliminate emissions for a period of time.

Air zoning establishes different air quality standards for different areas based on the most desirable and feasible use of land. As discussed earlier in this chapter, the 1977 amendments to the Clean Air Act allow each state to classify air areas as either class I, II, or III. Class I areas would remain virtually unchanged and class III could permit intensive industrial activity. Specific standards are established for each classification level. In all levels, however, protection of the public health is paramount. Insofar as air zoning is concerned, an industry should be able to choose its location and types of emission controls provided the air quality standards are not violated.

Although air zoning provides a system or basis for land use and development, sound planning can assist in greatly minimizing the effects of air pollution. A WHO Expert Committee suggests the following:[49]

1. The siting of new towns should be undertaken only after a thorough study of local topography and meteorology.

2. New industries using materials or processes likely to produce air contaminants should be so located as to minimize the effects of air pollution.
3. Satellite (dormitory) towns should restrict the use of pollution-producing fuels.
4. Provision should be made for greenbelts and open spaces to facilitate the dilution and dispersion of unavoidable pollution.
5. Greater use should be made of hydroelectric and atomic power and of natural gas for industrial processes and domestic purposes, thereby reducing the pollution resulting from the use of conventional fossil fuels.
6. Greater use should be made of central plants for the provision of both heat and hot water for entire (commercial or industrial) districts.
7. As motor transport is a major source of pollution, traffic planning can materially affect the level of pollution in residential areas.

It is apparent that more needs to be learned and applied concerning open spaces, bodies of water, and trees and other vegetation to assist in air pollution control. For example, parks and greenbelts appear to be desirable locations for expressways because vegetation, in the presence of light, will utilize the carbon dioxide given off by automobiles and release oxygen. In addition, highway designers must give consideration to such factors as road grades, speeds and elevations, natural and artificial barriers, interchange locations, and adjacent land uses as means of reducing the amounts and effects of automobile noise and emissions.

Air Quality Modeling

It is possible to calculate and predict, *within limits,* the approximate effects of existing and proposed air pollution sources on the ambient air quality.[50–53] A wide variety of models are used to estimate the air quality impacts of sources on receptors, to prepare or review new industrial and other source applications, and to develop air quality management plans for an area or region.

Air quality models can be categorized into four classes.

1. *Gaussian* Most often used for estimating the ground-level impact of nonreactive pollutants from stationary sources in a smooth terrain.
2. *Numerical* Most often used for estimating the impact of reactive and nonreactive pollutants in complex terrain.
3. *Statistical* Employed in situations where physical or chemical processes are not well understood.
4. *Physical* Involves experimental investigation of source impact in a wind tunnel facility.

Because of the almost limitless variety of situations for which modeling may be employed, no single model can be considered "best." Instead, the user is encouraged to examine the strengths and weaknesses of the various models available and select the one best suited to the particular job at hand.

The EPA has made a number of models available to the general public through its User's Network for Applied Modeling of Air Pollution (UNAMAP). These models can be obtained from the National Technical Information Service (NTIS).

The information needed to use an air quality model includes source emission data, meteorological data, and pollutant concentration data.

Source Emission Data Sources of pollutants can generally be classified as point, line, or area sources. Point sources are individual stacks and are identified by location, type and rate of emission, and stack parameters (stack height, diameter, exit gas velocity, and temperature). Line sources are generally confined to roadways and can be located by the ends of roadway segments. Area sources include all the minor point and line sources that are too small to require individual consideration. These sources are usually treated as a grid network of square areas, with pollutant emissions totaled and distributed uniformly within each grid square.

Meteorological Data The data needed to represent the meteorological characteristics of a given area consist of (as a minimum) wind direction, wind speed, atmospheric stability, and mixing height. The representativeness of the data for a given location will be dependent upon the proximity of the meteorological monitoring site to the area being studied, the period of time during which data are collected, and the complexity of terrain in the area. Local universities, industries, airports, and government agencies can all be used as sources of such data.

Pollutant Concentration Data In order to assess the accuracy of a model for a particular application, predicted concentrations must be compared against observed values. This can be done by obtaining historical pollutant concentration data from air quality monitors located in the study area. Air quality data from monitors located in remote areas should also be obtained to determine if a background concentration should be included in the model. Data should be verified using appropriate statistical procedures.

The accuracy of the model used depends upon the following factors:

1. How closely do the assumptions upon which the model is based correspond to the actual conditions for which the model is being used? For example, a model that assumes that the area being modeled is a flat plain of infinite extent may work well in Kansas but not in Wyoming.

2. How accurate is the information being used as input for the model? Of particular importance here is verifying the accuracy of source emission data. Some points to consider are as follows:
   a. Should the source emission data be given in terms of potential, actual, or allowable emissions? ''Actual'' emissions should always be used for model verification.
   b. Does emission rate vary by time of day or time of year?
   c. What level of production, percent availability, and so on should be assumed for each emission source? The emission rates for industrial sources will often decline significantly during periods of economic recession. Similarly, stationary fuel combustion sources (for space heating) will vary according to the severity of the winter.
   d. Are stack parameters correct? Are there nearby structures or terrain features that could influence the dispersion patterns of individual sources?
   e. Is the source location correctly identified?
   f. How reliable is the pollution control equipment installed on each emission source?

The user will often find that the job of verifying the input data is the most difficult and time-consuming part of the modeling process.

As the cost of computer services continues to decline, it is expected that air quality modeling will become an available technology for smaller agencies such as local health and planning departments. The person who performs this modeling will have to be knowledgeable not only in traditional air pollution control engineering but also in the fields of air pollution meteorology and computer programming.

PROGRAM AND ENFORCEMENT

General

A program for air resources management should be based on a comprehensive areawide air pollution survey including air sampling, basic studies and analyses, and recommendations for ambient air quality standards. The study should be followed by an immediate and long-term plan to achieve the community air quality goals and objectives, coupled with a surveillance and monitoring system and regulation of emissions.

MacKenzie proposes the following conclusions and decisions for the implementation of a study[46]:

1. Select air quality standard, possibly with variations in various parts of the area.

2. Cooperate with other community planners in allocating land uses.
3. Design remedial measures calculated to bring about the air quality desired. Such measures might include several or all of the following: limitations on pollutant emissions, variable emission limits for certain weather conditions and predictions, special emission limits for certain areas, time schedules for commencing certain control actions, control of fuel composition, control of future sources by requiring plan approvals, prohibition of certain plan approvals, prohibition of certain activities or requirements for certain types of control equipment, and performance standards for new land uses.
4. Outline needs for future studies pertaining to air quality and pollutant emissions and design systems for collection, storage, and retrieval of the resultant data.
5. Establish priorities among program elements and set dates for implementation.
6. Prepare specific recommendations as to administrative organization needed to implement the program, desirable legislative changes, relationships with other agencies and programs in the area and adjoining areas and at higher governmental levels, and funds, facilities, and staff required.

As in most studies, a continual program of education and public information supplemented by periodic updating is necessary. People must learn that air pollution can be a serious hazard and must be motivated to support the need for its control. In addition, surveys and studies must be kept current; otherwise, the air resources management activities may be based on false or outdated premises.

International treaties, interstate compacts or agreements, and regional organizations are sometimes also needed to resolve air pollution problems that cross jurisdictional boundaries. This becomes more important as industrialization increases and as people become more concerned about the quality of their environment.

It becomes apparent that the various levels of government each have important complementary and cooperative roles to play in air pollution control.

The federal government role includes research into the causes and effects of air pollution as well as the control of international and interstate air pollution on behalf of the affected parties. It should also have responsibility for a national air-sampling network, training, preparation of manuals and dissemination of information, and assisting state and local governments. In the United States, this is done primarily through the EPA. Other federal agencies making major contributions are the U.S. Weather Service; the Nuclear Regulatory Commission, in relation to the effects of radioactivity; the Department of Agriculture, in relation to the effects of air pollution on livestock and crops;

the Department of Interior; the Department of Commerce, including the National Bureau of Standards; and the Civil Aeronautics Administration.

The state role is similar to the federal role. It would include, in addition, the setting of statewide standards and establishment of a sampling network, the authority to declare emergencies and possession of appropriate powers during emergencies, the delegation of powers to local agencies for control programs, and the conducting of surveys, demonstration projects, public hearings, and special investigations.

The role of local government is that delegated to it by the state and could include complete program implementation and enforcement.

Organization and Staffing

Organization and staffing will vary with the level of government, the legislated responsibility, funds provided, government commitment, extent of the air pollution, and other factors. Generally, air pollution programs are organized and staffed on the state, county, large-city, and federal levels. In some instances, limited programs of smoke and nuisance abatement are carried out in small cities, towns, and villages as part of a health, building, or fire department program. Because of the complexities involved, competent direction, staff, and laboratory support are needed to carry out an effective and comprehensive program. A small community usually cannot afford and, in fact, might not have need for a full staff, but it could play a needed supporting role to the county and state programs. In this way, uniform policy guidance and technical support could be provided and local on-the-spot assistance utilized. The local government should be assigned all the responsibilities it is capable of handling effectively.

An organization chart for an air resources management agency is shown in Figure 6-11. There are many variations.

Regulation and Administration

A combination of methods and techniques is generally used to prevent and control air pollution after a program is developed, air quality objectives established, and problem areas defined. These include

1. public information and education;
2. source registration;
3. plan review and construction operation approval;
4. emission standards;
5. monitoring and surveillance;
6. technical assistance and training;
7. inspection and compliance follow-up;

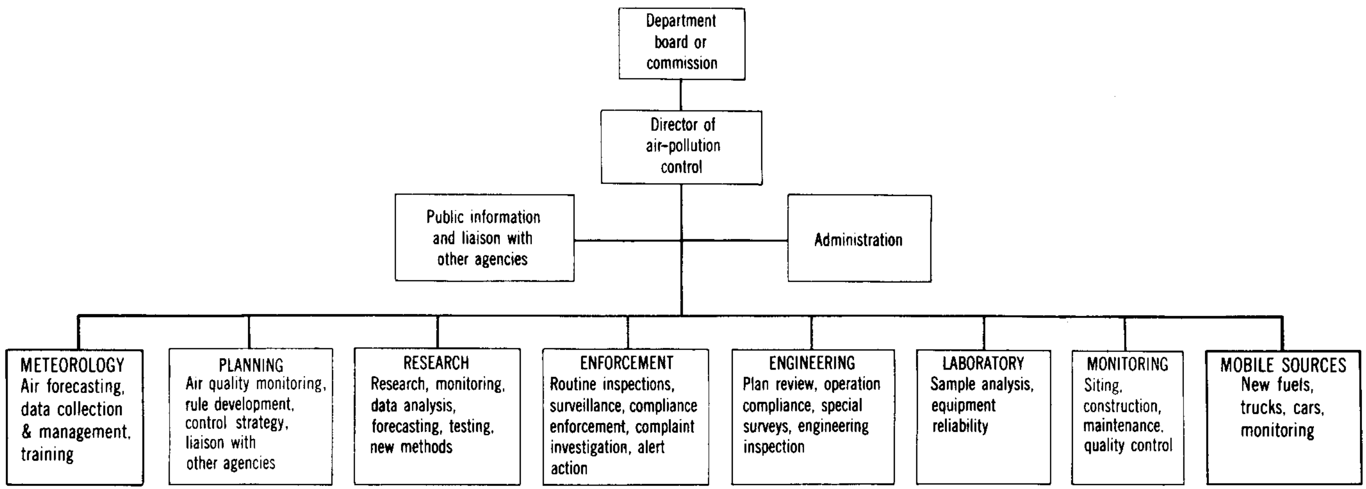

Figure 6-11 Air resources management functional organization chart.

8. conference, persuasion, and administrative hearing;
9. rescinding or suspension of operation permit; and
10. legal action—fine, imprisonment, misdemeanor, injunction.

Effective administration requires the development and retention of competent staff and the assignment of responsibilities. In a small community, the responsibilities would probably be limited to source location and surveillance, data collection, smoke and other visible particulate detection, complaint investigation, and abatement as an arm of a county, regional, or state enforcement unit.

Regulatory agencies usually develop their own procedures, forms, and techniques to carry out the functions listed above. Staffing, in addition to the director of air pollution control, may include one or more of the following: engineers, scientists, sanitarians, chemists, toxicologists, epidemiologists, public information specialists, technicians, inspectors, attorneys, administrative assistants, statisticians, meteorologists, electronic data processing specialists, and personnel in supporting services.

Detailed information on inspection and enforcement is given in the literature. *Air Pollution Field Operations Manual* Additional information is also given in Chapter 12 of the fourth edition.

Important in regulation is the development of working relationships and memoranda of agreements with various public and private agencies. For instance, government construction, equipment, and vehicles could set examples of air pollution prevention. The building department would ensure that new incinerators and heating plants have the proper air pollution control equipment. The police would enforce vehicular air pollution control requirements. The fire department would carry out fire prevention and perhaps boiler inspections. The planning and zoning boards would rely on the director of air pollution control and the director's staff for technical support, guidance, and testimony at hearings. Equipment manufacturers would agree to sell only machinery, equipment, and devices that complied with the emission standards. The education department would incorporate air pollution prevention and control in its environmental health curriculum. Industry, realty, and chain-store management would agree to abide by the rules and police itself. Cooperative training and education programs would be provided for personnel responsible for operating boilers, equipment, and other facilities that may contribute to air pollution. These are but a few examples. With ingenuity, many more voluntary arrangements can be devised to make regulation more acceptable and effective.

NOISE CONTROL

One of the most important tasks of architects, builders, acoustic engineers, urban planners, industrial hygiene engineers, equipment manufacturers, and public health personnel is to ensure that noise and vibration are kept to an acceptable level in the general environment, in the workplace, and inside dwellings. Noise is of special concern in occupational health where hearing loss has been documented.

The discussion that follows will touch upon some of the fundamentals of noise and its effects, measurement, reduction, and control. Special problems should involve experts such as acoustical consultants.

Definitions and Explanation of Selected Terms and Properties of Sound

Sound Sound, and therefore all noise, is physically a rapid alteration of air pressure above and below atmospheric pressure. Basically, all sounds travel as sound pressure waves from a vibrating body such as a human larynx, radio, TV, record player speaker, or vibrating machine.

A sound that contains only one frequency is a *pure tone,* which is expressed in Figure 6-12 as a sine curve. Most sounds contain many frequencies. In general, the waves travel outward from the source in three dimensions. The *pitch* of a sound is determined primarily by frequency: vibrations per second. The amplitude or magnitude of sound is the *sound pressure*.

The distance that a sound wave travels in one cycle or period is the wavelength of the sound. This is illustrated in Figure 6-12. Wavelength is given by the equation

$$\lambda = \frac{c}{f}$$

where λ = wavelength, ft
f = frequency, Hz (cycles/sec)
c = speed of sound, ft/sec

Sound travels through gases, liquids, and solids but not through a vacuum. The speed with which sound travels through a particular medium is dependent

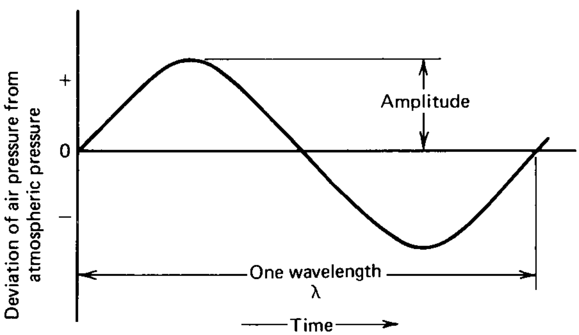

Figure 6-12 Pure tone, sine wave.

on the compressibility and density of the medium. Our own voice reaches us primarily through the bony structures in our head. Most sound reaches us through the air and less frequently through solids and liquids. The speed of sound through various media is given in Table 6-9.

As sound travels through a medium, it loses energy or amplitude in two ways: molecular heating and geometric spreading. For example, drapes absorb sound, releasing the energy as heat to the surrounding air. Air itself also absorbs sound to a smaller degree because it is not perfectly elastic. Plane waves emitted from a large distant source travel in a plane or front perpendicular to their direction of travel. There is no geometric spreading or energy loss in plane waves, neglecting molecular heating. Spherical waves, resulting from a small vibrating sphere in close proximity, spread in three dimensions. They lose energy according to the inverse square law, given by

$$I_{\text{ave}} = \frac{W}{4\pi r^2}$$

where I = sound intensity, watts/cm^2
r = distance to the source, cm
W = total source power, watts

TABLE 6-9 Speed of Sound in Various Media

	Speed	
Media	m/s	fps
Air, 69.8°F (21°C)	344	1,129
32°F (0°C)	331	1,086
Alcohol	1,213	3,980
Lead	1,220	4,003
Hydrogen, 32°F (0°C)	1,269	4,164
Water, fresh	1,480	4,856
Water, salt, 69.8°F (21°C), at 3.5% salinity	1,520	4,987
Human body	1,558	5,112
Plexiglas	1,800	5,906
Wood, soft	3,350	10,991
Concrete	3,400	11,155
Fir timber	3,800	12,468
Mild steel	5,050	16,570
Aluminum	5,150	16,897
Glass	5,200	17,061
Gypsum board	6,800	22,310
Copper	3,901	12,800
Brick	4,176	13,700

Source: A. J. Schneider, *Noise and Vibration Rocket Handbook,* Bruel & Kjaer, Cleveland, OH, p. 18; *IAC Noise Control Handbook,* Industrial Acoustics Co., New York, NY, 1982, p. A-6.

For every doubling of distance, the intensity is reduced by a factor of 4, or 6 dB. The sound from an infinite line source spreads geometrically in two dimensions so that energy is halved, or loses 3 dB, when the source distance doubles. When reflecting objects are near, a more complex sound field results.

Noise Noise is unwanted sound. It may be unwanted for a variety of reasons: causing hearing loss, interfering with communication, causing loss of sleep, adversely effecting human physiology, or causing just plain annoyance.

Noise Pollution Noise pollution is the condition in which noise has characteristics and duration injurious to public health and welfare or unreasonably interferes with the comfortable enjoyment of life and property in such areas as are affected by the noise.

Ambient Noise Ambient noise is the total noise in a given situation or environment.

Noise Level Noise level is the weighted sound pressure level in dBA* obtained by the use of an approved type [American National Standards Institute (ANSI)] sound-level meter. See (a) Decibel and (b) Sound Pressure below and, under Measurement of Noise, Sound-Level Meter.

Frequency Frequency of sound is the number of times a complete cycle of pressure variation occurs in 1 sec, both an elevation and a depression below atmospheric pressure. The frequency of a sound determines its *pitch*. Frequency is expressed in hertz (Hz), which is the metric unit for cycles per second (cps). For example, sounds with a frequency of 30 Hz are considered very low pitch; sounds with a frequency of 15,000 Hz are very high pitch. A young healthy ear can detect frequencies over a range of about 20 to 20,000 Hz, but the most common sensitive hearing range is between 1000 and 6000 Hz. Normal speech is in the range of 250 to 3000 Hz. However, the audibility of sound is dependent on both frequency and sound pressure level. This is illustrated in Figure 6-13 for a typical group of Americans. Since most sounds are made up of several frequencies, a narrow-band analyzer is used to determine the various frequencies in a sound. Most sounds are in the sonic frequency range of 20 to 20,000 Hz. Ultrasonic range is 20,000 Hz and above; infrasonic range is 20 Hz and below. See Sound Analyzer and Octave-Band Analyzer under Measurement of Noise in this chapter.

Decibel Decibel (dB) is a dimensionless unit to express physical intensity or sound pressure levels. The starting or reference point for noise-level measurement is 0 dBA, the threshold of hearing for a young person with very

*The A-weighted scale approximates the frequency response of the human ear.

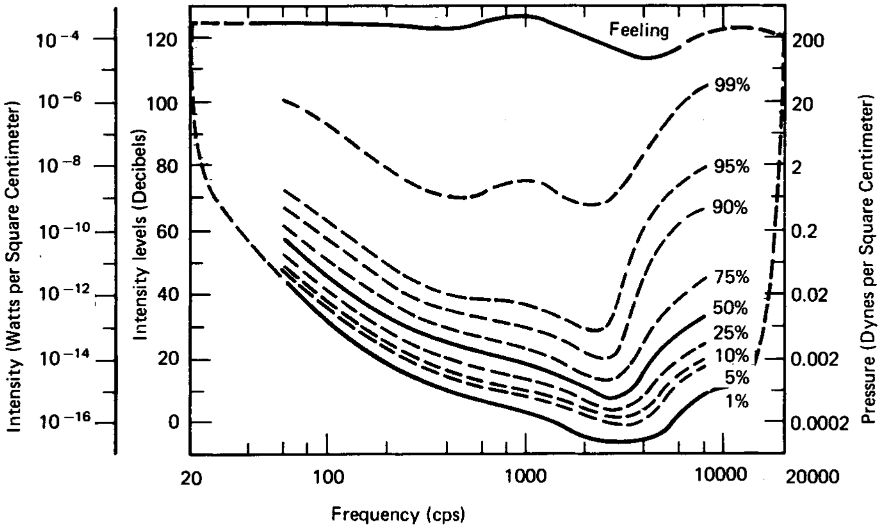

Figure 6-13 Absolute auditory threshold for a typical group of Americans. Curves are labeled by percent of group that could hear tones below the indicated level. (*Source: Toward a Quieter City,* A report of the Mayor's Task Force on Noise Control, New York, 1970.)

good hearing. The threshold of pain is 120 dBA. The decibel is one-tenth of the bel, a unit using common logarithms named for Alexander Graham Bell.

Sound Pressure The sound pressure level of a noise source is expressed by the relationship

$$\text{Sound pressure level (SPL) in dB} = 20 \log_{10} \frac{P}{P_0}$$

where P = pressure of measured sound, micropascals (μPa)
P_0 = sound pressure reference level of 20 μPa*; for measurements in air, this is the threshold of human hearing at 1000 Hz

A change in sound pressure level with distance from a source can be determined by

$$P_2 = P_1 - 20 \log \frac{d_2}{d_1}$$

*Equals 10^{-12} W for sound power and 10^{-12} W/m^2 for intensity, also 0.0002 dyn/cm^2, or 0.0002 μbar, or 0.00002 N/m^2 or 20 μN/m^2.

where P_1 = sound pressure level at location 1, dB
P_2 = sound pressure level at location 2, dB
d_1 = distance from noise source to location 1
d_2 = distance from noise source to location 2

The sound pressure level is measured by a standard sound-level meter. The meter has built into it electrical characteristics or weighting that simulates the way the ear actually hear sound.

Pascal (Pa) is a unit of pressure corresponding to a force of 1 N acting uniformly upon an area of 1 m^2; 1 Pa = 1 N/m^2.

Newton (N) is the force required to accelerate 1 kg mass at 1 m/s^2. It is approximately equal to the gravitational force on a 100*g* mass. The *A*-weighting, which simulates the frequency bias of the human ear, is most commonly used in measurements regarding impact on humans and the sound levels are read in dBA. The B, C, and D scales are normally used only for special occasions. For example, the D scale is used to measure and compare the effect of airplane noise on the human ear. The C scale is used for very loud sounds and the B scale for moderately loud sounds. See Sound-Level Meter under Measurement of Noise for further discussion.

Table 6-10 shows the calculated sound pressure levels in decibels for selected sound pressure values.

TABLE 6-10 Sound Pressures for Selected Decibel Values

Sound Pressure[a]		Sound Pressure Level
μbar	μPa	(dB)[b]
0.0002	20	0[c]
0.00063	63	10
0.002	200	20
0.0063	630	30
0.02	2,000	40
0.063	6,300	50
0.2	20,000	60
0.63	63,000	70
1.0	100,000	74
2.0	200,000	80
6.3	630,000	90
20	2,000,000	100
63	6,300,000	110
200	20,000,000	120
2,000	200,000,000	140

[a] 0.0002 microbars (μbar) for sound pressure in air = 20 μPa = 0.00002 N/m^2 (20 $\mu N/m^2$) = 2.9×10^{-9} psi = 0.0002 dyn/cm^2.
[b] Relative to 20 μPa or 0.0002 μbar = standard reference value.
[c] 0 dB = 2.9×10^{-9} psi = 10^{16} W/cm^2 = 10^{-12} W/m^2 for sound intensity = threshold of human hearing.

To add sound-level values, it is first necessary to convert each decibel reading to sound intensity using the formulas

$$\text{Sound intensity level in dB} = 10 \log_{10} \frac{I}{I_0}$$

$$= 10 \log_{10} \frac{I_1 + I_2}{I_0}$$

where I = unknown sound intensity, watts/m^2
I_0 = sound intensity reference base = 10^{-12} W/m^2
I_1 = sound intensity from source 1
I_2 = sound intensity from source 2

All sound intensities are added and then the sum is converted to a resultant decibel reading. A similar procedure is followed to subtract the numbers of decibels. For example, to add two sound levels dB_1 and dB_2, find the I_1 corresponding to dB_1; find I_2 corresponding to dB_2 and add to I_1 yielding I; then reconvert to decibels using the above formulas. This rather complex process is much simplified by use of Table 6-11. For example, consider the summation of a 50-dB sound with a 56-dB sound. For a difference of 6 dB, we find from Table 6-11 that 1 dB is added to the higher of the two sounds. The combined sound level is 57 dB. In adding several sound levels, start with the lowest.

Consider another example involving three noise sources. An industrial safety engineer wants to compute the total sound pressure level in a work area from the machinery nearby. An air compressor, a drill press, and venti-

TABLE 6-11 Approximate Increase When Combining Two Sound Levels

Difference between Levels (dB)	Decibels to Be Added to Higher Level
0	3.0
1	2.6
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
10	0.4
12	0.3
14	0.2
16	0.1

Source: A. C. Hosey (Ed.), *Industrial Noise, A Guide to Its Evaluation and Control,* PHS Pub. No. 1572, Department of Health, Education, and Welfare, Washington, DC, 1967.

lation fans contribute 85, 81, and 75 dB sound pressure levels, respectively. Starting with the lowest, according to Table 6-11, an 81-dB level and a 75-dB level sum to 82 dB. The 82-dB level and the 85-dB level sum to 86.8 dB. Note that if the 75-dB level were missing, the total would have been 86.5 dB, almost the same. A noise contribution less than 10 dB lower than the other noise contributions can usually be neglected.

It should be noted that in using the above formula the following generalization can be made: Any two *identical* sound levels will have the effect of increasing the overall level by 3 dB and any three will increase the overall level by 4.8 dB.

Intensity Intensity of a sound wave is the energy transferred per unit time (in seconds) through a unit area normal to the direction of propagation. It is commonly measured in $W/m1^2$ or $W/cm2^2$. For a pure tone (single frequency), there is a one-to-one correspondence between loudness and intensity. However, almost all sound contains multiple frequencies. The relationship is not simple because of the interference effects of the sound waves.[56] For example, increasing the sound pressure level by 3 dB is equivalent to increasing the intensity by a factor of 2. Increasing the sound pressure level by 10 dB is equivalent to increasing the intensity by a factor of 10, and increasing the sound pressure level by 20 dB is equivalent to increasing the intensity by a factor of 100. Expressed in another way, whereas 10 dB is 10 times more intense than 1 dB, 20 dB is 100 times (10×10) more intense, and 30 dB 1000 times ($10 \times 10 \times 10$) more intense.

Loudness Loudness, or amplitude, of sound is the sound level or sound pressure level as perceived by an observer. The apparent loudness varies with the sound pressure and frequency (pitch) of the sound. This is illustrated in Figure 6-14. It is specified in sones or phons. For a pure tone, each time the sound pressure level increases by 10 dB, the loudness doubles (sones increase by a factor of 2). Sound levels of the same intensity may not sound the same since the ear does not respond the same to all types of sound.

A 1000-Hz pure tone 40 dB above the listener's hearing threshold (0 dB) produces a loudness of 1 *sone*, which is a unit of loudness.[57–58] This loudness of 1 sone is equal to 40 phons. Loudness levels are usually expressed in phons. For practical purposes, each doubling of the sones increases the phons by 10—that is, 1 sone = 40 phons; 2 sones = 50 phons; 4 sones = 60 phons. Also for pure tones, a 10-dB increase in sound level would be perceived as a 10-phon increase in loudness by a person with good hearing in the frequency range of 600 to 2000 Hz.

For example, take a human listener with normal hearing who hears a 100-Hz pure tone with a SPL of 90 dB. What loudness does the listener perceive?

From Figure 6-14, a SPL of 40 dB at approximately 100 Hz equals a loudness of 10 phons. Since a 50-dB increase in SPL is equivalent to a 50-phons increase in loudness, the tone's loudness is 60 phons, or 4 sones.

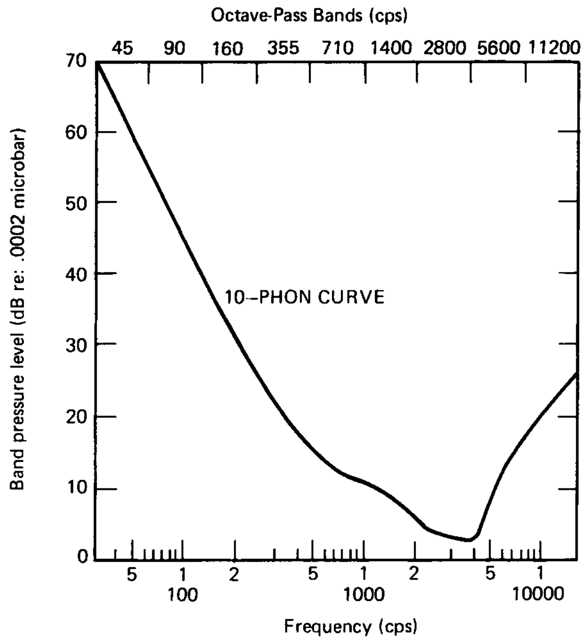

Figure 6-14 Equal loudness contour. (*Source: Toward a Quieter City,* A report of the Mayor's Task Force on Noise Control, New York, 1970.)

Noys Noys is a measure of the perceived noise level (PNL) (in decibel) in relation to the noisiness or acceptability of a sound level. Although similar to loudness, the ratings by observers when tested were different.

Procedures for the calculation of loudness and noisiness are given in standard texts.[58]

Day–Night Average Sound Level (DNL) System The day–night average sound level is the 24-hr average sound level, expressed in decibels, obtained after the addition of a 10-dB penalty for sound levels that occur at night between 10 p.m. and 7 a.m. It is recorded as L_{dn}. The DNL system has been adopted by the EPA, the Department of Defense, The Department of Housing and Urban Development (HUD), and the Federal Aviation Administration (FAA), specifically for describing environmental impacts for airport actions.[60]

Effects of Noise—A Health Hazard

Noise pollution is an environmental and workplace problem. Excessive noise can cause permanent or temporary loss of hearing. Loud sounds affect the circulatory and nervous systems, although the effects are difficult to assess. It interferes with speech, radio, and TV listening; disturbs sleep and relaxation; affects performance as reduced work precision and increased reaction time; and causes annoyance, irritation, and public nuisance. There is a hearing loss with age, particularly at the higher frequencies, and in younger people who have been exposed to loud noises. Occupation-related hearing loss has been documented since the sixteenth century and is still a serious problem. An estimated \$835 million compensation was paid workers from 1978 to 1987.[61] Sonic boom can cause physical damage to structures. David G. Hawkins, assistant EPA administrator reported (ref. 62):

> A poll conducted by the U.S. Bureau of the Census showed that noise is considered to be the most undesirable neighborhood condition—more irritating than crime and deteriorating housing.

Criteria for hearing protection and conservation have been established primarily for the worker. The major factors related to hearing loss are intensity (sound pressure levels in decibels), frequency content, time duration of exposure, and repeated impact (a single pressure peak incident). In measuring the potential harm of high-level noise, frequency distribution as well as intensity must be considered. Continuous exposure to high-level noise is more harmful than intermittent or occasional exposure. High- and middle-frequency sounds at high levels generally are more harmful than low-frequency sounds at the same levels. Greater harm is done with increased time of exposure.

Individuals react differently to noise depending on age, sex, and socioeconomic background. The relation of noise to productivity or performance is contradictory and not well established.

For workers, a sound level over 85 dBA calls for study of the cause. A level above 90 dBA should be considered unsafe for daily exposure over a period of months and calls for noise reduction or personal ear protection if this is practical.

An EPA report identified a 24-hr exposure level of 70 dBA as the level of environmental noise that will prevent any measurable hearing loss over a lifetime. Levels of 55 dBA outdoors and 45 dBA indoors are identified as preventing annoyance and not interfering with spoken conversation and other activities such as sleeping, working, and recreation.[63] Some common sound levels and human responses are noted in Table 6-12.

Other effects of noise are reduced property values; increased compensation benefits and possible accidents, inefficiency, and absenteeism; and increased building construction costs.

Sources of Noise

Transportation, industrial, urban, and commercial activities are the major sources of noise, plus the contributions made by household appliances and equipment. The major sources of transportation noise are motor vehicles, including buses and trucks, aircraft, motorcycles, and snowmobiles.

TABLE 6-12 Sound Levels and Human Response

Sources	Noise Level (dBA)	Response
Carrier deck, jet operation	140	Painfully loud
Live rock music	130	Limits amplified speech
Jet takeoff (200 ft)	120	Maximum vocal effect
Discotheque	115	
Rock band (10 ft)	115	
Auto horn (3 ft) loud	110	
Riveting machine	110	
Jet takeoff (2000 ft)	110	
Garbage truck, snowmobile	100	
Power lawn mower (operator)	95	
New York subway station	90	Very annoying
Heavy truck (50 ft)	90	Hearing damage (8 hr)
Food blender	90	
Pneumatic drill (50 ft)	85	
Diesel truck, 40 mph (50 ft)	85	
Dishwasher	80	
Alarm clock	80	Annoying
Garbage collection	80	
Freeway traffic (50 ft)	70	Telephone use difficult
Vacuum cleaner	70	
Normal speech	60	
Air-conditioning unit (20 ft)	60	Intrusive
Light auto traffic (100 ft)	50	Quiet
Living room	40	Quiet
Bedroom	40	
Public library	35	
Soft whisper (15 ft)	30	Very quiet
Broadcasting studio	20	
Breathing	10	Just audible
	0	Threshold of hearing

Sources: Sound Levels and Human Responses, Office of Planning Management, U.S. Environmental Protection Agency, Washington, DC, July 1973; *MMWR,* March 1986, p. 185.

Industrial, urban, and commercial noises emanate from factories, equipment serving commercial establishments, and construction activities. Construction equipment sources are power tools, air compressors, earthmovers, dump trucks, garbage collection trucks, diesel cranes, pneumatic drills, and chain saws. Compactor trucks manufactured after October 1, 1980 may not exceed a noise level of 79 decibels and may not exceed 76 decibels after July 1, 1982 measured on the A-weighted scale 7 m from the front, side, and rear of the vehicle while empty and operating.

Residential noise is associated with dishwashers, garbage disposal units, air conditioners, power lawn mowers, and home music amplifier units.

Measurement of Noise

Noise measurement equipment selection is dependent upon the task to be performed. For an initial survey, a sound-level meter is adequate for a rapid evaluation and identification of potential problem areas. To study and also determine the characteristics of a noise problem area, a sound-level meter, frequency analyzer, and recorder are needed to determine sound pressure distribution with frequency and time. More sophisticated equipment would be needed for research or solution of special noise problems.

Sound-Level Meter A sound-level meter is used to measure the sound pressure level; it is the basic instrument for noise measurement.

Meters are available to cover the range of 20 to 180 dB. The specifications usually refer to the American National Standards Institute (ANSI) and particularly to the standard *Specification for Sound Level Meters,* ANSI S1.4-1971. Three weighting networks, *A*, *B*, and *C*, are provided to give a number that best approximates the total loudness level for a particular situation, with consideration of the sound frequency, intensity, and impact levels. There are three types of meters. Type I is highest quality; type III is lowest quality and not suitable for public health professionals. Type II is the most common type used by public health officials. Most noise laws and regulations permit either type I or II but not type III meters.

The B and C networks are no longer normally used. The A-weighted scale is most commonly used. It discriminates against frequencies below 500 Hz and most nearly encompasses the most sensitive hearing range of sound, that is, 1000 to 6000 Hz. The symbol dBA is used to designate the A-weighted decibel scale, which combines both frequency and pressure levels; it measures environmental noise and should be supplemented by the time or duration to determine the total quantity of sound affecting people. The sound level meter provides the total quantity of sound affecting people. The sound-level meter provides settings for "F" (fast time response) and "S" (slow time response).

The most important part of the equipment is a calibrator that generates a known decibel standard. Without a calibration before and after a measurement, the measurement is suspect.

Noise Dosimeter The noise dosimeter will measure the amount of potentially injurious noise to which an individual is exposed over a period of time. A dosimeter can be set to the desired level and will then total the exposure time to noise above the set level. The noise dosimeter does not, however, identify noise sources. Therefore, if a study is being conducted to determine noise exposure and culpability, it is imperative that the dosimeter be coupled with a frequency analyzer or better still with a human observer to record noise source identities.

Sound Analyzer A frequency analyzer may be necessary to measure complex sound and sound pressure according to frequency distribution. It will supplement readings obtained with a sound-level meter. Noise analyzers cover different frequency bands. The octave-band analyzer is the most common. The impact noise analyzer is used to measure the peak level and duration of impact noise. Examples of impact noises are drop hammer machines and gun fire.

Cathode-Ray Oscillograph This makes possible observing the wave form of a noise and pattern. The magnetic tape recorder makes possible the collection of noise information in the field and subsequent analysis of the data in the office or laboratory. Environmental noise monitors are now available that can be located in a community and will retain noise levels in a memory.

Octave-Band Analyzer This has filters that usually divide a noise into eight possible frequency categories. Each category is called an octave band, with frequency ranges of 45 to 90, 90 to 180, 180 to 355, 355 to 710, 710 to 1400, 1400 to 2800, 2800 to 5600, and 5600 to 11,200 Hz (or cps). The bands are identified by their center or midfrequencies: 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. With center-frequency bands at 31.5 and 16,000 Hz, the audible frequency range of 20 to 20,000 Hz is then covered with 10 octave bands.

Background Noise Background noise is noise in the absence of the sound being measured that may contribute to and obscure the sound being measured. A rough correction could be made by applying the correction factors given in Table 6-13. However, such subtractions typically introduce significant error in the final result. The message to be obtained from Table 6-13 is that the background noise should be at least 10 dB lower than the noise being measured. This will introduce negligible error (less than 0.5 dB) due to interfering background.

Methods for Noise Control

Noise can be controlled at the source, in its path of transmission (through a solid, air, or liquid), or where it is received. Sometimes, because no one method is sufficiently effective, controls are instituted at two or at all three steps in the path of noise travel from the source to the receptor. In general, it is best to reduce the noise at the source. This should include establishment of clear, reasonable, and enforceable noise design objectives for manufacturers and installers.

Noise control generally involves adoption and effective enforcement of reasonable and workable regulations; protection of workers from hazardous

TABLE 6-13 Correction for Background Noise

Total Noise Level Less Background Level (dB)	Decibels to Subtract from Total Noise Level to Get Noise Level Due to Source
10	0.5
9	0.6
8	0.7
7	1.0
6	1.2
5	1.6
4	2.2
3	3.0
2	4.3
1	6.9

Source: H. H. Jones, "Noise Measurement," *Industrial Environment . . . Its Evaluation and Control,* PHS Pub. No. 614, Department of Health, Education, and Welfare, Washington, DC, 1958, p. B-21.

occupational noise levels; building quieter machines, use of vibration isolators, new product regulation, and product labeling for consumer information; improved building construction and use of rubber sleeves, gaskets, paddings, linings, seals, and noise barriers; compatible land-use planning and zoning; and informing the public of harmful effects of noise and methods to reduce noise to acceptable levels. Regulations may encompass ambient noise in general and industrial noise, motor vehicle noise, and aircraft noise as well as building and construction codes, housing occupancy codes, sanitary codes, and nuisance codes.

A WHO Expert Committee[64] suggests the following preventive measures to control noise and vibration:

(a) general measures such as locating noisy industrial plants, airports, landing fields for helicopters, railway stations and junctions, superhighways, and so on, outside city limits.
(b) improving technical processes and industrial installations with a view to reducing noise and vibration and installing noise suppressors (mufflers) on automobiles, motorcycles, and so on;
(c) improving the quality of surface highways and urban streets (also tire tread designs);
(d) creating green spaces in each neighborhood district;
(e) perfecting procedures for acoustic insulation; and
(f) adopting administrative regulations with a view to limiting the intensity of background noise within the urban environment.

The committee recommends close international collaboration and close cooperation between metropolitan planners and environmental health personnel to reduce noise and vibration to a minimum.

Control of Industrial Noise

Noise control should start in the planning of a new plant or when planning to modernize an existing plant. Consideration should be given at that time to minimizing the effects of noise on the workers, office personnel, and nearby residents. The control of an existing noise problem first requires suitable noise standards and an identification of the location, extent, and type of noise sources. This would be followed by the application of needed noise control measures to achieve the required or desired levels.

Factors to be taken into consideration in industrial noise control are as follows[65–67]:

1. Selection of building site that is isolated or an area where there is a high background noise level. Topography and prevailing winds should be considered, as well as the use of landscaping and embankments, to reduce the noise travel where it may cause a nuisance.
2. Building layout to separate and isolate noisy operations from quiet areas.
3. Substitution of low-noise-level processes for noisy operations, such as welding instead of riveting, metal pressing instead of rolling or forging, compression riveting instead of pneumatic riveting, and belt drives in place of gears.
4. Selection of new equipment with the lowest possible noise level (also modification of existing equipment with better mufflers).
5. Reduction of noise at its source through maintenance of machinery, covers and safety shields, and replacement of worn parts; reduction of driving forces; reduction of response of vibrating surfaces; intake and discharge sound attenuation and flexible connections or collars; use of total or partial enclosures, with sound-absorbing materials (also coatings or sound-absorbing materials on metals to dampen vibration noise); and isolation of vibration and its transmission. See (a) Noise Control and (b) Noise Reduction, this chapter.
6. Use of acoustic absorption materials to prevent noise reflections.
7. Control of noise in ventilation ducts or conveyor systems.
8. Use of personnel shelters.

Sometimes the only practical and economical method of noise control is through the use of personal protective devices. These may also be a supplement to the applied engineering, worker, and education controls. Personal ear protector types include properly fitted and sized earplugs, earmuffs, and helmets providing a good seal around the ear. They should meet established criteria for comfort, tension, sound attenuation (at least 15 dBA), simplicity, durability, and so on. To be effective, however, *the worker must cooperate by wearing the protective device* where needed. Dry cotton plugs do not provide significant sound attenuation.

Control of Transport Noise

Noise from various forms of transport and its transmission into the home may be reduced as follows[68]:

1. at the source, that is, by controlling the *emission* of noise;
2. by means of town and country planning and traffic engineering, that is, by controlling the *transmission* of noise; and
3. in the home, that is, by controlling the *reception* of noise by the occupants.

Some specific measures to reduce the effect of highway noise include the following:

1. Enclosure of highways going through residential areas.
2. Wider rights-of-way, that is, separation or buffer zone between the source and the receptor.
3. Walls designed to deflect or absorb noise (earth berms covered with vegetation are more effective).[69]
4. Changes in highway alignment and grade to avoid sensitive areas, minimizing stop-and-go traffic, and shifting to low gears.
5. Setting lower speed limits for certain sections of a highway.
6. Adjacent barriers, nonresidential buildings in sound transmission path, earth embankments or berms, and elevation or depression of highways. It is reported, however, that barriers provide little attenuation of low-frequency sounds and that a thick band of deciduous trees 200 to 300 ft in width is relatively ineffective in cutting down traffic noises, reducing them only on the order of 4 or 5 dB.[70] Separation distance is most effective in reducing noise from highways.
7. Establishing alternate truck routes.
8. Building codes requiring building insulation to limit interior transmission of noise. Additional measures are masonry walls, elimination of windows, use of double windows or glazing, soundproofing of ceilings, thick carpeting, overstuffed furniture, and heavy drapes.

Noise Reduction

Sound Absorption The amount of sound energy a material can absorb (soak up) is a function of its absorption coefficient (α) at a specified frequency. The sound absorption coefficient is the fractional part of the energy of an incident sound wave that is absorbed by a material. A material with an absorption coefficient of 0.8 will absorb 80 percent of the incident sound energy. A material that absorbs all incident energy, such as an open window, has an absorption coefficient of 1. The sound absorption of a surface is measured in sabins. A surface having an area of 100 ft^2 made of material having an absorption coefficient of 0.06 has an absorption of 6 sabin units (100×0.06). To determine the noise reduction in a room, the floor, walls, and ceiling surface areas multiplied by the absorption coefficient of each surface, at a given frequency, before and after treatment, must be added to obtain the total room surface absorption in sabin units.

The *noise reduction* (NR) in decibels at a given frequency of a surface before and after treatment can be determined by

$$\mathrm{NR} = 10 \log_{10} \frac{A_2}{A_1}$$

where A_2 = total room surfaces absorption after treatment, sabins
A_1 = total room surfaces absorption before treatment, sabins

Incremental noise reduction from a piece of machinery can be obtained by a rigid, sealed enclosure, plus vibration isolation of a machine from the floor using spring mounts or absorbent mounts and pads, plus acoustical absorbing material on the inside of the enclosure, plus mounting the enclosure on vibration isolators and enclosing, without contact, in another enclosure having inside acoustical absorbing material. If machinery air cooling and air circulation are needed, provide baffled air intakes. Insert a flexible connector, if a physical pipe or duct connection is needed between the machinery and other building piping or duct work, to reduce noise transmission.

However, sound energy can go around or through a particular material (around corners) or pass through openings (cracks, windows, ducts) and thereby nullify the sound absorption as well as transmission reduction efforts. For example, 1 $in.^2$ of opening transmits as much sound as about 100 ft^2 of a 40-dB wall.[71] This emphasizes the importance of sealing all cracks, pipe and conduit sleeves, electrical receptacles, or openings with nonsetting caulking compound.

Sound absorptive materials include rugs, carpets with felt pads, heavy drapes, stuffed furniture, and ceiling and wall acoustical materials designed to absorb sound. These materials absorb high-frequency sounds much more effectively than low frequency. Sound absorptive materials are most effective to the occupant when used in and near the areas of high-level noise. These materials can control interior noise, sound reflection, and reverberation*; however, noise easily passes through. Hard, smooth, impervious materials reflect sound. Some absorption coefficients at 1000 Hz are plate glass 0.03; brick wall 0.01 to 0.04; linoleum, asphalt, or rubber tile on concrete 0.03; smooth plaster on brick or hollow tile 0.03; $\frac{3}{8}$-in. plywood paneling 0.09; felt-lined carpet on concrete 0.69; velour (14 oz/yd^2) 0.75; painted concrete block 0.07; and unpainted concrete block 0.29.

Sound Transmission Sound transmission loss (TL) is the ratio of the energy passing through a wall, floor, or ceiling to the energy striking it—that is, how effective a material is in stopping the passage of sound. The sound transmission varies with the frequency of the sound, the weight or mass, and the stiffness of the construction. Hence, any reduction of noise transmission from outside to inside a building is accomplished through control of the design, thickness, and weight of wall, floor, door, window, and ceiling materials. Improved design of building equipment and its installation, noise and vibration isolation, and discontinuance or gaps in structural members are interior factors also to be considered. The transmission loss increases as the frequency increases. Hollow doors readily transmit sound; solid wood or solid core doors do not.

Mechanical equipment, household appliances, and other stationary sources of noise should be isolated from the floors or walls or on mountings by means of rubber or similar resilient pads to absorb vibration and prevent or reduce sound transmission to the structure, as noted above under Sound Absorption. Small-diameter pipe carrying water at high velocity causes noise to travel long distances. Air chambers on pipelines may also be needed to prevent water hammer.

Sound transmission class (STC) loss ratings for various types of materials are given in decibels in design handbooks, texts, and standards such as the National Bureau of Standards, Building Materials and Structures Report BMS 144 for "Insulation of Wall and Floor Construction." For example, 4-in. cinder block weighing 25 lb/ft^2 has an average approximate STC loss rating of 25 dB; if the block is plastered on one side, its rating is 40 dB. A 4-in. brick wall weighing 40 lb/ft^2 has a rating of approximately 45 dB. A 4-in. concrete slab with a resiliently suspended ceiling has a rating of 55 dB. A $\frac{1}{4}$-in. plywood sheet nailed to studs has an STC rating of 24 dB; $\frac{1}{2}$-in. gypsum board on studs has a rating of 32 dB. The frequency of the sound affects the sound transmission loss. In general, the sound transmission loss rating increases with frequency increase. Theoretically, transmission loss increases at the rate of 6 dB per doubling of the weight of the construction. Some building codes rec-

*The sound that persists in an enclosed space after the sound source has stopped, which is reflected by the wall, floor, or ceiling.

ognize the need to prevent sound transmission between apartments in a multiple dwelling or in row houses. A double *separated* wall with two layers of insulation is effective. A sound-pressure-level reduction of about 50 dB in the normal speaking range (250–3000 Hz) is suggested.

Since a room floor, wall, and ceiling are usually constructed of different materials, an average transmission coefficient must be calculated taking into consideration the coefficient for each material (including doors, windows, and vents) and its area to determine the room noise insulation factor in decibels. The total noise reduction level accomplished by a wall or other divider is a function of the wall transmission loss, the room absorption characteristics, and the absorption in the rooms separated. It is determined by measuring the difference in sound levels in the rooms. The types of windows (single or double-hung) and doors can have a major effect on the overall noise insulation factor. For example, opening a window can double the interior noise.

Numerous sample calculations for sound and vibration control situations are given in various texts, including the *ASHRAE Guide and Data Book, Systems, 1970* (see Bibliography).

Mechanical noises such as high-velocity noises require proper design of ventilation systems and plumbing systems to reduce flow velocity. Hammering noise in a plumbing system is usually due to a quick-closing valve in the plumbing system, which requires installation of an air chamber on the line or a pressure or vacuum-breaker air-relief valve to absorb the pressure change created when the momentum of the flowing water suddenly stops.

Separation distance between the sound source and receptor should be emphasized and not overlooked in the planning stages as a practical noise reduction method. In general, if there are no sound-reflecting surfaces in the vicinity, a sound pressure level will be reduced approximately 6 dB for each doubling of the distance. Doubling the air space between panels increases the transmission loss by about 5 dB. When a sound barrier, such as a wall, is erected between a source and a receptor, some sound is reflected back toward the source, some is transmitted through the barrier, and some is diffracted over and around the barrier. With a partition close to the source, part of the sound is absorbed, part is reflected back, and part is transmitted through.

Federal Regulations

Maximum acceptable or permissible noise levels are established for certain categories by federal or state regulations or by local ordinances. Some guides are given in Table 6-14.

In May 1969 the Department of Labor issued the first federal standards for occupational exposure to noise. The Occupational Safety and Health Administration (OSHA) sets and enforces regulations, under the Occupational Safety and Health Act of 1970, for the protection of workers' hearing. These standards have been made more stringent over the years as more human hearing loss research has become available. Table 6-15 shows the year 2000 American

TABLE 6-14 Some Guides for Maximum Acceptable Sound Levels

	Sound Level (dBA)	
Space	Maximum	Design
Auditoriums	30–45	25–30
Drafting rooms	55	35–50
Hospital rooms	40	25–35
Hotel rooms	45	30–40
Indoor recreational areas		30–45
Libraries	40–45	30–40
Manufacturing, light machinery		45–70
Movie theaters	35–45	30–35
Private offices	40–45	30–40
Residences, rural or suburban		20–30
Residences, urban		25–35
Restaurants	50	35–45
School rooms	30–40	30–40
Secretarial offices	55–60	35–50
Small conference rooms	35–40	25–35
Sports arenas		30–40
Stores, department and supermarkets		35–50

TABLE 6-15 Sound Pressure Levels as Suggested by American Conference of Governmental Industrial Hygienists for Permissible Noise Levels at Various Durations of Exposure[a]

Duration per Day	Sound Pressure Level (dBA)[b]	Duration per Day	Sound Pressure Level (dBA)[b]
24 hr	80	28.12 sec	115
16 hr	82	14.06 sec	118
4 hr	88	7.03 sec	121
2 hr	91	3.52 sec	124
1 hr	94	1.76 sec	127
30 min	97	0.88 sec	130
15 min	100	0.44 sec	133
7.50 min[c]	103	0.22 sec	136
3.75 min[c]	106	0.11 sec	139
1.88 min[c]	109		
0.94 min[c]	112		

[a] 2000 TLVs and BEIs, American Conference of Governmental Industrial Hygienists. No exposure to continuous, intermittent, or impact noise in excess of a peak C-weighted level of 140 dB.
[b] Sound level in decibels is measured on a sound-level meter, conforming as a minimum to the requirements of the American National Standards Institute Specification for Sound Level Meters, S1.4 (1983)[(2)] Type S2A, and set to use the A-weighted network with slow meter response.
[c] Limited by the noise source, not by administrative control. It is also recommended that a dosimeter or integrating sound-level meter be used for sounds above 120 dB.

Conference of Governmental Hygienists suggested daily durations and sound pressure levels. The federal regulatory approach is to start control at the point of manufacture.

The Federal Highway Act of 1970 led to design noise levels related to land use as a condition to federal aid participation. If the design noise levels shown in Table 6-16 are exceeded, noise abatement measures are required in the highway design. Federal highway funds may also be used to abate noise on previously approved highway projects.

The Noise Control Act of 1972 [Public Law (PL) 92-574] directed the EPA to promote an environment for all Americans free from noise that jeopardizes their health and welfare. It is required to set limits on noise emission, and the Act requires manufacturers to warrant product performance and label products. Regulation of noise from a broad range of sources and products is required. The EPA and the Department of Transportation (DOT) have been given the responsibilities to implement the law. The EPA estimates that 16 million people are exposed to aircraft noise levels with effects ranging from moderate to very severe.

The Aviation Safety and Noise Abatement Act of 1979 requires the FAA to develop a single system for measuring noise at airports and under certain conditions to prepare and publish noise maps. The Noise Abatement Criteria established by the Federal Highway Administration for residential areas, schools, parks, hospitals, and other sensitive areas is 67 dBA equivalent steady state and 72 dBA for commercial land use.*

The FAA, in the Department of Transportation, has primary authority for aircraft noise regulations and standards. The FAA has adopted noise emission standards for new aircraft and has a plan to retrofit older aircraft.

TABLE 6-16 Design Noise Level–Land Use Relationships

Design Noise Level (dBA)	Description of Land-Use Category
60 (exterior)	Areas such as amphitheaters, certain parks, or open spaces in which local officials agree serenity and quiet are of extraordinary significance
70 (exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, recreational areas
75 (exterior)	Developed land, properties, or activities not included in above two categories
55 (interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, auditoriums

Source: U.S. Department of Transportation, Policy Procedure Memorandum 90-2 Appendix B, Transmittal 279, February 8, 1973.

* A. Charabegian, ‘‘GIS/CAD Enhance Traffic Noise Study,’’ *Public Works,* November 1990, pp. 61–62.

The Quiet Communities Act of 1978 amended the Noise Control Act of 1972 to encourage noise control programs at the state and community levels.

The Housing Act of 1949 (PL 81-171), among other things, sets forth the national goal of ‘‘a decent home and suitable living environment for every American family.’’ This goal was affirmed by the Housing and Urban Development Act of 1968 (PL 89-117) (ref. 60, pp. 3–4).

The Department of Housing and Urban Development has criteria for the sound insulation characteristics of walls and floors in row houses, nursing homes, and multifamily housing units. These criteria must be met by housing of this type in order to qualify for HUD mortgage insurance.

The National Bureau of Standards and the National Science Foundation are concerned with research in noise control and abatement in factories, homes, offices, and commercial work areas.

The EPA has issued noise control regulations for interstate trucks, interstate railroad carriers, new medium and heavy-duty trucks, and new air compressors. The EPA and DOT regulations establish a maximum noise level of 90 dBA for interstate trucks and buses over 10,000 lb in speed zones over 35 mph and 86 dBA at 35 mph or less, measured 50 ft from the center line of the lane of travel. New trucks over 10,000 lb must achieve a sound level no higher than 83 dBA.

The EPA program for certain noise-emitting and noise-reducing products requires a noise rating giving the number of decibels (dBA) a product emits and a noise reduction rating. Noise emissions from new products (including portable air compressors) are not to exceed 76 dBA at 23 ft (7 m).

The HUD noise levels for new sleeping quarters are given in Table 6-17.

State and Local Regulations

New York State enacted a state highway antinoise law in 1965 and California followed in 1967. Chicago put into effect a comprehensive noise control

TABLE 6-17 Noise Levels for Sleeping Quarters in New Structures

Exterior	Interior
Does not exceed 45 dBA for more than 30 min per 24 hr (Acceptable)	Not greater than 55 dBA for more than an accumulation of 60 min in any 24-hr day
Does not exceed 65 dBA for more than 8 hr per 24 hr (normally acceptable)	Not greater than 45 dBA for more than 30 min during nighttime sleeping hr 11 p.m. to 7 a.m. and not greater than 45 dBA for more than an accumulation of 8 hr in any 24-hr day

Source: Department of Housing and Urban Development, Circular 1390, amended September 1, 1971.

Note: Not greater than 30 dBA preferred for bedrooms.

program in July 1971. Regulations require reduced noise levels after 1979 for vehicles, construction machinery, home-powered equipment, and like-manufactured equipment. St. Louis County has a noise code that limits noise in residential areas to 55 dBA and in industrial areas to 80 dBA. New Jersey enacted comprehensive noise legislation January 1972. Most states in the snow belt have established a maximum noise level for snowmobiles of 78 dBA at 50 ft. Some 12,000 states and municipalities have noise control legislation, but enforcement has been weak and spotty.

Local regulations consistent with federal and state laws and enforced locally are encouraged as being more practical for enforcement. Model noise control ordinances are available to assist local communities in the development of a local program.[72,73]*

Maximum acceptable sound levels for different situations are given in Tables 6-14, 6-16, and 6-17. Maximum permissible sound levels for workers in industrial plants and factories regulated by the Occupational Safety and Health Act are given in Table 6-15.

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*The EPA maintains up-to-date compilation of city and state noise control ordinances.

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7 Radiation Uses and Protection

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RADIATION FUNDAMENTALS

This section presents some of the basic background and definitions necessary to understand the uses of radiation and basic radiation protection. Radiation is commonly defined as energy that flows through matter or through a vacuum. Ionizing radiation, in particular, plays invaluable roles in medical diagnosis and therapy, industrial process control, research, and numerous other areas, but it also poses significant public health problems, because the production of ions within tissues can injure people, animals, and plants and cause genetic as well as somatic damage. Ionizing radiation is created by radioactive materials occurring naturally in the environment and by X-ray machines and radioactive substances produced in nuclear reactors and elsewhere. It can be quantified by detecting and measuring the amount of ions arising when it transfers its energy to various radiation-sensitive materials such as photographic film, semiconductor devices, and fluorescent materials. People and equipment can be protected from the harmful effects of exposure to ionizing radiation by confining and isolating the source of radiation, keeping it at the greatest practical distance, minimizing the duration of exposures, and using shields of lead, concrete, or other suitably dense materials.

Radiation and Ionization

Most radiations encountered in the practice of engineering involve the propagation either of mechanical disturbances, as with sound, or of electromag-

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0-471-41813-7

netic waves or particles. Quantum mechanics informs us that electromagnetic radiation behaves, in some ways, as a beam of particlelike quanta, called *photons,* and that conversely, "particles" like electrons have wavelike characteristics; except where noted otherwise, however, this chapter will adopt the simpler, classical terminology. Electromagnetic and charged or uncharged particulate radiations that are capable of directly or indirectly producing ions by interaction with matter, in particular, are referred to as *ionizing radiation*. Ionizing radiations are especially important not only because of their widespread use in medicine, industry, and elsewhere but also because they have the potential of causing cancer and other health effects. The forms found in standard application are X-rays and gamma rays, at the highest energy end of the electromagnetic spectrum, and particles such as beta and alpha particles, heavy ions, and neutrons.

For radiation in the form of waves, the wavelength (λ), frequency (f), and velocity (v) are related as

$$\lambda f = v \quad \text{(velocity of propagation of waves)} \tag{1a}$$

The wavelength is the distance between wave crests. The frequency is the number of waves per second passing per second, measured in hertz (Hz). The velocity depends on the medium through which it travels and, in general, on the frequency and/or energy of the radiation. The velocity of electromagnetic radiation in a vacuum, however, is independent of the frequency, and has been given the special designation c:

$$\lambda f = c = 3 \times 10^8 \text{ m/s} \quad \text{(velocity of electromagnetic radiation in vacuum)} \tag{1b}$$

A second fundamental expression concerning electromagnetic radiation comes to us from quantum mechanics and builds upon the notion that an electromagnetic wave is in some sense comprised of vast numbers of photons. It was found through experiment that the energy (E) of a (particlelike) photon increases with the frequency of the associated electromagnetic wave:

$$E = hf \tag{2}$$

where the constant of proportionality (h) is Planck's constant. Thus the shorter the wavelength, the higher the frequency and energy. Figure 7-1 shows radiation sources in the electromagnetic spectrum.

The standard measures of *energy* of ionizing radiation are the electron volt (eV), a thousand electron volts (keV), and a million electron volts (MeV), as applicable. An electron volt is the energy an electron gains in passing through a difference of potential of 1 V, and it is equivalent to 1.6×10^{-12} erg. The *intensity* of a beam of radiation refers to the quantity of energy passing

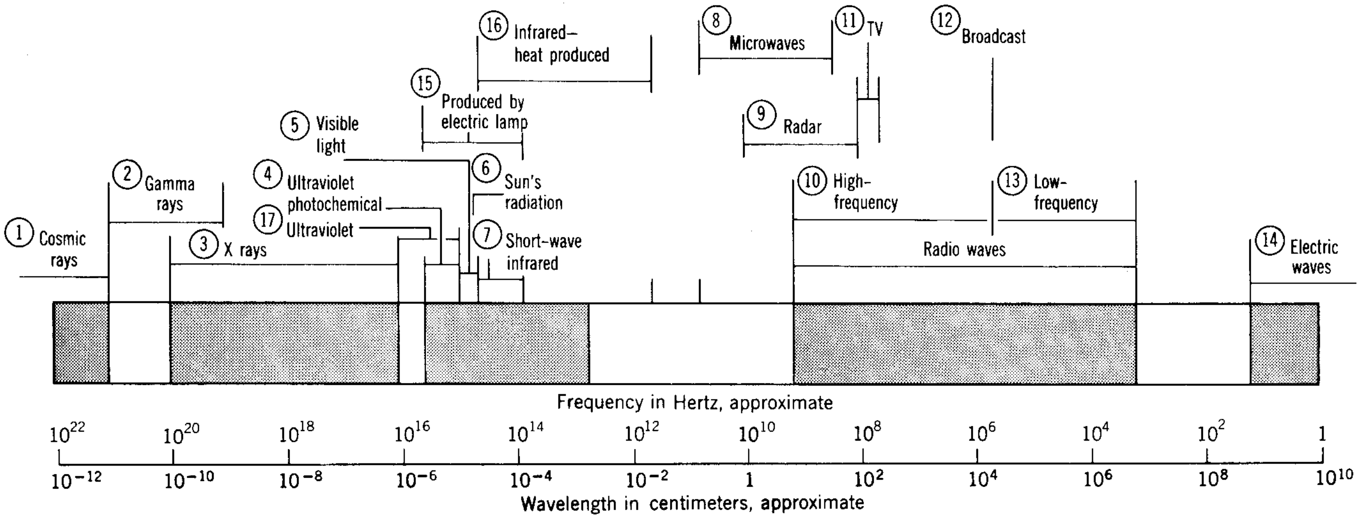

Figure 7-1 Electromagnetic radiations. The velocity or speed of radiation throughout the spectrum is that of light, or about 186,000 mi/sec. The nature of all radiation is the same, and the difference lies only in the frequency and wavelength, that is, frequency × wavelength = velocity. The range in wavelengths is from about 10 to 12 cm for cosmic rays to a length of 3100 miles for 60-cycle-electric current. One micrometer (μm) = 10^{-4} cm = 104 angstroms (Å). One centimeter = 104 μm = 108 Å.

(1) Cosmic rays, reaching earth from sky.
(2) Gamma rays.
(3) X-rays, high-frequency oscillations produced by X-ray tubes.
(4) Ultraviolet, photochemical–photoelectric and fluorescent effects, germicidal action and health maintenance by virtue of radiation absorbed by bacteria.
(5) Visible, seeing-discrimination of color and detail.
(6) Sun's radiation reaching the earth.
(7) Short-wave infrared, heat therapy-drying.
(8) Microwaves.
(9) Radar.
(10) High frequency.
(11) Television.
(12) Broadcast.
(13) Low frequency.
(14) Electric waves, produced by electric generators.
(15) Produced by electric lamps.
(16) Infrared, produced by heat.
(17) Ultraviolet.

(Adapted from *Lamps and The Spectrum,* General Electric, Nela Park, Cleveland, OH, and other sources.)

through a known area per unit of time, usually expressed in ergs per square centimeter per second.

For radiation protection, measures of radiation are based on the deposition of ionizing radiant energy in matter—and in particular, in human tissues. These measures refer to *dose* in matter, which can be computed from direct measurements, and they are of importance because they can be related to health risks, such as radiation burns and carcinogenesis. Definitions of dose all ultimately involve the concept of *ionization* of atoms and molecules. Before presenting definitions of dose, a brief overview of atoms and ions is warranted.

Atoms and Ions

Any *atom* consists of a nucleus, which contains one or more protons, neutrons, and a surrounding cloud of orbiting electrons. The charge on an electron is equal in magnitude to that of a proton but of opposite sign; since there are as many electrons held to the nucleus by the electrical force as there are protons, an atom as a whole is electrically neutral. The structure and components of an atom are shown in Figure 7-2. When atoms combine chemically, the resulting molecule usually has the same number of electrons as it does protons, so it, too, is electrically neutral.

The electron is the lightest part of the atom, and electrons are bound much less strongly to the nucleus than the protons and neutrons within the nucleus are bound to one another. There are various physical means by which an electron can be removed from an atom, resulting in a positively charged *ion;*

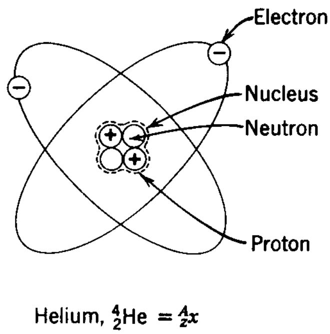

Figure 7-2 Atomic Structure. The electrons in the electron cloud orbit the nucleus, and each has a single negative electrical charge. Every proton in the nucleus has an equal but positive charge; the neutrons are neutral. The number of protons (Z) is called the atomic number and determines the chemical element type of the atom. Atoms in their natural state are electrically neutral; the number of electrons outside the nucleus is the same as the number of protons within the nucleus. The number of protons plus the number of neutrons is equal to the mass number (A). Isotopes of the same element have the same number of protons Z but different numbers of neutrons.

the freed electron will subsequently attach itself to some other atom, creating a negative ion. Thus, an ion is any atom or molecule that has a surplus or deficit of one or more electrons. An ion may be chemically unstable, and capable of interacting with other atoms or molecules, such as deoxyribonucleic acid (DNA), potentially with harmful consequences. Figure 7-3 illustrates the process of ionization.

Radiation Dose

Because of the potential health effects, it is important to be able to quantify radiation exposures. One common way of doing this for an irradiation event involves assessing the amount of ionization produced in various kinds of matter. For example, the ionization chamber, a standard instrument designed for this purpose, measures the amount of positive and negative ions produced in irradiating a well-defined volume or mass of air. Thus, the first important unit of exposure measures *ionization in air by X-rays and gamma rays:* the traditional unit is the *roentgen* (*R*) or the SI unit *coulomb per kilogram of air*. These units are *not* applicable to the deposition of other kinds of radiation, such as alphas, betas, and neutrons in air, or to energy deposition in other materials. One roentgen corresponds to the absorption of about 86 ergs of ionizing energy per gram (or one electrostatic unit per 0.001293 g) of dry air. Ion chambers, area survey meters, and related devices measure the ionization *rate* and thus often read in roentgens or milliroentgens (mR) per hour. Typical background measurements are in the range of 5 to 12 *micro*roentgens (μR) per hour.

The next important exposure unit measures absorbed energy or *absorbed dose*: the traditional unit *rad* (*r*adiation *a*bsorbed *d*ose) and the SI unit *gray* (*Gy*). One rad represents the energy absorption of 100 ergs/g of any material

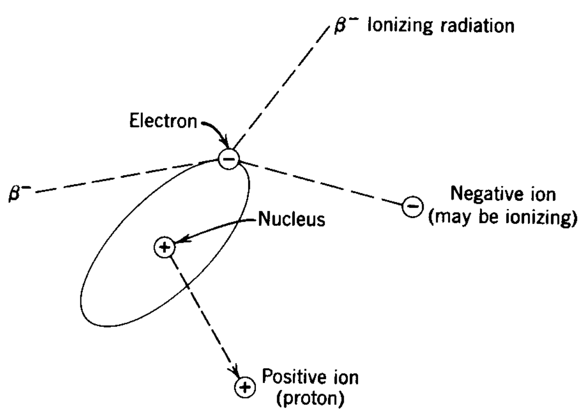

Figure 7-3 Example of Ionization. Removal of the electron from a hydrogen atom by a passing beta particle.

from any type of ionizing radiation; whereas 1 Gy is the absorption of one Joule of energy per kilogram (1 J/kg) of matter through which the radiation passes. The conversion is thus 1 Gy = 100 rad. For water and soft tissue, with X-rays and gamma rays having energies of up to 3 MeV, an exposure to 1 R gives rise to an absorbed dose of 0.93 to 0.98 rad.[1] An ordinary chest X-ray produces an exposure of about 0.01 to 0.02 rad to the skin where the beam the enters the exposed part of the body, but the beam's intensity falls off rapidly as it penetrates deeper; the dose at the exit beam, which is what exposes the film, may be only 1 percent or so of that at skin entrance. A very heavy fluoroscopy diagnostic series may give an entrance skin dose of about 10 rad. In radiotherapy, the traditional term rad has been largely replaced by the equivalent centigray (cGy).

The *rem* and its SI unit counterpart, the *sievert* (Sv), are risk-based measures of the dose that take into account the biological effects of different kinds of ionizing radiation and the different radiosensitivities of the various tissues of the human body. These units are used for a variety of dose measures, including *effective dose, dose equivalent,* and *effective dose equivalent*. The millisievert (mSv) is also commonly used to describe typical exposures. Additional details on calculation of these risk-based doses are described below in the section Biological Effectiveness and Organ Sensitivity under Biological Effects of Radiation.

The *person-rem* and *person-sievert* may be used to describe the exposure of populations to radiation, typically referred to as *collective dose*. For example, 5000 persons each exposed to an annual background of about 3 mSv = 0.003 Sv = 0.3 rem would represent a 1500 person-rem radiation exposure.

Radioactivity

Atoms with the same atomic number, *Z*, but with different numbers of neutrons, *N*, in the nucleus are said to be different *isotopes* of the *Z*th element. There are several notational systems commonly used to distinguish the isotopes: one gives the element name or chemical symbol followed by the atomic weight *A*, which is the total number of protons and neutrons in the nucleus ($A = Z + N$). Natural uranium, for example, is composed almost entirely of the isotope uranium-238 or U-238, which contains 92 protons and 146 neutrons. Alternatively, numeric prefaces may indicate the atomic weight and atomic number as with the fissile isotope ${}^{235}_{92}U$, with its 92 protons and 143 neutrons. Likewise, hydrogen (${}^{1}_{1}H$), deuterium (${}^{2}_{1}H$), and tritium (${}^{3}_{1}H$) all have the same atomic number of 1 but different numbers of neutrons, but all are members of the hydrogen family. Oxygen has six known isotopes, and tin has at least 23. The chemical properties of all isotopes of an element are, for practical purposes, the same; the nuclear properties may differ radically.

In particular, while many of the isotopes of the various elements are inherently stable, the vast majority come into being with an energetically unsuitable N/Z ratio, rendering them *radioactive*. A *radionuclide* is a particular radioactive isotope of an element. The nucleus of an atom of a *radioisotope* will undergo internal reconfigurations and attempt to adjust this nuclear imbalance by, sooner or later, undergoing radioactive *decay,* with the release of a high-energy photon or particle and the production of a new, *daughter* nucleus. Thus radioactivity is the property of certain nuclei to spontaneously undergo transformations that change the number of protons and/or neutrons present, usually with the emission of energy in the form of radiation as well.

By far, the three most frequently found radioactive emissions are the *gamma ray*, the *beta particle* or ray, and the *alpha particle* or ray. Of these, gamma radiation is often of greatest concern because it is the most commonly encountered, because alpha and beta emitters also normally produce gammas as well, and because gamma radiation is by far the most penetrating—both into the body and through any shielding present. The only physical distinction between X-rays and gamma rays is their source as both are photons: X-rays arise from electronic transitions and electron accelerations, while gamma rays arise in nuclear transformations and phenomena such as positron–electron annihiliation.

If, following a decay, the daughter nucleus is itself radioactive, further decays may occur. In the U-238 *decay chain,* for example, U-238 spontaneously decays to yield Th-234, which undergoes an emission to become Pa-234, thence to U-234, Th-230, Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210, and finally Pb-206. This process is illustrated in Figure 7-4.

For practical purposes, it is convenient to view radionuclides as being either *naturally occurring* or *man made*. Some naturally occurring radionuclides such as K-40, Rb-87, Th-232, and U-238, which have existed on earth since its formation, are said to be *primordial*. Uranium-238 gives rise to the production and decay of an entire chain of *terrestrial* radioactive nuclides. Other naturally-occurring radionuclides, such as C-14, are said to be *cosmogenic* since they are produced through the bombardment of atoms in the upper atmosphere by cosmic rays.

Important sources of man-made radionuclides are nuclear reactors, detonation of nuclear devices, accelerators, and bombardment by neutron sources. These processes produce radioactive material through *activation,* where a nucleus absorbs a neutron and becomes radioactive, or through *fission,* where a nucleus divides into two or more pieces. A particle accelerator such as a cyclotron may smash high-velocity protons or other atomic nuclei into a target and produce radioactive materials through activation. Also, exposure of a material to a source of neutrons, such as Cf-252, may lead to the creation of radioisotopes through activation if some of those neutrons are absorbed.

Some heavy isotopes, such as U-235 and Pu-238, have nuclei that not only pick up an extra neutron under neutron activation but also rapidly undergo fission: The activated nucleus splits into two new *fission product* nuclei, each of which has about half the mass of the original and is itself radioactive. For each fission, a few free neutrons and considerable radiant energy are given

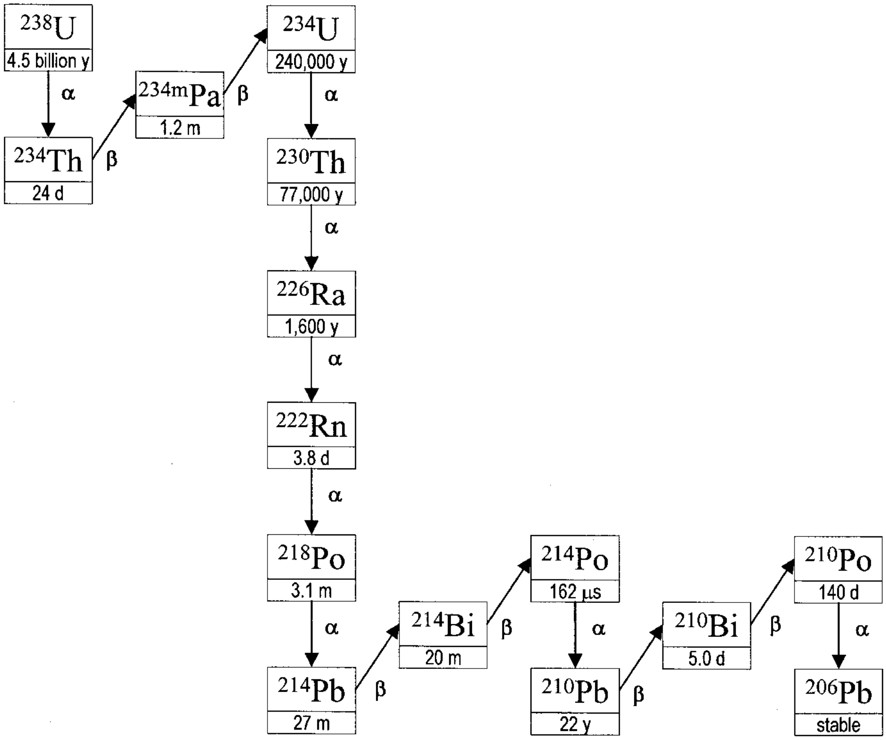

Figure 7-4 U-238 Decay Chain. Each radionuclide is labeled below by its half-life, and each transformation is labeled by the major type of radiation emission (α for alpha and β for beta).

off. If the conditions are right, the free neutrons can in turn cause additional fissions, thereby starting a chain reaction. This process forms the basis for nuclear power and the explosion of atomic weapons.

Radionuclides have particular application as tracers in many areas of medicine, industry, and research. Attaching a radionuclide to a stable substance, for example, makes it possible to study the path it follows and the physical and chemical changes it undergoes. The advantage of using radionuclides is that the radiation they emit allows them to be easily detected even in very small quantities.

Activity and Half-Life ($T_{1/2}$)

The rate at which radioactive decays are occurring in a given sample of a radionuclide at time t is known as its *activity,* and commonly designated $A(t)$. The activity of a sample is proportional to the number of atoms present at that time, $N(t)$. The constant of proportionality, which is unique to each particular radionuclide, is termed the *transformation coefficient* or *decay constant*, λ, and reflects the inherent tendency of a nucleus of that radionuclide to decay. Therefore, for $N(t)$ atoms at time t, the activity may be expressed as

$$A(t) \equiv \frac{dN(t)}{dt} = \lambda N(t) \tag{3a}$$

the solution to which is well known:

$$A(t) = A(0)\ e^{-\lambda t} \tag{3b}$$

Activity is measured in terms of the traditional unit *curie* (*Ci*) or the SI unit *becquerel* (*Bq*). One curie is defined as exactly 3.7×10^{10} disintegrations per second, whereas the becquerel is exactly one disintegration per second, so the conversion is 1 Ci = 3.7×10^{10} Bq. The historical basis for the Ci is the observation that the activity of 1 g of pure radium is approximately 1 Ci. A picocurie (pCi) is a trillionth of a curie (10^{-12} Ci), or 2.22 disintegrations per minute, and a nanocurie (nCi) = 10^{-9} Ci. Some radionuclides are also chemical toxins, and if they have low activity per unit mass, then their chemical toxicity may be more important. Examples include U-238 and Th-232, which are heavy metals but have very low activities per unit mass.

The rate at which a radionuclide decays is commonly characterized not only by the transformation coefficient but also equivalently by its *physical* or *radioactive half-life*, $T_{1/2}$. The half-life is the time it takes for half the atoms in a pure sample of radionuclide to transform through radioactive decay. If a radionuclide decays into a stable daughter and if a sample of it has an original activity of 1 Ci, then the activity will be $\frac{1}{2}$ curie after the passage of time $T_{1/2}$, $\frac{1}{4}$ Ci at time $2T_{1/2}$, and $(\frac{1}{2})^n$ after n half-lives. If the daughter is itself radioactive, then it also will now contribute to the sample's overall activity. Radioactive half-lives can range from less than a microsecond (one millionth of a second) to billions of years. If the radioactivity of a material is not known, periodic measurements can be made and a curve constructed with radioactivity plotted on the vertical axis and time on the horizontal axis. Measurement of half-life is often useful in identifying a particular radionuclide.

From consideration of Eq. (3b) at time $t = T_{1/2}$, it can be shown that

$$\lambda T_{1/2} = \ln(2) = 0.693\ldots \tag{3c}$$

Thus, from the physical half-life $T_{1/2}$, one can calculate the decay constant λ and therefore the activity $A(t)$ as a function of time.

In addition to the physical half-life, the concept of *biological half-life* is important. This is the time in which a living tissue, organ, or individual eliminates, through biological processes, one-half of a given amount of substance that has been introduced into it. Thus, the *effective half-life* is the time in which a radioactive substance fixed in an animal body is reduced to half the original amount, resulting from the combined actions of natural radioactive decay and biological elimination. The effective (eff), radioactive (phys), and biological (bio) half-lives are related as:

$$1/T_{1/2,\text{eff}} = 1/T_{1/2,\text{phys}} + 1/T_{1/2,\text{bio}} \tag{3d}$$

Types of Radiation

The common types of ionizing radiation are X-rays, gamma rays, alpha particles, beta particles, and neutrons. The types and characteristics of radiation emitted by representative radionuclides are given in Table 7-1.

Apart from the fact that they are emitted by radioactive nuclei, *alpha* particles are the nuclei of ordinary helium atoms, and consist of two protons and two neutrons, with a net positive electric charge. Because they are massive,

TABLE 7-1 Common Radioactive Materials

				"Generally Licensed," or "Exempt," Quantities	
Radionuclide	Half-Life	Type of Radiation	Typical Uses or Origin	Activity (μCi)	Exposure Rate (mR/hr at 1 m)
C-14	5730 years	Beta	Primordial/ medical	50	—
Cs-137	30 years	Beta, gamma	Medical	1	0.0003
Co-60	5.3 years	Beta, gamma	Medical	1	0.0013
Au-198	2.7 days	Beta, gamma	Medical	10	0.0023
H-3 (tritium)	12.3 years	Beta	Multiple	250	—
I-131	8.1 days	Beta, gamma	Medical	10	0.0022
Ir-192	74.4 days	Beta, gamma	—	10	0.0048
P-32	14.2 days	Beta	—	10	—
Po-210	138 days	Alpha	—	0.1	—
Ra-226	1620 years	Alpha, beta	—	0.1	0.00008
Ag-111	7.5 days	Beta, gamma	—	10	0.0002
Na-24	0.63 days	Beta, gamma	—	10	0.0187
Sr-90	28 years	Beta	—	0.1	—
S-35	87 days	Beta	—	50	—

Source: Radiation Protection in Educational Institutions, Report No. 32, National Council on Radiation Protection and Measurements, Washington, DC, 1966. Table 2. Reprinted with permission.

even highly energetic alpha rays (several MeV) travel steadily but relatively slowly through matter and create many ions per unit of pathlength. Thus, they dissipate their energy rapidly and penetrate only 3 to 5 cm of air. A thin sheet of paper will stop alpha particles, and they rarely pose an external radiation hazard, since they cannot penetrate the outer layers of skin. Alpha-emitting radionuclides are normally of risk only if they enter the body through ingestion, inhalation, injection, or open wounds. Alpha emitters are heavy elements, such as uranium, lead, plutonium, and radium.

Beta particles are generally high- energy electrons emitted by radionuclides of low mass number and carrying a single negative charge. Strontium-90, I-131, and Cs-137 are examples of beta emitters. Beta particles may also consist of positrons—the antiparticle of the electron that has a positive rather than a negative charge. Fluorine-18 is one example of a radionuclide that emits a positron and is currently used extensively in positron emission tomography (PET) imaging. Beta particles have lower specific ionization, dissipate their energies rather quickly, and are moderately penetrative but are stopped by a few millimeters of aluminum. Beta particles cause damage to tissues through either internal or external irradiation. One important property of beta particles is that they may give rise to penetrating X-rays through a process called *bremsstrahlung*. In particular, when beta particles are stopped by shielding, the rapid deceleration of the beta particles as they are stopped leads to the production of X-rays. Thus, proper precautions must be taken to ensure protection against both the beta particles and these secondary X-rays.

Gamma rays and *X-rays* are both photons. X-rays and gamma rays are much more penetrating than alpha and beta particles, so their ionizations tend to be relatively well separated. Unlike alpha and beta particles, which slow down and come to a halt in a tissue, with a finite range, a beam of X-rays or gamma rays is attenuated nearly exponentially with tissue depth, and a large fraction may pass through the tissue entirely. A typical X-ray beam can be virtually eliminated, however, with lead shielding a fraction of an inch thick.

Neutrons are uncharged and cannot interact with the constituents of an atom through electrical forces and hence are highly penetrating. They are generated primarily by nuclear reactions such as fission or fusion, but some man-made radionuclides, such as Cf-252, emit them. Neutrons are commonly classified by their energy. Thermal neutrons have kinetic energies similar to those of the atoms and molecules surrounding them and can be captured by atomic nuclei to form new nuclides—indeed, activation with thermal neutrons is perhaps the most common mechanism by which substances can be made radioactive. Fast neutrons have energies greater than about 0.1 MeV and typically interact through elastic collisions with atomic nuclei. In this way, they transfer their energy to those nuclei, turning them into highly energetic particles that can create dense trails of secondary ionizations. Neutrons can present major problems in areas around nuclear reactors and particle accelerators but are rarely a source of exposure to the general public.

ORIGIN OF HUMAN EXPOSURE TO IONIZING RADIATION

External and Internal Radiation Exposure

Ionizing radiation exposure occurs either from a radiation source outside the body (external or direct radiation) or as a result of taking radioactive material into the body (internal radiation). For the general population, natural background radiation is the most significant source of external radiation exposure. X-ray machines are the most commonly encountered man-made sources of external exposure, but in some situations radioactive emitters of gamma rays and beta particles can also be of concern.

Gamma rays as well as alpha and beta radiation are of concern for internally deposited radionuclides. While many gamma rays will escape the body without hitting anything, alpha and beta particles only travel a short distance, so all their ionizing energy is deposited in the body. Where and for how long a radionuclide is retained in the body are of importance. While most medical radionuclides are quickly excreted from the body, I-131 concentrates and stays in the thyroid, presenting a risk of thyroid cancer. Fortunately it has a physical half-life of only 8.14 days. Radium-226, Ra-228, and Sr-90 all tend to go to bone and emit from there for much longer, increasing the risk of bone cancer and leukemia.

Internal radiation exposure results from inhalation, ingestion, dermal contact, and injection of radionuclides. The most common source of inhalation exposure is from natural radon, a gas that results from the decay of natural uranium, thorium, and radium in soil and can seep into basements. Radon-220 and Rn-222 have long chains of daughter radionuclides, and radiation from these daughter products, which attach to dust particles that lodge in the lungs, constitute the primary hazard. For instance, epidemiological studies have shown a high incidence of lung cancer among uranium miners.

Internal exposure due to ingestion may be through the presence of radionuclides in water or food. For instance, some communities have significant natural radium in their drinking water. The U.S. Environmental Protection Agency (EPA) sets standards for the level of radioactivity in drinking water at 15 pCi/l for alpha radioactivity, 5 pCi/l for radium, and a dose limit of 4 mrem/yr for man-made beta/photon radioactivity. Uranium, K-40, and Ra-226 are naturally present in soils and fertilizers and are thus incorporated into foods consumed by people and animals. The Food and Drug Administration (FDA) has developed guidelines for radionuclide levels in food (FDA Derived Intervention Levels) for individuals from three months to adult.

Dermal contact and injection of radionuclides are generally minor contributions to internal exposure. Injected radionuclides, typically for medical diagnosis or therapy, are meant to have short effective half-lives so as to minimize the dose. Technetium-99m, the workhorse of any nuclear medicine department, has a half-life of only 6 hr. As for dermal contact, the percutaneous absorption of radionuclides is typically negligible, especially if the skin is washed immediately after exposure. In addition, except for tritiated water (water in which one of the hydrogen atoms is tritium, the isotope of hydrogen, H-3), any dose is typically limited to the skin.

Sources of Exposure

Important sources of radiation exposure include natural background, radioactive fallout from nuclear testing or use of nuclear devices, radiation from X-ray machines and radionuclides employed in medical diagnosis and treatment, and radiation from industrial and other man-made sources. To help understand and better appreciate the significance of radiation dosages, some radiations to which individuals are or might be exposed to are given in Table 7-2. As a rule of thumb, average natural background radiation doses in the

TABLE 7-2 Some Sources of Radiation to Which We Are or Might Be Exposed

Source	Dose
Cosmic rays	30–100 mrem/year
Naturally occurring radioactive substances in water, air, and soil[a]	36–110 mrem/year
Natural environment	
Denver	510 mrem/year including cosmic
San Francisco	145 mrem/year including cosmic
Airport luggage inspection system	2.1 mrem/year[b]
Indoor radiation, radon in air and groundwater	200–2400 mrem/year
Natural gas cooking ranges	5 mrem/year[b]
Natural gas heaters	22 mrem/year[b]
Radioluminous watches and clocks	40–104 mrem/year[b]
Radium dial watch (no longer made)	3 mrem/day
Smoke detectors, gas and aerosol	8 mrem/year[b]
Common X-rays, medical and dental[c]	20–500 mrem/year
In brick, stone, concrete block homes[d]	8–13 mrem/year
Cigarette smoker[b]	8000–16,000 mrem/year
Other man-made sources[e]	10 mrem/year

Note: Exposures are approximate.

[a]Exposure increases slightly with altitude and varies with latitude, soils, and rock natural radioactivity content. The main sources of background radiation are cosmic rays and potassium 40, thorium, uranium, radium, and their decay products, including radon.

[b]NCRP Report No. 95, NCRP, Bethesda, MD, Table 5.1, p. 65. Annual dose equivalent.

[c]May be exceeded with poor practice or equipment or if medically indicated.

[d]Will vary with radionuclides in the construction materials.

[e]*See Health Effects of Low-Level Radiation,* American Council of Science and Health, New York, March 1989, which includes consumer products and radioactivity redistributed by human efforts, including radioactivity present in soot from coal power generation, dust from high-phosphorus fertilizers, etc.

United States are on the order of 3 mSv (300 mrem) per year, of which 2 mSv (200 mrem) comes from indoor radon, but these may vary by a factor of 2 or more depending on the geographical location. On average, medical and consumer products contribute an additional 0.6 mSv (60 mrem) per year.

Natural Background Radiation Natural sources of ionizing radiation account for the majority of the radiation dose to the general public. On average, it is estimated that about 80 percent of one's radiation dose is due to natural sources (excluding radiation from smoking tobacco). Radon, potassium, radium, and cosmic radiation are the major sources of natural background radiation exposure.

The most significant source of natural radiation is inhalation of radon and its decay products. As mentioned earlier, it is estimated that more than half of natural radiation exposure, or about 2 mSv (200 mrem) on average, is due to radon. Radon inspection is now a common part of home inspections, and the EPA recommends taking action if radon concentrations are found to be greater than about 0.15 Bq (4 pCi) per liter of air. Because radon emits alpha particles, which are only weakly penetrating, the primary exposure route is through inhalation into the lungs. Once in the lungs, radon and its daughter products can directly irradiate lung tissue. High levels of radon, such as those experienced by uranium miners, are known to cause increased incidence of lung cancer. Studies at high levels of exposure are used to estimate the potential risks from low levels of exposure.

Potassium and radium are two other natural radionuclides that contribute significantly to average radiation exposures. The naturally occurring isotope K-40 is radioactive and emits both beta and gamma rays. Annual dose rates are around 0.15 to 0.19 mSv (15–19 mrem). Because potassium is an essential nutrient and there is no natural way to separate isotopes, some exposure to K-40 is unavoidable. However, because radiation from potassium is highly penetrating, bulk quantities of potassium may result in additional radiation dose simply due to external exposure. Radium is also naturally occurring and can be taken up in bone tissue if ingested. Average annual doses are about 0.17 mSv (17 mrem) but may be higher in certain geographic areas. For instance, well water in some locations contains relatively high concentrations of radium.

Cosmic radiation is radiation that originates in outer space. At sea level, cosmic radiation dose rate is about 0.3 mSv (30 mrem) per year. But since the atmosphere itself absorbs cosmic radiation, the radiation dose depends significantly on altitude. For instance, on the Colorado Plateau, the dose rate ranges from 0.5 to 1.0 mSv (40–100 mrem) per year, and flying at 40,000 feet gives a dose rate per year of 15 to 20 mSv (1500–20000 mrem). However, flying round trip across the continental United States (about 10 hr at 40,000 ft) would only give a dose of 0.017 to 0.023 mSv (1.7–2.3 mrem).

X-ray Machines and Equipment X-rays are used in a wide range of diagnostic and research equipment. They are produced by dental, radiographic (fixed and mobile), mammographic, and fluoroscopic machines, computed tomography (CT) scanners, X-ray therapy units, airport luggage inspection devices, X-ray diffraction devices, industrial X-ray and thickness gauge machines, and other diagnostic equipment. On average, medical X-rays are estimated to result in an annual dose of about 0.4 mSv (40 mrem).

An X-ray machine is essentially a particle accelerator in which electrons ''boil'' off a hot filament of the X-ray tube and are then accelerated through a vacuum by means of a high voltage until they reach the ''target'' anode. As they enter the surface layers of the target, they are rapidly slowed down by collisions with the nuclei and electrons in it and are diverted from their original direction of motion. It is well understood that any charged particle that is forced to accelerate or decelerate rapidly will emit electromagnetic radiation; that, in fact, is how electrons driven rapidly back and forth in an antenna give rise to radio waves. The same occurs in an X-ray machine. Each time an electron suffers an abrupt deceleration or change of course, some or all of its kinetic energy is transformed into X-ray energy. If the electron is jerked to rest in a single abrupt collision, then all its energy will reappear as one high-energy, short-wavelength photon. If the electron encounters a less drastic collision, a longer wavelength, lower energy photon will be produced. Thus, these bremsstrahlung X-rays emerging from an X-ray tube span a broad range of energies.

There is a second important process that can result in the emission of X-rays. So-called characteristic X-rays may be generated when some violent event causes a rearrangement of the inner electron orbitals of a heavy atom. Either way, bremsstrahlung and characteristic X-rays arise from what are essentially atomic electronic processes, as opposed to the nuclear deexcitation events that yield gamma rays. Tungsten is usually used as the target material of X-ray tubes and linear accelerators because of its high melting point and high atomic number (for which bremsstrahlung occurs more efficiently). Molybdenum is employed in the anodes of mammography tubes, on the other hand, because of the favorable energies of its characteristic radiation. See Figure 7-5.

The strength and quantity of X-rays are usually expressed in terms of electrical current between the filament and target within the X-ray tube. The energy is measured in thousands of volts or kilovolts (kV) in diagnostic machines. The ability of X-rays to penetrate materials usually increases with their energy, which is why the design thickness of concrete or lead shielding for a site is determined, in part, by the highest energy of the radiation to be generated.

The quantity of X-rays produced is directly proportional to the current through the tube and is measured as thousandths of an ampere or milliampere (mA). The dose or energy absorbed by an irradiated object or by shielding is thus a function of both the kilovolt and the milliampere settings of the machine as well as other factors.

As is well known, when X-rays pass through an object, they can produce a shadow picture of it on film or a special screen. Radiographic images (along with those of fluoroscopy and CT) are created by differential attenuation of

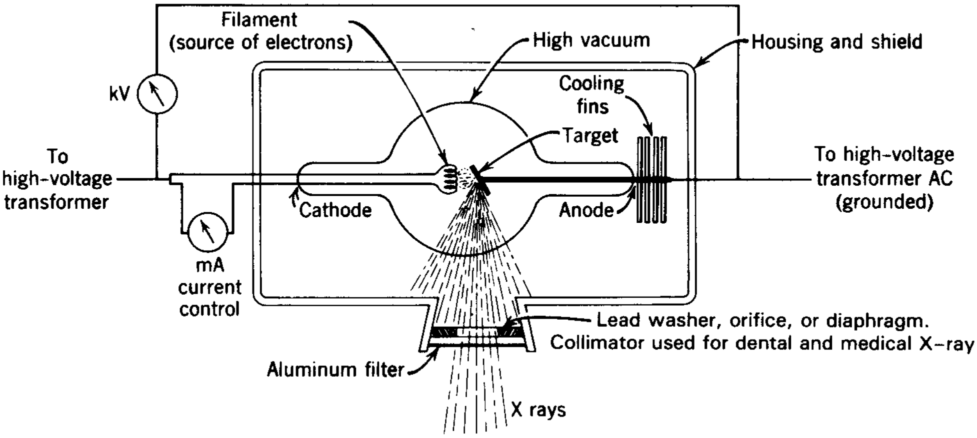

Figure 7-5 An X-ray machine. Diagnostic X-ray machines create images.

the beam by the various tissues of the body, which differ in density and effective (i.e., average) atomic number. In dental imaging, the shadowgram of a tooth is recorded directly on film. For a standard radiograph, the film is sandwiched between the two fluorescent screens of a *cassette,* and it is the light from the screens that exposes the film. In fluoroscopy, the life-sized X-ray pattern emerging from the patient is transformed by an electronic vacuum tube called an image intensifier into a small (2–3-cm), bright optical image that is either filmed by a still camera or viewed by a television camera.[2]

The CT scanner is a combination of X-ray machine and computer that, together with auxiliary equipment, can produce high-quality, three-dimensional anatomic pictures. In many diagnostic situations, CT scanners can show various intracranial or intra-abdominal abnormalities far more clearly than can simple radiographs. Their ability to locate, for example, tumors, blood clots, and anatomical malformations has largely eliminated the need for many kinds of exploratory surgery.[3]

X-rays are also produced as byproducts of machines that operate at high voltages. These include high-voltage television projection systems, color television sets, electron microscopes and power sources, high-power amplifying tubes producing intense microwave fields, radio-transmitting tubes, high-voltage rectifier tubes, and other devices producing penetrating electromagnetic radiation.

Radioactive Materials in Medicine Radioactive materials are used extensively in medicine. About one-third of all patients admitted to U.S. hospitals undergo diagnosis or treatment using radioisotopes, with a sum total of over 100 million procedures annually, and all major hospitals have specific departments dedicated to nuclear medicine.[4] Because of the potential hazards associated with radioactive sources in either diagnosis or therapy, handling and accountability procedures are required at places where they are used and stored.

Radioactive materials used as a diagnostic tool have the virtue of being able to provide information on the physiological status of various organ systems. The radioisotope Tc-99m, a gamma emitter with a 6-hr half-life and 140-keV gamma emission, is used in about 80 percent of nuclear diagnostic procedures. The radioactive material is attached to a tissue-specific *carrier* or tracer that, if injected, ingested, or inhaled, tends to concentrate in one organ or physiological compartment of the body, from which it emits penetrating gamma rays. The pattern of gamma emission is imaged by a *gamma camera,* and any region of excess or diminished emission can indicate an improper physiological condition in the region. Some medical *therapy* applications of radioisotopes are for the treatment of cancer—the radiation emitted (usually gamma rays) by the radionuclide helps to destroy cancerous tumors. Common radioisotopes for such treatment are Cs-137, Ir-192 and I-125.[2]

Positron emission tomography scanning is a technology that results in CT-like images that are created by gamma rays emitted from the body rather than by X-rays transmitted through it. A small amount of a positron-emitting radioisotope, attached to a tissue-specific carrier or tracer is injected into a patient, after which it collects in a specific organ. The positrons emitted travel typically less than 1 mm, whereupon they collide with electrons; this gives rise to a pair of 0.511-MeV "annihilation" photons traveling in near-opposite direction, and these can be extracted from any background noise through coincidence detection. The resulting PET image can yield invaluable information on both anatomy (like CT) and physiology (nuclear medicine) that neither a CT nor a gamma camera study alone can provide.

Radioactive Materials in Industry Radioactive materials are also used in many industrial processes. For instance, to determine whether a well drilled deep into the ground has the potential for producing oil, geologists use nuclear well-logging, a technique that employs radiation from a radioisotope inside the well to detect the presence of different materials. Radioisotopes are also used to sterilize instruments, to find flaws in critical steel parts and welds that go into automobiles and modern buildings, to authenticate valuable works of art, and to solve crimes by spotting trace elements of poison. Food irradiation to kill harmful bacteria also typically uses radioactive materials. Radioisotopes can also eliminate dust from film and compact discs as well as static electricity (which may create a fire hazard) from can labels.[5] Radionuclides commonly used in industry include Co-60, Pr-147, and Ir-192.

Consumer Products A number of consumer products contain radioactive materials. Natural radium was used for many years to produce luminous dials and faces for clocks, compasses, and other instruments. Because of the significant exposure hazard [localized doses of up to 3 mSv (300 mrem) per year], these have since been replaced with less hazardous radioactive materials such as tritium (H-3) and promethium. These new materials result in only a dose of a few microsieverts (0.1 mrem) per year. However, many items containing radium are still in circulation as antiques.

Other consumer products include smoke detectors and certain glazes and coatings. Many smoke detectors contain about a microcurie of americium, an artificially produced radionuclide (some newer models use photoelectric detectors, which do not involve the use of radioactive materials). The resulting dose is less than 0.01 mSv (1 mrem). Some glazing and tinting coatings contain uranium and thorium. Certain uranium glazes in pottery and dishes can produce dose rates of 0.1 to 0.2 mSv (10–20 mrem) per hour when people dine off of them.

Finally, tobacco typically contains two naturally occurring radionuclides: Pb-210 and Po-210. These nuclides are both decay products of natural radon and tend to stick to the leaves of tobacco plants. When a person smokes a cigarette, these radionuclides enter the lungs and result in a significant dose to lung tissue. The resulting equivalent dose to the respiratory system is estimated to be up to about 160 mSv (16,000 mrem) per year! This corresponds to a whole-body effective dose of about 13 mSv (1300 mrem), or almost four times the average natural background rate. An issue of interest to radiobiologists is the possible synergistic effects of radiation and chemical carcinogens in the lungs and elsewhere.

Nuclear Power As of 2001, there were over 100 nuclear power reactors operating in the United States and more than 400 such reactors worldwide. Although these reactors differ in design, there are several common processes that may be sources of radiation exposure. These can be divided into three main categories: production of nuclear fuel, power plant operations, and disposition of spent fuel.

The production of nuclear fuel involves the mining and milling of uranium, both of which can lead to exposure. Underground mines, in particular, are associated with elevated levels of radon and its decay products, and working in such mines has been directly correlated with increased incidence of lung cancer. In addition, mine wastes and mill tailings may contain higher than normal concentrations of radioactive materials such as uranium and radium, leading to exposure of nearby populations through airborne dust or leaching and runoff of liquid wastes. In some cases, tailings and mine waste have been used as construction materials for nearby homes, resulting in both direct exposure and inhalation of radon.

Routine nuclear power plant operations have virtually no effect on the public, but they do often lead to exposures to power plant workers. However, because of regulatory requirements, few workers at these plants even approach the annual dose limit of 50 mSv. Some leakage from nuclear power plants in the form of airborne or waterborne releases is inevitable, but this is monitored and limited by Nuclear Regulatory Commission (NRC) regulations. Collective doses from a single reactor have been estimated to be about 3700 person-Sv

(370,000 person-rem) over 45 years, which is less than 0.1 mrem per person per year.

Spent nuclear fuel is high-level radioactive waste and may be processed either for reuse or for disposal. Reprocessing of spent fuel (which, since the 1970s, has not occurred in the United States) involves separating the remaining uranium (and perhaps the plutonium) produced in nuclear power plant operation from the other fission products, which are then recycled into fuel for other nuclear power plants. High-level waste, coming either directly from or as a result of reprocessing of spent fuel, must be disposed of properly in order to prevent radiation exposure to the public. This subject will be discussed further below in the section describing waste management.

One major concern of nuclear power is the potential exposure due to nuclear accidents. Nuclear power plants in the United States are designed with many redundant safety features, but two major accidents, Three-Mile Island in Pennsylvania and Chernobyl in Ukraine, have heightened concern about the potential risks of nuclear power. The Three-Mile Island accident led to very little off-site contamination. It has been estimated that the highest doses from the Three-Mile Island accident were about 0.2 to 0.7 mSv and that collective doses were about 33 person-Sv to the neighboring population. This collective dose would imply about one or two excess cancer deaths in the lifetime of the exposed population. This amount of excess risk is far too small to measure in any epidemiological study. On the other hand, the Chernobyl accident lead to measurable global fallout. Although the only observable long-term health effects have been an increase in thyroid cancer among children, especially in Belarus, estimates of global collective doses range from about half to 1×10^6 person-Sv, most of which was received by the populations of the former Soviet Union and Europe. For comparison, it should be noted that natural background radiation leads to collective doses of around 10×10^6 person-Sv *per year.*

Nuclear Weapons Production and Testing Another source of radiation exposure is from nuclear weapons production and testing. Although older nuclear weapons used uranium, most nuclear weapons today employ plutonium produced in nuclear reactors. The steps leading through the reprocessing of spent reactor fuel are similar to those in producing weapons fuel—and this is the origin of the concern over nuclear proliferation from reprocessing of commercial spent fuel.

The testing of nuclear weapons has historically led to significant releases of radioactive materials into the environment. Radioactive contaminants (with their half-lives) from the detonation of nuclear weapons include I-131 (8 days); Sr-90 (28 years); Sr-89 (53 days); Cs-137 (30 years); and Ce-144 (275 days). From 1945 to 1980, nuclear tests were performed above ground and led to global fallout. The cumulative collective dose from such atmospheric testing as of 1993 was estimated to be about 7×10^6 person-Sv. Although the average dose from such atmospheric nuclear testing is generally relatively small, some local populations were significantly exposed. For instance, several atolls in the Marshall Islands, where the United States conducted many nuclear weapons tests, were evacuated and remain uninhabited. Some of the local residents showed skin lesions characteristic of exposure to acute doses of ionizing radiation. At the Nevada test site, which conducted tests between 1951 and 1962, thyroid doses to children living near the site may have been as high as 1 Gy (100 rad). Since 1963, the majority of nuclear tests have been carried out underground. The environmental effects of these tests have been relatively small, and little exposure to the general population has occurred. Similarly, the dismantling or decommissioning of nuclear weapons generally leads to little environmental release of radioactive materials—but the potential for nuclear proliferation is a significant concern.

BIOLOGICAL EFFECTS OF RADIATION

Effects of Ionizing Radiation on Cells

Ionizing radiation causes biological damage in a tissue by bringing about changes in the structure or function of its cells through energy transfer. The transfer of energy to the cell protoplasm can lead to direct change of cell components, such as the direct breaking of one or both strands of a DNA molecule, or to indirect changes, such as through the production of free *radicals,* which are highly reactive states of atoms or molecules that have just undergone certain chemical or physical reactions. These may cause subsequent chemical changes some distance away from the original ionizing event. High linear energy transfer (LET) radiation, such as alpha particles, in which the trails of the particles are dense with ionizations tend to do more damage to a cell. Low LET (gamma and beta) radiation will dissipate its energy and cause damage over a greater region, since it is more penetrating.

Damage to DNA can lead to reproductive death, point mutation, or even gene deletions, which are related to clinical outcomes such as cancer or birth defects. In many cases, cells can repair DNA damage, especially if only one of the two strands of DNA is damaged. The likelihood of a permanent change increases if the two DNA strands are simultaneously damaged, typically by high LET radiation. If the damage to cell structures is more severe, then cell death may occur. If enough cells in an organ or tissue are killed, as in a radiation burn, the entire organ or tissue may cease to function, and in extreme cases, the organism itself may die.

Biological Effectiveness and Organ Sensitivity

Different types of radiation may be more effective at damaging cells than others. In addition, some organs are more sensitive to radiation damage than others. These have led to the development of units of dose that take into account these different effects (radiation weighting factors) and sensitivities (tissue weighting factors). This approach for characterizing dose is summarized in Table 7-3. Note that the approach recommended by the International Commission on Radiation Protection (ICRP, 1977) has been codified in regulations. The ICRP, however, revised their recommended approach in 1991. Both are presented here for completeness.[6]

Recommended values of the so-called damage factor Q and of the radiation weighting factors w_R for various types of radiation are listed in Table 7-4. For medical radiation purposes, covering only X-ray and gamma-ray radiation, a dose in sieverts (rems) may be considered numerically equivalent to that in grays (rads). Some recommended values of the tissue weighting factors w_T are given in Table 7-5. Both radiation and tissue weighting factors are subject to occasional revision. In some cases, laws or regulations specify the weighting factors to use for regulatory purposes. Otherwise, the most recent ICRP recommendations are commonly employed.

Deterministic and Stochastic Effects

The relationship between radiation damage to cells and clinical outcomes is complex, but nearly all ultimate biological effects on an organism may be classified as being either deterministic or stochastic. *Stochastic effects* involve the increase in the *probability* of cancer or hereditary disorders, rather than its *severity,* and may have a long latency period between exposure and effect. These are thought to be caused primarily by damage to DNA. Stochastic effects are generally assumed for regulatory purposes to have no threshold dose, so that even very small amounts of radiation may increase the likelihood of the effect.

Deterministic effects are mainly caused by the death of damaged cells and involve the malfunctioning or loss of function of tissues or organs. These typically involve high levels of radiation exposure, arise not long after exposure, and have threshold doses below which they do not occur. When they do occur, their severity tends to increase with the degree of exposure. Some deterministic effects of acute exposures of ionizing radiation are listed in Table 7-6. Even relatively large doses usually show no immediate apparent injury. Whole-body doses over 5 Gy (500 rad) are typically fatal if untreated, but the time between exposure and death may range up to several months. This is because these high doses of radiation destroy the cells in organs, and death occurs as the organs stop to function properly. Some specific organs are particularly sensitive to radiation—acute exposures of several sieverts (several hundred rems) to testes or ovaries can lead to sterility, and high exposure to the eyes can lead to cataracts.

Whether cells can recover from radiation exposure depends strongly on the dose rate, that is, the dose per unit time. For example, a whole-body exposure of 6 Gy (600 rad) of X-radiation, equivalent to 6 Sv of equivalent dose, administered in 1 day, with no medical treatment, would mean almost

TABLE 7-3 Definitions of Dosimetric Quantities

Dosimetric Concept	Dosimetric Quantity	Symbol	Definition		Units
			ICRP 1977/10 CFR 20	ICRP 1991	
Absorbed energy	Absorbed dose	D	Energy absorbed per unit mass	Energy absorbed per unit mass	Gy or rad
	Average absorbed dose	D_{TR}	—	Average energy absorbed per unit mass in tissue T due to radiation type R	Gy or rad
Absorbed energy adjusted for the characteristics of different types of radiation	Dose equivalent	H	Absorbed dose (D) at point weighted by quality Q of radiation: $H = D \times Q$	—	Sv or rem
	Mean dose equivalent	H_T	Average of dose equivalent (H) in tissue T due to all radiations	—	Sv or rem
	Equivalent dose	H_T	—	Weighted sum over radiations R of average absorbed dose (D_{TR}) in tissue T: $H_T = \Sigma_R D_{TR} \times w_R$	Sv or rem
Absorbed energy adjusted for both different types of radiation and the sensitivity of different tissues	Effective dose equivalent	H_E	Weighted sum over all tissues T of mean dose equivalent (H_T): $H_E = \Sigma_T H_T \times w_T$	—	Sv or rem
	Effective dose	E	—	Weighted sum over all tissues T of equivalent dose (H_T): $E = \Sigma_T H_T \times w_T$	Sv or rem

Source: Ref 6.

TABLE 7-4 Radiation Weighting Factors

Radiation	Quality/Damage Factor Q 10 CFR 20	Radiation Weighting Factor w_R ICRP 1991
X-rays, gamma rays, beta particles, and electrons	1	1
Thermal neutrons	2	—
Fast neutrons, neutrons of unknown energy, high-energy photons	10	—
Neutrons energy < 10 keV	—	5
10–100 keV	—	10
>100 keV–2 MeV	—	20
>2 MeV–20 MeV	—	10
>20 MeV	—	5
Alpha particles, multiple charged particles, fission fragments, heavy charged particles	20	20

Source: Ref 6.

Note: Alpha particles, multiple charged particles, fission fragments, heavy charged particles.

certain death within 30 days. On the other hand, 6 Sv in daily increments over a period of 30 years would amount to an annual dose of 0.2 Sv, which is four times the federal occupational exposure limit of 50 mSv/year and may lead to an increased risk of cancer but is most unlikely to produce any deterministic effects. Thus, the difference in dose rate means the difference

TABLE 7-5 Tissue Weighting Factors

Tissue	Tissue Weighting Factor w_T 10 CFR 20	Tissue Weighting Factor w_T ICRP 60 (1991)
Gonads	0.25	0.20
Breast	0.15	0.05
Red bone marrow	0.12	0.12
Lung	0.12	0.12
Thyroid	0.03	0.05
Bone surface	0.03	0.01
Colon	—	0.12
Stomach	—	0.12
Bladder	—	0.05
Liver	—	0.05
Esophagus	—	0.05
Skin	—	0.01
Remainder	0.30	0.05

Source: Ref 6.

TABLE 7-6 Some Effects of Acute Exposure to Ionizing Radiation (Acute Radiation Syndrome)

Exposure		
Gy	rad	Effects
0–0.15	0–15	No observable symptoms
0.15–0.5	15–50	Subclinical: chromosomal breaks
0.5–1	50–100	Nonspecific toxicity: nausea/vomiting, temporary leukopenia
1–8	100–800	Hematopoietic syndrome. Four phases: (1) fatigue, headache, nausea/vomiting; (2) latent phase, marked by decrease in blood leukocyte counts and hair loss; (3) bone marrow depression phase, destruction of stem cells in the red bone marrow—can vary from serious to fatal (likely for >6 Gy); (4) recover phase, with general improvement over 3–6 months
8–30	800–3000	Gastrointestinal syndrome: damage of stem cells in gastrointestinal epithelium; nausea, diarrhea, fever, massive electrolyte imbalances, and ultimately death
>30	>3000	Central nervous system syndrome: violent nausea and vomiting, diarrhea, irrational behavior, circulatory system collapse, neuromuscular incoordination; convulsions, coma, death within 48 hr

between certain death in 30 days and possible increase in risk of cancer over a lifetime.

Another major factor in the biological effects of radiation is what part of the body is exposed. Large doses of radiation can be applied to local areas, as in therapy, with little danger. A person could expose a finger to 1000 rad and experience a localized injury with subsequent healing and scar formation. Cells that divide more rapidly are generally more sensitive to radiation damage. For example, white blood cells and the blood-forming organs, such as the, spleen, lymph nodes, and bone marrow, tend to be radiosensitive.

While the deterministic effects of ionizing radiation are relatively well understood, much uncertainty still surrounds the stochastic effects of radiation, such as the induction of cancer, birth defects, or hereditary effects. For instance, study of the effects on cancer, especially at low dose rates, are complicated by the long latency between exposure and malignancy, the presence of background cancer rates, and confounding exposures that may contribute to increased risk. More is known about the effects and mechanisms of damage from ionizing radiation, however, than about those from chemical carcinogens. For instance, it is known from studies of survivors of the atomic bomb that doses greater than about 0.2 Sv lead to a statistically significant excess in cancer incidence and mortality. However, the effects at lower doses are the subject of some controversy. In particular, a "linear, no-threshold" dose–response relationship has been assumed at low doses, and there is some biological and epidemiological evidence for it. As a rule of thumb, the lifetime fatal cancer risk due to radiation exposure under this hypothesis is about 0.05 per Sv (5×10^{-4} per rem). In any case, many believe that assuming a linear, no-threshold relationship is prudent, given the uncertainties. On the other hand, some experts have argued that there is also evidence for homesis—that is, beneficial effects at low doses—and that such effects should rule out the linear, no-threshold hypothesis. Still, a recent National Council on Radiation Proctection (NCRP) report has concluded that "there is no conclusive evidence on which to reject the assumption of a linear-non-threshold dose–response relationship." It states, furthermore, that "the probability of effects at very low doses . . . is so small that it may never be possible to prove or disprove the validity of the linear, non-threshold assumption."[7]

RADIATION PROTECTION PRINCIPLES AND STANDARDS

Basic Principles of Radiation Protection

National and international organizations that provide guidance relating to radiation protection (government laws and regulations will be addressed below) include the following:

- International Commission on Radiological Protection (ICRP),
- International Commission on Radiological Units and Measurements (ICRU),
- International Atomic Energy Agency (IAEA),
- International Labor Organization (ILO),
- World Health Organization (WHO),
- National Council on Radiation Protection and Measurements (NCRP),
- Conference of Radiation Control Program Directors of the States (CRCPD), and
- Health Physics Society (HPS).

The basic principles of radiation protection are developed by the International Commission on Radiation Protection (ICRP) and are summarized below.

Practices and Interventions There are two different categories of situations in which radiation protection is applied, called practices and interventions. *Practices* are activities that "increase the overall exposure to radiation, either by introducing whole new blocks of sources, pathways, and individuals, or by modifying the network of pathways from existing sources to man and thus increasing the exposure of individuals or the number of individuals exposed.''[8] The emission of radionuclides, including the emission of naturally occurring radionuclides from installations such as mines and waste disposal sites, is an example of situations treated as practices. On the other hand, *interventions* are activities that ''decrease overall exposure by influencing the existing form of the network. These activities remove existing sources, modify pathways, or reduce the number of exposed individuals.''[8] Radon in dwellings and radioactive materials, either natural or artificial, that are already in the environment, are examples of situations that can only be influenced by intervention.

Justification, Optimization, and Limitation The ICRP's fundamental guidance on radiation protection, which has been adopted virtually worldwide, has traditionally been based on a triad of practices known as justification, optimization, and limitation.

All activities related to radiation protection must be justified. In particular, any practice involving exposure to radiation should produce sufficient benefit to those exposed so as to offset the risks resulting from such exposure. An example of this is the use of medical X-rays, in which the benefits from the diagnostic procedure must outweigh the detriment due to the radiation exposure. For interventions that seek to reduce exposures, *justification* means that the procedure should do more good than harm. For instance, to justify the cleanup of a waste site, the reduction in public exposure and increase of other societal benefits (such as peace of mind) should outweigh the costs (monetary as well as health costs such as exposure to workers) that the cleanup would entail.

If an activity is justified, then it should be optimized in order to maximize the net benefits. *Optimization* implies that interventions should be implemented if a cost–benefit analysis indicates its appropriateness. In practice, optimization is associated with the idea that the magnitude of radiation exposures resulting from justified practices should be kept *as low as reasonably achievable* (*ALARA*), taking into account economic and social factors. In dental X-rays, examples of ALARA actions are reducing the frequency of X-rays and shielding the main torso. The NCRP has published some guidelines as to implementing ALARA.[9] For intervention, optimization means that the form, scale, and duration of an exposure should result in the net benefit (benefits minus costs) being maximized. Because optimization may result in substantial inequity in the costs borne by different individuals, it is recommended that optimization be constrained so as to limit this inequity. Such constraints often take the form of prescriptive limits on the dose or risk to individuals in the ''critical group'' that would reasonably be assumed to disproportionately bear the costs in radiation exposure from the activity.

The principles of justification and optimization are the centerpieces of radiation protection and often lead to acceptable results. However, for practices that are controllable, the principle of *limitation* also applies. In particular, individual exposures resulting from all controllable practices that result in radiation exposure should be subject to dose limits, and potential exposures (exposure that may or may not occur) should be subject to risk limits. The most recent NCRP recommendations for dose limits are summarized in Table 7-7.

TABLE 7-7 Summary of Dose Limit Recommendations

	SI Units	Conventional Units
A. Occupational exposures		
1. Effective dose limits		
a. Annual	50 mSv	5 rem
b. Cumulative	10 mSv × age	1 rem × age in years
2. Equivalent dose annual limits for tissues and organs		
a. Lens of eye	150 mSv	15 rem
b. Skin, hands, and feet	500 mSv	50 rem
B. Public exposures (annual)		
1. Effective dose limit, continuous or frequent exposure	1 mSv	0.1 rem
2. Effective dose limit, infrequent exposure	5 mSv	0.5 rem
3. Equivalent dose annual limits for tissues and organs		
a. Lens of eye	15 mSv	1.5 rem
b. Skin, hands, and feet	50 mSv	5 rem
4. Remedial action for natural sources:		
a. Effective dose (excluding radon)	>5 mSv	>0.5 rem
b. Exposure to radon decay products	>0.007 Jh/m^3	>2 WLM
C. Education and training exposures (annual)		
1. Effective dose limit	1 mSv	0.1 rem
2. Equivalent dose annual limits for tissues and organs		
a. Lens of eye	15 mSv	1.5 rem
b. Skin, hands, and feet	50 mSv	5 rem
D. Embryo–fetus exposures (monthly)		
1. Equivalent dose limit	0.5 mSv	0.05 rem
E. Negligible individual dose (annual)	0.01 mSv	0.001 rem

Source: Limitation of Exposure to Ionizing Radiation, Report No. 116, National Council on Radiation Protection, Bethesda, MD, 1993.

Notes: Medical exposures are excluded. Except for B.4, doses are the sum of external and internal exposures excluding natural sources. Working level month (WLM) is the cumulative exposure equivalent to exposure to one working level (WL) for a working month (170 hr). One WLM = 3.5×10^{-3} Joule-hours per cubic meter (Jh/m^3).

U.S. Government Agencies Responsible for Radiation Use and Protection

The production, management, use, and disposal of radioactive and other hazardous materials in the United States are guided and controlled ultimately by laws passed by Congress and signed by the president, such as the *Atomic Energy Act* (AEA) of 1946, later amended by the Atomic Energy Act of 1954. The AEA was the first nuclear-related legislation, and one of its important objectives was to direct the development, control, and safe use of atomic energy for peaceful purposes. Other statutes that relate to the management of radioactive materials are the Low-Level Radioactive Waste Policy Act of 1980, which was replaced in 1985 by the LLRW Policy Amendment Act (LLRWPA); the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA, or Superfund) as amended in 1986 by the Superfund Amendments and Reauthorization Act (SARA); the Nuclear Waste Policy Act of 1982; the Pollution Prevention Act of 1990 (PPA); and a variety of laws of the individual states.

These laws are general in nature but contain language that authorizes federal agencies to write and/or enforce specific regulations for its actual implementation. Such regulations bear the force of law but are promulgated federal agencies discussed below.

***Environmental Protection Agency* (*EPA*)** The EPA develops generally applicable environmental standards for other federal and state organizations to incorporate into their regulations. The EPA also develops regulations for implementation of these standards. In addition, under the responsibility that it inherited from the former Federal Radiation Council, the EPA develops guidance to all federal agencies in their formulation of radiation standards and the establishment and execution of programs of cooperation with the states. Finally, specific environmental statutes also address radioactive environmental pollutants (e.g., Superfund).

***Nuclear Regulatory Commission* (*NRC*)** NRC has considerable authority and responsibility, under the Atomic Energy Act, to write and enforce regulations on the civilian use and safe management of so-called *AEA materials* (special nuclear material, source material, and byproduct material; defined in 10 CFR 20), and for licensing their use. These materials include those used and produced by nuclear power reactors; nuclear research, test, and training reactors; fuel cycle facilities; and medical, academic, and industrial facilities. In addition, the NRC regulates the transport (along with the Department of Transportation), storage, and disposal of licensed nuclear materials and waste. The NRC's regulations are based on standards developed by the EPA supplemented by its own. The NRC passes on some of its authorities and responsibilities to states that demonstrate the willingness and ability to accept them. Such states are known as *NRC Agreement States*. The NRC has no jurisdiction over most naturally occurring radioactive materials (NORM) or radionuclides produced in accelerators, nor, in general, do they regulate the use of X-ray-producing equipment.

***Food and Drug Administration* (*FDA*)** The FDA, as part of the Department of Health and Human Services, establishes standards for the design and construction of X-ray machines and other electronic medical products that emit radiation. The Center for Devices and Radiological Health is the unit within the FDA primarily responsible for radiation-related issues.

***Department of Energy* (*DOE*)** The DOE is responsible for developing, constructing, and testing nuclear weapons; managing the radioactive wastes generated by such activities; and constructing and maintaining a repository for civilian high-level radioactive wastes and spent nuclear fuel generated by commercial nuclear reactors. The DOE develops its own standards but is also subject to some EPA regulations at its facilities.

***Department of Defense* (*DOD*)** The DOD is responsible for the safe handling and storage of nuclear weapons and other military uses of nuclear energy (such as nuclear-powered ships and submarines).

***Department of Transportation* (*DOT*)** The DOT, in cooperation with the NRC and the states, governs the packaging and transportation of radioactive materials as well as the carriers of those materials.

***Occupational Health and Safety Health Administration* (*OSHA*)** OSHA develops and enforces regulations to protect workers from radiation exposure not covered by other agencies.

State and Local Government State and local government agencies also have responsibilities with respect to radiation protection. In particular, X-ray machines and NORM (including uranium and thorium ores) are regulated by the states. Also, states have been licensed to regulate radioactive materials on behalf of federal agencies such as the EPA, NRC, and OSHA. For instance, as of 2002, there are 29 NRC Agreement States, which are states to which the NRC relinquishes the majority of its regulatory authority for inspection, enforcement, and licensing of the use of radioactive materials.*

In nearly all situations it is obvious which agency has authority and responsibility for writing and enforcing the applicable regulations for a law. Gaps and overlaps in the legal/regulatory framework do exist, however, and must be resolved through administrative arrangements or in the courts.

*Nuclear reactors, however, are still under NRC jurisdiction.

Major regulations applicable to ionizing radiation are listed in Table 7-8, including their location in the *Code of Federal Regulations* (*CFR*). In addition to regulations, federal agencies have published various guidance documents on the subject of radiation protection. Some of them are listed in Table 7-9.

METHODS OF RADIATION PROTECTION

Three crucial factors involved in effecting external radiation protection are distance from the source, duration of exposure, and shielding. Also important for protecting against internal and external radiation exposure is the control of contamination and the management of waste. These methods are particularly important in implementing the principle of ALARA and are implemented by a variety of personnel, engineering, and administrative controls that vary with the type and strength of the sources of radiation. Finally, surveillance and monitoring serve as both warnings of the breakdown of any safeguards as well as a quality check on their effectiveness.

Distance

The further away a person is from a radiation source, the less exposure he or she will receive. This is particularly true for a point source of radiation, such as the point of emission on the target of an X-ray tube; in accord with the familiar inverse square law, the subject exposure decreases inversely with the square of the distance from the source:

$$\frac{I_1}{I_2} = \frac{R_2^2}{R_1^2}$$

where R_1, R_2 = any two distances

I_1, I_2 = values of the intensity at the distances

For example, if at a distance of 5 ft one is exposed to an exposure rate or dose rate of A units per second, then at a distance of 10 ft the corresponding figure would be $\frac{1}{4}A$. In practice, this applies approximately to other than point sources of radiation, assuming that the radiation source is small relative to its distance from the exposed individual.

Duration of Exposure

When exposure to radiation is necessary or unavoidable, the duration time of such exposure should be kept as short as practicable to accomplish a particular task. In the case of occupational or similar situations, the cumulative exposure shall be kept below an individual's maximum permissible dose. This might

TABLE 7-8 Major Federal Regulations Relating to Radiation Protection

Agency	Title/Description	Reference
EPA	National Emissions Standards For Hazardous Air Pollutants	40 CFR 61
	Airborne emissions of radionuclides from selected facilities	
	National Primary Drinking Water Regulations	40 CFR 141
	standards for radioactivity in community drinking water systems	
	Environmental Radiation Protection Standards for Nuclear Power Operations	40 CFR 190
	Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-level and Transuranic Radioactive Wastes	40 CFR 191
	Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings	40 CFR 192
DOE	Occupational Radiation Protection	10 CFR 835
	standards for DOE facilities	
NRC	Standards for Protecting Against Radiation	10 CFR 20
	standards for occupational exposures	
	Domestic Licensing of Byproduct Material	10 CFR 30
	Domestic Licensing of Source Material	10 CFR 40
	Licensing Requirements for Land Disposal of Radioactive Waste	10 CFR 61
	Packaging and Transportation of radioactive material	10 CFR 71
FDA	Radiological Health	21 CFR 1000-1050
	includes medical X-ray machines and products emitting microwave, radio-frequency, light (e.g., lasers), and ultrasound	
	Mammography Quality Standards Act of 1992	21 CFR 900
FEMA	Radiological Emergency Planning and Preparedness	44 CFR 351
OSHA	Toxic and Hazardous Substances—Ionizing Radiation	29 CFR 1910, 1096

Note: More detailed summaries can be found in B. Shleien, L. A. Slaback, and B. K. Birky (Eds.), *Handbook of Health Physics and Radiological Health,* 3rd ed., Williams and Wilkins, Baltimore, MD, 1998, Chapter 4; ATSDR, *Toxicological Profile for Ionizing Radiation,* U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, GA, 1999, Chapter 7.

mean relocating or reassigning individuals to keep them within the dose limits shown in Table 7-7.

Shielding

Shielding is the interposition of an attenuating material between a source of radiation and the surroundings. A shield is typically some combination of concrete, steel, lead, and lead glass and may not only absorb ionizing radiation

TABLE 7-9 Guidance Documents Relating to Radiation Protection

Agency	Title	Reference
EPA	Radiation Protection Guidance to Federal Agencies for Occupational Exposure	52 FR 2822-2834
	Limiting values of radionuclide intake and air concentration and dose conversion factors for inhalation, submersion, and ingestion; Federal Guidance Report No. 11	EPA-520/01-88-020
	External Exposure to Radionuclides in Air, Water, and Soil; Federal Guidance Report No. 12	EPA-402-R-93-081
	Cancer Risk Coefficients for Environmental Exposure to Radionuclides; Federal Guidance Report No. 13	EPA-402-R-99-001
	A Citizen's Guide to Radon (September 1992)	EPA-402-K-92-001
	Manual of Protective Action Guides and Protection Actions for Nuclear Incidents	EPA 400-R-92-001
	Radiation Exposure and Risk Assessment Manual	EPA-402-R-96-016
FDA	Accidental radioactive contamination of human food and animal feeds: Recommendations for state and local agencies (August 13, 1998)	Center for Devices and Radiological Health, http://www.fda.gov/cdrh/dmqrp/84.html

but also protect from intense heat. The energy and type of the radiation to be attenuated and the human occupancy or use of the area of exposure are basic factors in the selection of the shielding material, its size, and thickness. The term ''half-value layer'' (HVL) is used to designate the thickness of a particular material that will reduce the intensity of radiation passing through the material by one-half. See Figure 7-6. Glass or plastic is commonly used to eliminate beta radiation. Table 7-10 is an example for X-ray sources.

A primary protective barrier is of a material and thickness to attenuate the useful beam to the required degree; a secondary barrier attenuates stray radiation. Radiation, however, will scatter and bounce off the floor and ceiling and from wall to wall. It can therefore be reflected around shields, around corners, over and under doors, and through ventilating transoms and windows. In some cases, the intensity of the scattered radiation may be as large as or greater than the primary radiation source. Shields must be placed to protect anyone who might have access to spaces above or below or on any side of the source. It is generally better to place shields close to the source of radiation because this will reduce the shielded area and the total weight of the shield.

Some of the characteristics of alpha and beta particles, X-rays and gamma rays, and neutrons are given earlier in this chapter. The ranges of alpha and beta particles in air are shown in Tables 7-11 and 7-12. Care also should be taken in designing shielding for beta particles to take into account the secondary bremsstrahlung X-rays that may be produced. Neutron shielding presents special problems around nuclear reactors and particle accelerators.

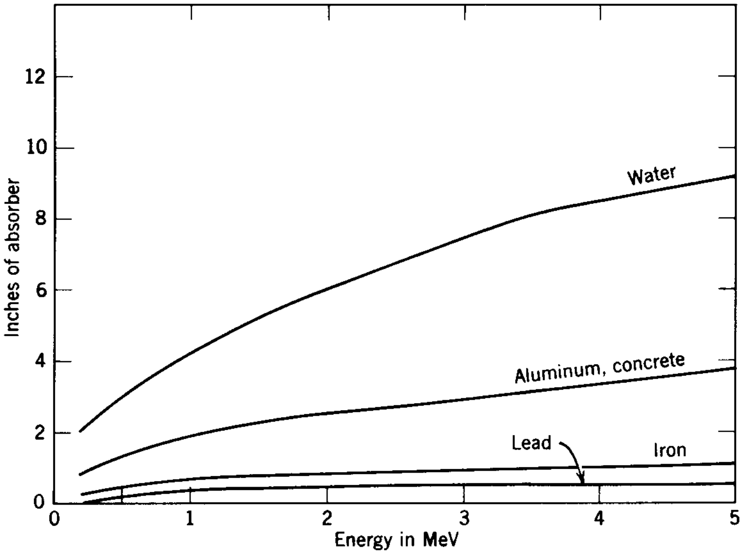

Figure 7-6 Half-value layers for different electromagnetic energies as related to thickness (in.) of iron and lead, aluminum, concrete, and water. [*Source: Atomic Radiation,* RCA Service Co., Government Services, Camden, NJ, 1959 (Contract No. AF 33(616)-3665).]

Additional factors to consider when designing shielding are the workload, the use factor, and the occupancy. The workload, usually expressed in milliampere seconds per week, is the milliamperage of the current passing through the X-ray tube times the sum of the number of seconds the tube is in operation in one week. The use factor is the part of the time a machine is in use that the useful beam may strike the wall, ceiling, or floor to be shielded. The occupancy factor is the time a person on the other side of a shielded wall, floor, or ceiling will be exposed to radiation when a unit is in operation.

TABLE 7-10 Thickness of Lead Required for Primary Barrier Located 5 cm from Focal Spot

Anode Current (mA)	Lead Thickness (mm)		
	50 kV_p	70 kV_p	100 kV_p
20	1.5	5.6	7.7
40	1.6	5.8	7.9
80	1.6	5.9	
160	1.7		

Source: General Safety Standard for Installations Using Nonmedical X-ray and Sealed Gamma-ray Sources, Energies Up to 10 MeV, NBS Handbook 114, National Bureau of Standards, Washington, DC, 1975.

TABLE 7-11 Range of Beta Particles in Air

Energy (MeV)	Maximum Range of Beta Rays in Air (m)
0.01	0.0022
0.02	0.0072
0.03	0.015
0.04	0.024
0.05	0.037
0.06	0.050
0.07	0.064
0.08	0.080
0.09	0.095
0.10	0.11
0.15	0.21
0.2	0.36
0.3	0.65
0.4	1.0
0.6	1.8
0.8	2.8
1.0	3.7
1.5	6.1
2.0	8.4
3.0	13.0
4.0	16.0
5.0	19.0

Source: Atomic Radiation, RCA Service Co., Government Services, Camden, NJ, 1959.

TABLE 7-12 Emission Energy and Ranges of Alpha Particles in Air

Radioisotope	Alpha Emission Energy (MeV)	Alpha Emission Range (cm)
Th-232	3.97	2.8
Ra-226	4.97	3.3
Th-228	5.41	3.9
Po-218	5.99	4.6
Po-216	6.77	5.6
Po-214	7.68	6.9
Po-212	8.78	8.6

Source: Atomic Radiation, RCA Service Co., Government Services, Camden, NJ, 1959.

Note: As a rule of thumb good to 10%, the range R of an alpha particle of energy E in MeV in air is $R = 0.56 \text{ cm} \times E$ for $E < 4$ MeV and $R = (1.24 \text{ cm} \times E) - 2.62$ cm for 4 MeV $< E <$ 8 MeV.

This factor will vary from 1 when there are people living or working in the adjoining space to $\frac{1}{16}$ when people may be exposed in a stairway or elevator.

The computation of shielding or barrier requirements is simplified by the use of tables and graphs.[10,11] As a rule of thumb, it takes 2 in. of lead, 4 in. of iron/steel, 8 in. of concrete, or 24 in. of water to reduce the dose rate by a factor of 10. For example, if the distance from the X-ray tube target to the wall (the controlled area to be protected) is 14 ft, the peak kilovolts (kV_p) of the X-ray therapy machine is 250, the workload is 20,000 mA-min/week, and the fraction of the workload during which the radiation under consideration is directed at a particular barrier (use factor) is $\frac{1}{4}$; required primary barrier thickness is 7.9 mm lead or 14.6 in. concrete for a controlled area. If the radiation is applied obliquely incident on a barrier, the required barrier thickness will be less. With a 200-kV_p machine under the same conditions, 4.5 mm lead and 12.8 in. concrete would be required, and with a 100-kV_p therapy machine, a workload of 2000 mA-min/week and a use factor of $\frac{1}{4}$, 1.35 mm lead and 4.5 in. concrete, would be required.

Contamination Control

Materials that emit alpha and beta particles present a particularly dangerous hazard if ingested or inhaled because their specific ionization is high and they irradiate the body continuously until they are eliminated. The seriousness of the hazard depends on the type of radioactive material, the type of radiation emitted, the energy of the radiation, its physical and biological half-life, and the radiosensitivity of the tissue and body organ where the isotope establishes itself. See Tables 7-1, 7-4, 7-5, and 7-7.

The primary objective of protection must therefore be to keep the radioactive materials out of the body in the first place. This is accomplished by the use of proper procedures and good practices, such as employing laboratory hoods, air filters, and exhaust systems; eliminating dry sweeping; wearing protective clothing and respirators when indicated; using proper monitoring and survey instruments; and prohibiting eating and smoking where radioactive materials are handled or used.

Entrance to areas that may cause or permit significant exposure to radiation or radioactive materials through occupancy, work, or general access must be controlled. Such areas may be found in hospitals; medical, dental, chiropractic, osteopathic, podiatric, or veterinary institutions, clinics, or offices; educational institutions; commercial, private, or research laboratories performing diagnostic procedures or handling equipment or material for medical uses; or any trucking, storage, messenger, or delivery service establishments or vehicles. High radiation areas are posted "Radiation Area," "Radiation Zone," or "Restricted Area," as required by the NRC and state regulations. These and similar types of installations and areas should be under the supervision of persons qualified by training and experience in radiological health to evaluate the radiation hazards and to establish and administer adequate radiation protection programs.

Waste Management

Radioactive waste from the use of radioactive materials must not endanger individuals, the public health, or the environment. The guiding principles should be prevention (reduction) and control of gaseous, liquid, and solid waste at the source, followed by segregation and the indicated collection, treatment, reuse, and storage or disposal. General principles of radioactive waste management are presented here. The case of waste from nuclear reactors is described in more detail below.

There are two general classifications of radioactive waste, namely high-level radioactive waste (HLRW or HLW) and low-level radioactive waste (LLRW or LLW). They are largely governed by two different federal laws and covered by two different sets of regulation. Disposal of high-level radioactive waste is the responsibility of the DOE. The licensing of high-level waste disposal facilities is the responsibility of the NRC, as specified in 10 CFR Part 60, ‘‘Disposal of High-Level Radioactive Waste in Geologic Repositories.’’ The actual disposal of HLW, which is generally taken to include spent nuclear fuel, is the responsibility of the DOE. Disposal of LLW is also subject to licensing by the NRC, the regulations for which are in 10 CFR Part 61, ‘‘Licensing Requirements for Land Disposal of Radioactive Waste.’’ The actual disposal facilities are administrated by regional groupings of states called Compacts.

Low-level radioactive wastes consist primarily of contaminated rags, clothing, filters, resins, and activated metals from power plants, laboratories, hospitals, and commercial and industrial facilities. The NRC regulations categorize this LLW into three classes: Class A wastes are materials that degrade to a safe (as determined by the NRC) radiation level within 100 years; class B wastes are materials with higher radioactivity; these degrade to a safe level within 300 years. Class C wastes are materials that do not degrade for up to 500 years. Class A wastes can be buried in solidified or absorbed form in containers. Class B wastes have to be solidified or buried in high-integrity containers. Class C wastes have to be solidified and buried at least 15 m (50 ft) deep.

The waste must also be processed in such a manner as to minimize the risk of exposure to the public. For instance, groundwater contamination should be minimized because it may be used to irrigate crops or fodder used for cows or processed as drinking water. Likewise, radioactive wastes may be taken in by the surface-water biota, which could then be consumed by people. Also, if the individual is in the vicinity of a release, there could be a direct exposure. Such processes have been studied extensively in recent year by means of computer-based *environmental pathway/transport models*, in the writing of regulations, the determination of release criteria, and the remediation of specific problems.*

Because of the different characteristics of solid, liquid, and gaseous radioactive wastes, each must be processed differently before release or disposal. Liquids are processed to remove the radioactive contaminants. These processes might include filtering, routing through demineralizers, boiling off some of the water (evaporation) and leaving the solids (which are then processed as solid radioactive waste), and/or storing the liquid for a time period to allow the radioactive material to decay. After processing, liquids will be sampled and, if they meet the required standards, they can be placed in storage tanks for reuse in the plant or even be released to the environment. If the samples show the water does not meet the release criteria, it must be processed further. Some materials, such as the evaporator bottoms (solids that remain after the water is evaporated), will be mixed with a substance like concrete to form a solid. This is also sometimes done with spent demineralizer resins. After mixing with a hardener, the material is processed as solid radioactive waste. Gaseous wastes are filtered, often compressed to take up less space, and then allowed to decay for some time period. After the required time has passed, the gases will be sampled. If the required limits are met, the gases will be released to the atmosphere or sometimes they will be reused in specific areas of the plant. Liquid and gaseous radioactive wastes may be released to the environment after processing if they meet the stringent release criteria specified in the site license. Careful monitoring and enforcement of release standards help ensure that members of the public are not put at risk by these releases. Remaining solid wastes are either stored on-site or transported to designated facilities for disposal.

Wastes that are not suitable for release may require further treatment into a solid waste form that can be safely disposed in a geologic repository. For high-level wastes, vitrification is a major solidification process. In this process, highly radioactive liquid and sludge are mixed with glass particles and heated to very high temperatures to produce a molten glass. This molten glass can be formed into glass marbles, blocks, or logs. When the mixture cools, it hardens into a stable glass that traps the radioactive elements and prevents them from moving through the air or water into the environment. Although effective, vitrification is a very expensive process and is performed only if the volume of wastes can be reduced to a reasonable amount.

In addition to proper handling, the proper disposal of radioactive waste will help to minimize the dose received by members of the public. Low-level

*One commonly used model for soil contamination is the RESRAD model developed by Argonne National Laboratory. See Yu et al., *User's Manual for RESRAD Version* 6, ANL/EAD-4, 2001. In addition, soil-screening models have been developed by the NCRP (Reports No. 123 and 129, NCRP, Bethesda, MD), and the U.S. EPA, (*Soil Screening Guidance for Radionuclides: User's Guide,* EPA/540-R-00-007, U.S. EPA, Washington, DC, 2000). One commonly used air dispersion model for radionuclides is CAP-88 (see B. Parks, *CAP-88 Version 2.0 User's Guide,* 1997).

sites should be isolated, remain stable for 500 years, and include monitoring for 100 years after closure. Although most of the radioactive materials decay rapidly, some radionuclides have long half-lives. These are generally small amounts in large volumes of material. Currently, low-level radioactive waste is accepted at three disposal sites presently operating. Barnwell, South Carolina, can accept all low-level waste except from North Carolina. Hanford, Washington, can accept waste from the northwest and Rocky Mountain compacts. Clive, Utah, is only authorized to accept class A, low-activity, high-volume waste. The Nuclear Waste Policy Act of 1980 gives states the responsibilities for management and disposal of most civilian low-level radioactive waste. Disposal is regulated by a state entering into an agreement with the NRC (agreement state).

There are various ways in which costs can be reduced through efforts to minimize quantities of LLW. But while market forces have had some effect in stimulating the intelligent use of resources, the waste minimization process has received only limited legislative and regulatory attention. There is no direct federal statutory requirement, in particular, for regulations on minimizing the generation of LLW. The Pollution Prevention Act, like ALARA, makes good sense, in general, and should be socially beneficial. Examples include recycling and source reduction. Still, there are a number of procedures one can follow, often quite easily, to reduce the amount of LLW in the first place—the most obvious being not to mix radioactive waste with non-radioactive materials if it is not necessary.*

In addition, the Waste Isolation Pilot Plant (also known as the WIPP), located in southeastern New Mexico, is the first geological repository in the United States for the permanent disposal of transuranic wastes. Transuranic waste, which contains man-made elements heavier than uranium (and therefore ''beyond uranium'' on the periodic chart), is produced during nuclear fuel assembly, nuclear weapons research, productions, and cleanup and as a result of reprocessing spent nuclear fuels. The waste generally consists of protective clothing, tools, glassware, and equipment contaminated with radioactive materials.

Space and Personnel Surveillance and Monitoring

A radiation installation should be responsible for its own monitoring program. A competent health–physics/radiation–safety unit should be established and given responsibility for safety monitoring and authority to take prompt corrective action whenever indicated. In-house safety rules governing operating

*The NCRP is preparing a report entitled *Management Techniques for Small Institutional and Laboratory Type Generators to Minimize the Need for Offsite Disposal of Low-Level Radioactive Waste* and will provide practical solutions and suggestions for improved low-level and mixed-waste avoidance, recycle, and management practices at small institutional laboratory and other generating facilities.

procedures are helpful. This should include control of the facility work and storage areas, sources, waste disposal, emergency procedures, and personnel monitoring. Common monitoring methods are summarized in Table 7-13.

A personnel monitoring system will determine individual exposure received and effectiveness of the control measures being taken. Commonly used dosimeters that allow assessment of beta, gamma, and X-ray exposure are thermoluminescent dosimeters (TLDs), film badges, and finger ring dosimeters. They may be supplemented by “pocket” dosimeters for work in areas where there is a suspicion of high dose rates. Some special instances may call for measurement of the radioactivity in the body or excreta. For instance, urinalysis may be employed for assessing exposure to tritium, C-14, S-35, or P-32, and persons working with radioiodine may require thyroid bioassays. Film badges should be processed and interpreted by a specialized laboratory or government agency.[12–14] The accuracy of other personnel monitoring devices should be determined by comparison with detectors calibrated at a nationally accredited laboratory approved for the types of radiation monitored. A personnel monitoring system should be in effect for individuals who may be exposed to radiation exceeding one-tenth of the maximum permissible effective dose equivalent values given in Table 7-7.

Instruments for detecting and measuring radiation are necessary for an effective monitoring program, and these must be selected with consideration of their sensitivity and purpose to be served. A summary of some radiation-detecting devices, including their characteristics, advantages, and disadvantages, is given in Table 7-14. It is important that all these instruments be properly calibrated. These “survey meter” devices are used to identify areas where contamination may exist. Wipe surveys may then determine the extent of the contamination (and tritium may only be detected through a wipe survey). For instance, appropriate media such as filter paper or cotton swabs are used to wipe a test area, and the presence of contamination may be detected by placing the test wipe in a liquid scintillation counter (with an appropriate “control” wipe to obtain a background count).[14]

Environmental Surveillance and Monitoring

An environmental monitoring program including a preoperational survey in and around a proposed nuclear facility can serve as a check on the various operations that might produce contamination.[15] It also permits evaluation of the exposure to the surrounding area and the need for preventive action. The program should be a cooperative one between health and other regulatory authorities and the facility management.

Industry has responsibility for internal housekeeping and monitoring of the types and quantities of all its radioactive waste discharges. Peripheral monitoring should be shared between the industry and the regulatory authorities. Maximum fallout from a stack will usually occur immediately after emission within a 1-mile (1.6-km) radius. This area should be secured by the plant.

TABLE 7-13 Radiation Monitoring Methods

Monitored Material	Preparation Method(s)	Device(s) Used
Body, or body part (X-rays and gamma rays)	Position individual in front of detector with area of interest shielded from extraneous radiation	Multichannel analyzer with Na–I detector for up to a few gamma emitters; germanium detector for any number of gamma emitters; planar germanium detector for alpha emitters that also emit X-rays
Urine, blood, or feces	Put any solids in solution; do chemical separation if multiple radioactive elements are present; deposit thin layer on a planchet or mix with liquid scintillation cocktail	Liquid scintillation for alpha or beta emitters; alpha spectroscopy for alpha emitters; Geiger–Muller counters for high-energy beta or gamma emitters; multichannel analyzer for gamma emitters
Personal monitoring of external radiation (beta and gamma rays)	Head dosimeter to produce thermoluminescence	Thermoluminescent dosimeter
	Develop film	Film badge
	None	Electronic dosimeter
Contamination (beta and gamma emitters)	None	Geiger–Muller counter
Contamination (alpha emitters)	None	Proportional counter

Source: Adapted from ATSDR, *Toxicological Profile for Ionizing Radiation,* U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, GA, 1999, Table 2-7.

TABLE 7-14 Radiation Detecting Devices

Detector	Types of Radiation Measured	Typical Full-Scale Readings	Use	Minimum Energy Measured	Directional Dependence	Advantages	Possible Disadvantages
Scintillation counter	Beta, X, gamma, neutrons	0.02–20 mR/h	Survey	20 keV for X-rays, variable for betas	Low for X or gamma	1. High sensitivity 2. Rapid response	1. Fragile 2. Relatively expensive
Geiger–Müller counter (including Packake GM detector)	Beta, X, gamma	0.2–20 mR/h or 800–80,000 counts/min	Survey	20 keV for X-rays, 150 keV for betas	Low for X or gamma	Rapid response	1. Strong energy dependence 2. Possible paralysis of response at high count rates or exposure rates 3. Sensitive to microwave fields 4. May be affected by ultraviolet light
Ionization chamber	Beta, X, gamma	3–500 R/h	Survey	20 keV for X-rays, variable for betas	Low for X or gamma	Low energy dependence	1. Relatively low sensitivity 2. May be slow to respond
Alpha counter	Alpha	100–10,000 alpha/min	Survey	Variable	High	Designed especially for alpha particles	1. Slow response 2. Fragile window
Film	Beta, X, gamma, neutrons	10 mR and up	Survey and monitoring	20 keV for X-rays, 200 keV for betas	Moderate	1. Inexpensive 2. Gives estimate of integrated dose 3. Provides permanent record	1. False readings produced by heat, certain vapors, and pressure 2. Great variations with film type and batch 3. Strong energy dependence for low-energy X-rays
Pocket ionization chamber and dosimeter	X, gamma	200 mR–200 R	Survey and monitoring	50 keV	Low	1. Relatively inexpensive 2. Gives estimate of integrated dose 3. Small size	1. Subject to accidental discharge
BF3 counter	Neutrons	0–100,000 counts/min	Survey	Thermal		Designed especially for neutrons	

Source: Radiation Protection in Educational Institutions, Report No. 32, NCRP, Washington, DC, July 1, 1966, Table 6, pp. 28, 29.

Note: All radiation survey meters should be standardized periodically against National Institute of Standards and Technology instruments.

Solid, liquid, and gaseous radioactive materials can be carried considerable distances by air and water and may adversely affect plant and animal life as well as people. It is essential, therefore, that a surveillance and monitoring program be maintained in and around installations from which radiation release is possible. These include nuclear power plants, fuel processing plants, uranium milling industries, university reactors, and certain industries and laboratories. The surveillance monitoring should be carefully planned with the advice and assistance of radiological health specialists and physicists, biologists, meteorologists, environmental engineers, geologists, and others familiar with the problem and the local area. The sampling for resulting contamination should include air, water, milk, food, biota, sediment, soil, and people. Interpretation of the sampling requires mapping of the surrounding area showing salient geographical and topographical features. When coupled with previously prepared air diffusion models and overlays, this information makes possible assessment of the risk associated with any release over a large area under various meteorological conditions. Mapping should show surface and groundwater hydrology, types of soil and vegetation, population centers, transportation systems, sources of water supply, recreational areas, and other land uses. Past meteorological conditions would include prevailing winds and speeds, temperature, and rainfall.

At a nuclear fuel processing plant there is a potential for discharge of I-131, Kr-85, and tritium. Release of I-131 is minimized by storage of fuel elements for at least 100 days before processing. Krypton release is greater than from a nuclear reactor and cannot as yet be effectively removed before release to a stack. Tritium is not yet removable and is discharged as a liquid or gaseous waste. Careful surveillance is necessary to ensure that discharges of these radionuclides are kept to a minimum and within acceptable limits.

Sampling at nuclear facilities may include any combination of the following, with consideration of the facility monitored:

Air Around the installation and at some distance, as noted above.

Water At plant outfalls, receiving stream and downstream; also groundwater from nearby wells.

Soil Immediately around the installation and at some distance, including stream bottom muds.

Biological Specimens Fish, deer, possibly cows, rodents, plants (especially those used for food); also, where available, shellfish, ducks, plankton, and other plant life.

Milk From dairy farms in vicinity.

Spaces Indoor spaces, containers, and conduits.

Table 7-15 gives suggested frequency of sampling and determinations.

Sampling stations are usually located on the site being monitored, in the immediate vicinity, and at some distance. Those on-site and in the immediate

TABLE 7-15 Suggested Monitoring Around a Nuclear Reactor or a Fuel Reprocessing Plant

Sample[a]	Frequency	Determination	Remarks
Water intake and effluent	Daily where indicated, composite or weekly grab	Gross alpha and beta of dissolved and suspended solids and gamma scans	Quarterly composite shall not exceed the standard established by the NRC. Make complete isotopic analyses if exceeded.
Receiving waters	Daily	Same as above	—
Fish, shellfish, mud, stream, water supplies, plankton	Quarterly[b] upstream and downstream from outfalls	Gross gamma and gross beta activity	Identification of radionuclides if standard exceeded; sample above and below outfall
Milk, farms in vicinity	Weekly	I-131, Sr-90, tritium, and Ce-137	Identification of radionuclides if standard exceeded
Air around facility	Continuous monitors, daily	I-131, Kr-85, gross beta on particulates	Shall not exceed standard established by NRC. If exceeded or approached, monitor environment and eliminate source.
Soil	Annually	Sr-90 and Ce-137 or gross beta	Sample farm soil downwind
Vegetation, animals	Growing season[b]	Gross beta	Same as for milk
Fallout, downwind	Daily cumulation, biweekly	Gross beta	Relate to fallout from weapons or other testing.

[a] Include meteorological data and stream flows.

[b] Quarterly or annually for radionuclides of long half-life; for short-lived nuclides, no more than two or three half-life intervals.

vicinity should preferably be fixed and continuous monitors. Stations at a distance could be used for periodic grab sampling, selected if possible with reference to other stations maintained by the Weather Bureau, a health department, a university, the U.S. Geological Survey, a radio station, or an airport that could provide supporting data. Stream samples include water, mud, and biota. Tiles, stones, or slides are suitable for the collection of biological attachments.

A monitoring station might contain a continuous water sampler, high-volume air sampler, silver nitrate filter, film badge, adhesive paper, silica gel, rain gauge, ionization chamber, and such other equipment or devices as may be indicated by a safety analysis and the nature of the facility being monitored. Table 7-15 shows the type of monitoring indicated around a nuclear reactor or fuels processing plant.[16]

The air monitoring around a boiling-water reactor is described by Thomas.[17] Within a 1-mile radius distributed on a 500-ft grid will be 50 thermoluminescent dosimeters; three air-monitoring stations will sample airborne particulates, radioiodine, heavy particulate fallout, and rainwater. Air filters will be scanned continuously by a beta-gamma-sensitive G-M tube, and readings will be reported at the control center. In addition, four air monitors about 10 miles away in an urban area will provide continuous reports to the control center. Weekly composite samples will also be collected from stations about 40 miles from the plant. Air monitoring is supplemented by the sampling of fish, mussels, algae, and other biota as well as milk, water, vegetation, and soil. State and federal agencies also have responsibilities to protect the public health.

GUIDELINES FOR MEDICAL USE OF RADIATION SOURCES

Medical and dental diagnostic examinations constitute a significant source of radiation exposure to the individual. In 1989, it was estimated that 3 million diagnostic examinations involving X-rays were made.[18] In addition, every year, over 6 million nuclear medicine examinations are made. Some of the common hazards associated with the medical use of ionization radiation sources are listed below. Education and motivation on the part of the medical and dental profession and their X-ray technicians can do more than anything else to reduce medical exposure.[19] Much progress has been made through education, certification, and image and dose control. Personnel exposure and workload records should also be kept.

Diagnostic X-ray Equipment

The usual operating conditions are 40 to 100 kV_p at currents up to 1000 mA, but usually for an exposure duration of only a small fraction of a second. The machine should be equipped with a calibrated voltage meter and timing device. Fast, sensitive film and proper developing techniques should be used. Lead shielding may be necessary behind the cassette holder for chest and upright X-rays or at any other primary beam areas if the "useful" beam penetrates into a waiting room or other occupied areas. An X-ray machine, although properly installed originally, may become hazardous later, for example because of alterations to the building, removal of the original shielding, or the loss of filters and lead diaphragms. In addition, the concentration of X-ray machines in one building may also increase the scattered radiation to unsatisfactory levels.

Some of the kinds of radiation protection and image quality problems that can arise are the following:

- failure to limit the X-ray beam to the part of the patient's body being examined and inadequate collimation;
- failure to use lead apron to shield the neck and gonads of the patient, especially children;
- operator cannot view and communicate with patient during an exposure;
- operator holding the patient or film during exposure;
- exposure switch is so arranged that it can be operated with a part of the operator's body outside the shielded area;
- direct-beam and scatter radiation passing through windows and into occupied regions nearby;
- scatter radiation under doors, around or over protective screens, or into control booth;
- improper skin to X-ray tube distance;
- exposure switch/timer, kV_p switch, and milliampere control, not accurate, for example;
- filters on the beam (to remove low-energy, diagnostically useless photons) missing or inadequate;
- improper film processing, as well as film processing demanding strict attention to time, temperature, and chemical quality, for example;
- overexposing film, compensated for by underdeveloping, resulting in poor image quality and excess patient dose; and
- inadequate darkroom conditions (light leaks, improper safe-lighting).

Dental units are usually operated at 50 to 100 kV_p at a tube current of 7 mA. Machine voltage should be properly calibrated. Fast, sensitive film and proper film-developing techniques are important. A 90-kV_p unit will require 0.5 sec exposure time compared to 1.5 sec for a 50- to 75-kV_p unit. A fast film will reduce exposure at skin surface by a factor of approximately 3 for a machine below 60 kV_p and by approximately 9 for an 80-kV_p or above machine as compared to slow film.[20] It is necessary to establish the correct exposure time for the kilovoltage, milliamperage, and source-to-skin distance for each examination.[21] Deficiencies in radiation protection that occur in some dental offices are similar to the ones just listed.

Fluoroscopy units differ from standard radiology machines in that they operate continuously for a number of seconds. A film gives greater detail with only a small fraction (5 percent) of the patient exposure, so fluoroscopy is normally used only where X-ray film will not provide the necessary information. The FDA performance standard for fluoroscopic equipment requires a primary protective barrier, field limitation, continuous pressure control (dead-man switch), minimum source to skin distances, and a timer and limits entrance exposure rates to 5 R/min (or 10 R/min with automatic exposure rate control).[22]

A presidential directive has been prepared by the EPA for the guidance of federal agencies in eliminating clinically unproductive examinations, using optimal techniques when examinations are performed, and employing appropriate X-ray equipment. This document is equally applicable to nonfederal institutions and may prove helpful. Although a little dated, it still contains much good advice and is reproduced here for convenience[23]:

1. General radiographic or fluoroscopic examinations should be prescribed only by licensable Doctors of Medicine or Osteopathy or, for specified limited procedures, postgraduate physician trainees and qualified allied medical professionals under their direct supervision; specialized studies should be prescribed only by those physicians with expertise to evaluate examinations in the particular specialty. Exception for specified procedures may be made for dentists and podiatrists.

2. Prescription of X-ray studies should be for the purpose of obtaining diagnostic information, should be based on clinical evaluation of symptomatic patients, and should state the diagnostic objective and detail relevant medical history.

3. Routine or screening examinations, in which no prior clinical evaluation of the patient is made, should not be performed unless exception has been made for specified groups of people on the basis of a careful consideration of the magnitude and medical benefit of the diagnostic yield, radiation risk, and economic and social factors. Examples of examinations that should not be routinely performed unless such exception is made are:

   a. chest and lower back X-ray examinations in routine physical examinations or as a routine requirement for employment,
   b. tuberculosis screening by chest radiography,
   c. chest X rays for routine hospital admission of patients under age 20 or lateral chest X rays for patients under age 40 unless a clinical indication of chest disease exists,
   d. chest radiography in routine prenatal care, and
   e. mammography examinations of women under age 50 who neither exhibit symptoms nor have a personal or strong family history of breast cancer.

4. Prescription of X-ray examinations of pregnant or possibly pregnant patients should assure that medical consideration has been given to possible fetal exposure and appropriate protective measures are applied.

5. The number, sequence, and types of standard views for an examination should be clinically oriented and kept to a minimum. Diagnosticians should closely monitor the performance of X-ray examinations and, where practicable, direct examinations to obtain the diagnostic objectives stated by clinicians through appropriate deletion, substitution, or addition of prescribed views. Technique protocols for performing medical and dental X-ray examinations should detail the operational procedures for all standard radiographic projections, patient preparation requirements, use of technique charts, and image receptor specifications.

6. X-ray equipment used in Federal facilities should meet the Federal Diagnostic X-ray Equipment Performance Standard, or as a minimum for equipment manufactured prior to August 1, 1974, the Suggested State Regulations for Control of Radiation (40 FR 29749). General purpose fluoroscopy units should provide image-intensification; fluoroscopy units for nonradiology specialty use should have electronic image-holding features unless such use is demonstrated to be impracticable for the clinical use involved. Photofluorographic X-ray equipment should not be used for chest radiography.

7. X-ray facilities should have quality assurance programs designed to produce radiographs that satisfy diagnostic requirements with minimal patient exposure; such programs should contain material and equipment specifications, equipment calibration and preventive maintenance requirements, quality control of image processing, and operational procedures to reduce retake and duplicate examinations.

8. Operation of medical or dental X-ray equipment should be by individuals who have demonstrated proficiency to produce diagnostic-quality radiographs with the minimum of exposure required; such proficiency should be assessed through national performance-oriented evaluation procedures or by didactic training and practical experience identical to, equivalent to, or greater than training programs and examination requirements of recognized credentialing organizations.

9. Proper collimation should be used to restrict the X-ray beam as much as practicable to the clinical area of interest and within the dimensions of the image receptor; shielding should be used to further limit the exposure of the fetus and the gonads of patients with reproductive potential (21 CFR Part 1000,50) when such exclusion does not interfere with the examination being conducted.

10. Technique appropriate to the equipment and materials available should be used to maintain exposure as low as is reasonably achievable without loss of requisite diagnostic information; measures should be undertaken to evaluate and reduce, where practicable, exposures for routine nonspecialty examinations which exceed the following Entrance Skin Exposure Guides (ESEG):

Examination (Projection)	ESEG (milliroentgens)[a]
Chest (P/A)	30
Skull (Lateral)	300
Abdomen (A/P)	750
Cervical Spine (A/P)	250
Thoracic Spine (A/P)	900
Full Spine (A/P)	300

Lumbo-Sacral Spine (A/P)	1000
Retrograde Pyelogram (A/P)	900
Feet (D/P)	270
Dental (Bitewing or Periapical)	700

Note: These levels can be reduced as new equipment, image intensifying X-ray screens, and better films are introduced.
[a]Entrance skin exposure determined by the Nationwide Evaluation of X-Ray trends program for a patient having the following body parts thicknesses: head, 15 cm; neck, 13 cm; thorax, 23 cm; abdomen, 23 cm; and foot, 8 cm.

11. X-ray examinations for dental purposes should be prescribed only by licensable Doctors of Dental Surgery or Dental Medicine or properly supervised postgraduate dentists on the basis of prior clinical evaluation or pertinent history; neither a full-mouth series nor bitewing radiographs should be used as a routine screening tool in the absence of clinical evaluation in preventive dental care. Exception may be made for justifiable forensic purposes.
12. Open-ended shielded position-indicating devices should be used with the paralleling technique to perform routine intra-oral radiography and should restrict the X-ray beam to as near the size of the image receptor as practicable.

The FDA performance standard for all kinds of radiographic equipment (e.g., radiography, dental, mammographic, fluoroscopic, digital fluoroscopic, CT,) requires control and indication of technique factors, timer termination conditions, accuracy and reproducibility specifications, indication and limits on field size and alignment, and a wide variety of other operational factors, depending on the technology involved.[24] In addition, many states have written and enforce regulations to help ensure optimal diagnostic utility of the films and, at the same time, minimum dose to the patient and radiology workers. In any case, the *only* strategy for making sure of safest and most productive operations is to institute a rigorous *quality assurance* (*QA*) *and radiation protection program,* with tests and checks of all equipment and processes occurring at regular scheduled times, the results of which reach top-level management.

Therapeutic X-ray Equipment

Therapy units are radically different from diagnostic machines in that they are produced by linear accelerators that operate at much higher energies, up to 20 MeV. The patient doses employed to treat cancer, moreover, are typically in the range of several tens of grays (several thousand rads). Thus even a small misapplication with a therapy can have large, and occasionally even lethal, consequences. The need for careful shielding design and a rigorous QA program is all the more important here and requires the oversight of experienced, skilled personnel. In addition to the kinds of problems noted above, occasionally inspectors find inadequate primary or scatter shielding, removal or failure of safety devices such as door interlocks, insufficiently frequent calibration, and electrical hazards.

Medical Therapy Using Radioisotopes

Also used in medical therapy are certain radioisotopes. While some of these may be injected (I-131 for thyroid cancer), others are confined within weld-sealed containers, such as cubic sources for external irradiation (Co-60), seeds (Ir-192), and hollow needles (Cs-137; Ra-226 was long used widely in this fashion but is no more). These materials require the same sort of careful considerations as do their electronic counterparts. In addition, medical personnel working with seeds or needles will be close to the source and may be exposed while inserting the source into tissue or removing it or during the time the patient is being treated. Because of this close proximity, it is important that all involved medical personnel receive special training and direct supervision. If a capsule is lost or broken, the state and local health departments should be immediately notified.

X-ray and Other Radiation Sources Used in Industrial, Commercial, and Other Settings

Industrial and commercial X-ray devices primarily include the following:

1. radiographic and fluoroscopic units used for the determination of defects in welded joints and in casting fabricated structures and molds;
2. fluoroscopic units used for the detection of foreign material, as in packaged foods;
3. ionizing radiation for the pasteurization of foods, sterilization of medical supplies, and other purposes;
4. security and antisabotage fluoroscopic examinations (devices only used for inanimate objects, such as in airports); and
5. sealed sources for measuring the density or thickness of products and determining liquid levels in closed tanks.

Radiation machines used in industry, training, and research include linear (electron) and other particle accelerators, neutron generators, and special X-ray units. Hazards associated with these high-voltage machines and sources are the same as those of medical equipment. The FDA performance standard for cabinet X-ray systems, such as carry-on baggage inspection systems, limits its radiation at 5 cm to 0.5 mR/hr under maximized operating conditions and door positions; restricts human access to the primary beam, and requires two interlocks on each door with one resulting in physical disconnection of energy to the generator, key control, two independent X-ray on indicators, warning indicators and labels, and user instructions.[25]

Projection television tubes, diffraction analyzers, and, for that matter, any equipment using high voltages are capable of generating X-rays. Even the home television tubes generate X-rays, but they are not considered to be a hazard since the "soft" X-rays generated are filtered out by the glass of the tube. However, if higher voltages are used than are allowed in order to get good images in color, or if designed with improper shielding, even these tubes may become a problem. The radiation should not exceed 0.5 mR/hr at any accessible point 5 cm (about 2 in.) from the surface under the most adverse operating conditions.* Viewing at least 6 ft from the tube is advised in any case.

As with medical diagnosis and therapy, initiation of a proper routine of inspection/QA procedures will reveal virtually all hazards to health and other problems associated with the use of ionizing radiation equipment and procedures. The detection of some machine or operational defects may require special test apparatus and the training and experience needed to use it properly, but the benefit-to-cost ratio of doing things right can be enormous.

NONMEDICAL RADIATION PROTECTION

Nuclear Reactor Waste Management

Some radionuclides commonly present in waste from nuclear reactors are as listed in Table 7-16.

TABLE 7-16 Radionuclides Commonly Present in Nuclear Waste

Material	Source	Radiation	Half-Life
Kr-85	Fission product	Beta, gamma	10 years
Sr-90	Fission product	Beta	28 years
I-131	Fission product	Beta, gamma	8 days
Ce-137	Fission product	Beta, gamma	30 years
C-14	Fission product	Beta	5770 years
Zn-65	Neutron activation product	Beta, gamma	245 days
Co-60	Neutron activation product	Beta, gamma	5 years
Fe-59	Neutron activation product	Beta, gamma	45 days
H-3 (tritium)	Neutron activation product	Beta	12 years

*Recommended by the International Commission on Radiological Protection and the National Council on Radiation Protection. Also, it is the limiting value in the United Kingdom and the FDA performance standard for units in the United States.

Spent fuel is classified as high-level radioactive waste. After a fuel assembly has been used in the reactor core to generate power, there is a large inventory of fission products held inside the cladding of the fuel. Since the spent fuel from commercial power plants in the United States is not reprocessed, it must be disposed of in some safe fashion. When the spent fuel is first removed from the reactor, it is stored for a period of time in the spent-fuel pool to "cool off" through radioactive decay. The spent fuel must be kept under water due to the heat being generated by the decay of the fission products and to limit the radiation levels in the area of the spent-fuel pool. The spent-fuel pools are usually located onsite. However, due to the amount of fuel some power plants must store, there are some off-site storage pools. After several years, the heat generated by the decay of the fission products decreases sufficiently to allow the storage of the spent fuel in an air-cooled, dry, above-ground storage facility. These facilities must be designed to remove the heat from the spent fuel and be designed to limit the radiation in the areas around the facilities. Presently, there are no permanent disposal facilities for commercial high-level radioactive waste. However, a site at Yucca Mountain, Nevada, has been the subject of intense study (and controversy) for the development of a permanent geologic disposal facility.

All radioactive waste that is not high-level radioactive waste is low-level radioactive waste. The principal sources of contamination in a nuclear power plant are the reactor coolant (water) and the components and equipment that come in contact with the coolant, which contains activation products and a very small amount of fission products. Low level radioactive wastes in the form of solids, liquids, or gases can be found, for example, at equipment leak-off points, valves, vents and drains; in a floor drain system; in spent filter cartridges; and in spent demineralizer resins. The activation products that are carried by the reactor coolant system are collected by the filters and demineralizers in the cleanup systems; when the filters and demineralizer resins are full, they must be disposed of as radioactive waste. A paper towel or rag used to wipe up radioactive oil or water is radioactive waste, as is a contaminated piece of clothing or equipment that is no longer usable

Radiological Emergency Response

Types of Emergencies Given the variety of radioactive materials and their uses, there are many types of emergencies that may occur involving these materials. These may include nuclear or radiological terrorism[26]; incidents at nuclear power reactors; accidents or natural disasters at federal sites and fuel fabrication and conversion facilities; nuclear weapons accidents; atmospheric reentry of space-vehicle nuclear power sources; transportation accidents; loss or abandonment of sources; radiation therapy overexposures; radiopharmaceutical accidents; and serious contamination of materials recycled for public use.

In any of these situations, it is possible that the public or the environment will encounter significant exposure to ionizing radiation. The purpose of radiological emergency response is to plan ahead to minimize or prevent such exposure and to be prepared to respond effectively to them if they do occur.

Planning and Response In the United States, the overarching plan for radiological emergencies is detailed in the Federal Radiological Emergency Response Plan (FRERP). The FRERP describes how the federal response will be organized. It includes guidelines for notifying federal agencies and states, for coordinating leadership of on-scene federal response activities, for coordinating federal public information activities, and for Congressional relations. The FRERP also suggests ways in which the state, local, and federal agencies involved can most effectively integrate their actions.

In addition, the EPA has issued a manual to assist in the establishment of local emergency response plans called the *Manual of Protective Action Guides and Protection Actions for Nuclear Incidents* (currently under revision).[27] It includes criteria for implementing specific protective actions, such as sheltering, evacuation, control of access, administration of stable iodine, decontamination, relocation, and food/water controls. Criteria for specific actions include projected doses that may result from the accident.

State and local government officials have the primary responsibility for protecting the public during a radiological emergency and must be prepared to respond immediately to it. State and local jurisdictions, as well as owners/operators of major nuclear facilities, should have compatible radiological emergency response plans that have been coordinated and tested for timely, effective emergency response. Federal assistance may be needed for emergencies that have the potential for significant off-site consequences such those involving multiple jurisdictions or those that extend beyond several hours and beyond the capabilities of the state/local community. In general, the NRC is the lead support federal agency for an incident at an NRC licensee site and the DOE and DOD at their own facilities. The EPA has the lead for response to emergencies that occur outside the United States, and the Federal Emergency Management Agency (FEMA) may play an active role in any of the above. The FRERP gives additional details as to how the federal response is coordinated.

In many cases, the presence of an emergency is readily apparent, but potential incidents such as radiological terrorism or small leaks from nuclear power plants may not provide such readily available signs. Environmental monitoring, however, may indicate if a previously unknown release of radioactive materials has occurred. The EPA, the NRC, and some state environmental and health departments routinely sample the air, water, and food supplies. Reports on the surveillance maintained are issued periodically by these agencies. Surveillance is also maintained over fallout.

The state, local, and federal governments have the obligation to assess an emergency situation, advise the public, and take action to minimize exposure to radiation. This might include evacuation, shelter, advisories on food and water use, and site access control. For the early phases of an incident, the EPA's protective action guide is 1 to 5 rem projected dose for evacuation or sheltering and a guide of 25 rem projected dose from radioiodine for the administration of stable iodine. Separate guidelines exist for workers performing emergency services. Additional guides have been established for the intermediate phase. Guidelines for contamination of food and animal feeds were updated by the FDA in 1998 and include derived intervention levels.[28]

The WHO has also developed public health guidelines for application after widespread radioactive contamination resulting from a major radiation accident.[29] The guidelines advise that when a whole-body radiation dose of 500 mSv (50 rem) is likely over a short period of time, sheltering, evacuation, and decontamination of individuals may be necessary, including administration of iodine tablets. At whole-body dose levels of 5 to 50 mSv, protective measures (sheltering and control of foodstuffs) are indicated. No action is indicated below 5 mSv. Food and liquid intake is measured in becquerel per kilogram (Bq/kg) or becquerel per liter. The responsibilities of a radiation safety officer and his qualifications, and personnel monitoring program recommendations are given in ref. 30. Guideline values for derived intervention levels and sample calculations of derived intervention levels are given in ref. 29. The objective is to ensure that no individual receives a dose greater than 5 mSv from dietary intake in the first year after an accident. This requires that national authorities monitor levels of contamination in food and drinking water and determine the total intake of specific contaminants, based on the type and amount of food consumed.

Example: Nuclear Power Plants Consider the example of a nuclear electric-power generating plant. Because of the large amount of radioactive material present, any such facility must have an emergency response plan approved by the NRC and FEMA before beginning operation. The plan must have been tested and contain detailed procedures for both on-site and off-site steps to be taken, and tests must be conducted at least every two years. On-site procedures are tested annually. The NRC and FEMA must observe and approve these tests and may require shutdown, until corrected, if serious deficiencies are found. The emergency plan must include a means for notification of the public living within 10 miles of the plant within a 15-min period. There must also be plans for immediate emergency monitoring and action in case of an accidental discharge to the environment. In extreme situations, there may be need for evacuation of the region within 10 miles of a plant and for special precautions downwind for 50 miles. Gross activity levels are useful for rapid measurements, as are samples from fixed air and water monitoring stations and food crops including milk.

NONIONIZING RADIATION

Nonionizing radiation refers typically to sound and all but the most energetic portion of the electromagnetic spectrum. In all its forms, it interacts with matter primarily through transmission, reflection, and/or absorption. Usually it is the absorption of the energy—and often the resulting heating—that can give rise to harmful health effects.

For nonionizing radiation, physical units of exposure are typically the watt per square centimeter (intensity of radiation) or watt per unit solid angle (radiant intensity). For microwave and radio-frequency radiation, a dose unit called specific absorption rate (SAR), measured in watts per kilogram, has been developed. The SAR depends significantly on the frequency of the radiation as well as the size, shape, and composition of the material in question. Furthermore, reflection of nonionizing radiation within complex materials (such as the human body) complicates the measurement of dose.

Some electronic products can emit harmful radiation if not properly designed, constructed, installed, or used. The FDA, part of the Department of Health and Human Services (DHHS), has the responsibility under the Radiation Control for Health and Safety Act and the Medical Devices Amendments to the federal Food, Drug, and Cosmetic Act to protect the public from unnecessary exposure to radiation from all types of electronic products including sonic, infrasonic, and ultrasonic waves and ultraviolet light. Electronic products, in addition to those mentioned below but excluding those producing ionizing electromagnetic radiation, include sanitizing and sterilizing devices, welding equipment, alarm systems, vacuum condensers, voltage regulators, vacuum switches, rectifiers, tanning lamps, black-light sources, radar microwaves, and other sources of intense magnetic fields. The FDA has issued performance standards or recommendations for laser products, mercury vapor lamps, microwave ovens, ultrasound therapy devices, sun lamps, and other electronic products.

Nonionizing Electromagnetic Radiations

Nonionizing electromagnetic radiations include microwave and intense electromagnetic field radiation such as found in microwave ovens and medical diathermy units; radar; infrared radiation; visible light for seeing detail and color; radio-frequency radiation; ultraviolet light used for sterilization, disinfection, and diagnosis and therapy; and lasers and masers, intense beams used in medicine, industry, military, and research (direct or reflected laser beams can cause damage to eyes, gonads, and central nervous system). Lasers can travel great distances and can be used for cutting, drilling, and welding; in communications systems; for surveying to establish lines and grades; in computer systems; for pollution detection; and in certain surgical procedures. Surgeons must be certified to use lasers.

Ultraviolet Light Ultraviolet radiation (UVR or UV) may emanate from natural sources (principally, the sun) or artificial ones. Artificial sources include mercury vapor lamps and various products that make use of the germicidal properties of UVR. These products are used in hospitals, laboratories, schools, and certain industries. Special lamps are used for the treatment of skin diseases and the prevention of vitamin D deficiency. Ultraviolet therapy produces a tan or sunburn. Improper therapeutic, occupational, or recreational uses, improper operation, or failure to wear protective goggles can harm the skin and eyes.[31] Ordinary window glass and most transparent materials absorb UVR; quartz and fluorite allow it to pass through

The FDA requires that sun lamps (tanning booths), which radiate ultraviolet rays, predominantly ultraviolet-A (320–400 nm), be equipped with a calibrated timer on each lamp that automatically shuts off at the end of a preset time interval based on the level of UV intensity; a manual switch; a base for the sunlamp bulb that cannot be used in a regular light socket; and protective goggles for the maximum number of people who can use the lamp at one time.[32,33] Also required are labels advising users taking any medications to first consult with their doctors and to carefully follow equipment use directions. The American Conference of Governmental Industrial Hygienists recommends that skin or eye exposure should not exceed 1 mW/cm^2 for periods greater than 1000 sec. Ultraviolet light in the UV-B band (290–320 nm) and UV-C band (<280 nm) are the most harmful. Natural sunlight that penetrates the atmosphere is composed of UV-A and UV-B.[34]

Mercury vapor lamps can cause severe eye irritation and skin burns at distances of 30 ft if the outer globe is broken and the inner part continues to operate, permitting harmful short-wavelength UV radiation to escape. Outbreaks of conjunctivitis and skin erythema traced to broken (unshielded) mercury vapor lamps in public gymnasiums have been reported.[35] Skin cancer, premature skin aging, and eye damage can result following repeated exposure; however, the effects may not become apparent for 10 to 20 years.

A current cutoff is required to provide protection when the outer globe is punctured or broken. The phosphor coating of the outer globe may be harmful if inhaled. Use of the lamps in gymnasiums, schools, stores, and industrial facilities without the cutoff switch introduces a danger of possible injury from hazardous short-wave ultraviolet radiation.[36–38]

Black lights or Wood's lamps contain a special glass that absorbs visible light but permits the transmission of UV radiation down to 250 nm, mainly at 366 nm wavelength of mercury. They are used to produce fluorescence of dandruff, certain dyes in very small concentrations, and soil in restaurants and for entertainment purposes.[39]

Lasers If the atoms of an object are somehow excited into higher energy states, they will give off photons of light as the electrons drop spontaneously back down to their lower energy configurations. In a laser (light amplification by stimulated emission of radiation), the atoms of the object tend to linger in the excited state, until they are simultaneously stimulated to make the same transition coherently and at the same time. This leads to the simultaneous emission of a large pulse of many photons, all of the same energy (or wavelength) and phase. This means that the intensity of the electric and magnetic fields of the radiation can be extremely high.

Lasers are used in a wide variety of applications in science, industry, and medicine. For many years, lasers were used largely for precision scientific or industrial measurements and advanced medical procedures. Since the advent of supermarket barcode scanners and laser pointers, lasers have become virtually ubiquitous. Laser eye surgery to correct nearsightedness has become a multimillion-dollar-a-year business.

But even though lasers have become more common, their safe use still requires a number of safeguards and precautions. Light can excite atomic or molecular electrons to higher orbital energy levels and/or vibrational states, and the excess energy may be dissipated as heat. This is particularly true of a laser beam, because of the excessively high energy density and electric field strengths where the beam strikes something.

The potential hazard depends on the wavelength at which the laser operates, often measured in nanometers (nm), and the power output of the laser, often measured in milliwatts (mW). Lasers operating near the visible wavelengths can cause injury to the eye cornea, lens, or retina. Lasers with wavelengths of 200 to 315 nm affect the cornea, 315 to 400 nm affect the lens, 400 to 1400 nm affect the retina, and 1400 to 3000 nm affect both the cornea and the lens. Exposure to UV laser light may, in addition to being an eye hazard, lead to increased risk of skin cancer or premature skin aging. High-power lasers can cause burns to the skin and be a fire hazard. In many cases, lasers that operate outside the visible wavelengths (such as UV or infrared) can be more dangerous because the beam is invisible. Finally, nonbeam hazards of laser operation include electric shock, chemical exposure, cryogenic liquids, compressed gases, and toxic fumes and gases.

Lasers are classified as to their potential hazard as follows:

Class 1 lasers are very low power (<0.5 mW), are considered incapable of producing dangerous radiation levels, and are exempt from most control measures.

Class 2 lasers emit visible radiation and are low power (<1 mW). They are potential eye hazards if the laser beam is viewed for more than $\frac{1}{4}$ sec.

Class 2a lasers also emit visible radiation but are not hazardous unless viewed for more than 1000 seconds.

Class 3 lasers have an output power of up to 5 mW but are not hazardous if momentarily viewed directly.

Class 3a lasers are medium-power lasers, with output power of 5 to 500 mW. Direct-beam as well as specular (mirrorlike) reflections are dangerous. Diffuse reflections are usually not a hazard.

Class 4 lasers are lasers whose power exceeds 500 mW. Direct beam and both specular and diffuse reflections can be dangerous to both eye and skin. These lasers may also present a fire hazard.

Lasers are subject to control measures that depend on their hazard classification. Engineering controls include protective housings, access restrictions, and physical barriers and enclosures. Administrative and procedural controls include requirements for standard operating procedures, warning signs and labels, and the use of personal protective equipment such as protective eyewear, face shields, laboratory coats, and gloves. For class 3 and class 4 lasers, safety training in their use is generally required.

More detailed information on laser safety can be found in the ANSI publication ‘‘Safe Use of Lasers’’ (ANSI Z136.1-2000) and includes an updated classification scheme.[40] This document is a widely accepted guide on laser safety. In addition, the FDA Center for Devices and Radiological Health has issued classification and performance standards for lasers. These performance standards specify classification and user logotype with precautions based on radiation accessible during use; limit radiation from viewing optics, ports, and displays to less than class 1; specify interlocks/labels based on radiation accessible during maintenance and service; require, based on increasing hazard class, radiation indicators, safety apertures, beam attenuators, emission indicators (some with time delay), remote door interlock, key control, and scanning safeguards; and require user, maintenance, and service manuals. In addition, they require indication of power levels on medical lasers with ± 20 percent accuracy; limit radiation to less than class 2a for surveying, leveling, and aligning lasers; and limit radiation to less than class 3a for demonstration lasers, including display or entertainment (note: variances, with extensive human access limitations, are often granted for laser light shows.).[41]

Microwaves High-power microwave radiation can cause thermal and nonthermal adverse biological effects, depending on the amount actually absorbed and other factors.[42] A primary mechanism of interaction of microwaves with tissue is the excitation of rotations and/or vibrations in molecules (such as water), which generally leads to a heating of the body. Nonthermal effects occur when a molecular structure is directly affected, causing cellular changes.

Microwaves are used in industry to test for flaws in equipment; in the home to operate TV remote controls and garage door openers; in radar at fixed installations and on police cars; and in transmitters, power systems, and communications using the telephone via satellites. Industry also uses microwaves to cure plywood, rubber, and resins; to raise bread and doughnuts; and to cook potato chips.

Microwave ovens and other electromagnetic energy sources (diathermy units, some radio frequencies, neon lights, and gasoline engines and their ignition systems) may interfere with the proper functioning of certain unshielded cardiac pacemakers. Pacemaker users should be alerted to the potential interference possibilities from outside electromagnetic sources. New pacemakers are supposed to be shielded.

Microwave ovens and similar devices have magnetron tubes that use electrical energy to generate high-frequency short-wave (microwave) energy. The Federal Communication Commission (FCC) has approved for ovens the use of 2450 and 915 MHz. Microwaves pass through paper, plastic, glass, and other clear materials; they are reflected by metals but are absorbed, refracted, or transmitted by nonmetallic materials such as water, food, and human tissue (eyes, internal organs, other) with the production of heat. By the time burning or pain is felt, the damage is done, but large amounts of microwave radiation are needed to reach this stage. Hence, metal, metal dishware, or dishware containing metal parts should not be placed in an oven; they may cause damage to the magnetron tube due to arcing or flashing.

Microwave ovens with poorly fitting doors, which can operate with the door open or partly open or with a safety interlock system that can be bypassed, can cause serious harm to the user. Microwave ovens are used in homes and restaurants and as an adjunct to quickly heat foods from automatic vending machines. Dirt, grease, or metal particles on door seals can permit microwave leakage; hence, cleanliness is essential. The door must form a tight seal. A densiometer or power density meter, although not entirely adequate, is used to monitor radiation leakage. Two independently operated safety locks are required on oven doors to stop microwave generation when the door is opened.

Some microwave exposure standards are given in Table 7-17.

In medical diathermy, heat produced by microwave radiation is used for therapeutic treatment. The heat can penetrate muscles as far as 2 in., increas-

TABLE 7-17 Microwave Standards

Maximum Exposure (mW/cm^2)	Source
10[a]	Underwriter Laboratories (U.S.)
10[a]	Standards Institute (U.S.)
10, continuous	U.S. Army and Air Force
10–100, limited	U.S. Army and Air Force
10, continuous	Great Britain (post office regulation)
1.0, prolonged	Sweden
1.0[b]	Public Health Service (PHS)/FDA
5.0[c]	PHS/FDA

[a] For 8-hr workday and 40-hr work weeks (OSHA) at 300 MHz to 300 GHz; however, less than 1 mW/cm^2 is advised for prolonged exposures.
[b] For microwave ovens at time of sale. Maximum leakage rate.
[c] Not more than 1 mW/cm^2 prior to oven sale and not more than 5 mW/cm^2 throughout the useful life of a microwave oven measured 2 in. (5 cm) from the external oven surface. Food and Drug Administration (FDA) *Performance Standards for Microwave and Radio Frequency Emitting Products, Microwave Ovens,* U.S. Department of Health and Human Services, FDA, Rockville, MD, 21 CFR 1030.10 (1994).

ing the flow of blood and nutrients to the area being treated through dilation of the blood vessels. This may reduce pain and promote healing. Microwave diathermy is also being used experimentally in efforts to destroy cancerous tumors. Improper use of microwave equipment can cause cataracts in patients and severe burns of the skin or underlying tissue. Short-wave and ultrasonic diathermy devices are also used for medical therapy.

Low- and Radio-Frequency Electromagnetic Fields The health effects of low-frequency electromagnetic fields (EMFs) generated by overhead high-voltage (500–765-kV) transmission lines, electrical wiring, and household appliances are not well understood. While these fields have too little energy to cause ionization, they can induce electric currents in conducting materials, such as blood and the protoplasm within cells, and these induced currents may have biological or health effects. The evidence thus far, however, has been inconclusive, although some studies indicate a possible link between EMFs and childhood leukemia and other forms of cancer. Some researchers have also looked at possible association between EMF exposure and breast cancer, miscarriages, depression, suicides, Alzheimer's disease, and other illnesses, but the general scientific consensus is that the evidence is not yet conclusive, one way or the other.[43]

With the explosion in the use of cellular telephones, concern has arisen over the potential health effects of the radio-frequency (RF) electromagnetic fields they emit. Exposure to these electromagnetic fields is similar to that of microwaves, and intense exposure can lead to heat-related or other effects. Most studies have found no significant correlation between exposure to lower levels of RF radiation and increased risk of cancer,[44] but others have raised questions.

More research is needed, such as on ways to reduce EMF exposure, thresholds for biological effects, possible association with cancer, and other biological effects. Some precautions have been implemented. For instance, no residences are allowed within a 350-ft right-of-way corridor surrounding each 765-kV power line in New York State.[45] In addition, cellular phone antenna towers have to comply with standards that protect workers and the public from the known heating effects of microwave exposure.

Magnetic Resonance Imaging An MRI device produces three-dimensional images (looking much like those of a CT scanner) of the brain, bone, heart, spinal, thorax, muscular, and other soft tissue. Its operation involves the application of an extremely strong, steady magnetic field to the patient's body, exposure to pulses of RF energy and, probably most significantly, the very rapid switching on and off of a second strong magnetic field. The nuclei of the hydrogen atoms of the water molecules within the tissues of the patient's body act like tiny, nuclear compass needles and align along the extremely strong, steady field. But as a result of the actions of the pulsing RF and the switching on and off of the gradient field, the hydrogen nuclei tend, in effect, to flip back and forth. This flipping can be detected by RF receiver coils outside the body and is employed in the generation of three-dimensional tissue maps.

The documented dangers from MRI machines have been mainly due to the extremely strong fields from the primary magnet, which can easily cause objects such as ferromagnetic screwdrivers and oxygen bottles to fly wildly across the room, sometimes resulting in severe injury to patient or staff. For this reason, there are strict requirements to ensure that the wrong kinds of metallic objects do not come near MRI machines.

Ultrasound

Mechanical radiation, or energy, travels at relatively slow velocities through some medium such as air, water, soil, or a solid material. Major forms are infrasound emitted by mechanical vibrations at a frequency usually too low to be heard by the human ear (20 Hz and below); sound that is in the range of human hearing of approximately 20 to 20,000 Hz (20 kHz)*; and ultrasound, which is in the range of 20 kHz and 10 megahertz (MHz). Ultrasound is used for medical therapy and diagnosis and in the cleaning of teeth and metals.[46]

Medical images reconstructed out of low-power ultrasound echoes arising at tissue interfaces are widely used in medical diagnosis. An ultrasonic transducer transforms electrical energy into sound (mechanical) waves. The sound waves enter the body, and some are reflected back by hard and soft tissue, bones, and organs. The sound waves reflected back produce a pattern that can be transformed into a visible image that can be studied, interpreted, and photographed. It is possible to study arterial blood flow, kidney disease, and possible gallstone, pancreas, and prostate problems. In obstetrics it is very valuable to study the age, position, and possible abnormalities of a fetus. Most diagnostic equipment operates in the frequency of 0.5 to 10 MHz. Typical intensity may vary, from up to 3 W/cm^2 for physical therapy to about 0.1 W/cm^2 or less in diagnostic ultrasound to visualize internal anatomy.

Higher power ultrasonic devices have been used to destroy tissues or cells and in the treatment of bladder and kidney stones.[47] The FDA has issued performance standards for ultrasonic therapy devices, requiring that they provide information on, for example, average and temporal peak power and/or intensity, pulse duration, pulse repetition rate, effective radiating area, beam nonuniformity, and spatial distributions. In addition, the power meter should have an accuracy of ± 20 percent and the timer an accuracy of ± 10 percent.[48]

Ultrasound is employed in dentistry to remove plaque from tooth surfaces and for gum treatment and in physical therapy to heat deep tissues and in

*Discussed in Chapter 6 under Noise Control.

hyperthermia treatment. It is also used in industry, in searching for defects in metal castings, and numerous other applications.

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8 Food Protection

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INTRODUCTION

While we believe that the U.S. food supply rates are among the safest in the world, the Centers for Disease Control and Prevention (CDC) estimate that as many as 76 million people get sick, more than 300,000 are hospitalized, and 5000 U.S. citizens die each year from foodborne illness.[1] This 1999 surveillance report is the collective efforts of multiple federal, state, and local public health agencies through a reporting program called FoodNet. Preventing foodborne illness and death is a major public health challenge. A significant watershed event that led to substantial changes in the way the federal government caries out its food safety public health mandate was the illness and death of several individuals from consuming ground meat that was contaminated with *Escherichia coli* 0157:H7—a pathogen that causes diarrhea and abdominal cramps and in severe cases may result in an illness called hemolytic euremic syndrome (HUS) and death. In the subsequent years, the U.S. Department of Agriculture (USDA) and the U.S. Food and Drug Administration (FDA) developed new regulations for their respective food safety mandates based upon the original concept of providing safe food for astronauts, commonly known as Hazard Analysis and Critical Control Points (HACCP).

Details on the new inspection procedures and pathogen control are outside the main focus of this chapter. However, the last decade of the twentieth century made clear that protecting the safety of food for consumers has become a public health priority. Specific web sites now exist for many public health programs.* The health and disease aspect of food and the prevention,

* See, e.g., http://www.FoodSafety.gov. See also http://www.cfsan.fda.gove and http://www.fsis.usda.gov.

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0-471-41813-7

control, and investigation of foodborne illnesses are discussed in Chapter 1. Program administration, including inspection, evaluation, education, and enforcement, is discussed in Chapter 12. This chapter focuses on the technical, microbiological, and sanitation aspect of food service and processing establishment design, operation, and maintenance. However, addressing some of these aspects of food protection will necessitate occasional reference to these new inspection programs.

FOOD SAFETY AND PROTECTION BACKGROUND

The original food safety laws and regulations developed in the early twentieth century served its intended purpose well, when, at that time, diseases associated with animal health were the major concern. At that time, invisible hazards such as pathogenic microorganisms and drug residues had not yet attracted the attention of public health authorities or the food industry in general. Time and the food industry have changed. Today's food industry producers are often large operations that move millions of pounds of product into commerce daily, animal disease has given way to concerns about microbial, chemical, and environmental contaminants, and there are substantial amounts of foods available through the rapidly growing international trade market that permit year-round access to popular foods. These simplified scenarios support the concept that the means by which assurances for food safety can be maintained or improved also need to change. While the traditional organoleptic, or sensory, system works in many respects, fundamental flaws exist. For example, rather than preventing contamination of foods, it focused on catching and controlling contamination after it occurred. Likewise, it is not capable of detecting either harmful bacteria or chemical and environmental contaminants that are not visible. In summary, it did not integrate systematic, preventive process control into the safe production of food. More contemporary science and technology are necessary to address these types of food safety and protection issues.

The new food safety approach to preventive process control changes that put controls in place to prevent contamination and verification systems to indicate that preventive controls are working. Significantly, it also puts a priority on preventing, not just identifying, contaminants of priority concern. The general concept of process control (i.e., HACCP) is founded on a basic seven-step process.* While the HACCP process control approach is a key component to the production of safe food, other significant components are

* HACCP plans are based on the seven principles articulated by the National Advisory Committee on Microbiological Criteria for Foods: 1, hazard analysis; 2, critical control point identification; 3, establishment of critical limits; 4, monitoring procedures; 5, corrective actions; 6, recordkeeping; and 7, verification procedures.

necessary, such as prerequisite programs for employee hygiene and sanitation standard operating procedures for facilities and equipment to reduce the likelihood that harmful bacteria will contaminate finished food products. A significant and noticeable change is a shift in responsibility that food producers are responsible for their production of safe foods and regulatory agencies are responsible for verification that the food producer HACCP programs are operating under defined controls. To further complement this food safety approach, food safety regulatory agencies are encouraging the development of new and innovative technologies that can be applied to foods to reduce levels of pathogens in food. Recently, the FDA approved irradiation for pathogen control (e.g., an expansion of prior approval of irradiation for control of parasites in food and control of insects in spices and seasonings).* Other major evolutionary changes will be noted in the text that follows.

FOOD PROTECTION, QUALITY, AND PRESERVATION

Recognizing that a comprehensive approach to food safety and protection starts at the source of production and ends with the ultimate consumer and includes all of the processes in between forms the basis for the recently pronounced U.S. initiative on food safety known as the ‘‘farm-to-table’’ initiative. Similarly, international food trading partners and international food standards organizations (e.g., Codex Alimentarius Commission) are ardently supporting the same approaches to food safety and quality. Not only is farm-to-table an important concept within the primary federal agencies responsible for food safety, but equally important is that the food safety initiative is ‘‘seamless’’ between agencies. It is important to ensure that each segment of the food production chain, ultimately including consumers, employ the best available science and information regarding food safety to minimize or eliminate, among others, contamination, recontamination, or temperature abuse of processed foods. This is a formidable task, requiring the cooperation of the food producer (e.g., good agricultural practices, personal hygiene of workers, management of soil quality, and safe use of pesticides), transporter, processor, distributor, wholesaler, and retailer, including vending machines, the food preparer, the server (hygiene, sanitation, and temperature control), and the consumer (storage, sanitation, and temperature control). To meet the desired objectives of the farm-to-table initiative, uniform standards and procedures are needed to guide all involved, including the regulatory agencies, food industry, and other concerned organizations and institutions. This need is being met in part by applying HACCP process control, standardized operating procedures for sanitation and hygiene using the best available science, and risk analysis procedures developed by federal agencies and international standard-

* See, e.g., http://www.cfsan.fda.gov. The regulation was published in December 1997.

setting bodies. Similarly, food safety and quality can be attained by programs developed by industry and trade organizations, for example, those proposed by the Interstate Conference for Food Protection, modeled after the National Conference on Interstate Milk Shipments. See Milk Program Administration later in this chapter. (Chapter 10 discusses vector control and pesticide use, including houseflies, roaches, ants, fleas, rats, and mice.) The presence of these vectors in any food establishment is prima facie evidence of poor sanitation and sanitary practices in the establishment.

Disease Control

The reader is referred to Chapter 1 and Figure 1-2 for more detailed information on the causes, prevention, and control of foodborne illnesses.

Food Handling and Temperature Control

Temperature control and food sanitation practices at every step in food processing and preparation should be the rule in kitchens and food-processing plants to minimize or eliminate potential contamination and foodborne illnesses. Significant food safety initiatives at the FDA's Center for Food Safety and Applied Nutrition (CFSAN) and the USDA Food Safety and Inspection Service (FSIS) have highlighted contemporary requirements for safe handling and uniform federal refrigeration requirements (45°F, or 7°C). For example, CFSAN published draft regulations for eggs specifically targeting shell eggs and the risk of illness caused by *Salmonella enteritidis,*[2]* while FSIS published a report in 1998 to help food safety experts determine the most effective ways to reduce the risk of foodborne illness due to eggs using a risk assessment report. It incorporates a farm-to-table computer model program that can help identify the interventions that provide the best return in terms of public health protection. Similarly, FSIS has recently published a final rule on updated sanitation requirements for meat and poultry establishments.[3] The USDA's Agricultural Research Service web site lists numerous studies on time–temperature controls, though many of these are for specific foodborne pathogens.† General guidance still applies pertaining to, for example, keeping all food contact surfaces and equipment used in preparation clean and in good repair.

In view of the *S. enteritidis* illnesses and deaths associated with the use of infected Grade A whole shell eggs, the USDA and FDA advise that eggs be thoroughly cooked, that the yolk and white be cooked until firm, that raw eggs or foods containing raw eggs be avoided, that lightly cooked foods containing eggs be avoided, and that utensils, equipment, and work surfaces

*The new regulations went into effect January 20, 2000.
† See, e.g., http://www.nps.ars.usda.gov.

coming into contact with raw eggs be cleaned and sanitized before reuse.[4] Pasteurized eggs, rather than fresh eggs, should be used in food service establishments and institutions where large quantities are prepared.

The minimum recommended internal cooking temperature for eggs, fish, and beef is 145°F (63°C); for poultry 165°F (74°C); for pork 165°F [microwave 170°F (77°C)]; and for leftovers, including stuffing, 165°F. Higher cooking temperatures are used for medium and well doneness.

Frozen meat, poultry, and other bulk frozen foods should be thawed in a refrigerator at 40°F (4.4°C).* This temperature requirement is a revision from previously recommended values. In addition, recommended procedures for thawing frozen turkey and other poultry products are provided for, such as use of cold-water thawing. The recommended guidance for thawed products *not to stand at room temperature overnight to thaw* remains. General guidance is to allow approximately 24 hr for every 5 lb of frozen product. See Table 8-1 for the time to thaw frozen turkey; the thawed turkey must then be immediately cooked or refrigerated. Table 8-2 gives the roasting time for fresh or thawed turkey. A microwave oven may be used if the food is immediately cooked to completion following manufacturer's directions. Frozen vegetables and chops need not be thawed but can be cooked directly. Prepared foods, especially protein types, should be served immediately, kept temporarily at a temperature of less than 40°F (4.4°C) or on a warming table maintained at a temperature of 140°F (60°C) or above until served. If not to be served immediately, the food should be frozen to 0°F or refrigerated within 30 min and cooled under refrigeration from 140 (60°C) to 40°F (4.4°C). Precooling using an ice tray is an option. Bulk foods should be cut into smaller pieces and refrigerated within 30 min of preparation unless immediately served. Potentially hazardous ingredients for food to be consumed cold, such as in a salad or pastry, should be chilled prior to preparation. Bacterial growth (including spoilage organisms) of cooked foods is minimized by prompt refrigeration. Suggested storage temperatures for various foods are given under Refrigera-

TABLE 8-1 Turkey Thawing in Refrigerator or in Cold Water

Weight (lb)	Thawing in Refrigerator (days)	Thawing in Cold Running Water (hr)
8–12	1–2	4–6
12–16	2–3	6–9
16–20	3–4	9–11
20–24	4–5	11–12

Source: Food News for Consumers, U.S. Department of Agriculture, Washington, DC, Holiday 1988, p. 14.
Note: Allow 24 hr for thawing a 3-lb frozen chicken.

* See, e.g., http://www.fsis.gov and http://www.cfsan.fda.gov (revised 1999 food code).

TABLE 8-2 Timetable for Roasting Fresh or Thawed Turkey in a 325°F (163°C) Oven

Weight (lb)	Unstuffed (hr)	Stuffed (hr)
4–6 (breasts)	$1\frac{1}{2}$–$2\frac{1}{4}$	Not applicable
6–8	$2\frac{1}{4}$–$3\frac{1}{4}$	3–$3\frac{1}{2}$
8–12	3–4	$3\frac{1}{2}$–$4\frac{1}{2}$
12–16	$3\frac{1}{2}$–$4\frac{1}{2}$	$4\frac{1}{2}$–$5\frac{1}{2}$
16–20	4–5	$5\frac{1}{2}$–$6\frac{1}{2}$
20–24	$4\frac{1}{2}$–$5\frac{1}{2}$	$6\frac{1}{2}$–7
24–28	5–$6\frac{1}{2}$	7–$8\frac{1}{2}$

Source: Food News for Consumers, U.S. Department of Agriculture, Washington, DC, Holiday 1988, p. 14.
Note: As soon as the turkey is done, *remove all stuffing.* Serve the turkey quickly while it is hot. Many public health authorities recommend cooking stuffing separately.

tion, this chapter. If food is to be refrigerated for more than four days, a storage temperature of 42°F (6°C) or less will minimize the growth of microorganisms associated with foodborne illnesses. The revised FDA 1999 Food Code should be consulted for more specific information.

The prevention of foodborne illness depends greatly on temperature control of wholesome potentially hazardous food from its source through preparation, storage, and service. A flow diagram identifying critical temperature points of menu item preparation to be temperature checked can alert the foodhandler and supervisor. Use the critical control point (HACCP) concept discussed under Food Protection Program Objectives, this chapter.

Personal Hygiene and Sanitary Practices

Personal hygiene and sanitation practices are thoroughly addressed in the new inspection regulatory initiatives noted above. Among the watershed changes in responsibilities for production of safe food, food processors are responsible for developing their own individual procedures such that they meet the general regulatory requirements. Some examples apply generally. For example, all employees involved with food handling and preparation have a basic responsibility to maintain a high degree of personal cleanliness and observe hygienic and safe practices, and they should be so advised. The owner or manager must insist that employees comply or be removed. One or more washbasins located in the kitchen or workroom supplied with warm potable, running water, a soap dispenser, and individual paper towels are necessary and conducive to greater personal cleanliness. Standard instructions to foodhandlers, including chefs, should include the following precautions, with emphasis on the special task performed by each:

1. Keep perishable foods covered and in the refrigerator or freezer until used. Cook, or reheat, foods to proper internal temperature and hold at proper temperature [140°F (60°C)] until served; if not served immediately, refrigerate rapidly to 40°F (4.4°C) or lower internal temperature. Do not allow food to stand at room temperature to cool down. Do not prepare food far in advance of intended service time. Follow good sanitation practices.
2. Wash hands thoroughly; before starting work; after using the toilet, smoking, or blowing the nose; after handling raw foods such as poultry, eggs, fish, and meat; and when soiled. Use plenty of soap and warm running water; rub hands together for at least 30 sec; and clean thoroughly between fingers and around fingernails.
3. Do not pick up food with the fingers during food preparation unless absolutely necessary and never when serving. Use a serving spoon, fork, spatula, tongs, or disposable plastic gloves.
4. Keep hands clean and fingernails short and clean. Keep fingers out of food, nose, and hair and off face.
5. Keep body and clothes clean and wear a head covering or hairnet.
6. Pick up cups, spoons, knives, and forks by the handles and keep fingers out of glasses, cups, soup bowls, and dishes.
7. Cover nose and mouth with a paper tissue when sneezing or coughing, then discard tissue and wash hands thoroughly. Do not smoke where food is prepared.
8. Report to a doctor and your supervisor at the first sign of a cold, sore throat, boils, vomiting, running sores, fever, or loose bowels. Stay at home. See a doctor if symptoms persist.
9. Help keep the entire premises clean. Store foods in a clean, dry place, protected from overhead drippage and animal, human, rodent, and insect contamination. Keep food preparation tables and utensils clean; avoid cross-contamination between food and unclean surfaces.
10. Store pesticides and cleaning and disinfecting liquids and powders in a separate cabinet, away from food, clearly labeled.
11. Thaw frozen food in refrigerator or under cold running water. See Table 8-1 and Refrigeration, this chapter.
12. Store and rinse wiping cloths in sanitizing (bleach) solution. Clean and sanitize cutting boards after each food preparation. Cleanse and boil wiping cloths daily.

Note that under the recently promulgated HACCP regulations, hygienic practices are a component of sanitary standard operating procedures. They should be reviewed consistent with the specific foods under consideration and the appropriate regulatory authority.

Foodhandler Examination and Responsibilities

The requirement for a foodhandler to have a medical examination prior to employment and periodically thereafter has been discussed and debated for some time.[5,6] A medical examination, even if thoroughly done with laboratory support, does not and cannot give the assurance expected because the results are only valid at the time of the examination. While a large number of new sensitive and reliable tests for microbial pathogens are now available, examinations for the presence of fecal material may give false or negative results because a laboratory may not always detect all the relevant pathogens or the pathogens are not being excreted at the time or the organisms are not uniformly dispersed in the specimen examined. It is believed that the time and expense involved in the medical examination and laboratory analyses of throat cultures, blood, urine, and feces are not commensurate with the public health protection obtained. Effort can be better devoted to improving foodhandler attitude, hygiene, and sanitary practices and by daily inspection of the foodhandler by *management*.* The foodhandler should be relieved from duty when suffering from a pyogenic skin infection on the face, arms, or hands; a bad cold; vomiting or diarrhea; or any other obvious infection or disease that could be transmitted directly onto or through food. However, the medical examination and specimen collections are an important part of a foodborne illness investigation.

The testing for sexually transmitted diseases, including acquired immunodeficiency syndrome (AIDS), is not indicated since the organisms are not found in the feces or spread by food or water. The human immunodeficiency virus (HIV) cannot be spread by casual contact or in food handling.[7]

Food Quality Inspection

Food for human consumption is expected to be clean, wholesome, unadulterated, and of acceptable quality. Purchased food should be in full weight and measure of the indicated grade and origin. The best time to check this is on delivery, against the order or invoice, before acceptance. After acceptance, inspection should ensure proper storage and rotation of foods. Frozen and other perishable foods must be promptly and properly refrigerated. Dry stores must be inspected when delivered and after storage for insect infestation and stored in clean, dry, insect- and rodent-proof enclosures at proper temperature. Bulk sale of dry foods must ensure proper handling and protection of the food. Although special training is needed to determine food quality, some general guides are summarized in Table 8-3. It has been estimated that one-quarter of the world's food supply is lost due to spoilage.

*Inspection is warranted even though a foodhandler may show no symptoms (carrier) or may be infectious before the appearance of symptoms (hepatitis A).

TABLE 8-3 Food Grading, Signs and Tests for Food Spoilage or Poor Quality, and Preventive Measures

Canned Food—Grade A, B, or C

1. Swelled top and bottom, or one end only[a]
2. Dents along side seam, deep rust, cut seam
3. Off-odor or molds
4. Foam, leaks
5. Milkiness of juice

This applies to canned vegetables, meats, fish, and poultry. Home-canned foods should not be used. Do not taste!

Fresh Fish—Grade A, B, or C (*Department of Interior*)

1. Off-odor
2. Gray or greenish gills
3. Eyes sunken, dull; pupils gray
4. Flesh easily pulled away from bones
5. Mark of fingernail indentation remains in flesh
6. Not rigid, scales dry and dull
7. Oyster and clam shells not tightly closed; shell gives dull sound on tapping

Raw Shrimp

1. Pink color on upper fins and near tail; soft, dull, sticky
2. Off-odor similar to ammonia

Some types of shrimp are naturally pink. Cooked shrimp are also pink. Both are wholesome if the odor is not abnormal.

Meat—Grade Prime, Choice, Select, Good, Standard, Commercial, Cutter, Canner, Cull

1. Off-odor, sourness, tainted
2. Slimy to touch
3. Beef soft, dark, coarse-grained; soft fat, yellow
4. Lamb or veal flesh dark, fat yellow

Beef usually spoils first on the surface. Pork spoils first at meeting point of bone and flesh in the inner portions. To test for spoiled beef or pork, use a pointed knife to reach the interior of the meat. An off-odor on the knife means spoilage. Fresh meat should be firm and elastic when pressed; not discolored. Store at 28°F (−2°C)

Pork graded No. 1, 2, 3, 4, medium, cull.

Leftover Food

1. Discoloration
2. Off-color
3. Mold

Dressed Poultry—Grade A, B, or C (*USDA*)

1. Stickiness or rancidity under wing, at the point where legs and body join, and on upper surface of the tail; sunken eyes

TABLE 8-3 (*Continued*)

2. Darkening of wing tips, soft flabby flesh

Dressed poultry should be washed thoroughly before cooking. Wash your hands after handling and sanitize cutting board.

Cereal

1. Insects
2. Lumps, mustiness, mildew

Spread the cereal on brown paper. If insects are present, they will be easily seen. If even one is observed, destroy the entire batch. These insects are not dangerous, but neither are they appetizing.

Smoked Meats

1. Pale color, soft, moist, flabby
2. Sausage, bologna, frankfurters slimy, moldy, discolored spots, internal greening

Cured Fish

1. Offensive odor, soft flesh

Eggs—Grade AA, A, B, or C (*USDA*)

1. Candling shows large air cell: jumbo 28 oz/doz, extra large 27 oz, large 24 oz, medium 21 oz, small 18 oz
2. Cracked, dirty or leaky shell
3. Frozen, liquid, or dried powder not pasteurized; salmonella free[b]

Butter—Grade AA, A, or B (*USDA*)

1. Off-flavor, fishy, stale, unclean, rancid or cheesy flavor—scored 83 to $87\frac{1}{2}$
2. Slightly objectionable flavor—scored 89–$91\frac{1}{2}$
3. Made from unpasteurized cream

A score of 92 indicates a clean, sweet butter lacking in rich creamy flavor. A score of 93–100 indicates a clean, sweet, creamy, excellent butter. Butter made from raw milk may contain pathogenic organisims.

Instant Nonfat Dry Milk—U.S. Extra Grade (*USDA*)

Milk should have a sweet and pleasing flavor and dissolve immediately.

Custard Pastries

Custard-filled pies, puffs, eclairs, and similar pastries, to be considered safe, should be:

1. Prepared with custard or cream filling that has been heated and maintained for at least 10 min at 190°F (88°C) or 30 min at 150°F (66°C), or
2. Rebaked for 20 min
3. Cooled to 45°F (7°C) within 1 hour after hearing and maintained below 45°F until consumed.

Custand Pastires

Only properly pasteurized milk or cream should be used; filling equipment should be cleaned and sterilized before each use, and no cloth filling bags are to be used.

Any food that has not been refrigerated below 45° (7°C) may be considered slightly spoiled. The off-odor of spoiled food is not always apparent. Do not keep cooked food such as ground meats, hollandaise sauce, cream fillings, cream sauces, custards, or ham, chicken, egg, or fish salads.

Bacterial spoilage of food begins as soon as it becomes warm. Refrigeration will delay this spoilage but will not destroy toxins previously formed due to contamination and improper storage.

Salads and Desserts

Chicken salad, tuna, and other fish salads, nonacid potato salad, all types of custard-filled pastries, and some types of cold cuts must be kept refrigerated at all times. All may have been touched with the hands during their manufacture and may be considered slightly contaminated.

2. Poorly developed leaves, dry or yellow, soft, loose, coarse, sprouted, slime, mold, insect infested, unclean
3. Fruits soft, blemished, molded, decayed, wormy; citrus fruits soft, light

The powder indicates spray residues.

Most of the chemicals used by growers are not dangerous but some may be. All fruits and vegetables must be washed before eaten or cooked. Cooking will not destroy the spray chemicals.

Refrigeration will keep contamination from increasing. Spoilage is often impossible to detect until foods are totally spoiled. Serve salads immediately after taking from refrigerator.

Frozen Foods—Grade U.S. A, B, or C (*USDA*)

Frozen foods will spoil if kept out of the refrigerator. Spoilage is caused by growth of bacteria on the food. Thaw poultry and roasts in refrigerator for 2–3 days before use. See Table 8-1.

Cook frozen vegetables thoroughly before serving to destroy any contamination that may be present. Do not overcook. Heat ready-to-eat dinners thoroughly [165°F (74°C)] before use.

Do not use refrozen fish or shellfish.

Avoid soft, mushy, discolored foods.

Fruits and Vegetables—Fancy, Standard, Substandard

1. White or grayish powder around stems of fruit and at juncture of leaves and stems of cabbage, cauliflower, celery, and lettuce
2. The filtrate, when alcohol is added to meat, will turn red or pink if artificial coloring has been added.
3. Shucked oysters with a pH of 5.4–5.8 are suspicious; pH can be 5 in oysters from certain beds. Use a drop of oyster liquid on chlorophenol red test paper and compare with standard. If washed oyster meat turns persistent red when methyl red indicator solution is used, oysters are spoiled. One teaspoon of crab meat in water plus 0.5 ml Nessler reagent turns deep yellow or brown if meat is spoiled.

TABLE 8-3 (*Continued*)

Cheese

1. Evidence of contamination or infestation; mold not characteristic of the product
2. Made from unpasteurized product or not stored at least 60 days above 35°F (2°C). Should be made from pasteurized product. Salmonella in milk in large numbers can survive extended storage in cheddar cheese of high pH.[c]

Chemical Tests[d]

1. Solution of malachite dye mixed with ground meat will turn bright red if sodium sulfite added to preserve or mask decomposition of meat.[e] Zinc plus dilute mineral acid emits H2S in presence of sulfite. Other methods may be used.[f]
4. Cadmium–plated utensils are detected by rubbing a swab moistened with 10% nitric acid and placing on moistened filter paper impregnated with 20% solution of sodium sulfite. A canary yellow stain indicates cadmium.
5. Cyanide is detected by a special test paper that turns orange and then brick red in 5–10 min when suspended in air space of bottle containing suspected polish if cyanide exceeds 0.5%.
6. Rodent urine stains fluoresce in ultraviolet light. Cook's test paper placed on stain turns black when moistened.
7. Arsenic may be detected by methods described in the AOAC International, *Official Methods of Analysis*, 17th edition.
8. The presence of fluoride is detected by a special test paper in the presence of citric acid.
9. Sulfites and bisulfites are not permitted in meats and should not be used on fruits and vegetables eaten raw.
10. Phosphates not allowed in hamburger. 425°F (218°C) or 30 min at 375°F (190°C)

Source: Adapted from Ohio Department of Health and other sources. See also Chapter 1.

[a] Sweller—both ends stay bulged when pressed. Springer—a sweller is one in which the end will give when pressed. Flipper—both ends flat, end will bulge out when end is pressed. See *A Pocket Guide to Can Defects,* ASFDO, York, PA, 1987.

[b] D. H. Bergquist, "Sanitary Processing Egg Products," *J. Food Protection,* July 1979, pp. 591–595.

[c] C. H. White and E. W. Custer, "Survival of Slamonella in Cheddar Cheese," *J. Milk Food Technol.,* May 1976, pp. 328–331.

[d] W. D. Tiedeman and N. A. Milone, *Laboratory Manual and Notes for E. H. 220,* Sanitary Practice Laboratory, School of Public Health, University of Michigan, Ann Arbor, 1952, revised 1971.

[e] Sodium and potassium sulfites, metasulfites, and sulfur dioxide might also be used.

[f] See, e.g., *Official Methods of Analysis,* AOAC International, 17th Ed., 2000. Methods are available for many of the tests described above as well as newer methods not noted above.

Food Additives

The Delaney amendment does not permit the use of a food additive if it has been shown to cause cancer in humans or animals at any oral dose. However, this clause has been subject to legislative change (e.g., saccharin) and interpretation through the FDA GRAS list (e.g., methylene chloride to decaffeinate coffee). The FDA groups chemicals added to foods into four categories for regulatory purposes: food additives, generally recognized as safe (GRAS) substances, prior-sanctioned substances, and color additives.[8]

A food additive is any substance the intended use of which results or may reasonably be expected to result, directly or indirectly, in it becoming a component or otherwise affecting the characteristics of food.[9] Thousands of food additives are approved for use by the FDA to maintain or improve nutritional value; add flavor; maintain freshness; make food more appealing; prevent spoilage caused by bacteria, molds, fungi, and yeasts; and help in food processing or preparation. Additives include sugar, salt, corn syrup, citric acid, baking soda, vegetable colors, mustard, and pepper. Other examples are iodine, vitamin D, iron, B vitamins, antioxidants butylated hydroxytolune (BHT) and butylated hydroxyanisole (BHA), and coloring and flavoring agents. The FDA, which controls the use of additives, considers irradiation as a food additive subject to regulation. The full compliment of approved food additives should be reviewed in the appropriate FDA and USDA regulations.

Examples of additives used in meat and cheese products and the purposes they serve, as listed in the USDA *Food News for Consumers,* Holiday 1990, and the *Code of Federal Regulations,* include the following[10]

Nitrate/Nitrite These natural salts are used in curing meat and inhibit the growth of *Clostridium botulinum*. They maintain bright meat color and give a tangy flavor. The USDA regulates limits on amounts used in meat and poultry products.

Sodium Ascorbate/Erythorbate Made from a carbohydrate and chemically related to vitamin C, they speed curing of meat and fix color. They are used in some meat products to prevent the formation of nitrosamines.

MSG The sodium salt of an amino acid, found in soybeans, sugar beets and seaweed. Monosodium glutamate (MSG) is a flavor enhancer.

BHT/BHA These antioxidants are synthetic substances used to prevent rancidity and off-flavors, retard deterioration, and protect fat-soluble vitamins.

Starter Culture These are acid-producing bacteria used for fermentation; they provide tangy flavor. They lower the pH of products and exhibit bacteriostatic or bacteriocidal effects.

Mono-/Diglycerides Emulsifiers or stabilizers that are derived from fats and keep ingredients distributed, mixed, and stabilized.

Isolated Soy Protein Extracted from soybeans, it binds meat and fat and may improve texture when used according to need.

Sodium Benzoate This salt of an organic acid inhibits mold and is used as a preservative in cheese.

Lecithin Substance in soybeans, corn, or eggs that acts as an emulsifier and keeps fat and water distributed in meat and cheese.

Acetic, Citric, or Lactic Acids Produced by fermentation using carbohydrates as a substrate, they act to lower the pH of foods, add tartness, and maintain quality during storage.

This list is limited in scope, and the current regulations for approved food additives should be consulted prior to use in any food product.

Questions are sometimes raised concerning the microbiological quality of wines. Wines typically have a high acidity (low pH) and high (ethyl) alcohol content compared to other foods. These characteristics discourage the growth of pathogenic organisms and most nonpathogenic organisms. Organisms that might be encountered include yeasts, molds, and lactic-acid- and acetic-acid-producing organisms. Although these organisms may cause spoilage, generally they are not of public health significance.[11]

Food Preservation Technologies

Food preservation processes include sterilization (canning), pasteurization, vacuum and controlled-atmosphere packaging, refrigeration, freezing and freeze drying, dehydration, salt curing, smoking, aging (uncut wheels of cheddar cheese), fermentation, proper concentrations of added chemicals (e.g., sugar, salt, spices, sulfur dioxide, carbon dioxide, benzoic acid), water activity control, pH control, pest control (e.g., fumigation), irradiation, and combinations thereof. It is essential that appropriate use of approved processes are carefully executed and recontamination prevented by barrier separation of incoming materials from finished product or equivalent measures.

Sterilization processes include canning and hermetically sealed sterile packaging. In conventional canning, the raw blanched product is placed in a nonsterile container, which is then sealed. The filled, sealed container is thermally processed to the point necessary to achieve commercial sterility. The hot container, with its commercially sterile food product, is then cooled, dried, labeled, coded, and distributed. In an aseptic processing and packaging system, the product is rendered commercially sterile and is promptly cooled in a separate operation; the package is filled and sealed in a sterile or an aseptic environment.[12]

Pasteurization may be accomplished by heat treatment (see Pasteurization, this chapter) or by ionizing radiation (irradiation).

In *freeze drying,* water is directly removed in a vacuum from the quick-frozen food by sublimation (reducing water activity levels), thereby prolonging the shelf life without refrigeration.

In *dehydration,* food is dried by artificial heat sources. The food may first be exposed to sulfur dioxide or its equivalent or it may be blanched using steam or syrup. If the food is dried outdoors, it should be followed by pasteurization to kill insects and larvae. Dehydration may also involve evaporation, condensing, and drying as with powdered milk. Dried foods should preferably be stored in the absence of air, moisture, and light at 60°F (15°C) or below.[13]

In *salt curing,* moisture is partially withdrawn to delay or prevent the growth of spoilage organisms using the dry or pickling method. Salt in cheese and salt and nitrite in cured meat have been historically and to this day effective in preventing botulism. These methods should not be discarded or compromised without proven prior safeguards. Nitrites are routinely added to most cured meat products, such as red meats and poultry, to inhibit the growth of *C. botulinum* spores.

Smoking is used primarily to impart a flavor, but it also provides some preservation due to chemicals in the smoke and surface drying. In smoking of processed meat products, elevated time and temperature are employed.

In *fermentation,* a chemical change takes place, for example, as in the making of vinegar from cider or wine (with effervescence), ripening of cheese, sugar from starch, or souring of milk. Fermentation takes place at pH 4.5 or less.

Chemical preservation involves the use of proper concentrations of sugar, salt, spices, sulfur dioxide, carbon dioxide, benzoic acid, and benzoate salts as well as fumigation and antibiotics. Two percent vinegar in pickled food or 8 to 10 percent salt will also kill *C. botulinum* spores. The safety of canned hams depends on the combination of pasteurizing heat treatment and the presence of curing salts.

*Sulfites** have been used for many purposes; however, they may cause problems. They are used as sanitizing agents and to prevent food spoilage, browning, or discoloration; to preserve freshness and color; to prevent bacterial spoilage; to increase storage life; as an antifungal agent; and in bakery products. However, the hazard to sensitive individuals, particularly asthmatics, makes the continued use of sulfites inadvisable. Women who are pregnant are advised to limit consumption of foods containing sulfites. Some states have prohibited retailers and wholesale distributors of food from adding sulfites to any food that is sold, offered, or served.[14] In 1997, the FDA stated that "retail operators shall not apply sulfiting agents to fresh fruits and vegetables for raw consumption or to foods considered to be good sources of vitamin B, including fresh meat (including poultry) products, nor serve or offer for sale such foods (except grapes) treated by others. These foods are not considered safe for human consumption." However, many processed foods, such as olives, tomato juice, and pickled peppers, may legally contain sulfites, but other

*Sulfiting agents include sulfur dioxide, sodium sulfite, sodium and potassium bisulfite, and sodium and potassium metabisulfite.

processed foods shall contain no more than 10 ppm sulfites unless labeled.[15] Labeling of the presence of sulfites is mandatory in many food products.

Irradiation, the controlled exposure of food or other materials to gamma rays from a radioactive source or to ionizing radiation can accomplish the equivalent of pasteurization or sterilization, disinfection, disinfestation, and inhibition of sprout growth, depending on the dosage. Approved dosages for certain foods in the United States are shown in Table 8-4. Canada has gamma irradiation regulations for onions, potatoes, wheat, and spices, but questions are being asked about the byproducts formed, long-term health effects, aflatoxin increase, taste, dosages, and other matters.[16] The World Health Organization (WHO) considers an overall average dose of up to 10 kGy as toxicologically safe for any food commodity.

Some vitamins and nutrients may be reduced or destroyed and appearance, flavor, aroma, or texture may be changed, but no more than in commercially processed food. Dairy products are an exception. Irradiated foods do not become radioactive. The FDA has concluded that at doses up to 100 krad the products formed are toxicologically insignificant. A study of the wholesomeness of irradiated foods for the U.S. Army concluded that "irradiation is effective in reducing microbiological spoilage of foods and the spread of foodborne diseases, and controlling factors which cause commodity loss such as sprouting and senescence, and disinfestation. Toxicity problems have yet to be demonstrated. Some vitamin losses are observed, but no more than the losses during other food processing methods."[17] However, there is a potential for an overgrowth of bacteria and aflatoxins since irradiation changes the microbial load. In addition, botulism spores may grow under anaerobic conditions (since only high doses of 23–57 kGy will kill them) if contamination is not prevented during processing and handling.[18] Irradiation of uncooked poultry was approved by the FDA in 1990 to control microbial pathogens such as *Salmonella, Campylobacter,* and *Yersinia* that cause foodborne illnesses.[19] Food irradiation can eliminate or reduce the use of chemical preservatives and chemicals for pest control. Irradiation is an accepted practice to sterilize disposable medical devices.

Reduced water activity level (a_w) has a preservative effect as well as a bacteriostatic effect on foodborne pathogens. Water activity is a measure of the relative availability of water (not amount) in a food on a scale of 0 to 1.00.[20] It is defined as the ratio of the water vapor pressure of the food to the vapor pressure of pure water at the same temperature. A pH below 4.6 and a low a_w retard or inhibit the growth of microorganisms. Pathogenic bacteria do not grow well or produce toxins in food with an a_w below approximately 0.86, but yeasts can grow at a_w of 0.72 to 0.86 and molds grow at 0.61 to 0.77 or 0.85. The shelf life of foods at a_w below 0.85 is improved, and fairly stable below 0.70. For example, the a_w for milk powder is 0.20, biscuits and crackers 0.30, cereal 0.10 to 0.20, egg powder 0.40, pasta 0.50, jams and jellies 0.70 to 0.94, salami 0.80, and cured meat 0.87 to 0.95, compared to 1.0 for fresh meat and fish.

TABLE 8-4 Food Irradiation Dose Limits

Food	Purpose	Dose Limit	Date Approved
Fruits and vegetables	To slow growth and ripening and to control insects	Up to 1 kilogray (kGy)	April 18, 1986
Dry or dehydrated herbs, spices, seeds, teas, and vegetable seasonings	To kill insects and control microorganisms	Up to 30 kGy	April 19, 1986
Pork	To control *Trichinella spiralis* (parasite that causes trichinosis)	Minimum 0.3 kGy–maximum 1 kGy	July 22, 1985
White potatoes	To inhibit sprout development	50–150 gray	August 8, 1964
Wheat and wheat flour	To control insects	200–500 gray	August 21, 1963

Source: FDA Consumer, July–August 1986.

Note: 1 rad = 0.01 gray; 1 gray = 100 rad. The FDA approved irradiation (150–300 krad) of uncooked poultry May 1, 1990. (*Food News for Consumers/Holidays,* USDA, 1990, p. 14.) See also *Food Irradiation, A Technique for Preserving and Improving the Safety of Food,* WHO, Geneva, 1988.

Freezing can also provide protection against trichinosis, taeniasis, and fish tapeworms, roundworms, and flukes. For pork less than 6 in. thick, the recommendations are as follows: 5°F (−15°C) for 20 days, −10°F (−23°C) for 10 days, −20°F (−29°C) for 6 days, −27°F (−33°C) for 3.5 days, and −30°F (−34°C) for 1 day. For fish, −31°F (−35°C) blast freezing for 15 hr and −10°F (−23°C) for 7 days have been recommended.[21] However, trichinae in polar bear meat remained viable after 24 months at 0°F (−18°C).

*Vacuum or modified controlled-atmosphere packaging of food,** intended for refrigeration during storage and distribution, is now a recognized procedure to extend the shelf life of food. The foods are partially or fully cooked in sealed impermeable plastic pouches by a regulated processor and distributed to a retailer for subsequent heat treatment before service. In view of the real possibility of refrigeration temperature rising above 45°F (7°C) from source to consumption, the growth of *Listeria, Yersinia,* and other pathogens at normal refrigeration temperature, the possible survival and growth of *C. botulinum* in the absence of oxygen, and the production of toxin, the FDA urges caution and advises against the use of these foods if they become temperature abused.[22] The Association of Food and Drug Officials recommends against the use of reduced oxygen packaging of foods where it cannot be safely used and carefully controlled; it advises usage only in settings where it is judged to be a safe process in order to prevent possible botulism.[23] The vacuum packaging of food in retail stores is prohibited by the FDA unless very specific controls can be ensured, including water activity, pH, curing of meats, temperature, shelf life, and storage procedures. Vacuum packaging of fish and fish products is prohibited by the FDA without special approval.†

Refrigeration is the most common method of preserving potentially hazardous foods. However, the traditional refrigeration temperature of 45°F (7°C) has been found inadequate to prevent the growth of *Yersinia enterocolitica, C. botulinum* type E, *Listeria monocytogenes,* and others. A refrigeration temperature of 38 to 40°F (3–4°C) or lower has been recommended. This is discussed separately in this chapter under Refrigeration.

Cook-chill and *cook-freeze* are food refrigeration preservation adaptations.[24] In cook-chill, the food is cooked, rapidly chilled, and stored at a temperature of 32 to 37°F (0–3°C) for not more than five days. The food is reheated to at least 165°F (74°C) and promptly served as needed. In cook-freeze, the food is cooked, rapidly frozen, and stored at 0°F (−18°C) or less. The food is subsequently reheated and promptly served as in cook-chill. The preparation, storage, and handling must be carefully controlled.

Low-acid food means "any food, other than alcoholic beverages, with a finished equilibrium pH greater than 4.6 and a water activity (a_w) greater than 0.85. Tomatoes and tomato products having a finished equilibrium pH less than 4.7 are not classed as low-acid foods."[25]

* See FDA guidelines.
† See FDA guidelines.

Other Preservation Methods The FDA has proposed that dry foods may be reconstituted and liquids fortified with dry products and served without cooking if pH is controlled to below 4.6, they are served within 4 hr, or they are made up directly in frozen dessert or similar equipment that automatically maintains a product temperature of 45°F (7°C) or below or in a container of no more than 1 gal that is cooled to that temperature within 4 hr, and any unused product is discarded after 24 hr.

Foodborne Pathogenic Organisms

A major concern in food preservation is to ensure that an environment is not created that will promote the growth of *C. botulinum* and the production of toxin. Vegetative forms are killed in 10 to 15 min at 176°F (80°C) and at boiling temperature [212°F (100°C)], but spores are not destroyed. Growth and toxin production is prevented at pH below 4.5; spores cannot germinate, but there are exceptions that require further study. The Codex Alimentarius Commission advises that "canned products with an equilibrium pH above 4.5 shall receive a processing treatment sufficient to destroy all spores of *C. botulinum* unless growth of surviving spores is permanently prevented by product characteristics other than pH." For commercial sterilization, the time–temperature relationships for a desired *C. botulinum* spore reduction are 2.45 min at 250°F (121°C), 8.79 min at 240°F (116°C), 31.55 min at 230°F (110°C), and 114.28 min at 220°F (104°C).[26] Two percent vinegar in pickled food or 8 to 10 percent salt will also kill spores.[27]

Clostridium botulinum type E is the most prevalent type in the marine environment, except in southern California, where type A predominates. The spores of *C. botulinum* type E are characterized by being inhibited at pH values of less than 4.6, water-phase salt concentration of 5 to 6 percent, and water activities of less than 0.96.* However, they can grow at temperatures as low as 38°F (3.3°C).[28] Uncooked salted air-dried whitefish and improperly fermented fish have been implicated in type E botulism outbreaks; seal meat has also been involved. It has been recommended that smoked fishery products be labeled "Keep refrigerated—store below 38°F (3.3°C)."[29]

While much attention should be given to *C. botulinum,* several other pathogenic bacteria deserve comparable attention. It is beyond the scope of this chapter to provide a detailed review of other pathogens; however, it is relevant to briefly describe other prevalent and serious public health pathogenic agents. Examples, based on the Council for Agricultural Science and Technology report, include *Salmonella* spp., *Campylobacter* spp., Shiga-like toxin producing *E. coli, L. monocytogenes, Vibrio* spp., *Toxoplasma gondii, Cryptosporidium parvum,* Norwalk virus, and hepatitus A.[30,31] Recent examples in a wide variety of foods can easily be found. Of the above pathogens, the

*The approximate minimum a_w value permitting the growth of *Clostridium botulinum* in food is 0.93 (FDA Code Interpretations, May 9, 1986).

most common source of foodborne illnesses based on CDC studies is *Campylobacter*; *E. coli* O157:H7 has been the source of numerous outbreaks and deaths over the past decade, while *L. monocytogenes,* while having a relatively low prevalence rate, has the highest mortality rate of any foodborne pathogen because of outbreaks in infants, elderly, and those individuals with compromised immune systems. Consequences of detected outbreaks of these pathogens in foods have resulted in the recall and destruction of approximately 100 million pounds of products over the last decade. These pathogens continue to receive an enormous amount of attention and resources by federal agencies to develop appropriate and effective mitigation strategies to reduce their incidence and prevalence in foods.

Microbiological and Chemical Standards, Guidelines, or Criteria

Natural microbial variations in different foods, food composition, and the statistical aspects of sampling present considerable difficulties in the establishment of firm standards. To address this serious issue, the FDA and USDA have conducted a large number of baseline studies for the major pathogens in several animal food products and produce to develop a scientific basis for their HACCP and pathogen control regulations. For example, the Food Safety and Inspection System used these types of studies to develop the performance standards for its 1997 HACCP/Pathogen Reduction regulations. Similarly, the Center for Food Safety and Applied Nutrition has developed its HACCP regulations for fresh produce, juices, and seafood, among others, through equivalent studies. These, as well as other food safety regulatory agencies, should be consulted for a full complement of microbiological studies, regulatory standards, and guidelines. Some of the parameters included in these studies are total aerobic count, toxigenic molds, number of coliforms, and number of *E. coli,* coagulase-positive staphylococci, *Salmonella* spp., shigella, *Clostridium perfringens, C. botulinum, L. monocytogenes,* and beta-hemolytic streptococci as indicated. Use of a variety of tests exemplified above can alert food producers to the need for investigation and corrective action before a problem develops.

While the first food safety priority is pathogenic bacteria, other chemical and physical hazards in regulated foods are pursued. In the past decade, for example, the Food Safety and Inspection Service has published laboratory guidebooks for a substantial number of chemical and microbiological methods. These can be readily found on the Internet.* As an example, by using enzyme-based methods, the Food Safety and Inspection Service can determine the internal temperature to which meat and poultry products have been pro-

*See http://www.fsis.usda.gov. Similar publications for FDA methods may be found at http://www.fda.gov.

cessed to ensure that trichinae have been destroyed in compliance with federal regulations.[32]

The FDA has established action levels for poisonous or deleterious substances in human food or animal feed. Action levels are, however, interim values subject to amendment. They are commonly used for those substances generally considered as unavoidable environmental contaminants such as aflatoxins and heavy metals but may include some chlorinated pesticides such as DDT because of their ubiquitous presence and environmental stability in soil. The action level is that limit at or above which the FDA will act to remove the contaminated product from the market. Current lists of action levels for these substances may be found at the FDA Center for Food Safety and Applied Nutrition.*

The USDA has regulatory authority for meat, poultry, eggs, peanuts, and grains. Within the USDA, the Food Safety and Inspection Service is responsible for regulatory programs pertaining to meat and poultry products and eggs consistent with its congressional mandate. The FDA samples other food types within its regulatory mandate, including milk, for compliance with pesticide residues, veterinary drugs (e.g., antimicrobial drug residues in milk), aflatoxin, heavy metals, decomposition, filth, microbial pathogens, and microbiological standards. The United States as well as other countries also have regulatory programs for the control of aflatoxins in food and feeds as well as other environmental contaminants.[33]

The Codex Alimentarius Commission, an international organization created by the WHO and Food and Agricultural Organization of the United Nations, (FAO) establishes, by scientific consensus, international standards for foods to protect the consumer and facilitate the international trade of foods.† In addition to food standards (maximum residue limits) for pesticide residues, veterinary drug residues and food additives and flavorings in food, the Codex Alimentarius Commission establishes guidelines on general principles of food hygiene, for example, and codes of practice, among its major activities.

The use of antibiotics for prophylactic use in food-producing animals is becoming a growing international concern and has been addressed by the WHO and Codex. Among other recommendations, the WHO has recommended withdrawing their use in animal feed and limiting use of antimicrobial substances to those not used in human medicine. There is evidence linking

* See, e.g., http://cfsan.fda.gov/~lrd.fdaact.html. Those in seafood should see http://www.cfsan.fda.go/~dms/foodcode.html. Single copies of FDA booklets are available from Industry Activities Staff (HFS-565), CFSAN/FDA, 200 C Street, S.W., Washington, DC, 20224. Copies of FDA's Compliance Policy Guides are accessible from http://www.fda.gov.

† There are more than 200 Codex recommended international food standards and related work on additives, pesticide and veterinary drug residues, hygiene, labeling, and all other aspects of the food and feed trade. Member countries number 138. See J. R. Lupen, "America's Agricultural Trade, GATT, and the U.N.'s Codex Alimentarius," *J. AFDO*, July 1990, pp. 35–38. See also the Codex website at http://www.fao.org listed under "Nutrition."

use of antimicrobial drugs (e.g., penicillin, tetracycline, and fluoroquinolones) in animal feed to drug-resistant strains of, for example, salmonella in humans. However, the presence of antimicrobial residues in food is an issue separate from antimicrobial resistance. The antibiotics promote animal growth and minimize disease in animals, but drug-resistant organisms develop (salmonella) that predominate and survive in the animal. The inadequate cooking of contaminated meat or poultry permits survival of the organisms. Ordinary cooking cannot be relied on to inactivate antibiotics such as penicillins and tetracyclines in meat. Antimicrobials not used in human therapy can be used if approved. The FDA's Center for Veterinary Medicine has the responsibility to approve use of veterinary drugs in food-producing animals. To be approved, substances must be shown to be safe and effective in animals and residues in foods to be safe for human consumption. Chloramphenicol has been associated with aplastic anemia and is not approved for use in food-producing animals.

Numerous microbiological standards, action levels, policy guidelines, good manufacturing practices, and criteria have been proposed and are in use for industry and regulatory control purposes to indicate food quality and the need for investigative action. Some are summarized in Table 8-5; however, food producers should review the rapidly changing regulatory procedures and guidance documents (e.g., the 1999 FDA Food Code and the FSIS HACCP/pathogen reduction performance standards). Analytical procedures and interpretation of laboratory results are given in various publications. Abrahamson has pointed out, based on many years of experience in New York City, that the publication of administrative microbiological standards is an excellent educational service. Successful results are obtained from more through understanding than by fiat.

Periodic sampling of the air and surfaces in food establishments (now referred to as environmental sampling), including dairy plants, can identify potential and actual sources of product contamination and causes of food spoilage and reduced shelf life. The sampling can also be used as a measure of sanitation practices and as an educational tool to improve management and worker hygiene and sanitation awareness. New HACCP/pathogen reduction regulations promulgated by the FDA and USDA include requirements for sanitation standard operating procedures for food production. Portable self-contained air samplers are available to sample air in selected work areas. An agar plate is exposed at a calibrated air flow, incubated at 90°F (32°C) for 48 hr, and the results reported as colony-forming units per cubic meter (CFU/m^3) of air flow. The convex contact agar plate is used for surface sampling. The plate is placed in contact with the surface to be sampled and then incubated. The results are reported as the number of CFU/m^2.[34] This is similar to the Rodac plate method. See also Cleansing and Sanitizing later in this chapter.

TABLE 8-5 Some Microbiological Guidelines for Foods[a]

Food	Total Count per Gram Not to Be Exceeded					References[b]
	E. coli	Plate Count	Coliform	Staphylococcus	Salmonella	
Prepared foods[c]	Negative	100,000	20	100	Negative	
Crab cakes and crabs	3.6	10,000	3.6	3.6	—	1
Frozen cream-type pies	(10)	50,000	50	(100)	(Negative)	6
Gelatin	—	3000	20	—	—	6
Frozen cooked seafoods and meals	—	100,000	20	100	—	2
Cheese	1000	—	1500	1000	—	3
Meat						
Frozen, fresh, ground	50	5,000,000	—	—	—	4
Cooked, smoked	10	1,000,000	—	—	—	4
Beef						
Ground unfrozen	100	10,000,000	—	100	Negative	5
Ground frozen	100	1,000,000	—	100	Negative	5
Oysters, fresh, shucked, frozen		500,000	230	—	—	7
Shrimp, raw, breaded, frozen		500,000	50	—	—	7
Dehydrated food—dependent on item	Negative	25,000–200,000	10–40	—	Negative	7
Uncooked poultry	20	1,000,000	100–1000	10	10	

TABLE 8-5 (*Continued*)

[a]Results should be interpreted in the light of a complete sanitation inspection. The counts noted are maximums.

[b]1. R. Angelotti, "Catering convenience Foods—Production and Distribution Problems and Microbiological Standards," *J. Milk Food Technol.,* May 1971, p. 231. Administrative guidelines for crab cakes—cooked, frozen; crabs—deviled, cooked, frozen. Examination of a minimum of 10 subs with the indicated count not exceeded in 20% or more of the subs; however, the plate count is the geometric average of the subs.
2. *An Evaluation of Public Health Hazards from Microbiological Contamination of Foods,* National Academy of Sciences, National Research Council Pub. 1195, Washington, DC, 1964, pp. 52–58. Conclusions of the Committee on Food Microbiology and Hygiene of the International Association of Microbiological Societies—Conference, Montreal, Canada, August 16–18, 1962. Counts considered attainable. Coliform count of 100 permitted by some standards.
3. D. L. Collins-Thompson, I. E. Erdman, M. E. Milling, U. T. Purvis, A. Loit, and R. M. Coulter, "Microbiological Standards for Cheese," *J. Food Protection,* June 1977, pp. 411–414. The counts listed are considered "unacceptable." "Acceptable" counts are: total coliform—500, fecal coliform—100, and *Staphylococcus aureus*—100.
4. K. E. Carl, "Oregon's Experience with Microbiological Standards for Meat," *J. Milk Food Technol.,* August 1975, pp. 483–486. The counts are used primarily as a tool to improve sanitation practices.
5. Proposed Microbial Standards for Ground Meat in Canada," *J. Milk Food Technol.,* December 1975, p. 639. Salmonella count is per 25 g.
6. *Fed. Reg.,* August 2, 1973. The counts for pies are for banana, coconut, lemon, and chocolate cream-type. Counts are the geometric mean of 10 analytical units.
7. E. M. Powers, "Microbiological Criteria for Food in Military and Federal Specifications," *J. Milk Food Technol.,* January 1976, pp. 55–58. The count for oysters is MPN fecal coliforms per 100 g at 112.1°F (44.5°C).

[c]Fecal streptococci should not exceed 1000, yeast and molds 20; *Clostridium perfringens* should be negative.

Ice

Water used in ice making must be from a source meeting drinking water standards. Ice has been implicated as a vehicle of infection.[36,*] The ice plant environment, plant construction and design, manufacturing process, equipment and controls, and storage and distribution must ensure protection of the ice from contamination, consistent with other entities that may come in contact with food. The plant should meet the basic sanitation requirements given in references listed under Basic Requirements, this chapter. The same principles apply to manufactured ice, packaged ice, and ice-making machines in restaurants, hotels, and public places.

Freezing is a bacteriostatic process; it does not kill pathogenic organisms. A WHO publication[37] points out that when water freezes, impurities present in the water tend to be "squeezed" toward the middle. Taking advantage of this phenomenon, ice manufacturers pass bubbles of air through the water during the freezing process, keeping it in motion and preventing precipitated

*More than 5000 people became ill in 1987 during the outbreak cited in ref. 35.

chemicals, solids, and bacteria from freezing into the ice crystals. The impurities are thus concentrated in the core section (i.e., the unfrozen water in the middle of the block of ice). In the final stages of manufacture, the core is removed (pulled) and fresh water added to reduce the concentration of foreign matter before the final freezing. Inspection of a block of ice shows how well the core is pulled; discoloration in the middle of the block indicates contamination. Some minerals and chemicals that cause problems in ice manufacture are iron, manganese, calcium and magnesium carbonates, aluminum oxide, and silica.

The suggested bacterial standard for ice is not greater than 2.2 coliform organisms per 100 ml using the multiple-tube method and not greater than 1 organism per 100 ml using the membrane filtration method. The heterotrophic plate count is not to exceed 500 colonies/100 ml.[36]

Dry-Food Storage

Practically all foods, whether canned, pickled, dried, or chemically preserved, deteriorate on storage. They change in color and texture, develop off-odors or off-flavors, and lose nutritional value. Storage temperature is the single most important factor that affects the storage life of food items. A temperature of 40°F (4°C) is good for the storage of canned and dehydrated foods three to five years. A temperature up to 70°F (21°C) is acceptable for short-term storage, but the useful storage life of most products at 100°F (38°C) is six months or less. Dried fruits are best stored at 32 to 40°F (0–4°C) and 55 percent relative humidity. In connection with food storage, it is also of practical value to know that insects become active at a temperature of approximately 48°F (9°C) and that most insects do not survive storage at 0°F (18°C) after seven days. In general, the storage or shelf life of canned or packaged food varies with the original quality and the type of food and additives used. The quality will be determined by the environmental stresses to which it is exposed, including temperature, moisture, oxygen, light, and the integrity of the container or packaging. Refrigeration will prolong the storage life of canned food.

Food storage rooms generally adjoin unloading platforms and connect as directly as possible with the food preparation areas of the kitchen. The storage room that provides a floor area of approximately 1 to $1\frac{1}{2}$ ft^2 per meal served per day is usually adequate in size. Storerooms should be clean, cool, dry, dark, ventilated, protected against the entrance of insects and rodents, and organized. Artificial lighting should provide 10 to 20 foot-candles of light. The floor should be well drained but without a floor drain, cleanable, and above any possible high-water or sewage flooding. Food must not be stored in basements that might be flooded. If sewer or waste pipes must pass through storerooms, the pipes should be provided with drip pans to carry off possible leakage or condensation, and food must not be stored directly beneath the pipes. Good ventilation is important. It can be obtained with screened windows opened at the top and bottom, an exhaust or circulating fan, and upper and lower wall and door louvered vents that do not open into a hot kitchen.

Storerooms should be furnished with shelves, pallets, and covered containers. With shelves 10 to 20 in. deep and at least 18 in. away from the walls, so as to be accessible from all sides, and the bottom shelf 12 in. or more above the floor, stock inventory and cleanliness are simplified. Food storage platforms should be movable (at least 12 in. off the floor and 12 in. away from the wall), and they should provide a 2-ft clearance between stored foods and the ceiling. Bulk items are stored in the original packing on pallets, and loose foods on shelves, in some predetermined order. Sugar, coffee, flour, rice, beans, and other dry stores are stored in metal or other waterproof containers with tight-fitting covers. Old stock should of course be used first; the dating of new supplies will help accomplish this objective. Provide a $3\frac{1}{2}$-ft aisle space between shelving, pallets, and walls. Do not store pesticides, cleaning compounds, disinfectants, or lubricating oil in food storage rooms. See also Refrigeration, this chapter.

Compliance with and Enforcement of Sanitary Regulations

The training of foodhandlers and managers of food service establishments is considered by many as an important part of a food protection program. This can be a formidable and unending task. Experience shows that the effectiveness of foodhandler training is limited and of short duration at best. Training of managers has been considered of greater value. However, Cook and Casey[38] found in a limited study that "management enrollment in and completion of the course did not produce significantly higher sanitation scores than those of equivalent establishments without trained managers." The effort expended should be carefully evaluated to determine if time and effort could be better devoted to more effective educational activities. New inspection regulations established by the FDA and USDA should be consulted regarding sanitation requirements for specific food production systems.

Management Responsibility[39]

Management has a primary and continuing responsibility for the education and supervision of employees in order to ensure that basic health requirements are met at all times. All kitchen employees and supervisors share the responsibility. The health authorities are responsible for ensuring that all food establishments comply with regulations adopted to protect the public health, and they should be empowered to enforce the regulations in a reasonable manner.

Study of the cause of reported foodborne outbreaks indicates the direction of management and foodhandler education to be taken. In developing their

HACCP plans, food-processing establishments must include corrective action for deviations in safe food production and systems to monitor the effectiveness of the corrective actions. Strengthening the roles of health authorities and managers or operators in relation to the provision of safe and sanitary food services could offer mutual benefits since each party could assume greater responsibility within its particular sphere of competence. Establishments controlled by a reliable and informed owner or operator would be subject to fewer inspections, and management would have full control over and responsibility for the hygienic and sanitation procedures in the establishment. The system proposed is not entirely new and is already in operation in various degrees. The procedure is as follows:

1. A legal responsibility is created for the health agency to approve or provide for the initial qualification and certification of the operator or manager of every food establishment. The certification is valid for a stated period of time subject to suspension or revocation after a formal inquiry. Qualification of the individual requires special education and training in the basic principles of sanitation and hygiene, and so on, and periodic attendance at refresher courses. Operation of an establishment by unqualified persons would be illegal.
2. The health agency is required to provide special education and training and refresher courses, either using the agency staff or through contractual agreements with a college or university, in addition to maintaining a food service inspection and public education program.
3. After certification, the operator or manager has sole responsibility to ensure full compliance with established sanitary regulations within the establishment. One is required on each shift.
4. The health agency is required to maintain a registry of all food establishments and make periodic comprehensive evaluations of the quality of food and food services. Evaluations should be based on statistical sampling and should cover all places at least once every three years; however, there should be a separate microbiological food quality sampling evaluation program for selected potentially hazardous foods. This is sometimes referred to as a sanitary audit.
5. An operator's certificate is suspended by the health agency upon evidence of a major violation of the sanitary regulations, and the establishment must be closed pending a formal hearing to determine if the certificate should be revoked.

Food Protection Program Objectives

Measures that will reinforce traditional sanitary inspection and quality control programs to reduce the widespread occurrence of foodborne diseases are summarized in the following American Public Health Association (APHA) position paper objectives[40]:

1. a renewed awareness that preventable foodborne diseases are costly and occur more frequently than necessary;
2. recognition that the usual sanitary inspections and quality assurance programs are no longer sufficient to reduce the incidence of foodborne illnesses in the United States;
3. an appreciation of the benefits to be gained by supplementing established food sanitation activities with other efforts, such as (a) certification of food establishment managers, (b) increased epidemiological investigation of suspected foodborne disease outbreaks, (c) hazards analysis and critical control point evaluations of food establishments, and (d) standardized evaluation of food quality and safety; and
4. acceptance of microbiological criteria as useful, supplemental measures for (a) maintaining the level of cleanliness in food-handling operations that will satisfy consumer expectations, (b) detecting exposure of foods to unsanitary conditions that may result in the spread of foodborne diseases as well as increased spoilage, (c) discouraging the use of microbiologically inferior ingredients in commercially formulated foods, and (d) establishing definitive microbiological limits for acceptance or rejection of some foods.

As indicated in a number of places above, federal agencies with food safety responsibilities have endorsed the HACCP procedure as a means for reducing the number of foodborne illnesses. The procedure requires that the industry and regulatory authorities[41]

1. assess the hazards and risks associated with growing, harvesting, raw materials and ingredients, processing, manufacturing, distribution, marketing, preparation, and consumption of the food;
2. determine the critical control points (CCPs) required to control the identified hazards;
3. establish critical limits that must be met at each identified CCP;
4. establish procedures to monitor CCPs;
5. establish corrective action to be taken when there is a deviation identified by monitoring a CCP;
6. establish effective recordkeeping systems that document the HACCP plan; and
7. establish procedures for verification that the HACCP system is working correctly.

A schematic flow diagram showing the steps each potentially hazardous food goes through from source to point of ultimate service, including ingredients and processing, can help identify where in the flow and in which range microbiological growth would be accelerated or where contamination or spoilage might take place. Identification of control points, corrective action, and responsibility assignment are necessary. Each HACCP program must be developed to the specific characteristics of an individual food production establishment.

In addition to the above, some specific observations or steps that might be taken, as appropriate, to supplement the process and control foodborne illnesses are as follows:

- Test for pesticide residue and antibiotic residue in raw food.
- Inspect food at unloading dock for spoilage, insects, and quality.
- Measure temperature of refrigerated food as it is received.
- Refrigeration temperature in storage.
- Prepared food pH and water activity level.
- Time hazardous food is exposed prior to and during preparation.
- Time to heat food to completion.
- Time prepared food is standing below 140°F (60°C) and above 45°F (7°C) before service.
- Time to cool prepared food from 140°F to 45°F (60 to 7°C) or less.
- Thickness of food or depth of food in container that is refrigerated.
- Internal temperature of food when considered cooked or reheated.
- Test for food additives.
- Refrigeration capacity and facilities adequate for volume of food likely to be prepared, including temperature control.
- Sanitizing cutting boards and surfaces between raw and cooked food uses.
- Hot-water heating facilities, storage, and recovery capacity.
- Adequacy and cleanliness of food service equipment.
- Availability and use of handwashing facilities.
- Foodhandler hygiene.
- Adequacy and quality of water supply and cross-connection control.

Attention to microbiological, chemical, and physical scientific fundamentals and their application should prevent many foodborne illnesses. Understanding the principles underlying favorable growth, inhibition, and destruction of pathogenic organisms; the effects of toxic substances and chemicals in or entering food; and the importance of heat, cold, ventilation, vermin infestation, and light should automatically alert and motivate the foodworker and manager to continually employ proper practices and procedures. This is similar to a quality assurance program used in industry. The same principles apply to food service equipment, food quality, and safety. Competent, adequately trained individuals are essential.

Additional information on the prevention and control of foodborne illnesses is given in Chapter 1 and throughout this chapter.

FOOD COMMODITY QUALITY AND SAFETY PROGRAMS

Three federal government departments have primary responsibility for food safety—two agencies in the Department of Health and Human Services (DHHS), three agencies in the USDA, and the EPA. Within the DHHS, there is the FDA [including the Center for Food Safety and Applied Nutrition (CFSAN) and the Center for Veterinary Medicine (CVM)] and the CDC. In the USDA, there are three agencies—the FSIS, the Agricultural Research Service (ARS), and the Cooperative State Research, Education, and Extension Service (CSREES). While there has been substantial interagency effort to develop a broad-based food safety program for the United States, they have different food commodity responsibility. The FDA has broad responsibility for produce, milk, seafood, and some egg products while the FSIS has responsibility for meat and poultry products and shell eggs, for example. As each food commodity has specific considerations, they are addressed individually as noted below.

Milk Quality

The quality of milk reaching the ultimate consumer is largely determined at the farm where the milk is produced. The type of herd, feed, and health of the cows are important; but unless the raw milk is obtained, handled, and stored in a sanitary manner, from the cow to the processing plant and ultimate consumer, the final product will be mediocre or even unacceptable. A screening program should include collection of a representative sample from the tank truck on arrival at the processing plant and visual inspection at the tank manhole, checking for off-odors, milk temperature below 40°F (4°C), microscopic examination, check for inhibitors, and cryoscopic freezing point.

A healthy milk herd is expected to be mastitis, tuberculosis, and brucellosis* free. Requirements for testing, accreditation, and disposition of reactors or segregation of unsound animals are established by the Animal and Plant Health Inspection Service (APHIS) of the USDA. Fewer than 0.1 percent of the cattle in the United States are found tuberculin positive, and less than 0.5 percent of the dairy herds are found to show a positive test for brucellosis (1984).[42] The USDA criteria for a Modified Accredited Tuberculosis Area

* Also known as Bang's disease, a cause of contagious abortion of cattle; spreads rapidly through a head. Blood tests before importation or addition to a herd can prevent the introduction of infection.

designation require testing of herds every five years. Decisions of the federal agency are usually accepted by the state agency having jurisdiction. The milk produced should not be bloody, stringy, or otherwise abnormal, and the milk should not be used within 15 days before calving or 5 days after calving. Milk from cows treated with antibiotics must be withheld for at least the time specified on veterinary product label. The reservoir of bovine tuberculosis, although greatly reduced, has not been eliminated; hence, the dairy farmer, agricultural department, and health department must be constantly on the alert against the introduction of the disease in a clean herd. Other illnesses that can be transmitted to humans via milk include brucellosis, Q fever, salmonellosis, shigellosis, infectious hepatitis, yersiniosis, listeriosis, diphtheria, staphylococci infections, campylobacter, and streptococci infections. (See Chapter 1.) Inspection of meat for tubercle lesions and blood testing at the slaughterhouse can lead to identification of infected herds. Calves can be vaccinated against brucellosis (about 65 percent effective). Staphylococci, streptococci, and coliform microorganisms are associated with mastitis. Every person having anything to do with the processing of milk should be free of communicable diseases or running sores. Raw or certified cow or goat milk cannot be guaranteed to always be free of disease microorganisms and therefore should not be consumed or made available.

The production of clean milk requires that abnormal milk be discarded; that milk be promptly cooled; that the utensils and equipment used, the udders and teats of all milking cows, and the flanks, bellies, tails, milker's hands and clothing, and milking area be clean; and that manure be properly managed. In addition, the milker's hands, milk utensils and equipment, and udders and teats should be rinsed or wiped with an approved bactericidal solution, and the water supply must be of drinking water quality. Although these elementary principles may be obvious, they require continual emphasis and reemphasis with some dairy farmers. If after repeated instruction a dairy farmer cannot be relied on to produce a clean milk, the milk should be excluded from the market.

The average production for an American dairy cow (1981–1985) is 1650 gal (more than 14,000 lb) per year, with top cows producing more than 2900 gal.[43]

Dairy Farm Sanitation

Routine inspections of dairy farms by representatives of industry, and occasionally by official agencies, should be made with the owner or manager so that unsatisfactory conditions and practices can be pointed out and discussed. Control programs usually include the collection of milk samples for bacterial examinations. A low-count milk can be produced at every farm. Experience shows that attention to the following procedures will result in a good-quality, low-count milk:

1. Keep milking equipment and utensils clean.
   a. Take all milking equipment apart immediately after each milking and rinse in lukewarm water. Replace equipment and utensils having open seams.
   b. Scrub all parts, including dairy utensils, in hot [120°F (49°C)] water with a brush and good washing compound; then disinfect. Hot water at a temperature of 180 to 190°F (82–88°C) is very good or use a strong (200-mg/l) chlorine solution or iodine sanitizer according to the manufacturer's directions to disinfect rubber, valves, and other parts. Store all equipment on a clean rack in the milkhouse.
   c. Remove milk-stone deposits with an acid cleaner. One ounce of phosphoric or gluconic acid or similar milk-stone remover per gallon of disinfecting water will help prevent milk-stone and water hardness deposits.
   d. Replace all worn rubber parts. Two sets of inflations used every other week will last longer.
   e. Boil rubber parts for 15 min once a week in a solution of 2 tbsp of lye in 1 gal of water. Soak rubber gaskets and teat cups, and other rubber pieces, for ½ hr or until next milking in a solution of hot water containing 1 oz of lye per gallon, or immerse for 5 min in water at a temperature of at least 170°F (76°C). Rinse the parts and store in a cool, dry, dark place. Disinfect before reuse.
2. Cool promptly all milk in a clean milkroom or milkhouse.
   a. Maintain water level above milk level in can cooler but do not submerge cans. Change water in cooler frequently. Maintain water temperature at 40°F (4°C) or less and provide circulation of water in cooler or
   b. cool milk in a refrigerated farm bulk-milk tank and keep at 36 to 38°F (2–3°C).
3. Prevent external contamination.
   a. Brush down cobwebs in barn and control dust.
   b. Keep barn and cows clean. Clip and clean flanks, tails, and udders of milking herd. Whitewash barn walls and ceilings at least once a year.
   c. Ensure proper sewage, wastewater, and manure disposal. Control flies and keep yard drained.
   d. Use a protected water supply that is safe and adequate. Contamination with psychrophilic bacteria can affect milk bacterial count and shorten raw milk storage life. Treatment (chlorination) may be necessary if psychrophiles are normally present in the water supply.
   e. Feed cows odorous feeds after milking.
4. Use good milking procedures.

   a. Massage and wash udders with a warm sanitizing solution just prior to milking and after forestripping. Wipe teats dry before attaching machine.
   b. Prohibit wet-hand milkings. Wash hands thoroughly and dry before milking.
   c. Use single-service paper towels to dry udders and hands and sanitize udders after milking.
5. Keep the milking herd healthy.
   a. Make monthly or quarterly chemical milk-screening tests on herd milk. Cows should be free from tuberculosis, brucellosis (Bang's disease), mastitis, and other diseases. Obtain veterinary diagnosis when mastitis is suspected and treat if necessary.
   b. Use a strip cup, check for abnormal milk, and use proper milking procedures.
   c. Provide ample clean, dry bedding and a ventilated environment. Avoid muddy conditions around feeders, waterers, and barn entrances; use pavement.

Detailed inspection report forms and explanations of regulations are available from the FDA, state and local health departments, or agricultural departments. Some industries provide supplementary information.

Insects and rodents should be effectively controlled on dairy farms, including all milkrooms. Cleanliness, proper manure handling, and elimination of potential breeding places supplemented by the judicious and proper use of approved and registered (EPA) pesticides, if necessary, will minimize the presence of insects and rodents. Pesticides must not contaminate milk, milk containers, equipment, utensils, feed, and water. They should be stored in a separate locked cabinet.

Barn

The milking barn should have 20 foot-candles of artificial light (10 foot-candles minimum), with 50 foot-candles at the cow's udder, as well as natural lighting. Adequate air space and ventilation are necessary to prevent overcrowding and condensation, excessive odors, and dampness. Hinged windows tilting open at the top, ridge exhaust openings, and other vertical or horizontal means of ventilation are suitable. A window area of 4 ft^2/60 ft^2 of floor surface, a minimum of 500 ft^3 of air space, and 50 ft^2 of bedded space per animal are recommended. Concrete manure gutters and walks at least 3 ft wide with a 6-in. coved curb at walls integral with the floor are easy to keep clean. A hose bib connection (protected against freezing if necessary) in the milking barn, stable, or parlor, connected with a safe water under pressure, simplifies the dairy cleaning operation. The water outlet should be equipped with a backflow preventer. In any case, the milking area must be clean and walls, ceilings, and windows constructed of cleanable material that keeps out dirt, flies, and odors. Manure must be spread on the fields or otherwise disposed of at least every four days in the fly season. Temporarily, it may be stored in a drained area not closer than 25 ft to any building, although daily removal is preferred. Storage pits, where provided, must be flytight. Manure storage pits generate methane. *Do not enter.*[44] See (a) Disposal of Animal Wastes and (b) Safety in Chapter 4.

Plans and assistance for animal management are usually available from the regulatory agency, the USDA, extension service, state land grant colleges, and equipment manufacturers.

Pen Stabling

Pen stabling, also referred to as loafing barn, loose housing, and straw shed, is a method in which the cattle are permitted to roam at will within a bedded area and to an adjoining open space. Feeding and milking areas in addition to the milkhouse are necessary adjuncts. The loafing area should be well drained and allow 70 ft^2 bedded area per animal plus an additional 25 ft^2 per animal for a paved feeding area. Mixed manure and fresh bedding, as needed to keep bedding dry, may be permitted to accumulate for three to six months to a year and then removed. However, a more frequent cleaning interval and manure removal before the fly season are recommended. The feeding area usually requires weekly cleaning. The milking area is separated from the loafing area and should be so constructed as to be cleanable. Centrally located milking areas or centers are encouraged. It is claimed that pen stables reduce the risk of injury to cattle, are less expensive to build, save labor, and result in greater milk production since the cattle are free to browse, eat, and rest at will.

Pipeline Milker

The pipeline milker is a labor-saving device on the farm. Milk flows from the teat–cup assembly and hoses of the milking machine to a special glass or stainless steel pipeline that terminates in a refrigerated bulk-milk storage tank or other container. This equipment requires special attention to ensure it remains clean. Off-flavors have been attributed to pipelines. A water heater of adequate capacity and equipment for circulating detergent solution mixed with air at a velocity of at least 5 fps are needed to clean the pipeline in place. At this velocity a 10-gal can is filled in 14 sec by a 2-in. stainless steel line, in 12.5 sec by a 2-in. glass pipeline, and in 22 sec by a $1\frac{1}{2}$-in. glass pipeline. Turbulent flows give better cleaning. Other parts, including the milking machine and teat–cup assemblies, air lines, air chambers, valves, fittings, gaskets, rubber and plastic surfaces, and dead ends, are disassembled and immediately brush cleaned by hand. The trend is toward the use of 3-in. lines.

Correct installation, adequate washing, and tight-fitting valves and hoses are essential. Pipelines can be cleaned as follows:

1. Prerinse with lukewarm water 100 to 120°F (38–49°C) immediately after use until water at outlet is clear. Do not recirculate. Milk fats dissolve at about 90°F (32°C).
2. Wash for 10 min by circulating an adequate volume of a proper alkaline detergent solution [140–165°F (60–74°C)], or as recommended by detergent manufacturer, through the system at a velocity (5 fps) that will give turbulent flow. Use an acid detergent solution once a week if alkaline detergent is normally used. The type of washing solution and cleaning procedure should take into consideration the characteristics of the water supply. Rinse out detergent with warm water.
3. Before reuse, rinse with 170 to 180°F (76–82°C) water measured at the outlet for at least 5 min (a separate booster heater for this purpose is recommended), 75 to 90°F (24–32°C) water containing 50 to 100 mg/l available chlorine solution, or other approved disinfectant for at least 2 min; open valves momentarily to allow contact with interior of valve. Cap the pipelines when finished.
4. If the total length of piping is less than about 50 ft, it will probably be easier and more economical to take the piping apart rather than attempt in-place cleaning. The system should be self-draining or dismantled.
5. Equipment must be thoroughly cleaned after each use and sanitized prior to reuse to ensure low bacteria counts. This includes air and vacuum hoses and pulsators.

The Northeast Dairy Practices Council[45] recommends the following minimum water-heating facilities for all pipeline installations, with water pressure at 20 to 25 psi:

Heater Type	Storage (gal)	Recovery Rate (gal per 100°F rise)
Electric	80	18
Gas fired	40	35
Oil fired	30	50

Dairy Equipment

The need for milk equipment standards acceptable to all that have jurisdiction over milk quality led to the development of 3-A Sanitary Standards. The standards are developed through the collaboration of manufacturers of dairy equipment, users of the equipment, the International Association of Milk, Food, and Environmental Sanitarians, and the U.S. Public Health Service (PHS)/FDA. Anyone can participate; but no one is bound by a standard. However, voluntary compliance or acceptance of the standards by the industry, the fabricator, and the sanitarian is in the mutual interest of all. It makes possible reference to a nationally accepted standard, sanitary design and construction of equipment, reduced fabrication costs, and simplified, more efficient and effective enforcement in the interest of the consumer. The criteria developed can be applied to equipment used in the food, beverage, pharmaceutical, and chemical industries.[46,47]

Milkhouse

A milkhouse of proper size and construction is a necessary part of a dairy farm. The provision of adequate facilities for the cleansing, disinfection, and storage of utensils and milking equipment and for the refrigeration of milk to a temperature of 38°F (3°C) is a basic essential. A milkhouse floor plan including details is shown in Figure 8-1. Plans and assistance are usually available from the USDA, state agricultural college, county extension service, power company, or building supply association.

Milking Parlors

Milking parlors are rooms for the milking of dairy animals in a sanitary, methodical, and efficient manner. Different milking arrangements are used, such as herringbone, individual, rotary tandem, and rotary herringbone. A milking parlor is considered when the herd size approaches 60. General features include the following:

1. Animals are elevated 30 to 36 in. above the operator's floor level.
2. Adequate water supply, water heating, and waste disposal facilities are required.
3. Constructed of easily cleaned, water-resistant, and durable materials. Consideration should be given to moisture barrier and heat conductance. Vapor barrier directly under the exterior wall finish.
4. Readily accessible to dairy barn and milkhouse; expandable and sited to avoid traffic.
5. Floor sloped at least $\frac{1}{4}$ in./ft to drains at the end and in the corners of both the cow platform and the operator's pit of fixed parlors or to drains under the cow platform from rotating platform and operator's pit.
6. Adequate wiring for all intended uses; one weatherproof 20-A grounded duplex outlet at each end of the operator's pit, with ground-fault interrupter protection; in compliance with national and local electric codes.

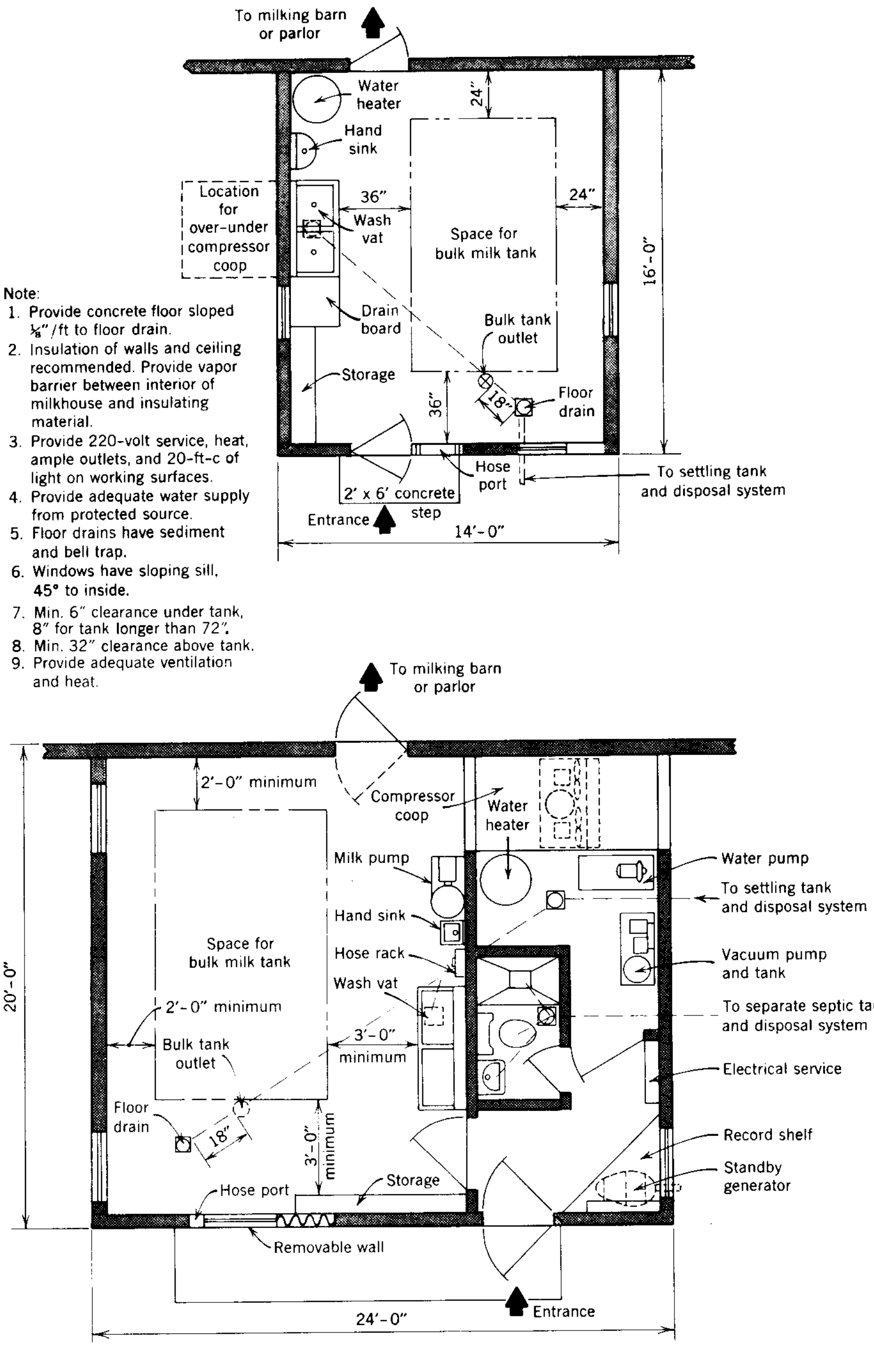


Figure 8-1 Milkhouse layouts show the arrangement of equipment on the floor plan for a small 14 × 16-ft milkhouse or large 20 × 24-ft milkroom with utility room. Size of bulk milk tank largely determines size of milkhouse. Tank sizes of 500 to 3000 gal are not uncommon. (*Source:* Adapted from R. W. Guest, W. W. Irish, and R. P. March, *Milkhouse for Bulk Tanks,* Agricultural Engineering Extension, Bulletin 326, Cornell University, Ithaca, NY, p. 5.)

7. Provision of 50 foot-candles at level of cow's udder plus supplemental lighting as needed.
8. Adequate ventilation for fresh air and moisture removal; heating and cooling for operator comfort.

Various publications are available from regulatory agencies, extension services, universities, and equipment manufacturers . The Northeast Dairy Practices Council (NDPC) guidelines are among the best.[48,49] Detailed plans for milkhouses, as well as recommendations for hot-water needs, insulation, lighting, and ventilation, are available from power companies, building supply associations, county extension agents, and state universities.

Precooling of fresh milk as it leaves the cow 96 to 100°F (36–38°C) can reduce the cooling load on the refrigerated bulk-milk tank and help ensure rapid cooling of the fresh milk and blended milk to the desired temperature of less than 40°F (4°C). Prolonged agitation is avoided and herd size can be increased somewhat without overloading the bulk tank refrigeration system. Precooling by means of plate coolers is accomplished using well water and/or chilled water. The temperature of milk as it leaves the cow can be reduced 10 to 40°F (6–22°C), to at least 70°F (21°C), depending on the plate assembly. Precooler water must be potable, under routine inspection, may not be returned to the source (well), but may be used for livestock. Control valves and vacuum breakers are required if the piping system may permit backsiphonage.[50]

Bulk Cooling and Storage

Bulk cooling and storage of milk on the farm reduce handling and the possibilities for contamination, result in rapid cooling of the milk, and require less space than cans. The cooling is accomplished in a stainless-steel-lined unit that also serves as a storage tank. It is placed 2 to 3 ft from walls or fixtures. The tank is insulated, mechanically cooled, and equipped with a motor-driven agitator, thermometer, thermostat bulb, outlet valve, and measuring stick.

A direct-expansion cooling system would require about 1 hp ($1\frac{1}{4}$ hp with air-cooled condenser) of compressor motor capacity per 50 gal of milk to be cooled at each milking. A chilled water or ice-bank system would require about $\frac{1}{3}$ hp of compressor motor capacity for each 50 gal of milk to be cooled. A can cooler would require $\frac{1}{8}$ hp per can for cooling both night and morning milk. In any case, farm-refrigerated milk storage tanks should be designed to cool the milk to 45°F (7°C) or less within 1 hr and to 36 to 38°F (2–3°C) in 2 hr and should comply with health and agricultural department regulations. The Interstate Milk Shippers program requires that the milk be cooled to 45°F (7°C) or less within 2 hr and that the blended milk, after the first and subsequent milkings, not exceed 50°F (10°C).

The theoretical milk-cooling capacity of the cooling system equals temperature reduction (°F) × 8.6 × 0.93 in Btu per hour per gallon. Add 15 percent for efficiency loss to obtain the recommended capacity. Milk with 3½ percent fat and 8.6 percent nonfat solids has a specific gravity at 68°F (20°C) of 1.033 and weighs 8.60 lb/gal. Milk has a specific heat of 0.93 Btu/lb. If the temperature of the raw milk is 90°F (32°C) and the final temperature is 37°F (3°C), the temperature reduction is 90°F − 37°F = 53°F (29°C); the average is 27°F. The theoretical milk cooling capacity is 27 × 8.6 × 0.93 = 216 Btu/hr/gal. The recommended capacity is 216 + 32* = 248 Btu/hr/gal in a direct-expansion bulk-milk cooling system. In an ice-bank system, 1 lb of ice takes 144 Btu to melt. To cool a gallon of milk from 90°F to 37°F will require the removal of 53 × 8.6 × 0.93 = 424 Btu from the milk, that is, the melting of 3 lb of ice.

Failure to properly cool milk in a farm bulk-milk tank can lead to the production of heat-stable enterotoxin in milk from a *Staphylococcus-aureus*-infected herd. The resulting food poisoning in individuals drinking the milk calls attention to the value of a recording thermometer for bulk-milk storage tanks for control purposes.[51] The temperature recorder can also control the cooling system and activate an alarm.

Milk is pumped out of a farm milk tank directly into a tank truck through a special hose carried by the hauler. The ends of the hose and outlet valve are sanitized by the hauler, who also rinses the farm tank thoroughly with lukewarm water after all milk is pumped out. Hot and cold water under pressure and a water hose in the milkhouse are practically essential to do a proper job. As soon as possible after rinsing, the agitator, thermometers, outlet valve plug, measuring stick, and strainers should be removed, brushed, and then washed in a warm chlorinated alkaline cleaning solution followed by a cold-water rinse. The inside tank surfaces and covers require the same treatment. The parts removed are reassembled and the entire tank is sanitized before being placed in use again. Make a visual inspection with a strong light. Use an acid rinse if needed. Farm bulk-milk haulers should be trained and certified in view of their responsibility for milk transfer, weighing, sampling raw milk, and rinsing the tank to remove heavy residue of milk and foam before washing.

Transportation

Milk should be hauled in insulated trucks to the receiving station or milk-processing plant as soon as it is removed from the cooler. In this way, milk that has been carefully produced will not deteriorate in quality while in transit.

The transportation of bulk milk is accomplished by insulated tank trucks designed and built to meet established standards. Equipment used to sample,

*Fifteen percent efficiency loss.

fill, and empty the tank must also be of sanitary design and construction. This equipment and the transportation tank are required to be cleaned and sanitized immediately after being emptied in a room provided for this purpose. The room should be clean, heated, drained, and provided with facilities for washing the milk tank, including an adequate supply of hot and cold water under pressure. The water supply must be of satisfactory sanitary quality and drainage disposal in accordance with local requirements and should not cause a nuisance.

Pasteurization

The PHS/FDA[52] define "pasteurization," "pasteurized," and similar terms to mean the process of heating every particle of milk or milk product in properly designed and operated equipment to one of the temperatures given below and held continuously at or above that temperature for at least the corresponding specified time:

Temperature	Time
145°F (63°C)*	30 min
161°F (72°C)*	15 sec
191°F (89°C)	1.0 sec
194°F (90°C)	0.5 sec
201°F (94°C)	0.1 sec
204°F (96°C)	0.05 sec
212°F (100°C)	0.01 sec

The asterisks indicate that if the fat content of the milk product is 10 percent or more or if it contains added sweeteners (half and half, cream, chocolate milk, etc.), the specified temperature shall be increased by 5°F (3°C) *provided* that eggnog and frozen dessert mixes shall be heated to at least the following temperature and time specifications:

Temperature	Time
155°F (69°C)	30.00 min
175°F (80°C)	25.00 sec
180°F (83°C)	15.00 sec

Other pasteurization processes may be approved by the FDA and the regulatory agency. The heat treatment should be followed by prompt cooling.

The effectiveness of pasteurization in the prevention of illnesses that may be transmitted through non-spore-forming milkborne disease organisms has been demonstrated beyond any doubt. The continued sale and consumption of raw milk must therefore be attributed to ignorance of these facts. Pasteurization does not eliminate pesticide residues, anthrax spores, or toxins emitted by certain staphylococci, but the production of toxins is nil when milk is properly refrigerated. See Foodborne Disease Outbreaks, Chapter 1.

The equipment used to pasteurize milk is described below. Complete plans showing the pasteurization process and all associated piping and equipment, including water supply, sewerage, heating and ventilation, are usually required to be approved by the regulatory agency. No changes are to be made without prior approval. A plant flow diagram should also be prepared and checked against the approved plans when inspections are made. In view of the size and complexity of modern-day pasteurization plants and to prevent cross-connections, raw product lines, pasteurized product lines, and cleaning-in-place lines should be color coded* and marked to show the direction of flow. Constant, competent operation control is essential.

Testing of pasteurization equipment and controls requires special expertise. Details are given in the *Grade A Pasteurized Milk Ordinance* (PMO).[52]

Holder Pasteurizer Holder pasteurizers are referred to as batch, pocket, and continuous-flow-type pasteurizers. They have a capacity of 100 to 500 gal or more. In the batch-type pasteurizer (Figure 8-2), the milk is heated in the pasteurizer vat or tank and held at 145°F (63°C) for 30 min, and then the milk is run over a plate or tubular cooler and bottled. The milk may be precooled in the pasteurizer vat to about 115°F (46°C) and then run over the surface cooler. The pocket, or multiple tank-type, pasteurizer, is no longer in general use. In the continuous-flow-type pasteurizer, consisting of a series of tubes, heated milk is pumped by a calibrated pump from the lowest tube and passed out at the top from the highest tube. All tubes are jacketed. Outlet valves must be of a leak detection type; recording, indicating, and airspace thermometers must be accurate and reliable, and the airspace temperature in the vat must be 5°F (3°C) above minimum pasteurization temperature.[53]

High-Temperature, Short-Time Pasteurizer The high-temperature, short-time (HTST) pasteurizer uses accurate and dependable controls, including the flow diversion valve or device, calibrated pump, and heat exchanger equipment to ensure proper pasteurization of large quantities of milk in a short time. In this type of pasteurizer, a large number of plates are carefully clamped together, with water and milk on alternate sides. It is compact and makes possible heating, holding, regenerating, and cooling all in one unit. The HTST systems include the milk-to-milk regeneration homogenizer upstream from holder, milk-to-milk regeneration surface cooler, milk-to-milk

*Suggested color coding: red—raw product lines; blue—pasteurized product lines; green—cleaning solution lines; yellow—stainless steel water lines; orange—sugar and dairy food ingredients.

regeneration booster pump, milk-to-milk regeneration homogenizer, and vacuum chambers downstream from the flow diversion device. See Figures 8-2 to 8-4.

In-the-Bottle Pasteurizer In-the-bottle pasteurization is a method of heating milk in the final bottle with hot water or steam to accomplish pasteurization as in the holder type followed by cooling. Indicating and recording thermometers, circulation of the hot water, auxiliary heating of the air above the milk level, and holding of the bottle and milk inside the bottle at the proper temperature are frequently wanting, making this method of pasteurization questionable unless carefully supervised. In an emergency, raw milk can be rendered safe to drink if heated in a water bath to a temperature of 165°F (74°C) and then immediately cooled. This method is no longer used. Microwave pasteurization was found to be unreliable and not completely effective. It cannot be recommended.[54]

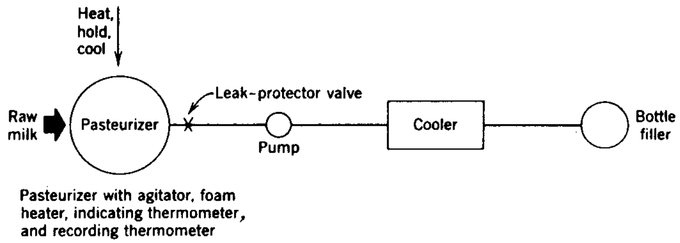
Ultrahigh-Temperature Pasteurizer (Higher Heat, Short-Time Pasteurizer)

Ultrahigh temperature (UHT) pasteurization of milk and milk products is heat treatment at a temperature of 191 to 212°F (88–100°C), with a holding time of 1.0 to 0.01 sec as previously noted. Timing in the holding tube and speed of response of the recorder–controller flow diversion valve system are critical, requiring sensitive equipment and competent supervision. This process requires built-in safety factors to ensure adequate heat treatment. Because of variations of particle velocity in laminar flow, the holding time or tube length is generally made twice the calculated hold. Milk can be stored without refrigeration for ‘‘long periods,’’ but special containers are needed.

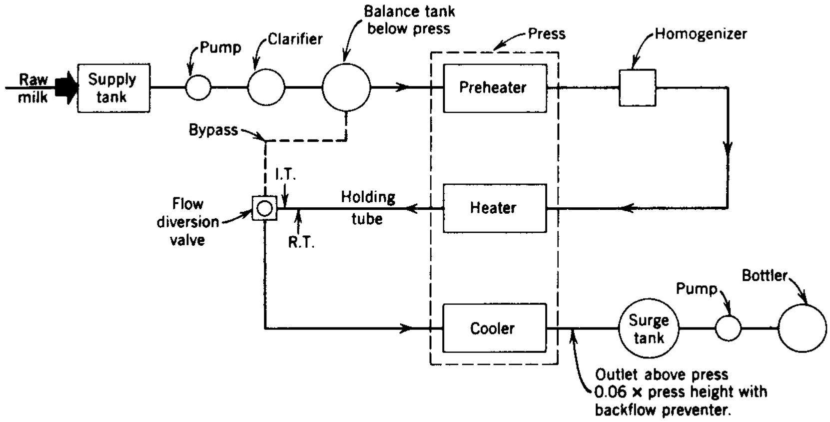
Ultrapasteurized A milk or milk product is considered ultrapasteurized when it has been thermally processed at or above 280°F (138°C) for at least 2 sec, either before or after packaging, to produce a product having an extended shelf life under refrigerated conditions.[55] The product has a limited shelf life when unrefrigerated, of about 3 months based on experience in Europe. In another high-temperature process, milk is ‘‘sterilized’’ at 275 to 300°F (135–149°C) for 1 to 5 s. Storage without refrigeration for up to 18 months has been reported without deterioration of quality, but flavor tends to deteriorate.

Cooler

Following pasteurization, the milk is promptly cooled to below 45°F (7°C) to keep the bacteria count from materially increasing. Reducing milk to a temperature no higher than 38°F (3°C) will improve the shelf life. This is accomplished by using a cooler. A common type is the plate or external tubular cooler. It may be a single series of tubes or a cabinet tube type. A surface



Batch-type pasteurizer



High-temperature short-time pasteurizer

Figure 8-2 Simplified pasteurizer flow diagrams. Testing of holding time involves the following steps.

1. I.T. = Indicating thermometer. R.T. = Recording thermometer. Holding tube slopes up at least $\frac{1}{4}$ in./ft. Pump may be substituted for homogenizer. Flow diversion valve is set to bypass milk when the temperature of the milk drops to 161.5 °F and to pasteurize milk when the temperature of the milk raises to 162°F.

2. Capacity of holding tube = $\frac{1}{4}$ $(\pi \times D^2) \times L \times 7.48 = A$ gallons, where D = inside diameter of tube (ft) and L = length of tube (ft).

3. Theoretical time to fill a 10-gal can and provide 16 sec hold = x; $16/A = x/10$; $x = 16/A$.

4. Test holding time by means of salt conductivity or improved test for precision.

5. Holding time for milk = 1032 $(TM_w)/W_w$, where 1.032 = specific gravity for milk with 4 percent fat at 68°F, 1.013 with 20 percent fat, and 0.995 with 40 percent fat; T = average holding time for water (sec); M_w = average time to deliver a measured weight of milk (sec); and W_W = average time to deliver an equal weight of water (sec). *Note:* Inspection should also include on-site tracing of all piping and equipment to ensure there is no cross-connection between raw milk and pasteurized milk pipelines and potable and nonpotable water lines or no possible backsiphonage or backflow.

See regulatory agency procedure to check holding tube length and time for 1.0 sec or less. See also ref. 56, pp. 189–238.

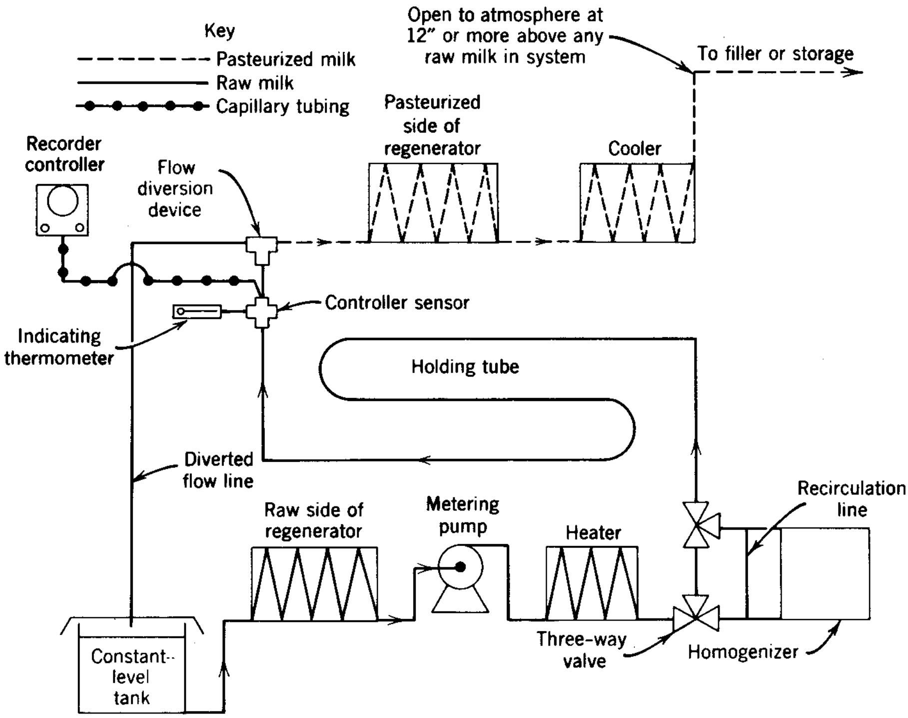


Figure 8-3 Milk-to-milk regeneration pasteurizers. Homogenizer upstream from holder. (*Source: Grade A Pasteurized Milk Ordinance,* 1989 Recommendations of the PHS/FDA, Pub. No. 229, Department of Health and Human Services, Washington, DC, 1990.)

cooler is usually divided into an upper and lower section. The upper section is generally cooled by water, and sometimes chilled raw milk, flowing inside the tubes. The lower section usually circulates brine, ammonia, ice water, or "sweet" water that has been cooled. The warm milk is distributed by means of a perforated pipe or trough over the top of the cooler and is cooled as it flows in a thin sheet over the surface of the cooler.

Another type of cooler is the internal tubular cooler. It may be a single series of tubes or a cabinet tube type. In this method, there are two concentric tubes: the milk flows in the center tube and the refrigerant flows in the outside tube.

When large volumes of milk are to be cooled, a plate heat exchanger or regenerator is generally used (Figures 8-2 to 8-4). Hot pasteurized milk on one side of the plate is cooled by cold raw milk, water, or brine on the opposite side of the plate. Dye tests should be made periodically to ensure there is no leakage to the pasteurized milk. The cooled milk is conducted to

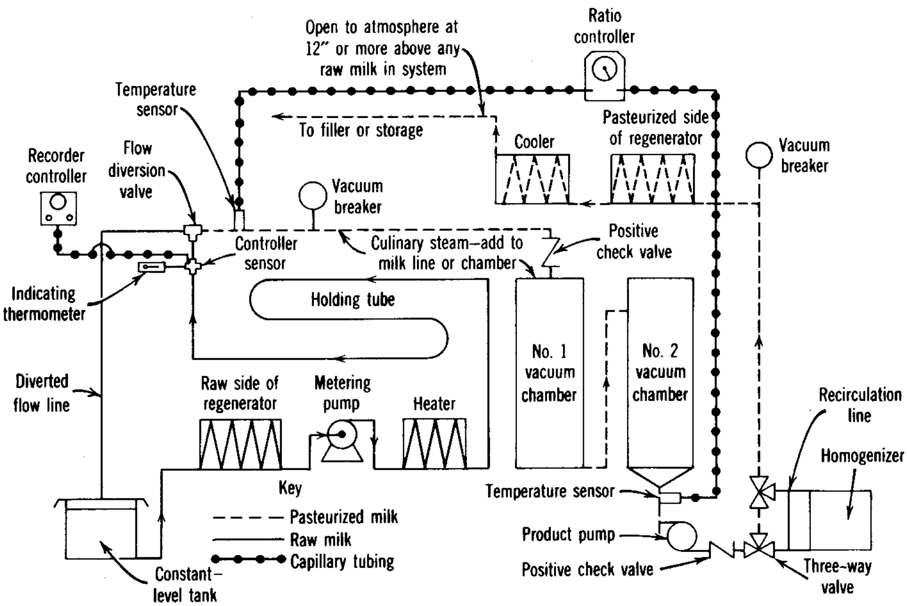


Figure 8-4 Milk-to-milk regeneration pasteurizers. Homogenizer and vacuum chambers downstream from flow diversion valve. (*Source: Grade A Pasteurized Milk Ordinance,* 1989 Recommendations of the PHS/FDA, Department of Health and Human Services, Pub. No. 229, Washington, DC.)

a filler and capper, where the milk is bottled or packaged. The milk containers are filled by means of a rotary gravity or vacuum-type filler. Empty containers are fed automatically from a conveyor to the filler. Bottled milk and filled cartons are placed in cases that are stored in a cooler until delivered. In very small operations, a hand-operated bottle filler and capper are used.

Cleaning and Sanitizing Milk Plant Equipment[56]

The maintenance of high-quality milk that will continuously meet regulatory bacteriological standards requires that all piping and equipment coming in contact with milk be cleaned and sanitized after each use.

A fundamental step in the cleaning process is the prompt rinsing of all equipment and parts after each use with warm potable water [approximately 100°F (38°C)]. This will remove most of the soil and minimize the formation of fat and protein organic films and inorganic films, such as milk-stone and iron, which harbor and permit the growth of bacteria, as well as reduce heat transfer where this is a factor. The wash step that follows requires the use of a suitable detergent at the proper concentration and temperature for a sufficient time to remove remaining soil, as recommended by the manufacturer.

The detergent manufacturer's representative can provide advice for specific concentration, temperature, and sufficient time to remove remaining soil. The detergent manufacturer's representative can provide advice for specific applications such as manual cleaning, out-of-place cleaning in a recirculation tank, in-place cleaning, spray devices, and high pressure–low volume. Although equipment may be cleaned in place, fittings and parts such as valves, gaskets, siphon breakers, and small lines need to be taken apart and cleaned by hand. The next step is the postrinse to thoroughly clean and rinse out remaining soil and detergent, preferably with acidified water. The assembled equipment is then sanitized just prior to being placed in operation (usually the next day) with hot water for not less than 5 min at 170°F (77°C) at the end of the system. Other methods include steam for at least 5 min at not less than 200°F (93°C) at the end of a closed system, a chemical solution at a temperature of 75 to 95°F (24–35°C) containing hypochlorite and at least 100 mg/l available chlorine or an iodophor containing 25 mg/l available iodine, and a quaternary ammonium compound at 100 mg/l* or an acid sanitizer at 200 mg/l. Chloramine compounds are slow acting and their use is not recommended. Quaternaries are affected by water hardness but are noncorrosive and less affected by organic matter. Quaternary ammonium sanitizers are reported ineffective against *Pseudomonas* and are not recommended for product contact surfaces.[57] The use of hypochlorite is usually preferred. Compounds containing phenols or heavy-metal salts such as mercury, silver, lead, zinc, copper, or chromium are not acceptable for use in milk and food-processing plants. Ultraviolet radiation and hydrogen peroxide have special auxiliary applications but must be used with care. Only permitted† boiler compounds suitable for culinary purposes may be used to treat boiler feedwater to make steam.

Cleaned-in-Place Piping and Equipment Modern milk plants use a cleaned-in-place piping and equipment system. It may include raw milk piping, homogenizer, HTST pasteurizer plate heat exchanger and pasteurizer, cooler, temperature control equipment, recirculation and constant-level tank, pump, chemical feed equipment, separate or existing heating facilities, tank-cleaning sprayers, and connecting piping, valves, and fittings. The piping and accessories are usually welded stainless steel with the interior surface finish of the product piping meeting 3-A Sanitary Standards.

Some of the concerns to ensure proper operation and control are

- piping supported and constructed to completely drain;
- removable and thoroughly cleaned gaskets, where used;

* The FDA considers food products containing residues of quaternary ammonium compounds to be adulterated.

† *Code of Federal Regulations,* Title 21, Section 173.310.

- rinse and wash water and solution pipe velocity not less than 5 fps for adequate time periods (15 to 30 or 40 min);
- indicating thermometers and temperature recorders and controls provided and functioning; and
- no potential for cross-connections.

Cleaned-in-place piping and equipment systems are complex and must be carefully engineered. They may be fully automated or designed for some of the equipment to be cleaned manually.

Detailed information on the cleaning and sanitizing of equipment is available from the NDPC,[60] the regulatory agency, extension service, and detergent manufacturers.

Bottle Washer

Although the bottle washer is not generally used, the trend to returnable bottles suggests that its operation is understood. Bottle washers are of various types, depending usually on the total number of bottles to be washed:

1. At small plants, bottle washing is a manual operation. The bottles are soaked, washed by hand on a revolving brush, rinsed, and then sanitized by steam or a hot-water spray in the case.
2. In the larger plant, a case washer is usually used. As the name implies, bottles placed in the case are individually subjected to water pressure cleansing by a washing solution, rinse, and final sanitizing rinse.
3. At large plants, a soaker-type washer is used. Bottles are placed in the machine slot or pocket and subjected to a prerinse, soaking in alkali solution for several minutes, an inside and outside alkali spray, sometimes automatic brushing, then a final rinse. The highest temperature reached is about 160°F (71°C), which is gradually reduced. The final rinse is fresh cold water, which usually contains a chemical sanitizer.
4. The bottle-washing solution used frequently determines the effectiveness of the entire washing operation. A good washing compound dissolves dried milk and foreign matter, rinses easily, and effectively disinfects. Experience shows that sodium hydroxide (caustic soda) is the compound of choice for machine use. It is used as a 2 to 3 percent solution. In hard-water areas the water should first be softened or a suitable detergent used. Addition of ¾ lb of 76 percent commercial caustic soda to 1 ft^3 of water, or 7½ gal, will make a 1 percent solution of sodium hydroxide.

Combinations of causticity, time, and temperature of equal bactericidal value for a soaker tank of soaker-type bottle washers [based on National Soft Drink Association (NSDA) Specifications for Beverage Bottles] are given below.*[52]

Temperature, °F	170	160	150	140	130	120	110
Temperature, °C	77	71	66	60	54	49	43
	Concentration of NaOH at 3, 4, and 7 min (%)						
3 min	0.57	0.86	1.28	1.91	2.86	4.27	6.39
5 min	0.43	0.64	0.96	1.43	2.16	3.22	4.80
7 min	0.36	0.53	0.80	1.19	1.78	2.66	3.98

When caustic soda is so used, subsequent final rinsing of the bottles shall be with water treated with heat or chemicals to ensure freedom from viable pathogenic or otherwise harmful organisms to prevent recontamination of the treated bottle during the rinsing operation.

The residual bacteria count of multiuse and single-service containers used for packaging pasteurized milk and milk products should not exceed one per milliliter of capacity when the rinse test is used or not over 50 colonies per 8 in. (1/cm^2) of product contact surface when the swab test is used in three out of four samples taken at random on a given day. All multiuse and single-service containers should be free of coliform organisms.

Cooler and Boiler Capacity

Adequate power and refrigeration capacities are necessary to the processing of milk. The advice of persons experienced in the design and operation of these units should be obtained when constructing a new plant or when making major modifications. A table of small boiler and refrigeration capacities for different-size plants is given below as a general guide.

Coolers for the storage of milk are of the walk-in type. Refrigeration is obtained by coils on walls circulating brine, by direct expansion of ammonia in coils on walls, and by unit coolers equipped with coils and a fan. The unit cooler keeps the room drier and provides better air circulation. Freon, carbon dioxide, methyl chloride, sulfur dioxide, and ammonia are common refrigerants.

*Circular 958, 1NYCRR Part 2, Agriculture and Markets Law, 1989, New York State. Department of Agriculture and Markets, Albany, NY.

Plant Capacity (gal of milk)	Steam Boiler Rated Horsepower Capacity	Refrigeration Unit Rated Capacity (tons)*
150	15	5
300	27	11
750	42	20
1500	72	23
2500	92	32

Quality Control

Quality control involves herd health, milk handling, refrigeration, transportation, processing, and distribution. Field and laboratory testing coupled with inspection, supervision, education, surveillance, enforcement, and evaluation are the major methods used. Surveillance of bulk-milk sampling from the tank to the laboratory is essential so that interpretation of laboratory results may be valid.[58] The quality control should include plant environmental sampling to detect and prevent postpasteurization contamination due to *Listeria* and other pathogens. Sources might include aerosols, equipment such as filling machines and ingredient feeders, and lack of plant cleanliness and sanitation.[59] Aerosols may contain bacteria, molds, yeasts, spores, viruses, pollens, and particulates. Plant and personnel cleanliness, air filtration, and low-level activity will minimize aerosol contamination.[60] *Listeria monocytogenes* is controlled by proper pasteurization.[61]

Testing

The tests used to control the quality of milk are explained in detail in *Standard Methods for the Examination of Dairy Products*.[62] The major tests are discussed here. Raw milk quality is determined by temperature; sediment; odor and flavor; appearance; direct microscopic counts, including clumps of bacteria, leukocytes, and streptococci; standard plate counts; abnormal milk tests; freedom from antibiotics; and thermoduric determination. Tests for brucellosis and animal health are also made. Pasteurized milk quality is indicated by the standard plate count, direct microscopic count, phosphatase test, coliform test, and taste and odor tests. Other common tests are for butterfat, total solids, and specific gravity, also keeping quality tests. Quality standards and sampling frequency are summarized in Tables 8-6, 8-6a, and 8-7. Care should be taken to ensure the collection of representative samples.

*1 ton = 288,000 Btu in 24 hr. This is also the amount of refrigeration accomplished by the melting of 1 ton of ice.

TABLE 8-6 Chemical, Bacteriological, and Temperature Standards

Grade A raw milk and milk products for pasteurization, ultra-pasteurization, or aseptic processing	Temperature	Cooled to 45°F (7°C) or less within 2 hr after milking, provided that the blend temperature after the first and subsequent milkings does not exceed 50°F (10°C)
	Bacterial limits	Individual producer milk not to exceed 100,000/ml prior to commingling with other producer milk Not to exceed 300,000/ml as commingled milk prior to pasteurization
	Antibiotics	No zone greater than or equal to 16 mm with *Bacillus stearothermophilus* disc assay method specified in Appendix G, page 184, of the *Pasteurized Milk Ordinance*
	Somatic cell count	Individual producer milk not to exceed 1,000,000/ml[a]
Grade A pasteurized milk and milk products and bulk-shipped heat-treated milk products	Temperature	Cooled to 45°F (7°C) or less and maintained thereat
	Bacterial limits[b]	20,000/ml
	Coliform	Not to exceed 10/ml: provided that, in the case of bulk-milk transport tank shipments, shall not exceed 100/ml
	Phosphatase[c]	Less than 1 μg/ml by the Scharer rapid method or equivalent
	Antibiotics	No zone greater than or equal to 16 mm with the *B. stearothermophilus* disc assay method specified in Appendix G, page 184, *Pasteurized Milk Ordinance*
Grade A aseptically processed milk and milk products	Temperature	None
	Bacterial limits	No growth by test specified in Section 6
	Antibiotics	No zone greater than or equal to 16 mm with the *B. sterothermophilus* disc assay method specified in Appendix G, page 184, *Pasteurized Milk Ordinance*.

Source: Grade A Pasteurized Milk Ordinance, Pub. No. 229, PHS/FDA, Washington, DC, 1989, p. 13.

[a] Lowered to 750,000 cells/ml by the National Conference on Interstate Milk Shipments, effective July 1, 1993.

[b] Not applicable to cultured products.

[c] Not applicable to bulk-shipped heat-treated milk products.

Note:

1. Raw milk odor and taste test are also advised.
2. Rinse of empty milk bottle, carton, or other container shall be free of coliform organisms and contain less than 1 bacteria/ml. Swab counts from five different 8-in.^{2} areas shall be free of coliforms and not exceed 250 colonies/40 in.^{2}
3. Sediment. Sample from off-bottom unstirred 40-qt can of milk shall contain less than 2 mg of sediment when compared to photographs of standards. (Obtainable from Photography Division, Office of Information, U.S. Department of Agriculture, Washington, DC.) Sample of stirred milk from a can, weigh tank, farm bulk-milk tank, plant storage tank, or transportation tank shall not exceed the 1-mg standard.
4. All milk samples must be representative, carefully collected using sterile technique and equipment, and shipped in a proper container that will prevent contamination and maintain the sample at proper temperature for examination in an approved laboratory. Sample must arrive at 32–40°F (0–4°C) and be examined within 36 hr of collection.
5. When one or two of the last four consecutive bacteria counts, somatic cell counts, coliform results, or cooling temperatures taken on separate days exceed the standard, send written notice. When three of last five exceed standard, suspend permit and withdraw product.
6. When phosphatase standard is exceeded, immediately determine cause. Milk involved shall not be sold. With the Scharer rapid phosphatase test, a value of 1 μg or more of phenol per milliliter of milk, milk product, reconstituted milk product, or cheese extract would indicate improper pasteurization or contamination with unpasteurized products. See ref. 62 for other tests.
7. When an antibiotic or pesticide residue test is positive, the cause shall be determined and corrected. An additional sample shall be collected and no milk be offered for sale until subsequent sample is free of antibiotic or pesticide residues or below the actionable level established for such residues. The *Bacillus stearothermophilus* test is reported to be a more sensitive test to detect the presence of antibiotics in bulk-milk tanks. Pesticide residues of up to 0.05 ppm in whole milk and 1.25 ppm on a milk-fat basis in manufactured dairy products are permitted under FDA tolerance levels. The maximums apply to DDT and its chemical degradation products DDD and DDE or any combination.
8. Commingled raw milk counts of less than 10,000 are readily obtainable in a well-run operation. Manufacturing-grade milk is usually of poorer quality, which influences the quality of the final product; the bacterial limit is 1 million per milliliter.
9. If pasteurized milk bacterial count is greater than 10,000, review handling prior to pasteurization. Bacterial count of less than 1000 is attainable.
10. Pasteurized milk coliform count of less than 1 is attainable.

This test is of limited value when made on mixed milk from bulk-milk tanks in view of the large dilution and generally effective cooling. The DMC method should not be used on very low-count milk.

TABLE 8-6a Quality Standard for Milk Products Used for Frozen Desserts[a]

Milk and Milk Products	Standards
Commingled prepasteurized milk	Standard plate count, not to exceed 300,000/ml
Prepasteurized milk	Standard plate count, not to exceed 100,000/ml
Pasteurized milk	Standard plate count, not to exceed 20,000/ml
Prepasteurized cream	Standard plate count, not to exceed 300,000/ml
Pasteurized cream	Standard plate count, not to exceed 20,000/ml
Butter, 80% cream, plastic cream, mixtures of butterfat, sugar or sweetening agent, moisture and flavoring, condensed milk, mixes, and all other similar products	Standard plate count, not to exceed 100,000/g Coliform count, not to exceed 20/g Yeast, not to exceed 100/g Mold, not to exceed 100/g
Pasteurized frozen desserts or frozen dessert mix	Standard plate count, not to exceed 100,000/g Coliform count, not to exceed 20/g
Nonpasteurized frozen desserts	Standard plate count, not to exceed 100,000/g Coliform count, not to exceed 20/g
Whipped cream, instant	Standard plate count, not to exceed 100,000/g
Whipped cream, instant vegetable topping, milkshake	Coliform count, not to exceed 20/g

[a]NYCRR Part 2 of the Agriculture and Markets Law, Circular 958, New York State Department of Agriculture and Markets, Albany, NY, 1989.

TABLE 8-7 Sampling Frequency for Milk and Milk Products

Milk or Milk Product	Number of Samples
Raw milk for pasteurization from each producer[a]	At least four during any consecutive 6 months
Raw milk for pasteurization from each milk plant prior to pasteurization[a]	Same as above
Pasteurized milk from each milk plant[b]	Same as above
Each milk product from each milk plant[b]	Same as above
Milk and milk products from retail stores[b]	As required by regulatory agency

[a]Perform bacterial counts, somatic cell counts, and cooling temperature checks. Also antibiotic tests on each producer's milk or on commingled raw milk at least four times during any consecutive 6 months; all sources tested if results positive.
[b]Perform bacterial counts, antibiotic tests, coliform determinations, phosphatase tests, and cooling temperature checks.

Temperature

Milk should be promptly cooled to 45°F (7°C) or less within 2 hr after milking* and maintained at that temperature until delivered to the receiving station or pasteurizing plant, unless delivered within 2 hours after milking is completed. The importance of proper cooling on the rate of bacterial growth is demonstrated by the results of studies at the Michigan Agricultural Station on freshly drawn milk. After 24 hr storage, milk having an initial count of about 4300 bacteria/ml decreased to 4100 at 40°F (4°C) and increased to 14,000 at 50°F (10°C) and to 1,6000,000/ml at 60°F (16°C). It is apparent, therefore, that milk that reaches the pasteurizing plant or receiving station 24 hr after milking at a temperature above 50 to 60°F will probably have a high bacterial count. Although fresh raw milk has bacteriostatic properties that help retard bacterial growth, the duration of this factor is variable.

In general, the kinetics of a chemical reaction (i.e., the rate of reaction) is approximately doubled for every degree Fahrenheit rise in temperature in the range of 50 to 100°F (10–38°C). The rate of microbial growth doubles with every 10°C (50°F) increase up to its thermal kill temperature. Regular raw milk freezes at a temperature of 31.5°F (−0.28°C). Any increase in freezing temperature is an indication of added water.

The *sediment test* shows the amount of extraneous material in milk but will not show dissolved material. A pint of milk from the bottom of an unstirred 40-qt can is strained through a Lintine or similar disc of absorbent cotton. When milk in a farm bulk-milk tank, plant storage tank, or transport tank is to be tested, a 1-gal, well-mixed sample warmed to 90 to 100°F (32°–38°C) is collected. The color of the stain produced on the disc, from yellow to brownish black, and particles retained are a simple visual indication of the amount of dirt and abnormal substances in the milk. The test and its interpretation are given in *Standard Methods*.[62] Failure to properly wash a cow's udder just prior to milking is the common cause of high-sediment test results. A clarified or strained milk will not show the dirt; hence, the test may only encourage straining of the milk at the farm rather than cleaner milking procedures. However, other tests will also reveal insanitary practices. The test is sometimes used on processed milk. Less than 1.5 mg is satisfactory for producer milk.

Odor, flavor, and appearance are physical tests are usually made at the receiving station or at the bulk-milk tank at the same time sediment tests are made. Off-odor or off-taste is more pronounced at a temperature of 60 to 70°F (16–21°C) or higher. Experienced inspectors can make very rapid and accurate determinations by sight and smell on the quality of a milk. Sour milk, dirt, and odors associated with mastitis, improper cooling, dirty utensils, horses, consumption of leeks and other weeds, or a disinfectant is easily

*Provided that the blend temperature after the first milking and subsequent milkings does not exceed 50°F. Cooling to 45°F (7°C) within 1 hr and to 40°F or less within 2 hr is preferred.

detected. Feed flavors can be prevented by the feeding of cows after milking or at least 5 hr before milking; removal of cows from a lush pasture 3 hr before milking; elimination from pastures of wild onions, leeks, skunk cabbage, and certain mustard weeds; and storage of silage or strong-smelling feed away from the cows. Barny or musty flavors and odors can be controlled by keeping the cows, milkers, and stables clean. Good ventilation and dry conditions without dust are important. Salty flavors are due to the use of milk from cows infected with mastitis or from cows being dried off (strippers). This milk should be discarded. Rancid milk is caused by use of milk from stripper cows, milk from cows late in lactation, slow cooling of milk, and especially excessive agitation. A malty flavor is caused by high bacteria count, dirty utensils and cows, poor cooling, and slow cooling. Very high bacteria count, dirty utensils, and slow or poor cooling cause sour milk. An oxidized or cardboard flavor is caused by milk coming in contact with copper, copper alloys, or iron equipment; exposure of milk to sunlight; copper or iron in the water supply; and possibly milk from special cows. Medicinal flavors are due to certain medications for the teats, creosote-based disinfectant barn sprays, and insect sprays used just before or during milking. Clean udders and milk-handling equipment together with rapid cooling and good barn ventilation will eliminate the major causes of off-flavors and off-odors in milk. Cooked flavors are caused by overpasteurization times. Off-odors are more apparent in milk warmed to 60 to 70°F (16–21°C). For flavor testing of raw milk, expectorate quickly or heat a sample to 160°F (71°C) and cool to 60 to 70°F before tasting.

When it is not possible to collect and examine a large number of samples for bacterial examinations, an indication of the sanitary condition of the milk can be obtained by means of the methylene blue *reduction test* or the *resazurin test*. These tests are no longer used.

The *direct microscopic count* (DMC) tells the number of isolated bacteria and groups of bacteria in stained films of milk dried on glass slides, as determined with the aid of a compound microscope. It is a rapid test used on small batches of raw milk to show the types of bacteria present and the possible source as dirty utensils (bacterial clumps), infected udders, or poor cooling (bacteria in pairs) provided the source, age, and temperature of the milk are known. On small volumes of pasteurized milk, it is possible to detect poor-quality raw milk, the presence of leukocytes and sometimes thermoduric, psychrophilic, thermophilic, and other types of bacteria that do not normally grow on standard agar plates, and contamination after pasteurization. Generally, most dead bacteria disintegrate within several hours after pasteurization; those that remain do not stain well, and hence, only a few of the dead bacteria are counted when the DMC is made. *Streptococcus lactis* organisms in pairs, three, or double pairs of oblong cocci generally indicate poor cooling or unclean equipment. Masses of bacteria indicate unclean utensils, milking machines, or tubing.

This test is of limited value when made on mixed milk from bulk-milk tanks in view of the large dilution and generally effective cooling. The DMC method should not be used on very low-count milk.

The *direct microscopic somatic cell count* (DMSCC) is a more precise test than the DMC. It gives the total leukocyte and epithelial cells in a sample of raw milk. Bulk-tank somatic cell counts less than 200,000 cells/ml indicate a good level of udder health, while counts over 300,000 cells/ml indicate subclinical mastitis in the herd, which results in poor milk quality and reduced production. The offending cows should be isolated and treated. A DMSCC of 1,000,000 cells/ml correlates with a milk loss of about 16 percent or more according to the National Mastitis Council. A leukocyte cell count over 500,000/ml or a total cell count of 1,000,000/ml, together with long-chain streptococci, gives strong indication of udder infection and effects of mastitis. Enforcement action is usually based on a somatic cell count of 750,000 to 1,000,000 per milliliter or more. In clinical mastitis, the quarter is swollen and the milk contains blood, flakes, and clots. In subclinical mastitis, the somatic cell count gives an indication of mastitis and the need for possible antibiotic treatment. Under ideal conditions, one bacterial cell can reproduce to 33,000,000 cells after 12 hr. A California mastitis test of 1+ or higher for two consecutive months indicates infection in one or more quarters.

Screening tests for mastitis (*an infection of the mammary glands*) are for the detection of abnormal milk.[63,64] Tests used are the California mastitis test (CMT), the Wisconsin mastitis test (WMT), the modified Whiteside test (MWT), the catalase test, and the electronic somatic cell count. However, only the DMSCC should be used as a basis for legal action and the possible shutoff of a farm's milk supply. The CMT, WMT, and MWT can be used as field tests. Elimination of the cause of high results includes milking hygiene, milking machine functioning control, dipping of teats in 4 percent hypochlorite solution after milking, and penicillin treatment of all quarters at the time of drying off. Veterinary assistance may be needed to bring difficult problems under control, especially when the leukocyte cell count exceeds 1,500,000/ml. A cell count greater than 1,000,000 requires a recheck.

When a recheck sample is above 1,000,000 cells/ml, the dairy farmer is usually expected to enroll in the state mastitis control program. An appropriate plan of corrective action to be followed by the dairy farmer is developed. The dairy farmer is expected to remain in the mastitis control program for at least six months and until three out of the last four routine monthly samples had a somatic cell count of 1,000,000 cells/ml or less.

The *standard plate count* (SPC) shows the approximate number of bacteria and clumps of bacteria that will grow in 48 hr on a standard medium held at a temperature of 90°F ± 1.8°F (32°C ± 1°C). A count of 10,000/ml or less indicates good-quality raw milk. Wide variations are common. The plate count is especially suited to products having low bacterial densities and as a measure of the bacterial quality of certified milk and pasteurized milk and milk products, except fermented milk products. It is also recommended for process sampling. High counts on freshly pasteurized milk suggest contamination of milk contact surfaces or that thermoduric bacterial counts be made on producer samples to learn the source. Studies show that the SPC is superior to the DMC in detecting poor-quality raw milk and hence is the method of choice, particularly with bulk-tank milk. But excessive numbers of psychrophilic bacteria are not detected by the routine plate count. Incubation at a temperature of 44.6°F (7°C ± 1°C) for 7 to 10 days followed by replating is suggested. For these reasons, an improved test is needed to measure the quality of both raw and pasteurized milk. In the *Moseley count,** the standard plate sample is stored for five days and then replated, giving an indication of the milk-keeping quality during refrigerated storage in a supermarket and at home.

A *preliminary incubation count* (PIC) of raw milk at 55°F (13°C) held for 18 hr can give an indication of the quality of the milk at a farm. Plate counts greater than 1,000,000/ml suggest dirty cows, poor udder-washing practices, slow cooling or storage temperatures above 40°F (4°C), failure to clean equipment (including milk meters, weigh jars, and automatic milker rubber parts) twice each day, failure to sanitize equipment before use, or a contaminated water supply.[65] The filler may be a major source of contamination in pasteurized milk. Counts greater than 50,000/ml should be investigated. The PIC does not correlate well with the SPC and should not be considered as an ''official'' count. The test also indicates the presence of psychrotrophic bacteria.

In practically all raw milk, a *coliform test* will show the presence of the coliform group of organisms, usually less than 100/ml in high-quality milk. Higher counts in bulk-tank milk suggest poor equipment and milk-handling sanitation and possible udder infection. Where pipeline milkers and farm bulk-milk tanks are used, the coliform count is a measure of utensil sanitization, udder cleanliness, and milking hygiene. Properly pasteurized milk will usually show the absence of coliform organisms. A positive test for coliform organisms in pasteurized milk greater than 10/ml (should be less than 3) is an indication of improper processing or excessive contamination following pasteurization by improperly cleaned and disinfected equipment, utensils, or dripping of condensate into pasteurized milk. Dust, exposure of the pasteurized milk to the air, flies, or other insects, and poor refrigeration may also contribute to high coliforms. Some authorities claim that strains of coliform organisms exist that are heat resistant and are not completely destroyed by pasteurization.

The *phosphatase test* shows whether milk has been properly pasteurized and whether it has been contaminated with raw milk after pasteurization. Phosphatase is an enzyme present in all raw cow's milk and is almost com-

*The Moseley test will also reveal the presence of psychotropic bacteria.

pletely inactivated by proper pasteurization. The enzymes surviving pasteurization release phenol from disodium phosphate substrate. Upon the addition of 2,6-dichloroquinonechloroimide (CQC), the liberated phenol reacts with CQC, producing an indophenol blue color, the intensity of which depends on the amount of enzyme present and, hence, the degree of pasteurization or raw milk added. In the Scharer rapid phosphatase test, a reading of 1 microgram (μg) or more of phenol per milliliter of milk, milk product, reconstituted milk product, or cheese extract is an indication of improper pasteurization or contamination with raw milk or milk product. Other methods are described in *Standard Methods*.[62] Sale of underpasteurized products should be prohibited.

A false-positive phosphatase test may be obtained on HTST or UHT pasteurized milk or milk products such as chocolate milk, cream or other high-fat products, and old cream having a high bacteria count, particularly when not continuously or adequately refrigerated. Differentiation of *reactivation,* from residual phosphatase, is explained in *Standard Methods*.[62] Sterile milk products that have been allowed to warm up may require microbiological tests to determine the quality. Additives such as vitamins, chocolate powder, and milk solids should always be added prior to pasteurization. An overpasteurized milk could conceivably have added to it a very small quantity of raw milk that would not be detected by the phosphatase test; however, this would undoubtedly introduce coliform organisms that would be detected by the coliform test. Pathogenic bacteria likely to be found in raw milk are destroyed more rapidly than the phosphatase enzyme.

The phosphatase test is the best single indicator of milk safety. When combined with the coliform test and bacteria count, a fairly complete indication is obtained of the sanitary quality of milk.

Psychrophiles or *cryophiles* are a species of bacteria that can best grow within the approximate range of 35 to 50°F (2–10°C). Raw milk and cream are particularly susceptible if stored for two or three or more days. The psychrotrophic bacteria count (PBC) is made at 45°F (7°C) for 10 days. The PBC is a good indication of raw milk quality. Psychrophiles are introduced into the milk by organisms (*Pseudomonas*) on dirty equipment, on unclean hands, or in a contaminated water supply used to rinse the equipment. Soil, compressed air, and improperly cleaned and sanitized storage tanks at the farm and processing plant are also sources. Milk stored at a temperature below 40°F (4°C) will retard the growth of psychrophiles; higher temperatures will favor their growth, depending on genera and species. Pasteurization will normally destroy most psychrophiles present in raw milk, except spore-forming gram-positive rods. Their presence in pasteurized milk is generally an indication of postcontamination but may also be due to an excessive number of psychrophiles in the raw milk, inadequately cleaned and sanitized contact surfaces, or use of a contaminated water supply. They also cause flavors in milk and poor keeping quality. This becomes important in the holding of raw milk and every-other-day milk delivery. Coliform microorganisms grow well but slowly with time in refrigerated pasteurized milk. *Listeria monocytogenes* causing listerosis grows well at a temperature of 39°F (4°C) in milk and milk products, emphasizing the importance of avoiding postpasteurized milk contamination and temperature abuse.[66] Proper cleaning and sanitizing of equipment in the pasteurization plant, protection of the equipment from contamination, use of a water supply of satisfactory sanitary quality, milk storage below 40°F (4°C), and processing of raw milk within 24 hr will control psychrophiles. Use of a chlorinated wash-water supply containing 5 to 10 mg/1 available chlorine is effective in controlling these bacteria.

Thermoduric bacteria withstand pasteurization at 145°F to 161°F (63–72°C). They grow best at temperatures of 70 to 98°F (21–37°C). Milk that is not properly refrigerated at the farm would permit the growth of thermodurics. The cow's udders, improperly cleaned utensils and milking machines, feed, manure, bedding, and dust are sources of thermoduric bacteria. Preheating equipment, pasteurizers, bottles, and piping that have not been properly washed and sanitized can harbor thermoduric bacteria. When high SPC are reported on pasteurized milk or cream, laboratory pasteurization of individual producer raw milk samples contributing to a batch will reveal the presence and producer source of thermoduric bacteria.

Thermophilic bacteria grow best at a temperature of 113 to 158°F (45–70°C). Their optimum temperature for growth is 131°F (55°C), but they can grow at 98.6°F (37°C) or lower. The presence of thermophiles in large numbers may be due to repasteurization of milk or cream, prolonged holding of milk or cream in vats at pasteurization temperatures, stagnant milk in blind ends of piping at pasteurization temperatures, continuous use of preheaters, long-flow holders or vats for more than 2 to 5 hr without periodically flushing out equipment with hot water, passage of hot milk through filter cloths for more than 1 to 2 hr without replacing cloth, residual foam on milk that remains in vats when emptied at the end of each 30-min holding period, and growth of thermophiles in milk residues on surfaces of pasteurizing equipment.

Mesophilic bacteria grow at temperatures of 59 to 113°F (15–45°C). They prefer a temperature of 98.6°F (37°C). Pathogenic bacteria are in this group.

Agglutination-type tests, including the milk ring test, are used to determine the presence of brucellosis. The ring test is made on samples of mixed milk from a herd, usually as delivered to the receiving station. A positive milk ring test can then be followed up by individual blood testing of the infected herd to determine the responsible animals. This makes possible more effective use of the veterinarian's time. The milk ring test will detect one infected animal in a herd of 500 when a sample of the pooled milk is examined.

Antibiotics are widely used to treat mastitis and other dairy cattle diseases, also for prophylaxis and growth promotion. They include penicillin, ampicillin, streptomycin, sulfa compounds, and tetracyclines. Farm milk containing antibiotics and salmonellae that is not pasteurized, inadequately pasteurized, or contaminated after pasteurization presents a public health hazard when used as fluid milk or in cheese. Some individuals are sensitive to some of the drugs. In addition, antibiotics interfere with the growth of bacteria needed for the processing of cheese and cultured products but do not affect salmonellae. Labelling directions should be carefully followed to ensure proper antibiotic usage, dosage, and segregation of treated animals. Rapid antibiotic screening tests are available.[67] Recognized tests include the *Bacillus stearothermophilus** or *B. subtilis* plate disc assay, Charm II, and the Delvotest P. methods.[68] The *B. stearothermophilus* method is not sensitive to low levels (10 ppb) of sulfonamides. The Charm II test is reported to detect a larger number of drugs than the disc assay. Antimicrobials not used for human therapy should be selected for animal treatment, including growth promotion, and to prevent survival of resistant pathogenic bacteria in animal foods. Newer methods will permit improved drug monitoring.

Pesticides are widely used in agriculture, including potential foods for dairy animals. Consumption of feeds containing unacceptable levels of pesticide residues by dairy animals may result in unacceptable residue concentrations in milk, butter, cheese, and other milk products. Chromotographic analysis can identify and quantify pesticide residues. For the above indicated entities, interested parties are encouraged to review the most contemporary guidelines and standards established by federal agencies either in the *Federal Register, Code of Federal Regulations,* or their web sites (which have been referenced previously).

MILK PROGRAM ADMINISTRATION

The milk industry and the regulatory agencies have a joint responsibility in ensuring that all milk and milk products consistently meet the standards established for protection of the public health. Inspection duplication should be avoided; instead, there should be a deliberate synergism of effort. With proper planning and cooperation, the industry and local, state, and federal governments can actually strengthen the protection afforded the consumer. The role of industry and official agencies to accomplish the objective stated is described below.

Certified Industry Inspection

Industry quality control inspectors are qualified by the official agency (usually health or agriculture) based on education, experience, and examination to make dairy farm inspection pursuant to the milk code or ordinance. Certificates are issued for a stated period of time of one to three years, may be revoked for cause, are renewed based on a satisfactory work record, and may require participation in an annual refresher course. Copies of all inspections,

*The only test accepted under the IMS program.

field tests, veterinary examinations, and laboratory reports are promptly forwarded to the official agency or to an agreed-on place and kept on file for at least one year.

Cooperative State–PHS/FDA Program for Certification of Interstate Milk Shippers (IMS)

The IMS Program, started in 1950, is a voluntary federal–state (agricultural and health) program designed to ensure a safe and clean milk supply and eliminate barriers to the movement of milk between political subdivisions. It is administered by the National Conference on Interstate Milk Shipments (NCIMS) through three councils with equal regulatory and industry representatives. Problems are assigned to one of the councils where they are freely discussed. Decisions are then made by the state regulatory officials, each state having one vote. The decision is submitted to the FDA for concurrence, rejection, or negotiation and implemented through a Memorandum of Understanding between the NCIMS and the FDA.

A state milk sanitation rating officer certified by the FDA makes a rating of a milk supply. Included are producers, receiving and transfer stations, and plants. The name of the supply and rating and published quarterly by the FDA. If the milk and milk products are produced and pasteurized under regulations substantially equivalent to the *Grade A Pasteurized Milk Ordinance* and are given an acceptable milk sanitation compliance and enforcement rating of at least 90 percent, they may be shipped to another area of jurisdiction participating in the IMS Program without further inspection.

The procedures for rating a milk supply are carefully designed with detailed instructions to be followed by the industry and the ratings officer.[69] Independent evaluations are made by FDA rating officers every 14 to 18 months to confirm ratings given or changes since the last rating and to ensure reproducibility of state rating results.

Official Local Program Supervision and Inspection

The official agency regularly reviews the industry inspection files mentioned above, takes whatever action is indicated, and at least annually makes joint inspections with the industry inspector of a randomly selected significant number of dairy farms, including receiving stations. The quality of work done is reviewed, the need for special training is determined, and recommendation concerning certificate renewal is made to the permit-issuing official. A similar review is also made of the sample collection and transportation and the procedures, equipment, and personnel in the laboratory making the routine milk and water examinations.

In addition, the local regulatory agency collects official samples as required by the state milk code, advises the industry having jurisdiction of the results and corrective action required, participates in training sessions, and serves as the state agent in securing compliance with the state milk code. The authorized local city or county agency usually has the responsibilities of routine inspection of processing plants, sample collection, and overall program supervision for compliance with the code. The agency sanitarian may serve as a consultant to the industry in the resolution of the more difficult technical, operational, and laboratory problems. This whole procedure makes possible better use of the qualified industry inspector and the professionally trained sanitarian, with better direct supervision over dairy farms and pasteurization plants and more effective surveillance of milk quality. In some states, the local activities are carried out in whole or in part by the state regulatory agency.

Official State Surveillance and Program Evaluation

The state department of health, and in some instances the state department of agriculture, share responsibility for milk sanitation, wholesomeness, and adulteration. The responsibility is usually given in state law, sanitary code, or milk code and in rules and regulations promulgated pursuant to authority in the law. Most states have adopted the FDA Recommended *Grade A Pasteurized Milk Ordinance* or a code that is substantially the same. This makes possible a reasonable basis for uniformity in both interstate and intrastate regulations and interpretation. However, short-term and alleged economic factors frequently limit reciprocity and interstate movement of milk. Both industry and regulatory agencies need to cooperate in the elimination of milk codes as trade barriers. There usually is no objection to reciprocity where milk quality compliance and enforcement are certified under the IMS Program.[70] However, not all states or farms participate in the program.

The IMS Program also gives the state regulatory agency a valuable tool to objectively evaluate the effectiveness of the local routine inspection and enforcement activities. The types of additional training needed by the qualified industry inspector, the assistance the dairy farmer should have, and the supervisory training needed by the regulatory agency sanitarian become apparent. Changes in technology and practices are noted, and the need for clarification of regulations, procedures, laws, and policies are made known to the state agency.

A common function of a state regulatory agency is periodic in-depth evaluation of local milk programs. This includes the effectiveness with which the local unit is carrying out its delegated responsibilities as described above, quality of work done, staff competency and adequacy, reliability of the official laboratory work, recordkeeping, equipment and facilities available, number of inspections and reinspections made of dairy farms and processing plants, and their adequacy or excessive frequency. The state agency usually has responsibility to approve all equipment used in milk production and service from the cow to the consumer. The standards recommended by national organizations are generally used as a basis for the acceptance of equipment.

Federal Marketing Orders for Milk

The Agricultural Marketing Agreement Act is a pricing system that encourages dairy farmers to maintain large enough herds to meet drinking milk needs during the season of lowest production. Excess milk, usually during the spring and summer months, goes into ice cream, butter, cheese, cottage cheese, and milk powder. Orders under the Act regulate only grade A milk known as class 1, which is the fluid milk used for drinking. Excess grade A milk is priced at a lower level that relates to the market prices for the milk products mentioned. The orders are issued by the Secretary of Agriculture after a request is made by dairy farmers or dairy organizations. The Department may then hold a public hearing where anyone affected by the proposal can be heard. A ‘‘recommended’’ decision is made by the USDA, and a ‘‘final decision and order’’ are issued after all comments heard are considered. The dairy farmers vote individually or through their cooperative on the decision. The price is put into effect as an order if at least two-thirds of the dairy farmers approve. The order has the force of law and the USDA Agricultural Marketing Service is responsible for its compliance.

PRODUCE, JUICES, AND SEAFOOD

This diverse group of foods is considered collectively because they are all within the legislative mandate of the FDA's Center for Food Safety and Applied Nutrition (CFSAN) and the same general food safety principles apply to all. As indicated above, milk safety is also primarily a CFSAN responsibility. Consistent with other federal food safety organizations, the FDA has and continues to apply HACCP principles to its guidance documents and regulations for food safety.

The FDA recently released a report from the FDA Retail Food Program Database of Foodborne Illness Risk Factors.* A *Federal Register* notice of the report was published as well. The report established a baseline to measure how effecive industry and regulatory efforts are in changing behaviors and practices that directly relate to foodborne ilness in the retail food industry. By collecting these data, the FDA is better able to measure compliance with its Food Code—a food safety guideline developed for maintaining food safety in restaurants, grocery stores, nursing homes, and other institutional and retail entities. Principal findings indicated that the risk factors needing greatest attention were improper holding times and temperatures, contaminated equipment and cross-contamination, and poor personal hygiene. Using these data the FDA expects to make further improvements regarding compliance with the Food Code provisions that address these risk factors.

* See http://www.cfsan.fda.gov/~lrd/pressarc.html.

Consistent with the above findings, the FDA has developed guidance on advising awareness of safe handling and preparation practices for fresh fruits and vegetables to assist in reducing the potential for foodborne illnesses. Some of the consumer guidance includes purchasing produce that is not bruised or damaged and that has been properly refrigerated, proper chilling and refrigeration after purchased, washing hands often before and after handling fresh produce (or raw meat, poultry, or seafood), washing fresh produce immediately with tap water before eating, washing food contact surfaces often, and taking preventive steps to eliminate cross-contamination.*

Fruits and Vegetables

In compiling data on the sources of foodborne illness from the FDA and CDC, fruits and vegetables (including sprouts) have been noted as a relatively frequent source of human foodborne illness. Acting upon this information, CFSAN prepared a guide for the safe production of fruits and vegetables as voluntary guidance for producers, packers, and shippers of fresh produce. It provides science-based guidance that will help reduce microbiological hazards common to the growing, harvesting, washing, sorting, packing, and transporting of fruits and vegetables. The document, titled *Guidance for Industry: Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables,* is intended for use by both domestic producers of raw agricultural products and foreign producers who would export such products to the United States (see FDA Talk Papers at http://www.fda.gov). It includes information on agricultural and management practices they may apply in order to enhance the safety of their fresh produce. Categories of production practices covered by the guide include control of water, manure and biosolids, worker health and hygiene, field and facility sanitation, and transportation. The guidance also includes suggestions on how to maintain records to aid in tracing food items back to the source to help identify and eliminate the pathway of a pathogen associated with a foodborne illness outbreak

Safety from pathogens in sprout production has been a major initiative for the FDA as its studies have indicated that sprouts have been implicated in at least 1300 cases of foodborne illness (see, e.g., FDA Talk Papers on the FDA web site). For example, following recent outbreaks of *Salmonella* and *E. coli* O157 infections attributed to sprouts, the FDA issued a health advisory warning high-risk groups not to eat raw alfalfa sprouts. The advisory included all raw sprouts and all consumers because of the continued increase in the incidence of illness attributed to sprouts. In public meetings, several measures were noted to improve food safety of sprouts, but sprout-associated foodborne illness outbreaks have continued.

* See FDA Talk Papers at http://fda.gov.

In response to the food safety issues regarding sprouts, the FDA has prepared two guidance documents. The guides are entitled *Guidance for Industry: Reducing Microbial Food Safety Hazards for Sprouted Seeds* and *Guidance for Industry: Sampling and Microbial Testing of Spent Irrigation Water During Sprout Production* (see FDA Talk Papers). The guidance advises sprout producers and seed suppliers of steps they should take to reduce microbial hazards common to sprout production. A companion guide provides producers with the latest information about testing spent irrigation water, an important step to ensure the safety of sprouts. The FDA also asked the National Advisory Committee on Microbiological Criteria for Food (NACMCF) to review the current literature on outbreaks of sprout-associated foodborne illness, identify the organisms and production practices of greatest public health concern, set research priorities, and recommend intervention and prevention strategies. The guidance documents are based largely on recommendations from the NACMCF report.

Raw sprouts present unique food safety problems because conditions under which they are produced—growing time, temperature, water activity, pH (a measure of acidity), and nutrients—are ideal for the rapid growth of bacteria. If pathogens are present on or in the seed, these conditions are likely to encourage proliferation. To counter this risk, the FDA guidance recommends seed disinfection (with solutions such as calcium hypochlorite) combined with microbial testing of used irrigation water from each batch or production lot to determine whether the pathogens *Salmonella* and *E. coli* O157:H7 are present.

Juices

Foodborne illnesses from fruit juices, primarily unpasteurized juices, are estimated at 16,000 to 48,000 cases per year, some of which are especially dangerous among the more sensitive populations and have resulted in deaths.* The FDA required warning labels to be applied to all untreated frut and produce juices in 1998. In addition and as a consequence of continued foodborne outbreaks including the 1996 *E. coli* O157:H7 outbreak associated with apple juice products and two citrus juice outbreaks attributed to *Salmonella* in 1999 and 2000, the FDA recently published a rule based on HACCP principles for juice processing. The HACCP-based rule calls for a science-based analysis of potential hazards, determination of where the hazards can occur in processing, implementing control measures at points where hazards can occur to prevent problems, and rapid corrective actions if a problem occurs. Firms will be required to maintain records in association with implementation of their HACCP plans and verification of those plans. It will be implemented sequentially in large companies in 2002 while small companies must comply

* See the CFSAN web site at http://www.fda.gov/bbs/topics/NEWS2001/NEW00749.html.

in 2003 and very small companies must comply in 2004. Processors must continue to use the previously required warning label statement until they implement HACCP programs. In the interim, the FDA will continue to inspect juice-processing facilities to assure that they are producing safe juice and juice products. As alluded to previously, HACCP systems are already federally required for seafood, meat processors, and poultry processors.

The juice HACCP regulation applies to juice products in both interstate and intrastate commerce. Juice processors will be required to evaluate their manufacturing process to determine whether there are any microbiological, chemical, or physical hazards that could contaminate their products. If a potential hazard is identified, processors will be required to implement control measures to prevent, reduce, or eliminate those hazards. Processors are also required to use processes that achieve a 5 log, or 100,000-fold, reduction in the numbers of the most resistant pathogen in their finished products compared to levels that may be present in untreated juice. Juice processors may use microbial reduction methods other than pasteurization, including approved alternative technologies (such as the recently approved UV irradiation technology) or a combination of techniques.

Citrus processors may opt to apply the 5 log pathogen reduction on the surface of the fruit, in combination with microbial testing to assure that this process is effective.

Seafood

The FDA and seafood industry initiated a new system of controls designed to enhance seafood safety on an industry wide basis. The HACCP system was the culmination of more than two years of cooperation among the FDA, the seafood industry, and state health officials.*

The HACCP safeguards apply to all foreign- and domestic-based seafood processors marketing products in interstate commerce within the United States. While this program does not directly apply to fishing vessels or transporters, seafood processors have to take responsibility for the safe condition of incoming fish obtained from vessels and transporters. For example, if the supplier does not provide satisfactory information about the area where the fish were caught or handled, the HACCP rules strengthen the processor's position in refusing to accept the shipment.

The seafood HACCP regulations were published in December 1995. The rule indicated that it would enter into force two years following publication to give firms the time they needed to fully understand the new rules, evaluate their particular circumstances, and establish their HACCP plans. During the two-year period, thousands of individuals including members of the seafood industry, the FDA, state and local regulators, foreign regulatory officials, and

* See http://www.fda.gov/bbs/topics/NEWS/NEW00608.html.

representatives from academia joined in training sessions to facilitate implementation of the new rules.

Subsequent to the HACCP seafood regulations, the FDA has undertaken related food safety efforts. An important one was recently published.* The FDA made available a draft risk assessment report on the estimated public health risks associated with raw oysters containing pathogenic *Vibrio parahaemolyticus,* a bacterial species that occurs naturally in oysters and occasionally causes illness in humans following the consumption of raw oysters. In recent years, several outbreaks have been caused by *V. parahaemolyticus,* involving dozens to hundreds of consumers. Also, though rare, the organism can produce a life-threatening septicemia, especially in people having underlying medical conditions such as liver disease or immune disorders.

The draft risk assessment evaluated factors that affect the prevalence of *V. parahaemolyticus* in oysters before and after harvesting. It also estimated the impact of several preventive and intervention measures aimed at reducing the incidence of *V. parahaemolyticus* in oysters, including the Interstate Shellfish Sanitation Conference (ISSC) guidance of limiting viable *V. parahaemolyticus* to 10,000 or fewer cells per gram of seafood. The draft risk assessment addressed several specific questions, including how often *V. parahaemolyticus* bacteria occur in water and shellfish, the relationship of the level of *V. parahaemolyticus* ingested to the severity of illness, the differences in dose–response for consumers with different health conditions, and the influence of postharvest handling on the numbers of *V. parahaemolyticus* in oysters. The FDA plans to review and evaluate all public comments and make modifications as appropriate.

It is worth noting that the Codex Alimentarius Commission, through the Committee on Food Hygiene (CCFH), has requested a joint expert consultation of FAO and WHO experts to evaluate the microbiological risk associated with *V. parahaemolyticus.* The report likely will not be available before 2002. The Codex Committee on Fish and Fish Products is actively engaged in developing guidance documents for fish products based on HACCP concepts and principles.

MEAT AND POULTRY

Meat and poultry food protection responsibilities are within the USDA. The primary agencies include the Animal Plant Health and Inspection Service (APHIS) and the FSIS Animal-health-related responsibilities reside in APHIS. Within APHIS, Veterinary Services has responsibility for protection and improving the health, quality, and marketability of our nation's animals, animal products, and veterinary biologics by preventing, controlling, and/or elimi-

* See http://www.fda.gov.bbs/topics/answers/2001/ANSO10667.html.

nating animal diseases and monitoring and promoting animal health and productivity. The FSIS provides food protection for meat, poultry, and egg products. This includes all raw beef, pork, lamb, chicken, and turkey, as well as processed meat and poultry products, including hams, sausage, soups, stews, pizzas, and frozen dinners (generally, products that contain 2 percent or more cooked meat and poultry or 3 percent or more raw meat and poultry). Examples of processed egg products regulated by FSIS are dried egg yolks, scrambled egg mix, dried egg powder, and liquid eggs.

HACCP and Pathogen Control

As referenced previously, FSIS has introduced a new regulatory system for meat and poultry safety within the meat and poultry plants it regulates. The new, science-based system is already demonstrating improvements in food safety. For food safety and protection of public health, FSIS first requires that the plants it regulates implement HACCP systems as a tool for preventing and controlling contamination so products meet regulatory standards. Second, FSIS established food safety performance standards that food production and processing plants must meet and is conducting testing and other activities to ensure the standards are met. Third, FSIS trains its inspectors to provide the oversight that is necessary to ensure that the meat and poultry industries are meeting the new regulatory standards. Fourth, the agency has strengthened its enforcement procedures to deal with plants that do not meet regulatory standards.

The HACCP/Pathogen Reduction rule addresses the serious problem of foodborne illness in the United States associated with meat and poultry products by focusing more attention on the prevention and reduction of microbial pathogens on raw products that can cause illness. One of the significant changes is that FSIS defined the standards that the industry must meet regarding reduction of pathogens and what industry must address in its HACCP plans. The FSIS no longer defines specific “command and control” procedures to be applied to produce finished products. Industry is accountable for producing safe food consistent with its specific needs, products, plant environment, and other germane factors. The FSIS is responsible for setting appropriate food safety standards, providing inspection oversight to ensure those standards are met, and maintaining a strong enforcement program to deal with plants that do not meet regulatory standards. For this reason, there will not be a very proscriptive set of procedures as noted in the comprehensive discussion on milk.

The Pathogen Reduction and HACCP rule (1) requires all meat and poultry plants to develop and implement a system of preventive controls, known as HACCP, to improve the safety of their products, (2) sets pathogen reduction performance standards for *Salmonella* that slaughter plants and plants producing raw ground products must meet, (3) requires all meat and poultry plants to develop and implement written standard operating procedures for sanitation, and (4) requires meat and poultry slaughter plants to conduct microbial testing for generic *E. coli* to verify the adequacy of their process controls for the prevention of fecal contamination. Implementation of the rule began in January 1997 in the large establishments and was completed in January 2000 in the very small establishments. The FSIS prepared extensive materials to provide technical assistance to small plants. Details of the new regulations and other background materials may be found on the FSIS web site.*

The FSIS has many responsibilities in addition to meat and poultry inspection activities. It sets requirements for meat and poultry labels and for certain slaughter and processing activities, such as plant sanitation and thermal processing, that the industry must meet. The FSIS tests for microbiological, chemical, and other types of contamination and conducts epidemiological investigations in cooperation with the CDC based on reports of foodborne health hazards and disease outbreaks. In addition, FSIS conducts enforcement activities to address situations where unsafe, unwholesome, or inaccurately labeled products have been produced or marketed. To ensure the safety of imported products, FSIS maintains a comprehensive system of import inspection and controls. Reinspection of all imported meat and poultry products entering the United States verifies that the importing country's inspection system is working.

It is important to recognize that FSIS regulatory responsibilities begin when food animals and poultry are presented for inspection at federal establishments—there is no on-farm regulatory authority by FSIS. The FDA's Center for Veterinary Medicine does have on-farm regulatory authority to conduct compliance-related activities on good veterinary practices and residue control concerns. Within FSIS, Animal and Egg Production Food Safety program area provides leadership in identifying food safety concerns associated with animal production, transportation, marketing and preslaughter preparation of livestock, and poultry, and production of eggs. It is also responsible for outreach and liaison activities to develop and sustain risk reduction strategies in animal and egg production.

The FSIS has historically focused on the manufacturing of meat and poultry products through its inspection program within plants, but FSIS now also considers hazards before animals reach the plant and after products leave the plant as part of its comprehensive public health strategy to prevent foodborne illness. The FSIS has also been conducting risk assessments to assess the public health risks associated with the consumption of meat, poultry, and egg products. The farm-to-table risk assessment approach as implemented by FSIS provides various interventions and controls to improve food protection mech-

*See http://www.fsis.usda.gov. The published rule is in *Code of Federal Regulations,* Title 9, Section 300, et seq.

anisms throughout the food chain. The FSIS is developing similar changes for egg products.

Sanitation and Performance Standards

The FSIS final rule sets updated sanitation requirements for official meat and poultry establishments. The rule converted many of the previously highly prescriptive sanitation requirements to performance standards and consolidated sanitary regulations applicable to both official meat and poultry establishments. The rule, published in October 1999 in the *Federal Register,* indicated that establishments are free to determine practices that meet sanitary requirements. Henceforth, FSIS will verify that the requirements are met.

Performance standards define the results to be achieved by sanitation, but not the specific means to achieve those results. Establishments now have flexibility to determine what is appropriate and sufficient in maintaining sanitary conditions and preventing the adulteration of product; therefore, they can meet the sanitation performance standards in different ways. The performance standards are based on current science and are consistent with the HACCP philosophy of placing the responsibility for ensuring food safety on establishments. If establishments were in compliance with the past sanitation requirements, they may continue their current sanitation practices and still be in compliance with the performance standards. Establishments that want to be innovative may do so if they can maintain sanitary conditions and prevent the adulteration of product.

Because some of the past regulations impeded innovation and blurred the distinction between establishment and inspector responsibilities for maintaining sanitary conditions, FSIS completed a comprehensive review of the regulatory procedures and requirements. It identified, redesigned, and eliminated redundant, difficult-to-understand, outdated regulations; differences between the sanitation requirements for meat and poultry processes; and inconsistencies with HACCP systems and standard sanitation operating procedure regulations. Examples of revisions are described below.

Previously, implements such as knives or saws used in dressing diseased meat carcasses had to be cleansed either with 180°F water or a sanitizer approved by FSIS. This requirement limited the flexibility of establishments to use innovative means to sanitize such implements and to prevent the adulteration of product. The new performance standard requires that equipment and utensils are maintained in sanitary condition so as not to adulterate product. Establishments, therefore, have both the responsibility and the flexibility to determine the means that are most appropriate and effective within their processing environment to prevent product adulteration by dirty equipment and utensils.

The final rule also eliminated redundancy in the prior approval by FSIS of pesticides, cleaning compounds, and sanitizers that have already been approved by federal agencies such as the EPA or the FDA. The new performance standard requires only that cleaning compounds, sanitizing agents, processing aids, and other chemicals used by an establishment must be safe and effective under the conditions of use. These chemicals must be used, handled, and stored in a manner that will not adulterate product or create unsanitary conditions.

To eliminate overly prescriptive procedures and inconsistencies between the meat and poultry regulations regarding the lighting in establishments, FSIS revised the rule to make the lighting requirements the same for both meat and poultry establishments. The old regulation required poultry establishments to have 30 foot-candles of light intensity on all working surfaces, while regulations for meat establishments only stated that establishments have abundant light, of good quality, and well distributed. The new rule states there must be enough light of adequate quality to monitor sanitary conditions and processing operations to examine product for evidence of adulteration. Under the new performance standards, FSIS inspection program employees continue to have the authority to take enforcement action to prevent adulterated product from entering commerce.

Risk Assessment

A second major change in food protection strategies has been the integration of risk assessments to direct additional food safety and protection activities. A recent example of this addresses the FSIS egg safety strategy. The *Salmonella enteritidis* risk assessment report addressed one of the most commonly reported causes of bacterial foodborne illness in the United States. It incorporated a farm-to-table computer model program that identified the interventions that provide the best return in terms of public health protection from a broadly based set of options that are more likely to be effective than a policy directed solely at one area of the egg-production-to-consumption chain. The risk assessment model applied risk assessment formulas to five areas of concern—egg production, shell eggs, egg products, preparation and consumption, and public health. Using available data and risk assessment techniques available from government, industry, and academic sources, the report estimated that 2.3 million of 46.8 billion shell eggs produced each year in the United States are infected with *S. enteritidis,* resulting in an estimated 883,705 cases of illness.

The FSIS is using the results of its *S. enteritidis* report to identify and evaluate future policies and practices that could reduce the risks associated with consuming shell eggs and egg products contaminated with the bacterium. The risk assessment model for *S. enteritidis* will make it possible for risk managers to predict the effects of possible interventions and determine which ones provide the best and most economic public health protection. Through the Codex Alimentarius Commission work, the Committee on Food Hygiene has worked with expert consultations convened by the FAO and the WHO to develop risk assessments on priority pathogens, including *S. enteritidis*. The reports of these activities can be found on the FAO web site.*

Microbiological Testing

A third major change in the HACCP initiative has been an extensive microbiological testing program for pathogens in meat and poultry products. The FSIS established a series of baseline data collection programs to acquire information that provided general microbiological profiles of meat and poultry for selected microorganisms. The objective was to use this information as a reference for further investigations and evaluations of new prevention programs. Baseline studies are also used to develop pathogen reduction performance standards that plants must meet. The early baseline studies (steer/heifer, cow/bull, broiler chicken, market hog, and young turkey) and surveys (raw ground beef, raw ground chicken, and raw ground turkey) included microbial analyses for *E. coli, C. perfringens, S. aureus, L. monocytogenes, Campylobacter jejuni* and *C. coli, E. coli* O157:H7, and *Salmonella.* Subsequent baselines (cattle, swine, turkeys, geese) included *Salmonella* spp. and *E. coli*. A recent baseline for young chickens included microbial analyses for *C. jejuni* and *C. coli, Salmonella,* and generic *E. coli*. These baseline profiles for meat and poultry will provide a basis for measuring the effectiveness of changes in slaughtering and processing on microbial contamination of raw products.[71] Additional studies have been and are being pursued, and the information is being used to develop additional food protection and safety initiatives for pathogens such as *L. monocytogenes.* This pathogen is a major food safety concern for produce, some cheeses, juices, and seafood as noted above.

HOSPITAL INFANT FORMULA

Diarrhea of the newborn has been responsible for deaths in hospital nurseries. Enteropathogenic *E. coli* is commonly recovered from the stool. Enteroviruses and *Salmonella* are also recovered; *Shigella* rarely. Infant botulism caused by *C. botulinum* type B spores found in honey and corn syrup has led to warnings against their use in infant formula.

Although infant diarrhea is no longer a major problem in developed countries, it remains as a serious problem in developing countries.[72] Contaminated infant formula has been a major vehicle in the transmission of the disease. Hospital infant formula at one time was prepared at infant nurseries, but this is no longer the case in developed countries. Where formula is prepared at a hospital, the control program should initially be presented as a consultation

* See http://www.fao.org. The expert consultation reports may be found under the Nutrition menu by selecting Microbiological Risk Assessments.

service furnished through the cooperation of the hospital administrator and the health department. The health department would make available its combined epidemiological, nursing, medical, sanitation, and laboratory resources. After the initial surveys and compliance with accepted standards, the hospital would be expected to carry on its own inspection program, but the health department team would be utilized whenever a problem appeared. A baby formula inspection program should include the following:

1. Establish appropriate lines of communication between the hospital personnel and the health department to ensure continuing supervision and consultation service.
2. Assist in establishing procedures to minimize contamination of baby formulas, bottles, and nipples during the handling and bottling processes and assist in the control of formula constituents.
3. Assist in establishing procedures designed to ensure that terminal sterilization is adequately carried out and that infections are not introduced into the nursery through poor hygiene and sanitation practices.
4. Assist in establishing procedures to ensure proper handling of the terminally sterilized product until time of consumption by the infants.
5. Arrange for routine weekly bacteriological testing of one bottle of each product out of every 50 prepared, the test specimen to be selected and collected by health department personnel for laboratory examination. Emphasis is to be placed on the sanitary survey and day-to-day surveillance, the bacteriological testing being only ancillary and confirmatory to the techniques followed and equipment provided.

Control of Communicable Diseases in Man gives additional information.[72] A total plate count of less than 10/ml in terminally heated formula is easily obtainable, and a count of 3 or less is practical.[73] Rinse samples of 8-oz bottles that have only been properly washed should show a plate count of less than 300/ml, with no coliform microorganisms present.

Precautions to follow include the following:

1. Discard scratched and chipped bottles as well as old and porous nipples.
2. Thoroughly rinse all bottles and nipples with lukewarm water immediately after use to simplify and make more effective the subsequent cleansing operation.
3. Each week treat all bottles and nipples by soaking in a 1 percent acid solution to prevent the buildup of mineral deposits by the use of a milk-stone remover found effective in the dairy industry.
4. Use a suitable detergent, followed by a clear water rinse, based on the water characteristics, in washing bottles and nipples (never use green soap or bar soap).

5. After washing and rinsing nipples, boil in water for 5 min.
6. Use a maximum-registering thermometer in each batch of formula terminally heated.
7. Ensure that bottles used in the nursery are not mixed with baby bottles from other parts of the hospital.
8. See that daily records are kept, showing the maximum temperature of the maximum-registering thermometer for each batch of formulas together with the pressure and temperature during terminal heating, the number of formulas and other fluid bottles heat treated, and the temperature of the refrigerator in which formulas are stored.
9. Ensure that materials for formula preparation are stored in a separate locked room.
10. Keep hands clean. Wash hands frequently.

Commercial preparation, sterilization, and distribution of formulas in single-service bottles simplify control. The infant formula inspection and control activity is only one part of the program for the prevention of diarrhea of the newborn. It should be integrated with special medical and nursing preventive techniques as well as the environmental protection aspects of water supply, air sanitation, cross-connection and backflow prevention control, infection control, and food sanitation. The heating of damp feeding equipment (bottles and nipples) in a microwave oven until hot is not considered a reliable sterilization method.[74] Where baby formula and other infant foods are prepared or reconstituted, either at a central point or in the home, it is extremely important that potable water, clean sterile bottles, handwashing facilities, and adequate refrigeration be available, particularly in underdeveloped areas of the world. Their lack may set the stage for diarrheal diseases that not only debilitate the infant but also cause malnutrition and possibly death.* Breast-feeding is encouraged where possible.

The latest information on infant formula and related issues may be found on FDA (http://www.fda.gov) and WHO (http://www.who.int) web sites.

REGULATION OF RESTAURANTS, MEAT AND POULTRY, AND OTHER FOOD ESTABLISHMENTS

A major reason for the regulatory oversite of food establishments is the prevention of foodborne illnesses, as discussed in Chapter 1. Federal, state, and local agencies, in cooperation with the food processing and preparation industry, share this responsibility in addition to ensuring wholesomeness of the food and maintenance of its nutritional value. Supervision of food establish-

*See International Code of Marketing of Breastmilk Substitutes, World Health Assembly, WHO and UNICEF, 1981.

ments such as restaurants, caterers, delicatessens, commissaries, pasteurizing plants, frozen-dessert plants, frozen-prepared-food plants, vending-machine centers, slaughterhouses, poultry-processing plants, bakeries, shellfish shucking and packing plants, and similar places is in the public interest. This responsibility is usually vested in the state and local health and agricultural departments and also in the FDA, PHS, USDA, and U.S. Department of Interior. As a rule, the industry affected also recognizes its fundamental responsibility.

Basic Requirements

It is to be noted that certain basic sanitation requirements are common to all places where food is processed. McGlasson has proposed a set of standards under the following headings.[75]

1. Location, construction, facilities, and maintenance
   a. Grounds and premises
   b. Construction and maintenance
   c. Lighting
   d. Ventilation
   e. Dressing rooms and lockers
2. Sanitary facilities and controls
   a. Water supply
   b. Sewage disposal
   c. Plumbing
   d. Restroom facilities
   e. Handwashing facilities
   f. Food wastes and rubbish disposal
   g. Vermin control
3. Food product equipment and utensils
   a. Sanitary design, construction, and installation of equipment and utensils
   b. Cleanliness of equipment and utensils
4. Food, food products, and ingredients
   a. Source of supply
   b. Protection of food, food products, and ingredients
5. Personal
   a. Health and disease control
   b. Cleanliness

A related set of basic standards can be found in the *Code of Federal Regulations* (21 CFR 110, 2000). General sanitation requirements should be supplemented by specific regulations applicable to a particular establishment or operation. Emphasis must be placed at points in the food-processing flow or travel where temperature abuse, contamination and cross-contamination, or deterioration may take place, at each establishment, from the food source to the ultimate point of use. Also required is cooperation between and among federal, state, and local agencies and the industries involved to maintain continuity of protection and surveillance.

Excellent codes, compliance guides, and inspection report forms are available from many regulatory agencies. Interested parties are encouraged to review the relevant federal agency on current regulations and guidelines because of the rapid developments of new food safety and quality regulations and guidance materials that have been developed since 1997. Some additional historical sources of information are the following:

1. "AFDO Guidelines for the Inspection and Enforcement of GMP Regulations for Handling and Manufacturing Packaged Ice," *J. Assoc. Food Drug Officials,* December 1989, pp. 70–74.
2. *AFDOUS Frozen Food Code,* Vol. XXVI, No. 1, Association of Food and Drug Officials of the United States, York, PA, January 1962 (adopted June 22, 1961).
3. *Retail Food Market Code,* Association of Food and Drug Officials of the United States, York, PA, 1973.
4. *Bakery Establishments,* Recommendations, Addendum B for study purposes only, DHEW, PHS, Environmental Sanitation Program, NCUI, Cincinnati, OH, 1969.
5. *Bakery Industry Sanitation Standards,* Baking Industry Sanitation Standards Committee (BISSC), Chicago, IL, 1990.
6. *Beverage Establishments,* Recommendations, Addendum C for study purposes only, DHEW, PHS, Environmental Sanitation Program, NCUI, Cincinnati, OH, 1969.
7. *Code of Federal Regulations* (CFR), 2000: "Current Good Manufacturing Practices in Manufacturing, Packaging, or Holding Human Food," Title 21 CFR Part 110; "Bottled Water," Title 21 CFR Parts 103, 110, and 129; "Packaged Ice," Title 21 CFR Parts 103 and 110; "Meat Inspection Regulations," Title 9 CFR Part 318; "Poultry Products, Inspection Regulations," Title 9 Part 381. Office of the Federal Register, General Services Administration, U.S. Government Printing Office, Washington, DC.
8. *Food Protection Unicode,* FDA, Center for Food Safety and Applied Nutrition, PHS, Washington, DC (proposed March 10, 1988).
9. *Food Service Equipment and Related Products, Components and Materials,* National Sanitation Foundation, Ann Arbor, MI, June 1, 1990.
10. *Food Service Sanitation Manual,* DHEW Pub. (FDA) 78-2081, Recommendations of the FDA, Washington, DC, 1976.

11. *Frozen Desserts Ordinance and Code,* Recommended by the PHS, Washington, DC, 1958.
12. *Grade A Pasteurized Milk Ordinance,* Pub. 229, Recommendations of the PHS, FDA, Washington, DC, 1978.
13. *Methods of Making Sanitation Ratings of Milk Supplies,* PHS, FDA, Washington, DC, 1978.
14. *Model Food Salvage Code,* U.S. Department of Health and Human Services, PHS, FDA, Washington, DC, 1984.
15. *Poultry Ordinance,* PHS Pub. 444, Recommendations developed by the PHS in cooperation with interested states and federal agencies and the poultry industry, Washington, DC, 1955.
16. D. E. Brady, M. L. Esmay, and J. McCutchen, "Recommendations and Requirements for Slaughtering Plants," *Missouri Coll. Agric. Bull.,* No. 634, September 1954.
17. "Regulations Governing the Inspection of Eggs and Egg Products," USDA, 7 CFR Part 59, June 30, 1975.
18. *Retail Food Store Sanitation Code,* AFDO, U.S. Department of Health and Human Services, PHS, FDA, Washington, DC, 1982.
19. *Sanitary Standards for Food-Processing Establishments,* Recommendations for study purposes only, DHEW, PHS, Environmental Sanitation Program, NCUI, Cincinnati, OH, 1969.
20. *Sanitary Standards for Manufactured Packaged Ice,* Packaged Ice Association, Raleigh, NC, June 26, 1989.
21. *Sanitation of Shellfish Growing Areas, Part I,* DHHS, PHS, FDA, Washington, DC, July 1988. Presented at the Interstate Sanitation Conference, Phoenix, AZ.
22. *Sanitation of the Harvesting, Processing, and Distribution of Shellfish, Part II,* DHHS, PHS, FDA, Washington, DC, July 1988. Presented at the Interstate Sanitation Conference, Phoenix, AZ.
23. *Sanitation Standards for Smoked Fish Processing, Part 1,* Fish Smoking Establishment Recommendations, U.S. Department of the Interior, Fish and Wildlife and Parks, DHEW, PHS, Washington, DC, 1967.
24. *Vending of Food and Beverages,* Recommendation of the FDA, Washington, DC, 1978.
25. *Vending Machine Evaluation Manual,* National Automatic Merchandising Association, Chicago, IL, 1984 (includes Water Vending Machines).
26. *Voluntary Minimum Standards for Retail Food Store Refrigerators,* Health and Sanitation (CRS1-67), Commercial Refrigeration Manufacturers Association, Chicago, IL, 1999.
27. *Food Code,* U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition, Washington, DC. The document can be found on the FDA web site at http://www.cfsan.fda.gov.

28. *HACCP in Microbiological Safety and Quality,* International Commission on Microbiological Specifications for Foods, Blackwell Scientific Publishers, Oxford, England, 1988.
29. *An Evaluation of the Role of Microbiological Criteria for Food and Food Ingredients,* National Academy of Science, National Academy Press, Washington, DC., 1995.

Manuals and inspection guides are not a substitute for the exercise of intelligent and mature judgment. They are, however, indispensable administrative aids that, with their continual revision and the supervision of field personnel, will help maintain the uniform quality enforcement of a sanitary code. The reasonable and intelligent interpretation of the regulations and what represents good practice requires an understanding of the basic microbiological, chemical, sanitation, engineering, and administrative principles involved. These are discussed below and throughout this text.

Inspection and Inspection Forms

Routine or frequent inspections of food-processing and food service establishments alone will not be adequate to ensure the maintenance of proper levels of sanitation. This must be supplemented by education, motivation, persuasion, legal action, management supervision and self-inspection, qualified workers, selected laboratory sampling at critical points, and quality (including flavor) control. The primary responsibility for proper food preparation, refrigeration, heating, cleanliness, and sanitation rests with management. Inspection frequency, enforcement, administration, and program evaluation are discussed in Chapter 12. See also Compliance with and Enforcement of Sanitary Regulations, this chapter. The usual visual and olfactory inspection of poultry does not ensure the absence of pathogenic organisms such as *Salmonella* and *Campylobacter*. Special sampling for microorganisms and toxic chemicals during production, slaughter, and packing and at point of sale can assist in sanitary control.

Inspection report forms are valuable tools to help ensure complete investigations and uniform policy procedures, but they are not an end in themselves. They must be supplemented by professional knowledge. See Figures 8-5 and 8-6. With the advent of new inspection regulations in food categories, for example, described previously in this chapter, reference to appropriate inspection forms should be sought from the appropriate federal agency (e.g., FDA or FSIS). Inspection report forms can also be made available to the industry to help in self-policing and greater cooperation between the industry and official agencies. Preparation of an inspection form that is self-explanatory in showing what is acceptable, supplemented by a satisfactory compliance guide including special precautions for potentially hazardous foods, can have a very desirable educational effect. A report form checked

Establishment Name ____________ Address ____________ Zip ________

Operator ____________ Seating Capacity ___ Inspection: Satisfactory ___ Unsatisfactory ___

Items checked "Yes" are satisfactory, "No" unsatisfactory, "CM" correction made. Explain defects on back.

	Yes	No	CM
A. *Food From Approved Sources, Not Adulterated*			
1. Milk and milk products pasteurized			
2. Water and ice from approved source			
3. Foods from approved sources—meats, shellfish tagged, canned goods			
4. Cans not swollen, leaking, rusted, severely dented			
5. Shell eggs clean, not cracked, liquid and frozen eggs pasteurized			
B. *Foods Protected*			
1. Cutting boards and surfaces cleaned and sanitized after raw food use.			
2. Workers wash hands after handling raw foods or when hands soiled			
3. Potentially hazardous foods not re-served			
4. Workers do not have transmissible illness			
5. Workers wash hands after use of tiolet, coughing, blowing nose, and tissue use			
6. Workers use tongs, spoons, spatulas, plastic gloves to dispense food			
7. Toxic chemicals properly labelled, stored			
8. Acid foods not stored in zinc, leaded, cadmium, antimony plated containers			
9. Foods and utensils protected from overhead drippage, flooding, and contamination in transportation, storage, display			
10. Utensils and equipment clean, sanitized, properly stored			
11. Single service items properly stored, dispensed; not reused			
12. Accurate thermometer available			
13. Raw foods properly washed before service			
C. *Potentially Hazardous Foods Protected*			
1. Food storage depth 4 in. or less			
2. Foods cooled to 45°F in 4 hours			
3. Salad ingredients cooled before preparation			
4. Adequate refrigeration storage			
5. Hot foods held above 140°F			
6. Poultry and stuffing heated to 165°F			
7. Pork and pork products heated to 150°F			
8. Other foods heated to 140°F or above			
9. Cooked refrigerated foods rapidly reheated to 165°F or above			
10. Frozen foods heavier than 3 lb thawed under refrigeration before being cooked			
D. *Hygiene*			
1. Workers are clean and have clean dress			
2. Tobacco not used by workers			
3. Dressing room provided, clean, adequate			
E. *Equipment and Utensil Cleanliness*			
1. Clean, cleanable, no open seams, or pitted			
2. Wash and rinse water for dishwashing at proper temperature and time			
3. Accurate thermometers; pressure gauge cocks to monitor dishwashing			
4. Wiping cloths clean, stored in sanitizing solution			
F. *Sanitary Facilities*			
1. Adequate hot and cold water, and pressure			

Figure 8-5 Eating place inspection form.

Establishment Name ______ Address ______ Zip ______
Operator ______ Seating Capacity ___ Inspection: Satisfactory ___ Unsatisfactory ___

Items checked "Yes" are satisfactory, "No" unsatisfactory," "CM" correction made. Explain defects on back.

	Yes	No	CM
2. Proper sewage and wastewater disposal			
3. Plumbing and fixtures clean and operate properly			
4. Toilet facilities adequate, convenient, clean, soap and paper towels, toilet paper			
5. Handwashing facilities in work areas with soap and paper towels			
6. No direct connection between dishwater, cooking kettle, warming table, or cooler drains with sewer			
G. *Garbage and Rubbish Storage and Disposal*			
1. Adequate, leakproof, cleanable, vermin-proof, covered containers provided			
2. Food waste grinders, compactors, and storage areas clean			
H. *Insect and Rodent Control*			
1. No evidence of insects or rodents			
2. Entrance prevented, no harborage			

	Yes	No	CM
3. Pesticide application supervised by certified applicator and as labelled			
I. *Construction and Maintenance*			
1. Floors, walls, ceilings cleanable and clean			
2. Lighting and ventilation adequate, fixtures shielded; hoods, fans, filters, ducts clean. No grease accumulation			
3. Living quarters completely separate, no animals or birds, or excess equipment			
4. Cleaning equipment, linens, laundry properly stored			

J. *Water Heater Capacity*
- Storage in gal ______
- Recovery capacity in Btu per hr ______
- Thermostat setting °F ______
- Adequate: Yes ______ No ______

K. *Refrigeration Capacity*
Tons per 24 hr ______
Cubic feet walk-in ______
Cubic feet freezer ______
Cubic feet upright ______
Adequate: Yes ______ No ______
Comments ______

Signature of person in charge | Signature of inspector | Date

Figure 8-5 (*Continued*)

off entirely in the "yes" column would indicate the establishment is in substantial compliance with existing regulations. Items checked "no" would indicate deficiencies that should be followed up on subsequent reinspections. Deficiencies are documented on a separate sheet. When these conditions are corrected, the third column, "CM," would be checked, indicating correction made of a previously reported deficiency. The date could be inserted in the

Name ______________________ Operator ______________________

Address ______________________ Wholesale ______ Retail ______

Personnel: M_____ F_____ Products______________________ Permit No.____________

	Yes	No	CM
1. Location on or above ground level, in clean surroundings			
2. Structure in repair, rodent-proof, screened, window display enclosed, baked goods protected, lighting adequate			
3. Floor finish smooth, cleanable, and nonabsorbent, sloped to drain that is trapped, kept clean and in repair			
4. Walls and ceilings cleanable, kept clean and in repair			
5. Ventilation adequate to prevent condensation, remove smoke and odors. Hoods equipped with proper exhaust fans and ducts			
6. Rats, mice, roaches, flies, silverfish, beetles, weevils, lice, mites, moths, ants, effectively controlled			
7. Extermination and cleaning program in effect with responsibility established in a sanitary supervisor who has authority to make corrections			
8. Water supply satisfactory, of sanitary quality, easily accessible, with adequate volume and pressure			
9. Wastes disposed of to proper sewer or private sewage disposal or treatment system			
10. Toilets and washrooms convenient, have wash basins with warm water, soap, and individual towels (1 w.b. to 10 to 15); adequate waterclosets (1 wc. to 10 to 15);† handwashing sign; cleanable floors, walls, ceilings; adequate light and ventilation; tissue; kept clean			
11. Locker and dressing space, storage place for clean and soiled linen, uniform, and aprons; lighted and clean			
12. Personnel clean, head covering, clean habits, good health, supervised			
13. Design and construction of equip. cleanable and kept in repair (pans, kettles, molders and rollers, dough troughs, mixers, beaters, flour bins and chutes, conveyors, deep fat fryers, ovens, retarder and proof bins, sieves), equipment cleaned at end of each day and kept clean*			
14. Bakery and confectionery products free of vermin and other filth; flour, meal, farina, etc. stored in original pkg. at least 6″ off floor or in tight receptacles; raw ingredients from approved source; perish-			

Figure 8-6 Bakery and confectionery inspection form.

"CM" square in place of a checkmark to show when the correction was made. It is usually good practice to leave a copy of the original inspection report form with the owner, operator, or other responsible person. When subsequent reinspections fail to show improvement, it is customary to confirm the deficiencies in a letter, with reference to previous inspections and notifications and a scheduled date for final inspection before taking further action. Inspections should concentrate on food preparation and process temperature, holding time, and service that will minimize potential for food contamination and microorganism growth. Restaurants with poor inspection scores and violations of proper temperature controls of potentially hazardous foods were found more likely to have outbreaks than restaurants with better results.[76] In any

	Yes	No	CM		Yes	No	CM
able products stored at 45° F or less and frozen products at 0° F or less				kept below 45° F. Frozen prod. at 0° F.			
15. Equip. and facilities adequate for cleaning and disinfection; includes wash sinks, automatic hot water, detergents, and disinfectants, scrapers, and brushes				17. Disposition of leftovers satisfactory			
16. Refrigeration adequate for perishables; custards and creams refrigerated, perishable products so labeled and marked				18. Adequate containers for storage of refuse, clean, no accumulations			
				19. Delivery trucks clean, baked goods protected, perishables refrigerated			
				20. Display cases and racks clean, self-service products completely wrapped			

*Equipment meets standards of Bakery Industry Sanitation Committee, 3 "A" Standards Committee, National Sanitation Foundation.

†Ratio may be reduced to 1 to 40 with over 150 employees.

(Ultraviolet light, "black light," shows urine stains. Microanalysis of food and ingredients reveals presence of rodent hairs, dirt, and fragments of pellets and insects.)

Remarks: ______ Inspection substan. satisf. Yes____ No____

______ Reinspect ______

Inspected by ______ Date ______

(over)

Figure 8-6 (*Continued*)

case, imminent health hazards require immediate correction or closure of the operation.

Regulatory agencies usually have standard inspection report forms covering activities under their supervision. Some forms for the sanitary inspection of eating places, slaughterhouses, poultry processing plants, and bakeries are reproduced here as examples. It must be remembered that inspection forms or checklists never specifically cover all details that should be investigated as required by a code. They must be supplemented by professional interpretation and judgment.

Shellfish

Shellfish include oysters, soft-shell and hard-shell (quahaug) clams, scallops, cockles, and mussels as well as the crustacea lobster, crab, and shrimp. For control purposes, oysters, clams, cockles, and mussels (molluscan shellfish) are given primary consideration.

Shellfish from the west and east coasts of North America, Central and South America, Asia, England, and Europe contain, at certain times of the year, a toxin (paralytic shellfish poison) that is not destroyed by cooking. The toxin is also found in the broth from cooked shellfish. The problem has also been reported in shellfish waters off New Brunswick and Prince Edward Island, Canada, and Maine, Massachusetts, Rhode Island, and Alaska.[77] The quarantine toxin level is 80 μg/100 g of shellfish meat. Shellfish samples are collected from affected areas and analyzed using a standard mouse bioassay procedure. The toxin that causes paralytic shellfish poisoning is produced by a marine organism (dinoflagellates) that creates massive algal blooms known as "red tides." Shellfish can become toxic even in the absence of such blooms. California has a quarantine on sports harvesting of mussels (clams, cockles, and scallops) from May 1 to October 31, the period during which outbreaks have been reported. Outbreaks have been reported on the east coast from August through October.

Shellfish can also transmit hepatitis A, typhoid fever, cholera, dysentery, primary septicemia (*Vibrio vulnificus*), and viral gastroenteritis; it can concentrate toxic chemicals such as mercury, radioactive materials, pesticides, and certain marine biotoxins. In recent years, hepatitis A and viral gastroenteritis have been more frequently associated with the consumption of raw or inadequately cooked oysters and clams.[78] Lobsters, shrimp, crabs, and scallops are less likely to cause viral or bacterial illness as they are usually thoroughly cooked before being served, and the pathogens are concentrated in the intestinal tract of the shellfish, which is not eaten. Improper handling of these shellfish before or after service can, however, introduce contamination.

The pollution of shellfish waters with sewage and industrial wastes decreases the fish and shellfish population and introduces a disease transmission hazard. Typhoid fever outbreaks traced to contaminated shellfish between 1900 and 1925 led to PHS certification of dealers involved in interstate shipment and to control by state and local regulatory agencies. The early outbreaks led first to the establishment of the voluntary National Shellfish Sanitation Program in 1925, administered by the FDA, and then to the Interstate Shellfish Sanitation Conference in 1982. Both are expected to be combined.[79] A model shellfish sanitation code and an updated operation manual have been developed jointly by the FDA, the states, and industry.[80] These publications are excellent references. A third manual on administration is being developed.

The FDA evaluates compliance with minimum standards by inspection of a representative number of handling and processing plants. The state regulating agencies should adopt adequate laws and regulations for the sanitary control of shellfish from the source to the consumer. The local industry is expected to comply with established procedures regarding identification information on each package of shellfish, recordkeeping from the point of origin to the point of ultimate sale, and sanitary control of shellfish. Numbered certificates issued by the authorized state agencies are accepted by the FDA for approved producers and dealers engaged in interstate commerce. The FDA maintains a current list of approved shellfish shippers. It can control only food (shellfish) transported in interstate commerce and imported into the United States.

The National Marine Fisheries Service, Department of Commerce, provides an inspection service for a fee to seafood processors, packers, brokers, and users on a voluntary basis. Included is raw fish and shellfish processing and preparation and certification of the quality and condition of the final product. The EPA is responsible for environmental quality of waters. The Fish and Wildlife Service monitors trends and levels of contaminants in freshwater fish.* The major control point to ensure seafood safety should be at the point of harvest.

Fresh and frozen shellfish or shucked shellfish (oysters, clams, or mussels) must be identified with the name and address of the original shell-stock processor, shucker-packer, or repacker, and the foreign, intrastate, and interstate certification number issued according to law. The identification tags are to be retained for 90 days and data regarding source kept in a permanent ledger.

Spawning takes place when the water is warm, usually between May and August. The shellfish seed or spat is released at this time, attaches itself to some hard surface, and grows. Oyster shells dumped back into shellfish beds provide a ready growing surface. The parent shellfish is not as meaty or of best flavor during the spawning season but is edible. Problems in refrigeration during warm weather mitigate against the production and distribution of shellfish in areas lacking refrigeration equipment and facilities. Oysters grow best at pH of 6.2 to 6.8 and at a temperature of 41°F (5°C). The pH can be as low as 5.0. The best salinity of the water is 0.24 to 0.27 percent. A salinity greater than 0.31 percent is unsuitable. Optimum conditions may vary for other mussels.

Oyster shell stock or shucked oysters sampled at the source (wholesale market) should not show a most probable number (MPN) of 230 or more fecal coliform organisms per 100 g of shellfish or more than 500,000 total plate count per gram. An MPN of 2400/100 g may be occasionally permitted, provided needed corrections are promptly made. The coliform test does not indicate the presence of viruses, such as hepatitis A or Norwalk virus commonly associated with gastrointestinal illnesses. A practical test for the identification of viruses is needed. Fortunately, oysters are reported to free themselves of contaminating viruses and bacteria within 12 to 24 hr of exposure in purified water.[81] Another study[82] found seven days adequate for healthy oysters relaid in clean water above 50°F (10°C).† However, oysters contaminated with viruses when harvested will probably remain contaminated in the food establishment or home. It has also been found that *C. perfringens* spores are more persistent in seawater than *E. coli*. The presence of *C. perfringens* in oysters after depuration (48 hr immersion) would indicate heavy original contamination, and hence, they would not be fit for consumption. A

* "Monitoring Fish and Seafood Quality," *Dairy Food Environ. Sanitation,* November 1990, p. 673 (USDAERS Farmline 1990).

† Longer periods are specified by regulatory agencies.

combination of tests for *E. coli* and *C. perfringens* would be a more stringent procedure than for *E. coli* alone.[83]

Shucked shellfish are shellfish that are taken from the shell and washed and packed in clean containers constructed of impervious material. The operation should be conducted under controlled sanitary conditions. The packer's certificate number and state, name and address of the distributor, and contents are permanently stamped on the container. Shucked shellfish should be stored as noted in Figure 8-7. The best storage temperature for clams in

Name of establishment ______________ Certificate No. ______________
Address ______________ Operator ______________
Shellfish obtained from area ______________ Products ______________

	Yes	No	CM
1. *Water storage*			
(*a*) Shellfish stored in fill and draw or continuous flow tanks			
(*b*) Water meets EPA drinking water standards and is of proper salinity			
(*c*) Fill and draw tank emptied within 24 hours and water maintained of satisfactory sanitary quality by chlorination			
(*d*) Continuous flow tanks supplied with satisfactory chlorinated water at rate to replace water in not more than 24 hours			
(*e*) Tanks side walls extend 4 in. above surrounding floor and 1 ft above high water			
(*f*) Tanks maintained in a sanitary condition and employees wading in tanks wear clean rubber boots			

	Yes	No	CM
2. *Shellfish from approved source*			
(*a*) Shellfish packaged by person having permit. If in interstate traffic, person has permit from other state whose program is certified by the PHS			
(*b*) Shellfish tagged with name, address, and certificate or permit number of shipper, the contents and source of shellfish, date of shipment, name and address of consignee			
(*c*) Receiver of shellfish keeps record of quantity and source and sale			
(*d*) Boats clean, bilge water disposed away from shellfish, watertight receptacles for excreta, receptacles emptied on shore in sanitary manner			
3. *Buildings*			
(*a*) All buildings kept clean, free of debris and unused material			
(*b*) Adequate toilet facilities			
(*c*) Toilets clean, separate from workrooms; sewage disposal proper			
(*d*) Washbasins with hot and cold water, soap and sanitary towels, convenient, "Wash Hands" signs posted			
(*e*) Buildings adequately lighted, ventilated, screened			

Remarks (explain "No" items on back) (CM indicates correction made)

Inspection substantially satisf. Yes ____ No ____

Reinspect ______________

____

____

____

Inspected by ______________ Date ______

Figure 8-7 Shellfish control inspection form.

	Yes	No	CM
(*f*) All walls, ceilings, and floors cleanable and floors drained			
(*g*) Approved water supply			
(*h*) Cleanable shell stock storage bins and rooms			
4. *Shucking*			
(*a*) Shucking and packing rooms separated, cleanable, free of insects			
(*b*) Shucking benches nonabsorbent, cleanable, disinfected, and cleaned			
(*c*) Shucking blocks free of cracks, cleaned			
(*d*) Containers for waste material, and waste material disposed of in a sanitary manner			
(*e*) Shucked shellfish washed with cold water of satisfactory sanitary quality			
(*f*) All shucking equipment cleanable			

	Yes	No	CM
(*g*) Refrigeration for shucked shellfish above freezing and below 40° F			
(*h*) Shucked shellfish stored and shipped at temperature between 32° and 40° F, not in contact with ice, in clean and new metal or equal containers, adequately sealed			
(*i*) Containers embossed with certificate number of shipper preceded by state			
5. *General*			
(*a*) Personnel clean and have clean habits			
(*b*) No person in plant ill or has communicable disease			
(*c*) Shellfish handled and shipped in clean containers and at temperature to keep them alive			
(*d*) Cars and trucks in which shellfish shipped clean			

Figure 8-7 (*Continued*)

the shell is 45°F (7°C); a temperature of 32°F (0°C) is reported to kill clams. Do not store live shellfish in water or airtight containers.

Microbiological limits for seafood are shown in Table 8-8. Other information dealing with shellfish sanitation is available in government publications.*

TABLE 8-8 Microbiological Limits for Seafoods (New York City Health Department)

Organism	Crabmeat	Shellfish	Prepared Fish and Crabmeat
Staphylococcus aureus	<100/g		
Coliform	<100/g		
Enterococci	<1000/g		
Standard plate count	<100,000/g	≤500,000/g	≤100,000/g
Fecal coliform	—	<230/100 g	None
Salmonella	—	—	None

*See ref. 80, *Part I,* pp. APB-1 to APB-2, APC-1 to APC-6, C-1 to C-6, APA-1 to APA-4, APD-1 to APD-4, DEF-1, and DEF-3.

Sanitary Survey of Growing Areas

A sanitary survey of a shellfish growing area is extremely important to determine the long-term water quality of the growing area and to ensure seafood safety. The survey should include maps identifying the area, shellfish species, harvesting practices, pollution sources, hydrographic and meteorological characteristics, water quality studies, and an evaluation of the interrelationship of these factors. The classifications below are extracted from the *National Shellfish Sanitation Program Manual of Operations* (NSSP Manual).[80]

Classification of Growing Areas

Growing areas are classified as approved, conditionally approved, restricted, conditionally restricted, or prohibited. A brief selected description of each follows.

Approved Areas Growing areas may be designated as approved when the sanitary survey and marine biotoxin surveillance data indicate that fecal material, pathogenic microorganisms, and poisonous and deleterious substances are not present in the area in dangerous concentrations.

The bacteriological quality of every sampling station in those portions of the area exposed to fecal contamination shall meet one of the following standards:

The total coliform median or geometric mean MPN of the water does not exceed 70/100 ml and not more than 10 percent of the samples exceed an MPN of 230/100 ml for a five-tube decimal dilution test (or an MPN of 330/100 ml for a three-tube decimal dilution test).

The total coliform standard need not be applied if it can be shown by detailed study verified by laboratory findings that the coliforms are not of direct fecal origin and do not indicate a public health hazard.

The fecal coliform median or geometric mean MPN of the water does not exceed 14/100 ml and not more than 10 percent of the samples exceed an MPN of 43/100 ml for a five-tube decimal dilution test (or an MPN of 49 100 ml for a three-tube decimal dilution test).

This is the classification of a state shellfish growing area that has been approved by the state shellfish control authority for growing or harvesting shellfish for direct marketing. The classification of an approved area is determined through a sanitary survey conducted by the state shellfish control authority in accordance with Section C of the manual.[80] An approved shellfish growing area may be temporarily made a closed area when a public health emergency resulting from, for instance, a hurricane or flooding is declared.

Conditionally Approved Areas Growing areas that are subject to intermittent microbiological pollution may be classified as conditionally approved. This option is voluntary and may be used when the suitability of an area for harvesting shellfish for direct marketing is affected by a predictable pollution event. The pollution event may be predicated upon the attainment of an established performance standard by wastewater treatment facilities discharging effluent, directly or indirectly, into the area. In other cases, the sanitary quality of an area may be affected by seasonal population, non-point-source pollution, or sporadic use of a dock or harbor facility.

This is the classification of a state shellfish growing area determined by the state shellfish control authority to meet approved area criteria for a predictable period. The period is conditional upon established performance standards specified in a management plan. A conditionally approved shellfish growing area is a closed area when the area does not meet the approved growing area criteria and is temporarily closed by the shellfish control authority.

Restricted Areas An area may be classified as restricted when a sanitary survey indicates a limited degree of pollution. This option may arise when levels of fecal pollution or poisonous or deleterious substances are low enough that relaying or purifying as provided for in Part I, Section D, and Part II, Section I, of the manual[80] will make the shellfish safe to market. State shellfish control authorities should establish a restricted area only when sufficient relay or depuration (purification) studies have been conducted that have established raw product quality requirements and when they have sufficient technical and administrative resources necessary to survey the area, monitor pollution sources, and control harvesting.

For restricted areas to be used for harvest of shellfish for controlled purification, the bacteriological quality of every sampling station in those portions of the area exposed to fecal contamination during adverse pollution conditions shall meet one of the following standards:

The total coliform median or geometric mean MPN of the water does not exceed 700/100 ml and not more than 10 percent of the samples exceed an MPN of 2300/100 ml for a five-tube decimal dilution test (or 3300/100 ml for a three-tube decimal dilution test).

The fecal coliform median or geometric mean MPN of water does not exceed 88/100 ml and not more than 10 percent of the samples exceed an MPN of 260/100 ml for a five-tube decimal dilution test (or 300/100 ml for a three-tube decimal dilution test).

These are state waters that have been classified by the state shellfish control agency as an area from which shellfish may be harvested only if permitted and subjected to a suitable and effective purification process.

Conditionally Restricted Areas Growing areas that are subject to intermittent microbiological pollution may be classified as conditionally restricted. This option is voluntary and may be used when the suitability of an area for harvesting shellfish for relaying and depuration is affected by a predictable pollution event. The pollution event may be predicated upon the attainment of an established performance standard by wastewater treatment facilities discharging effluent, directly or indirectly, into the area. In other cases, the sanitary quality of an area may be affected by seasonal population, non-point-source pollution, or sporadic use of a dock or harbor facility.

This is the classification of a state shellfish growing area determined by the state shellfish control authority to meet restricted area criteria for a predictable period. The period is conditional upon established performance standards specified in a management plan. A conditionally restricted shellfish growing area is a closed area when the area does not meet the restricted growing area criteria and is temporarily closed by the shellfish control authority.

Prohibited Areas A growing area shall be classified as prohibited if there is no current sanitary survey or if the sanitary survey or other monitoring program data indicate that fecal material, pathogenic microorganisms, poisonous or deleterious substances, marine biotoxins, or radionuclides may reach the area in excessive concentrations. The taking of shellfish for any human food purposes from such areas shall be prohibited.

These are state waters that have been classified by the state shellfish control agency as prohibited for the harvesting of shellfish for any purpose except depletion. A prohibited shellfish growing area is a closed area for the harvesting of shellfish at all times.

Acceptable laboratory procedures, standards, and criteria are available and must be followed.[80,84–87]

To be representative, water samples should be taken during different seasons of the year and at varying tides, depths, and watershed runoffs. An approved area classification shall be based upon a minimum of 15 samples collected from each station in the approved area. Sanitary surveys of shellfish growing areas and tributary watersheds, including chemical and bacterial examinations of the waters and inspections of shellfish plants, should be made at least annually by the state shellfish regulatory agency. All actual and potential pollution sources and environmental factors having a bearing on shellfish growing area water quality are evaluated.[80]

The quality of the water source of shellfish will determine the need for special treatment and a cleansing period for shellfish before being placed on the market. Two methods are generally used: cleansing by depuration for not less than 48 hr and relaying in clean water for not less than 21 days; 14 days may be acceptable. However, the purification process does not remove excessive levels of hydrocarbon, pesticide, heavy metal, radionuclide, and dinoflagellate toxin.[88,89] The depuration time, water temperature, and salinity vary with shellfish species.[90]

Cleansing or purification processes for shellfish from restricted or prohibited areas (but not grossly polluted areas), referred to as ‘‘controlled purification’’ or depuration, involve the placing of bivalves in tanks fed with clean disinfected seawater for 48 hr under the direction of the control agency. An alternative method is ‘‘relaying,’’ in which shellfish are harvested from contaminated waters and moved to an approved area for two weeks (some states require three weeks). The shellfish are then reharvested.[91] Filtration of recirculated seawater and disinfection of the water by ultraviolet light are also acceptable methods. The ultraviolet system requires weekly cleaning and disinfection. Grit and sand are removed from mussels by purging them for 24 hr in tanks of clean flowing seawater under regulatory supervision. Small numbers of potentially pathogenic microorganisms are frequently found, but these may be insufficient to cause illness; this needs confirmation. It should be noted that the bacterial tests for total and fecal coliforms do not show the presence or absence of viruses, toxic chemicals, or biotoxins. Further study is needed.

Sanitary handling and processing must be ensured to maintain a satisfactory product from the source to the consumer. This includes thorough washing at the source, clean packing, and storage at temperatures that will keep the shellfish alive and active without loss of shell liquor. Sand trapped in the shell will irritate and cause a loss of shell liquor, with general weakening of the bivalve.

Burlap and jute sacks used to transport shellfish must be kept clean and dry because damp or wet sacks will cause bacteria to multiply rapidly. Clean barrels, boxes, or baskets are better shipping containers.

Fresh oysters can keep for two weeks or somewhat longer on ice. Frozen oysters can be kept six months or more. Soft-shell clams and mussels should not be kept more than two days. Shellfish shipped to market in the shell are required to be handled in a sanitary manner, stored at a temperature of 36 to 40°F (2–4°C), and kept alive. Repacking of fresh oysters as breaded frozen oysters or a breakdown in sanitary precautions introduces health hazards. An effective shellfish control program requires the active participation of state and local regulatory agencies. Shellfish should be obtained only from certified dealers.

The consumption of undercooked or raw clams, oysters, scallops, or mussels may be dangerous. The usual method of steaming clams for 1 min, until the clam opens, is not sufficient to kill the pathogenic virus (Norwalk) if present. Six to 8 min is required, but the food may be too tough to eat. In any case, one should not eat shellfish harvested from unapproved or questionable sources.

DESIGN OF STRUCTURES

Location and Planning

The essential elements of a preliminary investigation to determine the suitability of a site for a given purpose were discussed in Chapter 2. Time and money spent in study, before a property is purchased, is a good investment and sound planning. For example, a food-processing plant that requires millions of gallons of cooling or processing water would not be located at too great a distance from a lake or clear stream unless it was demonstrated that an unlimited supply of satisfactory well water or public water was available at a reasonable cost. An industry having as an integral part of its process a liquid, solid, or gaseous waste would not locate where adequate dilution or a disposal facility was not available, following economical waste recovery or treatment. Existing regulations, the effect on the environment, and public attitudes need to be studied and cost of compliance determined.

Such factors as topography, zoning, environmental regulations, drainage, highways, railroads, airports, watercourses, raw materials, exposure, flooding, swamps, prevailing winds, noise, rainfall, dust, odors, insect and rodent prevalence, geology, availability and adequacy of public utilities and manpower, the need for a separate power plant, and water, sewage, or waste treatment works should all be considered and evaluated before selecting a site for a particular use. An environmental impact analysis of the proposed structures and uses on the surroundings and the prevention of deleterious effects in the planning stage will minimize public opposition, future costs, nuisance conditions, and environmental hazards.

Complete plans and specifications, including details, should be submitted to the regulatory agencies by every food service and processing establishment prior to new construction, alteration, or rehabilitation. Floor plans, equipment, refrigeration, dishwashing, and hot-water design details are shown in this chapter.

Structural and Architectural Details

The structure design is an engineering and architectural function that should be delegated to individuals or firms expert in such matters. Certain design and construction details will be shown and discussed here as they apply particularly to food establishments, although the basic principles will also apply to other places.

The construction material used is dependent on the type of structure and operation. Some materials can be used to greater advantage because of location, availability of raw materials, labor costs, type of skilled labor available, local building codes, climate, and other factors.

Floors There are many types of floor construction; a few of them will be briefly discussed. Floors in food-processing plants, dairy plants, kitchens, toilet rooms, and similar places should be sloped $\frac{1}{8}$ to $\frac{1}{4}$ in./ft to a drain. A trapped floor drain is needed for every 400 ft^2 of floor area, with the length of travel to the drain not more than 15 ft.

Concrete Floors Wear causes dust and pitting. New floors require at least seven days for curing and must be kept wet during this time. Concrete can be colored and requires a good seal. Special finishes include rubber resin enamel, concrete paint or sealer, chemical treatment, wax over paint, or sealer. Warm linseed oil treatment makes concrete acid resistant. Wire-mesh reinforcement will reduce cracking, particularly in coolers and driers where large temperature variations are expected. Floors in receiving rooms should be armored. Trucks and dollys with rubber or composition wheels reduce concrete wear and noise. Use alkaline cleaner.

Wood Strip or Block Flooring This flooring must be close grained, seasoned, and carefully laid. A new floor requires sanding, two coats of a penetrating-type sealer or primer, buffing, and a wax, resin, or other finish. Avoid use of water.

Vinyl Tile and Flooring Use water sparingly. Strong soap, lye, varnish, or lacquer causes this covering to shrink, curl, and crack. Use a mild cleaner and, if recommended, wax, usually water based. Vinyl flooring is resilient and durable and can be used below grade with waterproof adhesive. It also comes in sheets, is easier to install than individual tiles, and is less likely to provide insect harborage. Damp mop. The ‘‘wear layer’’ should be at least 10 mils in depth.

Terrazzo and Mosaic Floors This flooring requires six months for curing. Clean with warm water and treat with terrazzo seal. Clean with neutral soap and damp mop. Solvents, oils, strong alkalis, and abrasives cause discoloration and destruction.

Marble Floors First clean with clear, clean hot water. Then use an abrasive cleaner, if needed, mixed in a pail of hot water and mopped or scrubbed by hand or machine with a little water. Then rinse the floor with clean water and dry with a mop or squeegee.

Vitreous Tile, Ceramic Tile, and Packing-House Brick Tile This type of floor is hard, nonabsorbent, and acid resistant and cannot be scratched by steel or sand. Cement joints should be a full $\frac{1}{16}$ in. A firm base and competent installation are essential. Ceramic or quarry tile (nonslip) properly laid is best for kitchens, dairies, breweries, bakeries, shower rooms, and similar places. Wash with hot water and neutral cleaner and damp mop to keep floor in good condition. Soap and hard water cause discoloration. Do not use unglazed tile.

Cork Floors These are treated with a filler and water emulsion wax. Avoid use of water. Provide furniture rests. To clean, rub lightly with fine steel wool. Do not use directly on basement concrete floors. Not suitable for heavy traffic. Has good sound-deadening qualities.

Oxychloride, Magnesite, and Composition Cement Flooring Used for marine decking, industrial building flooring, and other purposes. A penetrating-type dressing about every six months and waxing are the usual maintenance. Excessive water causes deterioration.

General New or renovated floors require a conditioning or primary treatment. This usually involves a preliminary cleaning, then sealing and finishing to prevent harborage of vermin and penetration of moisture, soil, fungi, and bacteria; it also improves the wearing qualities of the floor. Following the conditioning, the floor should be cleaned periodically and properly maintained to keep down dust and the microorganism population, prevent accidents due to slippage, and remove fire hazards. Manufacturers of flooring can give specific advice for the sealing and care of their particular material.

Accidents due to slippage on kitchen floors are usually caused by settlement on the floor of airborne grease arising from frying, grilling, and roasting and from steam carrying fat in suspension. The condition of the floor surface, type of shoe worn, and actual cleanliness of the floor can also contribute to the potential accident hazard. Some floors can be given a smooth textured finish or a chemical nonslip floor treatment. A good floor cleaner is all purpose and neutral, requiring no rinsing; it should dissolve completely, have a low surface tension to pick up soil, and be economical and easy to use. A proper maintainer has a nonoil base and does not harm the floor material, furniture, walls, or equipment. It must not soften the floor finish; it should be applied either as a spray or powder, reduce slippage, be noninflammable and easily removed from the mop or applicator, impart a pleasant aroma, and have good spreading or coverage quality. Regular use of a mop and wet vacuum machine is usually necessary to minimize contamination and accidents in commercial kitchens. Ensure proper ventilation when using chemical cleaners. Rope off wet floors until dry.

Walls and Juncture with Floor The line or point of juncture between the wall and floor and with built-in equipment should form a tight, sanitary cove and a smooth, flush connection. Some typical base details are illustrated in Figure 8-8. Walls should be smooth, washable, and clean. Many materials have been used for interior walls and wall finishes. These include glass blocks, plaster, cement, clay tile and cement, dense concrete block, marble, concrete, glazed ceramic tile, glazed brick and tile, and architectural terra cotta wall blocks. Absorbent materials such as wallboard and rough plaster require careful treatment and maintenance where moisture or water is an integral part of a process. These surfacings are to be avoided in such cases if possible. The wall finish should be a light color in work and processing rooms. Window sills that are sloped down at an angle of about 30° simplify cleaning.

Hollow walls and partitions, hung ceilings, and boxed-in pipes and equipment will provide a channel of communication, shelter, and protection for insects and rodents. They should be eliminated or, if this is not possible, special entrance openings or ducts should be provided to facilitate simple and

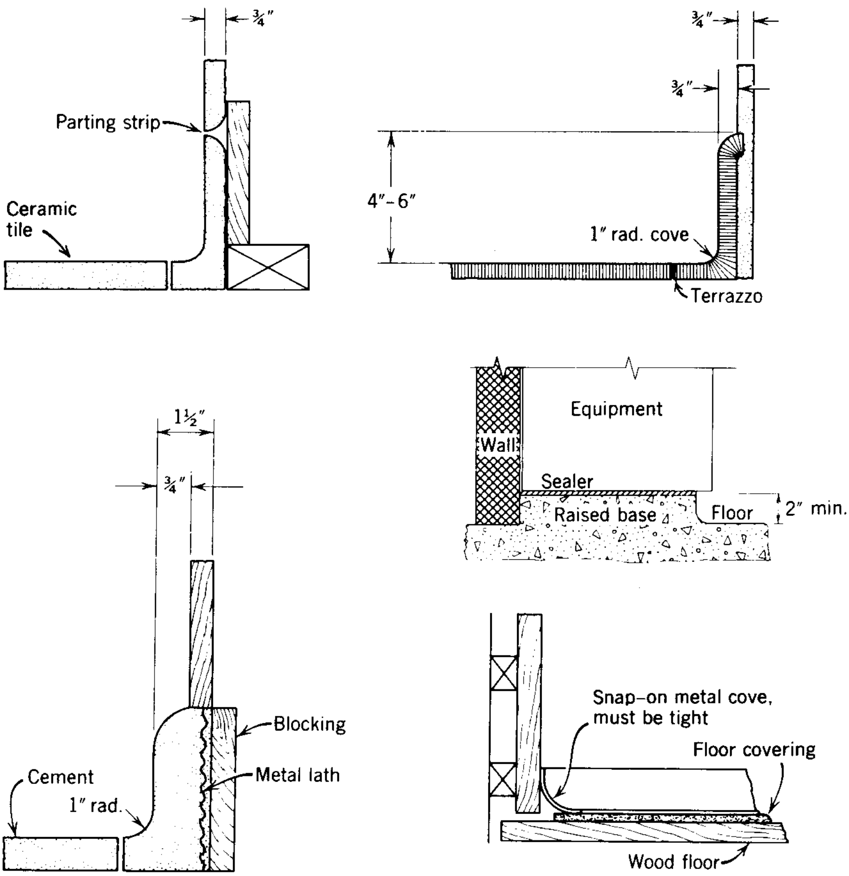


Figure 8-8 Floor and wall-base details.

direct fumigation and access if necessary. The use of gypsum blocks is not recommended where water or dampness might be encountered. Obtain approval of material and surface finish at USDA-inspected plants.

Mechanical Details

Consideration should be given to high-volume and high-pressure air supply for high-pressure or foam cleaning of equipment and special-parts washer sinks with integral circulation pumps and washing jets, automatically cleaned ovens, and hoods over stoves, cookers, and fryers. Use good building and plumbing codes.

Condensation A difficult problem in food plants and restaurants is the condensation of moisture on cold pipes or surfaces, with resultant dampness, mildew, annoying dripping of water, and possible contamination of food and food preparation tables. Condensation is caused by warm, humid air in contact with cool pipes or surfaces below the dew-point temperature. Lowering the humidity of the air, cooling the air, or increasing the temperature of the surface above the dew point will prevent condensation. Dehumidification can be accomplished by mechanical means and indirectly by good ventilation, especially over cooking stoves, which also would cause a lowering of the air temperature. The increase of the temperature of the surface is generally accomplished by insulation; the type and thickness of insulation are determined by the particular air temperature and humidity.

Lighting Adequate light, with consideration to interior surface finish and color, is essential to proper operation and the maintenance of cleanliness. A minimum of 30 and up to 100 foot-candles is recommended on work surfaces, depending on the tasks to be performed.

Washing Facilities, Toilets, and Locker Rooms

The provision of adequate, convenient, and attractive sanitary facilities including dressing rooms or locker rooms not only is required by most health, industrial hygiene, and labor departments but also is a good investment. Contented employees make better workers, and the habitual practice of personal hygiene in food establishments is especially essential. Wall-hung fixtures and toilet partitions in washrooms and the proper selection of floor and wall materials substantially reduce cleaning costs.

The number of plumbing fixtures to provide depends on the type of establishment and the probable usage. Local standards are usually available, but in the absence of regulations, the suggestions given in Table 11-6 for public buildings can be used as a guide. Washbasins and showers should be connected with both hot and cold running water or with tempered water. Soap or a suitable cleanser and sanitary towels are standard accessories. Extra washbasins with warm water, soap dispensers, and paper towels at convenient locations in all workrooms help promote cleanliness.

Water Supply

An improperly constructed and protected water supply is a common deficiency at food establishments and particularly at dairy farms located in areas not served by community water systems. This condition prevails probably because the water supply is related to the production of milk and food only indirectly and, hence, is considered unimportant in the spread of disease or in product quality. It is also possible that the average inspector, being inexperienced in water supply sanitation, overlooks weaknesses in the development and protection of the water supply source.

A safe and adequate water supply under pressure is fundamental to the promotion of hygiene and sanitary practices at a restaurant, dairy farm, pasteurization plant, and other types of food-processing plants. It is good practice to oversize the piping and provide extra tees at regular intervals to permit future connections. Where a contaminated or potentially contaminated water supply under pressure is also available, it must not be connected to the plant potable water system under any circumstances. The availability of an unsafe water supply in a plant is dangerous; it must be eliminated. An inadequate water supply will hamper and, in many instances, make impractical good sanitary practices and procedures. Contaminated water can become a link in the chain of infection and, in addition, lead to the production of food of poor quality. The development, protection, and location of wells and springs and the treatment of water are discussed in Chapter 3.

If cooling water is to be used, maintenance of a free chlorine residual of 2 to 5 mg/l will give reasonably good water quality control.

Water to produce steam of culinary quality for use in food processing must be of drinking water quality. It is advisable to use a heat exchanger to generate steam indirectly with stainless steel equipment. Cross-connections and cross-contamination must be prevented. A contaminated water supply may be the source of *Pseudomonas aeruginosa,* an infrequent cause of *Pseudomonas* mastitis in dairy herds, and milk contamination.[92]

Liquid and Solid Waste Disposal

Where the disposal or treatment of industrial wastes is a problem, the sanitary sewer and waste drainage systems should normally be separate. Clear, unpolluted water should not as a rule be mixed with the sewage or industrial wastes, and thus aggravate these problems, but can be disposed of separately without treatment. The waste treatment problem can usually be reduced by good plant housekeeping. Solid wastes are collected and stored for separate disposal; liquid wastes are kept at a minimum by careful operation and supervision; where possible, wastes are salvaged. Information concerning the treatment and disposal of sewage and industrial wastes is given in Chapter 4. Solid waste management is discussed in Chapter 5.

DESIGN DETAILS

Typical Kitchen Floor Plans

Some floor plans are included here to suggest the factors involved and the approach that should be used when a new establishment is constructed or major alterations are proposed. Many details, equipment, facilities, and trades are involved, all of which require specialized knowledge.[93] The preparation of scale drawings and plans by a competent person, such as a registered architect or engineer who has had the related experience, invariably saves money and anguishing frustrations. It is strongly recommended that preliminary plans be reviewed by the local building department, health department, or other agencies responsible for inspection and supervision of the particular operations regardless of whether this is a requirement of any sanitary code, regulation, or law. Equipment manufacturers may be of assistance. Most official agencies are happy to be consulted in advance rather than require major corrections after a job is completed and business started. Regulatory agencies usually require the submission and approval of plans for compliance with sanitary, building, and fire codes before any new construction or rehabilitation. There is a need for uniform design requirements

General Design Guides

Restaurant and equipment design, including equipment arrangement, is a specialized field. In many instances, however, basic sanitation problems are incorporated rather than eliminated in the design. Food handling, storage, preparation, and service should receive careful consideration. Some guides in planning that result in efficient, economical, and sanitary operations are summarized below and illustrated in Figures 8-9 to 8-11. Planning starts with study of food flow and type of service. Information regarding siting, water supply, wastewater disposal, solid waste management, and air pollution is given in Chapters 2 through 6.

1. Aisle spaces should be not less than 36 in.
2. Unless built in in a sanitary manner, equipment should be spaced 18 to 30 in. from other equipment or walls and 12 to 18 in. above the floor to make cleaning possible. A smaller space that is still completely accessible for cleaning may be permitted.
3. Built-in or stationary equipment that eliminates open spaces, crevices, and rat and insect harborage and provides a coved or smooth joint where equipment abuts other equipment, the wall, ceiling, or floor will simplify sanitary maintenance.
4. The floor finish or covering selected for different spaces should recognize the type of traffic and uses to which the spaces will be put. The same would apply to wall and ceiling finishes. Vinyl or asphalt tile that is not grease resistant, for example, is not a suitable floor covering for restaurant kitchens; quarry tile is ideal. The limitations of various floor coverings are discussed under Structural and Architectural Details, earlier in this chapter. Consideration should be given to effective floor drainage.
5. Wooden shelving should be 12 to 18 in. above the floor, planed smooth, but not painted, shellacked, or varnished. Oilcloth or paper lining complicates the housekeeping job.
6. Bins, cutting and work boards, meat hooks, shelving in walk-in and reach-in refrigerators, and other equipment that comes into contact

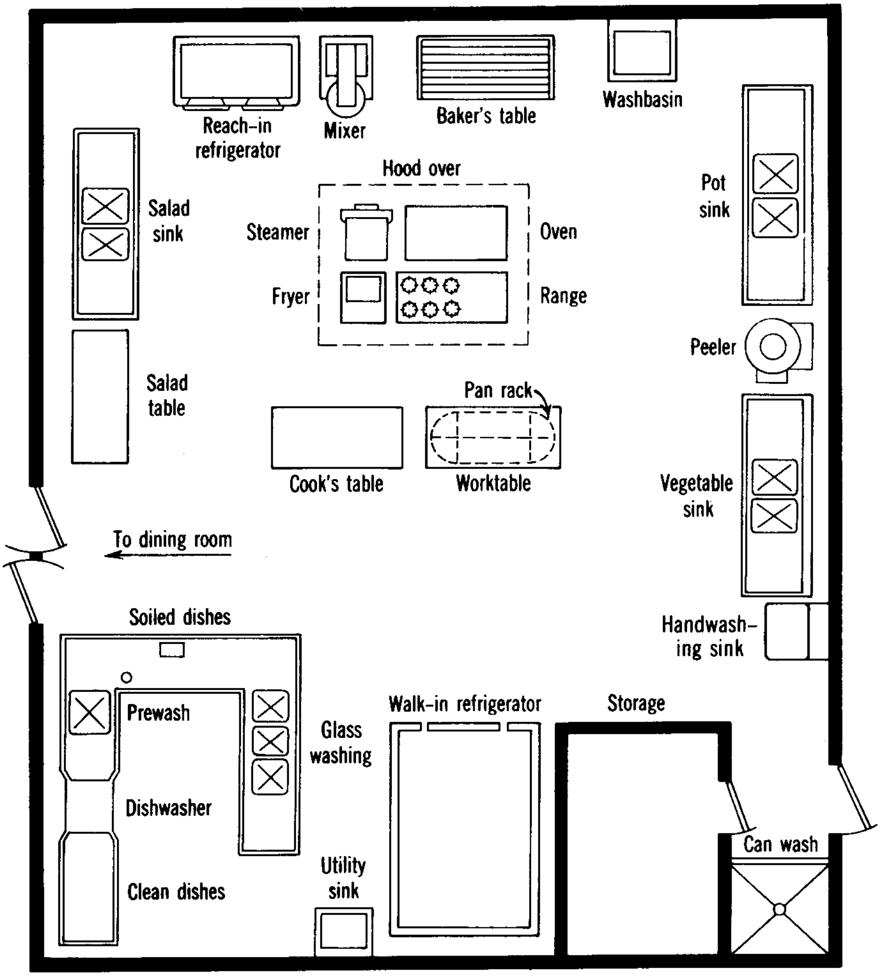


Figure 8-9 Layout of kitchen equipment. (*Source: Environmental Health Practice in Recreational Areas,* PHS Pub. 1195, Department of Health, Educations, and Welfare, Washington, DC, 1965, p. 70.)

with food should be removable for cleaning. Woodwork surfaces should be replaced with nonabsorbent, cleanable synthetic materials.

7. Provision should be made in the kitchen for a washbasin with soap and paper towels and a utility sink, connected with hot and cold running water, for the convenience of food workers.
8. A garbage-can storage room is a practical necessity in the larger restaurants. This problem is discussed in greater detail in Chapter 5.
9. Garbage grinders are very desirable in the dishwashing area, the vegetable preparation space, and the pot-washing area.

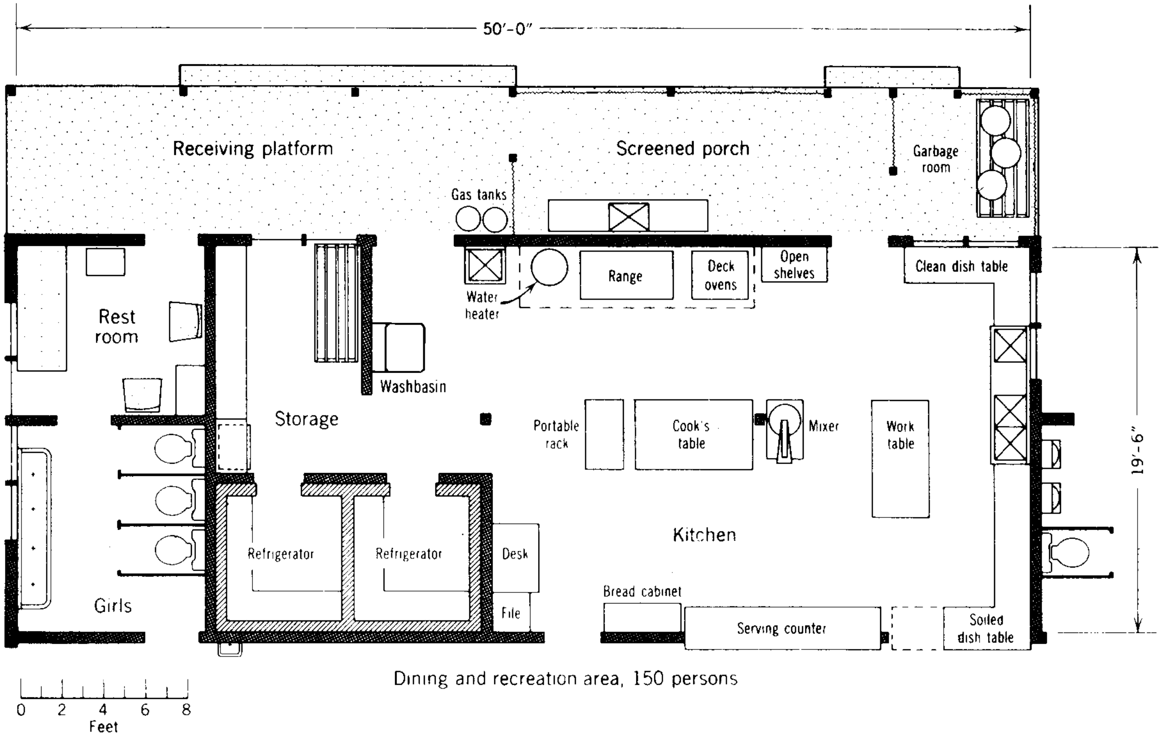


Figure 8-10 Plan of kitchen receiving platform and porch and food storage rooms. Dishwashing center along wall at extreme right. (*Source: Cornell Miscellaneous Bull.*, No. 14, New York State Colleges of Agriculture and Home Economics, Cornell University, Ithaca, NY, March 1953.)

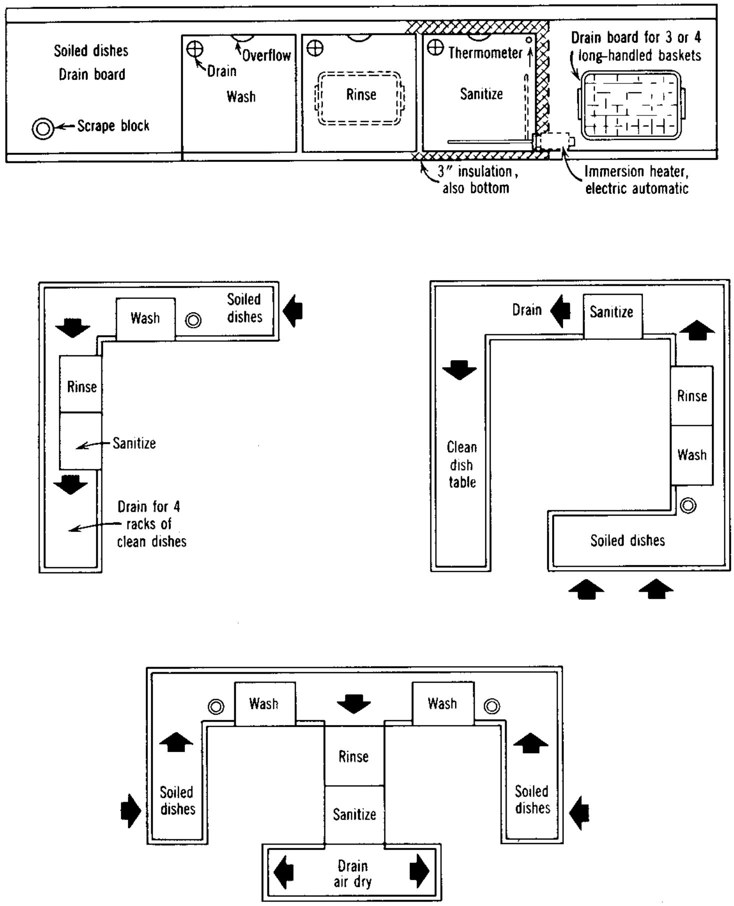


Figure 8-11 Hand dishwashing plans for small to medium operations. Dishwashing machine is recommended where possible. Dish counters 24 to 36 in. wide.

10. Avoid submerged water inlets; provide backflow prevention devices on water lines to fixtures or equipment that might permit backflow. Inlet lines should be 2½ pipe diameters and not less than 1 in. above the overflow rim. Run wastelines from potato-peeling machine, egg boiler, dishwashing machine, steam table, refrigerator, air-conditioning equipment, and kettles to an open drain or to a special sink. See the section on plumbing for greater details.
11. Pipes passing through ceilings should have pipe sleeves with protective caps extending 2 in. above the floor surface.

Lighting

Proper lighting is essential for cleanliness, accident prevention, and fatigue reduction. Proper lighting takes into consideration the task, spacing of light sources, elimination of shadows and glare, control of outside light, and lightness of working surfaces, walls, ceilings, fixtures, trim, and floors. Some desirable lighting standards are given in Table 8-9. Minimum lighting is 20 foot-candles on all food preparation surfaces and at equipment or utensil-washing work levels, in utensil and equipment storage areas, and in lavatory and toilet areas and 10 foot candles in walk-in refrigerating units and dry food storage areas.[94]

Typical color reflection factors are white, 80 to 87 percent; cream, 70 to 80 percent; buff, 63 to 75 percent; aluminum, 60 percent; cement, 25 percent; and brick, 13 percent.

Ventilation

Ventilation is considered adequate when cooking fumes and odors are readily removed and condensation is prevented. This will require sufficient windows that can be opened both from the top and bottom or ducts that will induce ventilation. Hoods with removable filters and exhaust fans should be provided with the base of the hood normally 3 to 4 ft above the cooking surface.[95] The hood should extend 6 in. beyond the open sides of ranges, ovens, deep fryers, rendering vats, and steam kettles and over any other equipment that gives off large amounts of heat, steam, grease, or soot. Mechanical ventilation can be provided for kitchens with fans having the capacity of 15 to 25 air changes per hour, depending on the amount of cooking. It is advisable to draw fresh air in from a high point, as far away as possible from the exhaust fan, to

TABLE 8-9 Lighting Guidelines

Space	Foot-candles	Space	Foot-candles
Bakery	30–50	Restaurant	—
Brewery	30–50	Dining room	3–30
Candy making	50–100	Kitchen	70
Canning	—	Dishwashing	30–50
General	50–100	Quick-service	50–100
Inspection	100	Food quality control	50–70
Dairy	—	Cooler, walk-in	30
Pasteurization	30	Storage rooms	20
Bottle washer	100	Toilet rooms	20–30
Milkhouse	20–30	Dressing rooms	20–30
Inspection	100	Offices	70–100
Laboratory	100	Corridors, stairways	20
Gages, on face	50	Other spaces, minimum	5
Milking, at cow's udder	50	Recreation rooms	20–30
Meat packing	—		
Slaughtering	30		
Cleaning, cutting, etc.	100		

prevent drafts and inefficient ventilation. Hood ventilation is given in Table 8-10. Hoods and filters require regular cleaning. They can become fire hazards. Grease accumulates on a filter, runs down the face, and drops into a drip tray from which it should drain into an enclosed metal container not exceeding 1-gal capacity.[95] The grease also clogs the filter, reduces ventilation efficiency, and can drip on food.

Uniform Design and Equipment Standards

There is a distinct need for reasonably uniform standards and criteria to guide the manufacturing industry as well as design architects and engineers. In this way, food service equipment, materials, and construction would meet the requirements of most regulatory agencies, and manufacturers would not need special equipment design for different parts of the country. Such standards, codes, and criteria have been established by regulatory agencies and joint committees representing industry, business, the consumer, professional and technical organizations, and regulatory agencies. The FSIS no longer conducts design and equipment reviews under the new inspection regulations (it is the industries' responsibility to do this so that design and equipment will meet the sanitation and other performance requirements. Many standards have received wide acceptance; some are listed below. They are highly recommended for reference and design purposes. See also the listings under Basic Requirements and the Bibliography, this chapter.

1. *BISSC Sanitation Standards,* Baking Industry Sanitation Standards Committee, Chicago, IL, January 1, 1990.
2. *BOCA Basic Building Code,* Building & Code Administrators, Homewood, IL, 1981.
3. Bureau of Commercial Fisheries, U.S. Department of Interior, Washington, DC.

TABLE 8-10 Equipment Ventilation

Equipment	Rate of Ventilation (cfm/ft^2)
Range hoods, four exposed sides	150
Range hoods, three exposed sides	100
Range hoods, two exposed sides	85
Hoods for steam tables	60

Note: Required exhaust fan = hood length × width × cfm for canopy hoods less than 8 ft long. For canopy hoods 8 ft or longer, the required exhaust fans in cfm = 200 × perimeter of the open sides of the hood in feet. Check proposed design with local fire, building, health, and labor departments and the local gas company. For national standards and regulations, see the National Fire Protection Association, Underwriters' Laboratories, and the American Gas Association.

4. *Code of Federal Regulations,* Title 21 Parts 100–169, U.S. Government Printing Office, Washington, DC, April 1, 1989.
5. *Food Service Equipment and Related Products, Components and Materials Standards,* National Sanitation Foundation, Ann Arbor, MI, June 1, 1990.
6. *National Building Code,* American Insurance Association, New York, 1967.
7. *National Electrical Code Handbook,* National Fire Protection Association, Batterymarch Park, Quincy, MA, 1984.
8. *National Plumbing Code,* ASA A40.8-1955, American Standards Association, American Society of Mechanical Engineers, New York.
9. *3-A Sanitary Standards,* Committee on Sanitary Procedures, International Association of Milk, Food and Environmental Sanitarians, Sanitary Standards Subcommittee, Dairy Industry Committee; PHS/FDA, Washington, DC.
10. *Uniform Plumbing Code,* International Association of Plumbing and Mechanical Officials, Los Angeles, CA, amended 1974.
11. *Vending Machine Evaluation Manual,* National Merchandising Association, Chicago,IL, October 6, 1978.
12. *Vending of Food and Beverages,* DHEW Pub. No. (FDA) 78-2091, PHS/FDA, Washington, DC, 1978.
13. See also state and local standards, regulations, and guidelines (listed earlier under Basic Requirements, this chapter).

Space and Storage Requirements

A common problem in existing restaurants is the inadequate space in the kitchen for the number of meals served. Inefficiency and the resultant confusion compound the problem. Some suggested average space requirements are listed in Table 8-11; however, complete scale drawings should be made to fit individual situations. How the space is used is as important as the space available.

Refrigeration

Refrigeration slows microbial growth and helps preserve food. It is frequently stated that food stored at a temperature of 45°F (7°C) is adequately protected against bacterial growth and spoilage. This generalization can be very misleading unless such factors as storage method; frequency of opening and closing of the refrigerator door; insulation; type of food stored; length of storage; box outside temperature; compressor capacity; type of cooling; temperature, weight, depth, and thickness of food placed in the storage box; maintenance; and similar variables are taken into careful consideration. Actually, a temperature of 45°F (7°C) will permit the growth of *S. enteriditis*

TABLE 8-11 Suggested Space Requirements for Kitchens

Type of Food Service	Kitchen[a] (ft^2 per seat)	Dining Room (ft^2 per seat)
Children's camp	7–9	12
School lunchroom	$5\frac{1}{2}$–$6\frac{1}{2}$	10
Restaurant	$7\frac{1}{2}$–$9\frac{1}{2}$	14
Lunchroom (counter, service, and tables)	8–12	15–20[b]
Hospitals	20–30 per bed	12–15 per bed
Cafeteria	12	15[b]

[a] Includes storage, receiving, and dishwashing spaces, also employees' toilet rooms and locker space; deduct 4–5 ft^2 per seat if not included. Larger areas are suggested for the smaller places. The greater the turnover per hour, the larger the kitchen per seat. Another basis for kitchen area—food preparation, refrigeration, serving, dishwashing, and office—is $1\frac{1}{2}$–2 ft^2 per meal served per day.

[b] Includes serving area. Experience shows that with experienced help a cafeteria can serve 300 people per hour in the line and 600 people per hour with a limited menu. With counter service, allowing 2 ft per stool, 4 persons can be served per hour. With table service, the turnover is 3 to 4 times per 2 hr.

and other microorganisms. Studies show that the growth of salmonellae and staphylococci in perishable foods is inhibited when the internal temperature is at or below 42°F (5.5°C).[96] *Clostridium botulinum* type E, *Y. enterocolitica,* enterotoxigenic *E. coli, L. monocytogenes,* and *Aeromonas hydrophilia* are capable of growth, although slowed, in foods at temperatures of 37 to 41°F (3–5°C). *Salmonella enteriditis, S. aureus, V. parahaemolyticus,* and *Bacillus cereus* may grow at temperatures slightly above 41°F (5°C).[97] Some *B. cereus* can survive cooking. Normal reheating does not destroy the toxin once it is formed.[98]

It is extremely important to distinguish between the air temperature in a refrigerator and the internal temperature of the food. A temperature of 38 to 40°F (3–4°C) has been found more satisfactory in practice for the storage of most foods that are to be used within 24 to 48 hr. Frozen foods should be stored compactly below 0°F (−18°C). Ice cream is commonly held at −10°F (−23°C), frozen meat at 14°F (−10°C). Temperatures of −15°F to −22°F (−26 to −30°C) are being used for bulk storage. It is recommended that fish be stored at 32°F (0°C) and meat that is not frozen at a temperature of 35°F (2°C). Low-temperature, heat-treated, hermetically packed foods, such as cured hams with salt and pasteurized canned hams, also require refrigeration. All canned food is not necessarily sterilized. In some instances, the can merely serves as a container for a meat or other food product that has been subjected to sufficient heat only to inhibit the growth of spoilage organisms without showing swelling of the can.

In general, for short storage, fresh meats should be stored at a temperature of 34 to 38°F (1–3°C); fresh fish at 32 to 34°F (0–1°C); poultry at 34 to 38°F; fresh fruits at 35 to 40°F (2–4°C); dairy products, including eggs and salads, at 40 to 45°F (4–7°C); leafy green and yellow vegetables at 40°F; tomatoes, potatoes, onions, lemons, cucumbers, and melons at around 50°F (10°C); cured meats at 40°F in a dry, well-ventilated space; and butter at 40°F (for best results).

Accurate outside thermometers and warning bells with thermometer stems located in the warmest compartments of refrigerators will show the adequacy of refrigeration. Sandwich and salad mixtures and cut or leftover food should be placed in covered shallow pans at a depth not greater than 3 in. to accelerate the rapid cooling of such foods. Hot foods are usually cooled down to about 130 to 140°F (54–60°C) before being placed in the refrigerator but in any case should be refrigerated within 30 min. In this way, bacterial growth is retarded and the cooling capacity of the refrigerator is not exceeded. Small quantities of hot foods in shallow pans placed on ice trays can be precooled rapidly before being placed in the refrigerator. Rapid-chill refrigerators are more efficient than walk-in coolers; it appears to be the only way to meet FDA food service requirements. Food should be cooled to 45°F (7°C) or less in less than 4 hr. This includes food taken home from a restaurant or food market.

The storage of fish, ham, bacon, cabbage, onions, and similar odorous foods in the same cooler or refrigerator with milk, butter, eggs, salads, desserts, and fruit drinks that pick up odors and flavors should be avoided. Dairy products and meats are best stored in a separate refrigerator. Large pieces of meat should be hung so that they do not touch, and all foods, including roasts, chops, and steaks, should be arranged so that air can circulate freely. Wrapping should be removed and the food kept loosely covered. Smoked meats may be kept tightly wrapped. If not stored separately, wrap butter and cheese tightly.

Refrigeration in a food establishment, camp, or institution is adequate when it is possible to store and maintain all perishable foods at a proper temperature, at least over weekends, without packing and crowding. The refrigerator should be relatively dry and permit air to circulate freely.

The size refrigerator to provide for a particular purpose is dependent on many variables, most of which can be controlled. The number and type of meals served, the delivery schedules, and the purchasing methods all affect the required storage space. As a guide, a refrigerator capacity of 0.15 to 0.3 ft^3 per meal served per day, with 0.25 ft^3 as a good average, has been found adequate to prevent overloading over weekends and holidays. Where food purchase is done twice a week, the refrigerator should provide 2½ ft^3 per person served three meals a day; 3 to 3½ ft^3 is preferred. In practice, many foods are purchased or delivered five days a week; hence, the required refrigerator volume should be adjusted accordingly. Additional storage space is needed for bottled-beverage cooling and for frozen foods. Allow 1 ft^3 for 50 to 75 half pints of milk and 0.1 to 0.3 ft^3 (30–35 lb/ft^3) per meal served per day for frozen-food storage.

The storage racks in a refrigerator or walk-in cooler should be slotted to permit circulation of cold air in the box and should be removable for cleaning.

If the box is provided with a drain, it must not connect directly to a sewer or waste line but rather connect to an open sink or drain that is properly trapped.

If cans or boxes are stored in a cooler or refrigerator, it is advisable to provide duckboards or racks on the floor. This makes possible better air circulation and helps keep the floor and supplies clean. In any case, refrigerators need daily cleaning and inspection for possible drippage and food spoilage. Washing the inside at frequent intervals with a warm, mild detergent solution followed by a warm-water rinse containing borax or baking soda and drying will keep a box sweet and clean. Wipe the door gaskets daily. Do not use vinegar, caustic, or salt in cleaning solutions.

Many types of refrigerators on the market use different principles and refrigerants. When possible, provide entrance to a walk-in refrigerator through an air lock to prevent the cold air inside from rolling out and the outside warm air from pouring in. An efficient arrangement for refrigerators is a plan providing a group of walk-in coolers opening into a central room that can serve as a general cold storage room for certain foods that do not require a low temperature and as an access room from the unloading platform or kitchen. Another alternative would be two boxes in series with entrance to the freezer room through the cold room.

Because of the extensive new regulations for food commodities referenced above, the appropriate federal agency should be contacted for the most appropriate guidance on refrigeration, cooling, and storage of product.

Thawing Frozen Foods

Frozen food should be maintained at a temperature of 0°F (−18°C) or lower until ready for use. There is no need to thaw small cuts of meat or fish for extended periods of time. Large pieces such as roasts, turkeys, and chickens should be thawed under refrigeration not warmer than 45°F (7°C). Thawing times for frozen turkey are given in Table 8-1. As an alternative, the frozen roast, turkey, or chicken may be placed in a plastic bag in running water not warmer than 70°F (21°C). Do not thaw at room temperature.

Do not cook frozen or partially thawed food greater than 4 in. thick, as inadequate cooking and pathogen survival and growth may occur.

A reduction in the microbial population occurs at low temperatures. For vegetables, approximately 25 to 30 percent of the microorganisms survived at a storage temperature of 0°F (−18°C) after 24 months of storage. *Salmonella* in chicken chow mein was reduced to less than 40 percent in 14 days and to less than 20 percent after 50 days at storage temperature of −14°F (−25.5°C).[99]

Refrigeration Design

The proper refrigeration of food is one of the most important precautions for the prevention of food poisonings and infections as well as for food preservation. Refrigeration is the extraction of heat from a mass, thereby lowering its temperature. Ice has been used for many years to preserve food and is the standard that serves as a base for the measure of refrigeration. One pound of ice in melting will absorb 144 Btu of heat. A ton of refrigeration is 288,000 Btu/24 hr = 2000 lb of ice × 144 Btu.

The amount of heat required to lower 1 lb of a product 1°F is known as the specific heat. For example, the amount of heat to be extracted from 1 lb of water to lower its temperature 1° F is 1 Btu, up to 32°F. To change the 1 lb of water to ice requires the extraction of 144 Btu from the water; this is known as its latent heat of fusion or the heat absorbed due to a change from the liquid to the solid state. But to lower the temperature of ice at 32°F (0°C) requires the extraction 0.5 Btu per pound of ice per degree of drop in temperature. Similarly, each food product has its own specific heat, before freezing and after freezing, and its latent heat of fusion. For example, it is generally assumed for calculation purposes that the freezing point of most food products is about 28°F (−2°C). Fresh pork has a specific heat of 0.6 Btu/lb before freezing, 0.38 Btu after freezing, and a latent heat of fusion of 66 Btu/lb. One cubic foot of air at a temperature of 90°F (32°C) and 60 percent relative humidity that is cooled to 35°F (2°C) will release 2.43 Btu. Calculation of refrigeration compressor capacity takes into consideration the sources of heat through wall losses, air changes and leakage, pounds of products refrigerated, and miscellaneous losses such as electric light bulbs, men working, and heat released due to respiration of fruits and vegetables.

Heat transmission through walls, floors, and ceilings is by convection, conduction, and radiation. The amount of heat transferred depends largely on the overall coefficient of heat transmission of the wall materials in Btu per hour per square foot of surface per degree difference in temperature. Computation of heat transmission coefficients is explained in detail in *The American Society of Heating, Refrigeration, and Air-Conditioning Engineers Guide* (ASHRAE Guide, Atlanta, GA, 1970) and other related standard texts. For example, 1-in. typical corkboard has a conductivity of 0.30 Btu per hour per square foot per degree Fahrenheit, or 7.2 Btu/24 hr. Sawdust (dry) has a conductivity of 0.41 Btu per inch thickness, or 9.84 Btu per 24 hr per square foot per degree. One inch of cement plaster has a conductivity of 8.0 Btu, or 192 Btu/24 hr.

Air changes in a refrigerator each time the door is opened. Cold air rolls out and warm air enters, thereby raising the temperature of the air in the refrigerator. A walk-in cooler having a volume of 300 ft^3 will probably have about 35 air changes per 24 hr due to door opening and infiltration. This will amount to 10,500 ft^3 of air. If the air has a temperature of 90°F (32°C) and 60 percent relative humidity and is to be cooled to 35°F (2°C), it will represent 2.43 Btu/ft^3 of air, or in the instance cited 10,500 × 2.43 = 25,500 Btu of heat per 24 hr to be replaced by the refrigerating unit. In restaurants, where refrigerators normally receive heavy usage, it is good practice to estimate a 50 percent increase over normal in the number of air changes. Rapid-chill refrigerators typically require double or more airflow and cooling capacity.

When food is placed in a refrigerator, it is usually necessary to remove heat in the food in order to cool it to the desired temperature. The heat load is dependent on the weight of the product, its specific heat, the temperature reduction, and the speed with which the product is to be cooled. If 100 lb of fresh poultry is to be cooled from 65 to 35°F (18 to 2°C) in 6 hr, the heat load will be:

$$\frac{100 \text{ lb} \times 0.80 \text{ specific heat} \times 30^\circ \text{ temperature reduction} \times 24 \text{ hr}}{6 \text{ hr}}$$

$$= 9600 \text{ Btu/24 hr}$$

If the products refrigerated are fresh fruits or vegetables, adjustment must also be made for the heat released by these foods in storage. For example, it is estimated that strawberries stored at 40°F (4°C) give off about 3 Btu/lb per 24 hr.

Miscellaneous losses include 3.42 Btu per hour per watt of light bulb, 3000 Btu per hour for each motor horsepower, and 750 Btu per hour per person working in a box. A safety factor of at least 10 percent is added to the total load, and compressor capacity is based on a 16-hr operating day to provide for a defrosting cycle. A horsepower hour is 2546 Btu or 0.7457 kilowatt hour. Keep motor and refrigerating unit free of lint and dirt to permit air circulation, and be sure door gaskets keep cold air from escaping.

An example will serve to illustrate the refrigeration design principles and data for the calculation of refrigeration load.

Given: A box 10 × 10 × 8 ft outside, 3-in. cork insulation standard construction with two layers of insulation paper and sheathing inside and outside, room temperature 95°F (35°C) and box temperature 35°F (2°C), 100 lb of fresh poultry received at 65°F (18°C) and 150 lb of lean beef received at 65°F cooled to 35°F in 24 hr and 50-W electrical load.

Solution.

1. Box outside surface area: 520 ft^2.
2. Temperature reduction: 60°F.
3. Wall loss = 1.8 Btu/ft^2 per degree temperature reduction (see Table 8-12)
   = 1.8 × 520 = 60 = 56,200 Btu/24 hr.
4. Air change = 9 × 9 × 7 ft (assume inside dimension 1 ft less than outside)
   = 567 ft^3 × 23 air changes per 24 hr (see Table 8-13)
   = 13,040 ft^3.

TABLE 8-12 Heat Transmission Coefficients

Insulation Material	Wall Heat Loss[a] per °F Room Minus Cooler Temperature
Corkboard, 1 in.	7.2
Single glass	27
Double glass	11
Corkboard paper and sheathing on both sides	3.6 for 1-in. cork
	2.4 for 2-in. cork
	1.8 for 3-in. cork
	1.5 for 4-in. cork

[a] Btu/24 hr/ft^2 of outside surface see *ASHRAE Guide* for other coefficents.

5. Btu to cool 1 ft^3 of air from 95 to 35° F = 2.79 (see Table 8-14). Hence, to cool total air change requires

$$3040 \times 2.79 = 36{,}500 \text{ Btu/24 hr}$$

6. Product load of poultry and beef:

Specific heat of poultry

= 0.80 Btu/lb (see Table 8-15)

Specific heat of beef

= 0.77 Btu/lb

$$= \frac{100 \times 0.8 \times (65 - 35°\text{F})}{24} + \frac{150 \times 0.77\ (65 - 35°\text{F})}{24} \times 24$$

Product load

= 2400 + 3460 = 5860 Btu/24 hr.

TABLE 8-13 Air Change for Storage Rooms (32 to 50°F) Caused by Door Opening and Infiltration[a]

ft^3	Air Change per 24 hr	ft^3	Air Change per 24 hr
250	38.0	800	20.0
300	34.5	1000	17.5
400	29.5	1500	14.0
500	26.0	2000	12.0
600	23.0	4000	8.2

[a] Data for the calculation of refrigeration load adapted from *Kramer Engineering Data,* Catalog No. R-114, Kramer-Trenton Co., Trenton, NJ.

TABLE 8-14 BTU/ft³ of Air Removed in Cooling to Storage Conditions[a]

Storage Room Temperature (°F)	By Temperature of Air Outside, Assumed at 60% Relative Humidity			
	85°F	90°F	95°F	100°
65	0.85	1.17	1.54	1.95
60	1.03	1.37	1.74	2.15
55	1.34	1.66	2.01	2.44
50	1.54	1.87	2.22	2.65
45	1.73	2.06	2.42	2.85
40	1.92	2.26	2.62	3.06
35	2.09	2.43	2.79	3.24

[a] Data for the calculation of refrigeration load adapted from *Kramer Engineering Data*, Catalog No. R-114, Kramer-Trenton Co., Trenton, NJ.

7. Electrical load = 3.42 Btu/W/hr (assume 8-hr lighting)
   = $3.42 \times 50 \times 8$ = 1368 Btu/24 hr.

Total load = 56,200 (wall) + 36,500 (air change) + 5,860 (product) + 1368 (electric)
= 99,928 Btu/24 hr + 10% safety factor 0.1 (99,928)
= 99,928 + 9993 = 109,921 Btu/24 hr.

Compressor capacity, based on 16-hr operation, is then

$$\frac{109{,}921}{16} = 6875 \text{ Btu/hr}$$

Approximate calculation:

Usage heat loss = 1.52 Btu/ft³/°F/24 hr (see Table 8-16)
= $1.52 \times 567 \text{ ft}^3 \times 60°\text{F}$ = 52,000 Btu/24 hr

Total = 52,000 (usage) + 56,200 (wall) = 108,200 Btu/24 hr

Compressor capacity (based on 16 hr operation):

$$\frac{108{,}200}{16} = 6760 \text{ But/hr}$$

Cleansing and Sanitizing

The effectiveness of cleansing, including bactericidal treatment of equipment and utensils, can be determined by visual inspection and laboratory methods.[85,100] A standard measure is the bacteriological swab test. One swab for each group of five or more similar utensils, cups, glasses, or five 8-in.^{2} surface

TABLE 8-15 Specific Heat, BTU/lb[a]

Product	Btu/lb/°F Before Freezing	Btu/lb/°F After Freezing	Latent Heat of Fusion (Btu/lb)
Asparagus	0.95	0.44	134
Berries, fresh	0.89	0.46	125
Beans, string	0.92	0.47	128
Cabbage	0.93	0.47	130
Carrots	0.87	0.45	120
Dried fruit	0.42	0.27	32
Peas, green	0.80	0.42	108
Potatoes	0.77	0.44	105
Sauerkraut	0.91	0.47	129
Tomatoes	0.95	0.49	135
Fish, fresh	0.82	0.41	105
Fish, dried	0.56	0.34	65
Oyster, shell	0.84	0.44	115
Bacon	0.55	0.31	30
Beef, lean	0.77	0.40	100
Beef, fat	0.60	0.35	79
Beef, dried	0.34	0.26	22
Liver, fresh	0.72	0.40	94
Mutton	0.81	0.39	96
Poultry	0.80	0.41	99
Pork, fresh	0.60	0.38	66
Veal	0.71	0.39	91
Eggs	0.76	0.40	98
Milk	0.90	0.46	124
Honey	0.35	0.26	26
Water	1.00	0.50	144

[a] Data for the calculation of refrigeration load adapted from *Kramer Engineering Data,* Catalog No. R-114, Kramer-Trenton Co., Trenton, NJ.

areas is used. A standard plate count [98.6°F (37°C) for 48 hr] of less than 100 per utensil, or not more than 12.5 colonies per square inch of surface examined, and the absence of coliform organisms indicate a satisfactory procedure. The Replicate Organism Direct Agar Contact (RODAC) agar plate (approximately 4-in.^{2} area, with slightly convex surface) method is preferred for flat surfaces. The acetate tape and filter pad method is also widely used. In the rinse solution method, a measured volume of sterile solution or nutrient broth is flushed or circulated over or through a surface. The bacterial population is found by plating or with a membrane filter. Laboratory testing of dishware and equipment is not intended for routine use but is of value for special studies and to provide specific information. There are many field meth-

TABLE 8-16 Usage Heat Loss, Interior Capacity per °F Difference between Room and Box Temperature per 24 hr

Volume (ft^3)	Heat Loss (Btu/ft^3 Service) Normal	Heat Loss (Btu/ft^3 Service) Heavy	Volume (ft^3)	Heat Loss (Btu/ft^3 Service) Normal	Heat Loss (Btu/ft^3 Service) Heavy
15	2.70	3.35	400	1.62	2.38
50	2.42	3.10	600	1.52	2.28
100	2.12	2.85	800	1.48	2.22
200	1.85	2.60	1000	1.42	2.15
300	1.70	2.45	1200	1.38	2.10

ods to determine the cleanliness of surfaces and effectiveness of cleansing materials and operations.[101–103] Some are discussed below.

Single-service eating and drinking items usually have very low bacteria counts and contribute to proper sanitation in food service. They have particular application in emergency situations and in fast-food service operations.

1. The suitability of a detergent can be roughly determined by rinsing it off the hands (if not a caustic) in the available water. It should not leave a greasy or sticky feeling. A normal solution in warm water should completely dissolve without any precipitate. Dishes and utensils should show no spots or stains. A measure of rinsability is the alcohol test. A drop of alcohol on the dry surface allowed to evaporate should leave no deposit. Another field test uses phenolphthalein. A drop of standard phenolphthalein is added to the wet surface of the utensil to be tested. If the water turns red, it is an indication of residual alkalinity and hence poor rinsing. If the pH of the tap water is above 8.3, the surface to be tested should be wetted with distilled water. The cleanliness of a glass can be observed by filling it with water and watching it drain. A clean glass would show a continuous unbroken water film; breaks in the water film would indicate unremoved soil. Metal parts, however, could have a uniform coating of soil that would not give a water break. Salt sprinkled over the utensil or equipment to be examined, while still wet, will not adhere to surfaces that have not been cleaned. A simple field test is the pouring of plain soda water in a glass. Gas bubbles will cling to unclean areas. Other aids are a good flashlight, paper tissues, filter pads, a spatula, and studied individual observation.
2. A fluorochromatic method uses a nearly colorless fluorochrome such as brilliant yellow uranine, fluorescent violet 2G, ultraviolet light (black light), and others. Dishes, for example, would be preflushed, immersed a few seconds in a fluorochrome solution, and washed in the usual

manner. The dishes on the clean-dish table are then examined under ultraviolet light. Any soil remaining would be fluorescent.

3. The efficiency of cleansing materials and operations can be determined by various methods with greater accuracy in a laboratory. Methods particularly suited for research use a standard soil, radioactive tracers, and fluorescent dyes.
4. Pots, pans, and other equipment require brushing in the detergent washing operation. Rancidity, staleness, and other off-flavors and odors in prepared foods can frequently be traced to incompletely removed food or mineral films on food preparation equipment. Three-compartment sinks, each 24 × 24 in. or 24 × 30 in., with 3-ft drainboards, and a steam or electric immersion heater or gas booster under the last two sinks are practical necessities. A mechanical pot and pan washer is also used.
5. A method of detecting residual grease and protein or starch films on china, plastic, glass, or silverware is the use of a dry mixture of 80 percent talcum dust (not commercial powder) and 20 percent safranin by weight. The mixture is placed in a saltshaker covered with cheesecloth to limit the flow and dusted over the surface of the utensil or article to be tested. It must be dry. Then hold the utensil under an open tap for at least 30 sec, tilt to drain off water, and examine for any red color. The intensity of the color is an indication of the amount of residual soil present.[104]

Proper cleansing involves the use of a washing compound or detergent suitable for the water hardness and pH; the water should have a temperature that will result in the removal of fats, proteins, and sugars, usually referred to as "soil" or organic matter. The detergent must be used in adequate amounts. Too little does not accomplish cleansing; too much means greater expense and more care and time for satisfactory rinsing.

In some cases, chemical disinfectants[105] and combination cleanser–sanitizers are used because an adequate supply of hot water is not available in the first place. As a result, some operators of eating and drinking places resort to chemical compounds in an effort to obtain clean, disinfected dishes and utensils.

Chemical disinfection is less reliable than 170 to 180°F (77–82°C) hot-water disinfection, and it retards air drying. Chemical sanitizers are not effective on dishes or utensils that are not properly cleansed. When properly used, hypochlorite solutions can produce satisfactory results. A solution strength of 100 mg/l available chlorine should be used. It can be prepared by mixing $\frac{1}{4}$ oz of $5\frac{1}{4}$ percent bleach with 1 gal of water. Immersion for at least 10 sec is required. The solution should be replaced when the concentration falls to 50 mg/l or when the water cools below 75°F.* The equivalent of a three-compartment sink is essential to rinse the soil off between the wash and disinfection step, as organic matter and milk use up chlorine, thereby making it ineffective as a disinfectant. A 200-mg/l solution is recommended when the hypochlorite is used as a spray. It should also be pointed out that chlorine turns silver black. Hypochlorite solutions affect stainless steel. Immersion for at least 1 min in a clean solution containing 12.5 to 25 mg/l of available iodine and having a pH not higher than 5.0, or as specified by the manufacturer, and at a temperature of 75 to 120°F (24–49°C) is also acceptable. If a cyanuric acid is approved for use, the required concentration is 100 mg/l for at least 1 min. With a chloramine solution, the minimum concentration should be 50 to 100 mg/l at pH 7.0 for 2 min and at pH 8.5 for at least 20 min.

Other chemical disinfectants, such as quaternary ammonium compounds, have definite limitations. Bicarbonates, sulfates, magnesium chloride, calcium chloride, and ferrous bicarbonate interfere with the bactericidal quality of quaternary ammonium compounds. Quaternaries should therefore only be used where their successful performance has been demonstrated in the establishment concerned. The limits within which satisfactory results can be ensured should be specified by the manufacturer of the sanitizer, as water chemical quality can be expected to vary from community to community. Immersion in a 200-mg/l solution for 1 min at not less than 75°F (24°C) is usually required.

The so-called detergent–sanitizer combinations have been reported to be effective under certain conditions. They are more likely to be weakened in cleansing and disinfecting power by organic matter and incompatibility under conditions of use.

Equipment should be provided and tests made by the operator to ensure that the sanitizer is maintained at the proper strength. This objective may be difficult to achieve in practice. As noted above, with the new performance-based food safety regulations and guidelines, interested parties should consult with the appropriate federal agency on acceptable agents and approved uses of sanitizing agents.

The type of dishwashing method or machine that may be used depends on the number of dishes or pieces to be washed per hour, the money available, hot-water storage and heating facilities, individual preferences, and other factors. For example, if fewer than 400 pieces are to be washed per hour, a three-compartment sink or single-tank dishwashing machine can be used. If 1200

*May drop to 55°F (13°C), provided the solution free available chlorine residual is 100 mg/l and the pH does not exceed 10.0. A temperature of 40°F (4°C) may be permitted with a residual of 100 mg/l, provided the solution pH does not exceed 8.0 and the sanitizing rinse solution contact time is at least 15 sec. (See FDA interpretation No. 5–103, August 29, 1985.)

pieces are to be washed per hour, then three three-compartment sink arrangements or one single-tank dishwashing machine may be used. If 2400 pieces are to be washed per hour, a two-tank dishwashing machine may be the best answer. It soon becomes apparent that the cost of labor alone becomes the factor to be weighed against the cost of a dishwashing machine. Manufacturers of approved-type dishwashing machines are in a position to make recommendations for specific installations.

Soiled silverware requires special handling to ensure removal of soil. It has been found that silverware that has been allowed to soak at least 15 min at 130 to 140°F (60°C) in a good detergent can be hand or machine washed with uniformly good results. Pot, pan, and utensil commercial spray-type washing machines are available as well as dishwashing and glass washing machines using a chemical sanitizing rinse.

Mold Control A temperature of 32 to 42°F (0–6°C) and humidity of 80 to 95 percent make an excellent environment for the growth of mold and yeast. The relatively high humidity in most food establishments and the incompleteness of many routine cleaning operations favor the development of molds and odors. Molds grow in refrigerators and on foods, floors, walls, ceilings, and equipment. Since mold spores are carried by air currents, packing, and dirt, they are difficult to keep out; hence, their control depends on cleaning, humidity reduction, and treatment. A recommended mold control program includes cleansing of the affected area with an alkaline detergent, spraying with a 5000-mg/l sodium hypochlorite solution with care to materials that might be harmed, drying of the hypochlorite, spraying with a 5000-mg/l quaternary ammonium compound, and then respraying of the entire section with a 400- to 500-mg/l quaternary solution every week or two.[106] Practically all off-odors in food establishments are due to decomposing food, grease, or other organic material. Their control rests on proper design and routine cleanliness. The use of deodorants or special odorous disinfectants temporarily masks the odor but cannot substitute for a warm detergent solution and "elbow grease." Ozone generators may be used to prevent the growth of molds and spores as well as to deodorize and freshen, maintain a sterile atmosphere, and slow the ripening of certain fruits and vegetables.

Hand Dishwashing, Floor Plans, and Designs

For hand washing, a three-compartment sink and long-handled wire baskets are required. See Figure 8-11. The following steps are recommended:

1. *Scrape and flush* all dishes and utensils promptly—before the food soil has a chance to dry. A spray-type flusher delivering water under pressure at a temperature of 120°F (49°C) or a pan of hot water and brush will remove most of the heavy soil.

2. *Wash* in the first compartment with water at a temperature of 110 to 120°F (43–49°C) using an effective washing compound (detergent). The detergent solution strength must be maintained. Glasses will require brushing; wash, rinse, and sanitize separately from dishes.
3. *Rinse* in the second compartment by immersion in hot water. The dishes, cups, and utensils from the washing operation can be placed directly in the wire basket, previously submerged in this sink, to save an extra handling. Place cups and glasses in a venting position. A hot-water spray is also suitable for rinsing if thoroughly used and the drain is kept open.
4. *Sanitize* in the third compartment by immersing the basket of dishes in water at a temperature of 170 to 180°F (77–82°C) or higher for at least 30 sec, although 2 min is generally recommended. Steps 3 and 4 can also be accomplished by thorough spraying of carefully racked dishes with 180°F water in a properly designed and maintained single-tank stationary-rack dishwashing machine or in an improvised spray–rinse cabinet.
5. *Air dry*—do not towel! Toweling is an expensive, time-consuming, and unsanitary operation. Towels become moist and warm and are collectors and spreaders of germs. Store dishes, cups, and utensils in a clean, dry place and handle them in a sanitary manner. Cups should face down; knives, forks, and spoons with handles up. Dishes and utensils properly sanitized with scalding hot water will dry in less than 1 min. Plastic dishes will take longer unless a drying agent is used in the rinse water.

Glass washing becomes a special problem where facilities are inadequate. The glass, being transparent, is subject to critical visual inspection on being raised to one's lips, thereby creating the demand for a glass that looks clean. In any case, glasses should receive cleansing and sanitization treatment equal to that given dishes and utensils. A procedure that has been found effective requires the washing of glasses separately from dishes and includes the following steps:

1. *Remove* cigarette butts, papers, ice, liquid, and straws. Then prerinse the glasses with warm water to remove milk and syrup. This will also warm up the glasses and prevent them from cracking when placed in hot water. If glasses cannot be prerinsed promptly, soak them under warm water to prevent the milk, syrup, and soil from hardening.
2. *Wash* glasses in warm [110–120°F (43–49°C)] water containing an organic acid detergent using a stiff bristle brush to remove lipstick and stubborn soil. Stationary and motor-driven cluster-type brushes that are placed in the bottom of wash tanks are available.
3. *Rinse* the glasses in clean warm water or in a hot-water spray. If a basket is used, care should be taken to stack the glasses in a venting position. Use a special basket that holds glasses in place.

4. *Sanitize* the glasses as described for dishes (item 4) or in clear hot water containing $\frac{1}{4}$ oz of $5\frac{1}{4}$ percent hypochlorite solution per gal (100 mg/l) of water in the sink. Make up a fresh tank of hot water and chlorine solution when the water cools to below 75°F (24°C) or the solution strength is less than 50 mg/l available chlorine. Provide a minimum 10 sec of contact. A water softener or a special solution added to the final rinse tank may prevent the formation of spots. Drying the bottom of the glass will also help prevent the formation of spots. Quaternaries and iodophors may also be reliable disinfectants under controlled conditions.
5. *Air dry* the glasses by placing them bottom up on a wire or plastic draining and drying rack after the disinfecting rinse. Do not towel dry the glasses.

Some establishments have found it more convenient to wash and sanitize glasses in the kitchen sinks or dishwasher instead of at the fountain or bar. Although this procedure will entail keeping a somewhat larger stock of glasses, it is offset by increased efficiency, less confusion at the counter, and improved service. Where a dishwasher is used, the glasses should be washed before the dishes. If this is not possible, the dishwasher should be thoroughly cleaned, new detergent solution made up for the wash tank, and fresh rinse water added in a two-tank machine before the glasses are washed. Special hot-water glass washers and sanitizers that greatly simplify the entire cleansing routine are also available. In either case, glasses should first be washed in a sink with stationary or rotating brushes and washing solution to ensure the consistent removal of all lipstick and stubborn soil. Glasses that have become coated or clouded can be made sparkling clean by soaking in an organic acid solution similar to that used in the dairy farm or milk plant for milk-stone removal or by the use of an organic acid detergent. Where equipment and personnel are not available to produce clean glasses, paper cups should be used. Paper service for drinking water, ice cream, milk, and other drinks will greatly reduce the dishwashing problem and frequently improve public relations.

A fundamental objective in the design of a dishwashing space is the continuous movement of dirty dishes through the cleansing operation to the point of distribution or storage without interruption or pile-up. This requires an efficient floor plan that eliminates confusion and provides adequate soiled-dish drainboard, space for air drying of long-handled baskets, an adequate number of long-handled baskets, sufficient personnel, and properly designed water-heating facilities. Some floor plans or flow diagrams are shown in Figure 8-11. In operation, an extra long-handled basket can be kept in the rinse compartment when the wash and rinse tanks are adjoining. Then as dishes are washed, they can be placed directly in the basket to be rinsed, sanitized, and air dried without further individual handling. If the wash and rinse tanks are not adjoining, the basket can be placed on the drainboard alongside the wash tank. In small establishments, one person can perform all operations. During rush periods or when the number of dishes is large, the tasks can be divided between two persons, extra wash tanks provided as illustrated, or duplicate three-compartment sink arrangements can be installed. About 400 pieces can be washed per hour.

Hot-Water Requirements for Hand Dishwashing Maintenance of the water in the sanitizing compartment at the proper temperature requires auxiliary heat. This is also desirable in the wash and rinse compartments, unless the water is replaced frequently. A gas burner beneath an insulated sink or an electric immersion heat in or under the sink are the common methods of keeping the water in the third compartment at 180°F (82°C) or higher. Other heat sources are gas- or oil-burning units, steam and hot-water jackets, ''side-arm'' heaters, or the equivalent. Consult with manufacturer's representative.

Thermostats that automatically control water temperatures and tank insulation are useful accessories that help maintain proper water temperatures and reduce heat losses. A thermometer installed on the third compartment is necessary to show the dish washer when the water is at disinfection temperature. Thermometers on the wash and rinse tanks are also useful. When an open flame is used beneath the sink to heat the water, a copper sheet placed against the sink bottom will prevent burning out the bottom of the sink. Dial thermometers and gages are frequently inaccurate. They should be checked against a reliable standard. If an adequate number of sinks is not available, a 20-gal pot of hot water can be kept on a stove and dishes immersed in boiling water with the aid of a special basket as a temporary expedient. The three-can method used by the U.S. Army is very satisfactory for field use. The first can contains hot water with a detergent and brush, the second can boiling water for rinsing, and the third can boiling water for sterilization. An under-sink gas heater requires a vent.

An example is given below showing the calculation of the amount of energy required to heat water in sinks.

Given: A sink 18 in. × 24 in. contains 12 in. of water at a temperature of 120°F (49°C). The sink is open at the top and uninsulated. One cubic foot of water weighs 62.4 lb. Room temperature is 80°F (27°C). Water surface loss is approximately 1430 Btu for 100°F (38°C) temperature difference per hour per square foot. For 80°F temperature difference the loss is 940 Btu, and for 120°F the loss is 2320 Btu. Failure to insulate the tank results in a heat loss of 215 Btu/ft^2/hr when the temperature of the hot water is 180°F (82°C) and the air temperature is 70°F (21°C), or about 1.95 Btu/hr/°F/ft^2.

Required: The heat energy to keep the water temperature at 180°F, with air temperature at 80°F, to disinfect 100 to 400 pieces per hour. Assume the temperature of the wash water is 100°F, and a dish, saucer, and cup weigh 2 to 3 lb; say 3 lb or an average of 1 lb per piece. The specific heat, or the amount of heat required to raise 1 lb of crockery one degree, is 0.22 Btu. The specific heat of water is 1.00 Btu/lb at 39°F (4°C).

1. Heat loss through sides and bottom of sink with no insulation, in Btu/hr	=	ft^2 of surface area × wall loss in Btu/per hr deg × deg temperature difference between water and room
	=	10 × 1.95 × 100
	=	1950 Btu/hr
2. Heat loss from open water surface, in Btu/hr	=	ft^2 of water surface × surface loss in Btu for 100°F temperature difference between water and room
	=	3 × 1430
	=	4290 Btu/hr
3. Heat absorbed by 100 dishes, in Btu/hr	=	weight of dishes in lb × specific heat of crockery in Btu × temperature rise in deg
	=	100 × 0.22 = 100
	=	2200 Btu/hr
4. Heat required to raise temperature of water in sink 18 × 24 in. containing 12 in. water from 120 to 180°F, in Btu/hr	=	lb of water × specific heat of water × total temperature rise (rather than average)
	=	(1.5 × 2 × 1)62.4 × 1 × 60
	=	11,250 Btu/hr

Therefore: The total heat loss is the sum of the loss from the sink sidewalls and bottom, water surface, and heat absorbed by the crockery sanitized in 1 hour.

Total heat loss for—100 pieces = 1950 + 4290 + 2200 = 8440 Btu/hr
(after temperature of 180°F is reached)—200 pieces = 6240 + 2(2200) = 10,640 Btu/hr
—300 pieces = 6240 + 3(2200) = 12,840 Btu hr
—400 pieces = 6240 + 4(2200) = 15,040 Btu hr

The heater provided should be at least capable of conducting 11,250 Btu/hr to the water in the sink. This heat will be adequate to disinfect about 250 pieces per hour as noted above. If 400 pieces are to be disinfected per hour, the heater should be capable of conducting 15,040 Btu/hr. Hence, an electric immersion heater would have

$$\text{Capacity} = \frac{15{,}040}{3412} = 4.5 \text{ kW/hr}$$

An open-gas flame heater, being only about 50 percent efficient overall, would have

$$\text{Capacity} = \frac{15{,}040}{0.50} = 30{,}080 \text{ Btu/hr}$$

Note: The wall heat loss of the sink can be reduced to approximately 0.24 Btu per degree temperature difference per hour with 3-in. insulation. The water surface heat loss of 4290 Btu during buildup of water temperature can be reduced to 429 Btu ($\frac{1}{10}$) by providing an insulating cover. One kilowatt-hour (kW-hr) = 3413 Btu/hr.

Electric immersion heaters for sinks require a 115-V circuit for the lower capacities of 1500 to 3000 W and a 230-V circuit for the higher capacities, thermostat control, variable or three-point heat switch, and burnout protection or low-water cutoff controls. Immersion heaters are commercially available. If sink bottom and wall insulation is omitted, radiation heat losses will be increased by about eight times and must be compensated for by increased wattage.

Where a gas or oil burner is used beneath a sink, *precautions must be taken to fire retard the space around the burner*. Consult with the local utility company. This space should be vented to the outer air and a flame guard provided. In addition, a copper sheet placed between the flame and the bottom of a stainless steel or other type of sink will prevent burning out of the bottom. The American Gas Association recommends, for furnishing 180°F (82°C) water in sinks supplied with 140°F (60°C) inlet water, the following gas burner inputs in Btu per hour for under-sink burners:

26,000 Btu/hr for 16 × 16 to 18 × 18-in. sinks,
30,000 Btu/hr for 18 × 20 to 20 × 20-in. sinks,
34,000 Btu/hr for 20 × 20 to 22 × 22-in. sinks, and
38,000 Btu/hr for 22 × 24 to 24 × 24-in. sinks.[107]

For example, a sink 24 × 24 in. with 12 in. of water will hold (2 × 2 × 1)62.4 = 249.6 lb of water. If the water enters at 120°F and is to be heated to 180°F, the heat required equals 249.6 × 60 = 14,976.0 Btu/hr. The heat loss through the bottom and sides of the tank without insulation is equal to surface area × wall loss × degrees temperature difference between water and room, or 12 × 1.95 × 100 = 2340 Btu/hr. Heat loss from open water surface is 1430 Btu/ft^2 for a 100°F temperature difference, which for 4 ft^2 = 5720 Btu. The total heat loss, assuming a 1-hr temperature buildup, is = 14,976 $\frac{1}{2}$ (2340) + $\frac{1}{2}$ (5720) = 19,006 Btu. With an open-gas flame heater assumed to have an overall efficiency of 50 percent, the heat input is 19,006/0.50 = 38,000 Btu/hr.

Machine Dishwashing, Floor Plans, and Designs

When more than about 400 dishes and cups must be washed per hour, either a duplicate three-compartment sink and drainboard installation is required or a mechanical dishwasher should be provided. Of course, a dishwashing machine can be provided regardless of the number of dishes washed. Machines are available to serve the average household and up to 50, 125, 250, 400, or 3000 persons.* In any case, the equipment, including the hot-water supply, must always be proper and adequate to meet peak operating requirements. Since the average person does not know which dishwashing machines will produce satisfactory results, the recommendations of the National Sanitation Foundation should serve as a guide and a machine purchased that bears its mark or its equal.

For proper machine dishwashing, the following steps are recommended to help ensure consistently satisfactory results:

1. *Scrape* All dishes should be scraped clean of food and soil by hand or with a rubber scraper. This operation can also be accomplished by a pressure water spray or a large recirculated stream of water at a temperature of about 110°F (43°C). A garbage grinder or food-waste disposer is a very desirable unit to incorporate in this operation. The dishwashing layout should provide a soiled-dish table equipped with a removable strainer the width of the table, just ahead of the machine, to intercept liquid garbage before it enters the dishwashing machine.
2. *Rack Dishes* Place dishes in racks or on the conveyor belt. Do not stack or otherwise overcrowd the dishes. Spray the rack of dishes with a manual preflusher delivering water at a temperature of 140°F (60°C) under pressure or preflush each dish by hand. See Figures 8-12 and 8-13.
3. *Wash and Sanitize* Feed racked dishes into the dishwashing machine at the established speed for the machine. The time for the wash and rinse cycles, the volume and temperature of water required, and other details for each type of machine are given in Tables 8-17 and 8-18. For satisfactory results, the proper use of a good washing compound or detergent suitable for the water hardness is necessary. The concentration of detergent should be maintained at 0.2 to 0.3 percent. This can be obtained at the beginning with about 1 lb or $1\frac{2}{3}$ cups of washing powder to 50 gal of fresh wash water. But the detergent must be supplemented during the dishwashing operation to compensate for the soil, rinse water, and make-up water entering the wash-water tank and diluting the detergent concentration. This is accomplished by automatic detergent feeders or by hand feeding detergent. Follow the manufacturers' directions. Studies show that the detergent concentration becomes ineffectual after 10 to 15 racks of dishes are washed. An automatic detergent feeder

*Machines are available with operating capacities as high as 450 racks (20 × 20) and 15,000 to 22,000 dishes per hour. (See *Listing of Food Service Equipment,* National Sanitation Foundation, Ann Arbor, MI.)

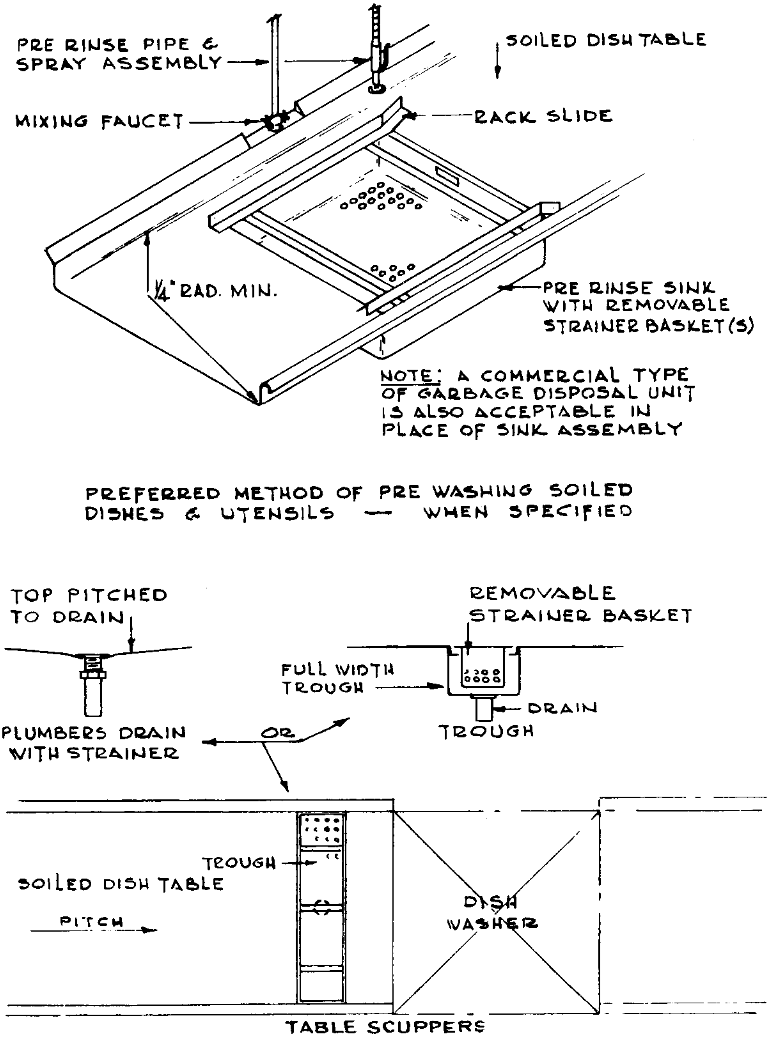


Figure 8-12 Cleaning facilities and accessories. (*Source: Food Service Equipment Standards.* NSF International, P.O. Box 130140, 789 N. Dixboro Road, Ann Arbor, MI 48113, September 1978, pp. 45–46.)

requires cleaning after each dishwashing period, just like a dishwashing machine. Another problem concerns the wash- and rinse-water temperatures. Provision for heating the water in the dishwashing machine wash tank or tanks is often made by the manufacturer, but this should be checked under operating conditions. The connection of an adequate volume of 180°F (82°C) water to the machine final spray-rinse line is usually under a separate contract and is often neglected, unless the machine

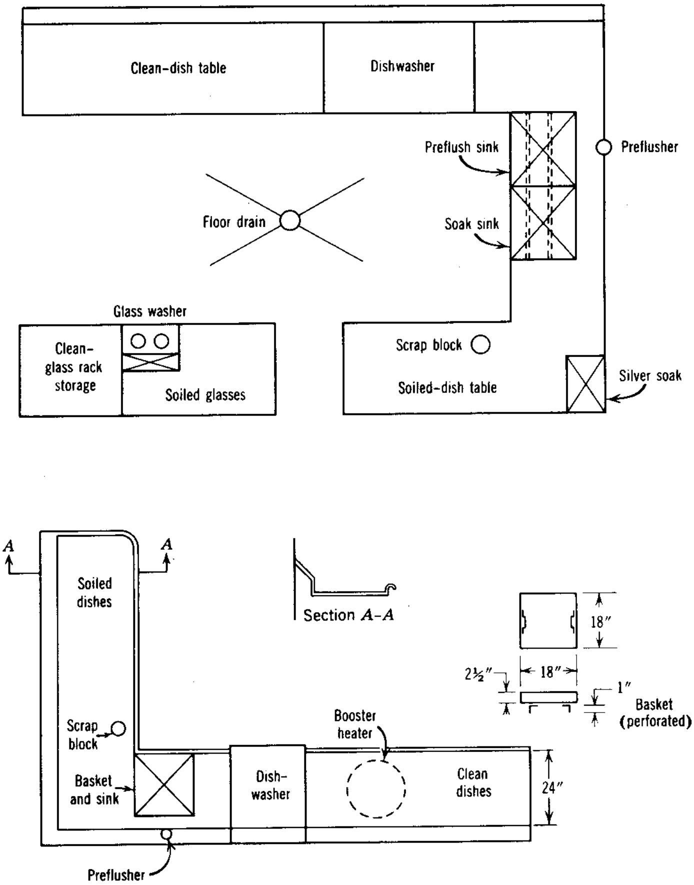


Figure 8-13 Dishwashing arrangements—machine.

representative, designing architect or engineer, health official, or plumbing contractor calls attention to the need. This problem and its solutions are discussed separately under Hot Water for General Utility Purposes in this chapter.

In a single-tank pot, pan, and utensil washer, the wash temperature is 150°F (66°C) and the final rinse is 180°F (82°C). A water temperature of 165°F (74°C) may be acceptable in a single-tank, stationary-rack, single-temperature machine. Some dishwashing machine hot-water sanitizing rinse cycles are being converted or designed for chemical sanitization; however, corrosion of machine parts may become a problem.

4. *Air Dry* Dishes should be air dried while in the racks. If rinsed at the proper temperature, china dishes will dry in less than 1 min. Plastic cups, dishes, and trays dry slowly. Plastic is hydrophobic, causing water to form in droplets that take longer to evaporate than a film. Drying

TABLE 8-17 Stationary–Rack Dishwashing Machine—Wash- and Rinse-Water Volume, Temperature, and Time

	150–160°F Wash Cycle per Rack[a]			Alternate Wash Cycle per Rack[b]		Rinse, 180–195°F[c]	
Rack (in.)	Water Volume (gal)	Time; Not Less Than (sec)	Pump Capacity (gpm)	Water Volume (gal)	Minimum Pump Capacity (gpm)	Time; Not Less Than (sec)	Water Volume (gal) 20 psi
20 × 20	92	40	140	92	75	10	1.73
18 × 18	75	40	112	75	50	10	1.44
16 × 16	60	40	90	60	40	10	1.15
Other	0.23 × rack, area, in^2	40	0.35 × rack area, in^2	0.23 × rack area, in^2	0.15 × rack area, in^2	10	0.43 gal/100 in^2 of rack area

Source: Adapted from NSF International, *Food Service Equipment Standards,* September 1978, pp. 87–89 (NSF International, P.O. Box 130140, 789 N. Dixboro Road, Ann Arbor, MI 48113). See Standard No. 5 for hot-water equipment.

Note: This is illustrative. See manufacturer and local health department for specific requirements; also PHS/FDA *Food Service Sanitation Manual,* 1976.

[a] Wash-water temperature thermostatically maintained at 150–160°F. Temperature not less than 165°F in single-temperature door-type machine.

[b] Time of wash cycle increased beyond 40 sec to apply not less than the indicated volume of wash water per rack.

[c] Rinse-water flow pressure on line at machine controlled between 15 and 25 lb. (A pressure control valve adjusted to keep the line pressure at 20 psi at all times is strongly recommended. If pressure in line can fall below 15 psi, a hydraulic analysis and correction are required.) In single-temperature door-type machine, minimum rinse time shall be 30 sec and spray volume 23 gal for each 400 in^2 of rack area, wash- and rinse-water temperature 165°F; used rinse water is discharged to waste.

TABLE 8-18 Conveyor Dishwashing Machine–Wash and Rinse Water Volume, Temperature, and Time

	Wash Cycle[a]			Recirculated Rinse, 160°F[b]			Final Rinse, 180–195°F
Machine Type	Volume of Water per Linear Inch of Conveyor Length	Minimum Period of Wash (sec)	Pump Capacity (gpm)	Volume of Water per Linear Inch of Conveyor Length	Minimum Period of Rinse (sec)	Pump Capacity (gpm)	Minimum Flow
Single-tank conveyor (dishes prewashed or water scraped)	3 gal/20-in. width; 2.7 gal/18-in. width; 3.3 gal/22-in. width; 3.6 gal/24-in. width (160° minimum)	15	140	None	—	—	6.94 gpm across conveyor to cover space of at least 6 in. in direction of travel measured 5 in. above conveyor, with rack or conveyor width of 20 in.
Multiple-tank conveyor with dishes in inclined position or in racks (dishes prewashed or water scraped)	1.65 gal/20-in. width; 1.48 gal/18-in. width; 1.82 gal/22-in. width; 1.98 gal/24-in. width (150°F minimum)	7	125	1.65 gal/20-in. width; 1.48 gal/18-in. width; 1.82 gal/22-in. width; 1.98 gal/24-in. width	7	125	4.62 gpm across conveyor to cover space of at least 3 in. in direction of travel measured 5 in. above conveyor with conveyor width of 20 in.

Source: Adapted from NSF International, *Food Service Equipment Standards,* September 1978, pp. 90–92 (NSF International, P.O. Box 130140, 789 N. Dixboro Road, Ann Arbor, MI 48113). See Standard No. 5 for hot-water supply and equipment.

Note: This is illustrative. See manufacturer and local health department for specific requirements; also PHS/FDA *Food Service Sanitation Manual,* 1976.

[a] Each linear inch sprayed from above and below.

[b] Rinse-water flow pressure on line at machine controlled between 15 and 25 lb. (A pressure control valve adjusted to keep the line pressure at 20 psi at all times is strongly recommended. If pressure in line can fall below 15 psi, a hydraulic analysis and correction are required.) Conveyor speed 7 fpm maximum for single-tank and 15 fpm maximum for multiple-tank conveyor.

agents are available that can be fed into the rinse water, thereby overcoming this difficulty. Sufficient space on an airy dish table is necessary for the air drying to take place promptly. Consideration should be given to adequate ventilation to prevent condensation. The use of lower temperature final rinse water will prolong air drying and introduce potential problems of storage, bacterial growth, and service of wet dishes and utensils.

Design should provide for some wasted rinse water due to inefficiency in operation; in practice, machines are not operated without interruption and are racks are not always fully loaded. Some designers say the machine is actually in operation only about two-thirds of any hour, add 50 percent should be added to the hourly flow to compensate for wasted 180°F (82°C) rinse water such as with partially filled racks or conveyors. Check actual rinse water usage with manufacturer and actual water flow under operating conditions. Flow is based on 20 psi at machine. Do not use a push-through-type machine as the amount of rinse water depends on the ''human element''; require automatic wash and rinse timers. Assume a 20 × 20-in. rack holds 24 pieces, an 18 × 18-in. rack 20 pieces, and a 16 × 16-in. rack 16 pieces. A common estimate is that an average complete restaurant meal results in 8 dishes or pieces, a luncheon in 6 pieces, a cafeteria meal in 4 pieces, and an elaborate dinner in 10 pieces.

An efficient floor plan adapted to each establishment is necessary to realize the advantages associated with the use of a dishwashing plan. Some plans that show the essential elements are illustrated in Figures 8-8, 8-9, and 8-13.

Hot-Water Requirements for Machine Dishwashing* To meet the hot-water demands of a dishwashing machine, it is necessary to have a separate heater and storage tank, a two-stage heater, a separate instantaneous heater, or a booster heater. Thermostatic hot-water controls, including a flow control valve or pressure-reducing valve close to the dishwashing machine, and a hot-water circulation pump will help ensure a dependable water supply at proper temperature. A vacuum breaker† is necessary at the high point before the hot-water line enters the machine to prevent possible backflow of wastewater. The machine drain must not as a rule connect directly to a waste, soil, or drain pipe. See Figures 8-14 and 8-15. The required volume of hot wash and rinse water is indicated in Tables 8-17 and 8-18. To this should be added the amount of water required to fill the wash and recirculating rinse tanks.

*For design details, see ref. 108.

† American Society of Sanitary Engineers (ASSE) Standard No. 1001, *Pipe Applied Atmospheric Type Vacuum Breakers,* to be installed in accordance with ASSE No. 1004, Commercial Dishwashing Machines.

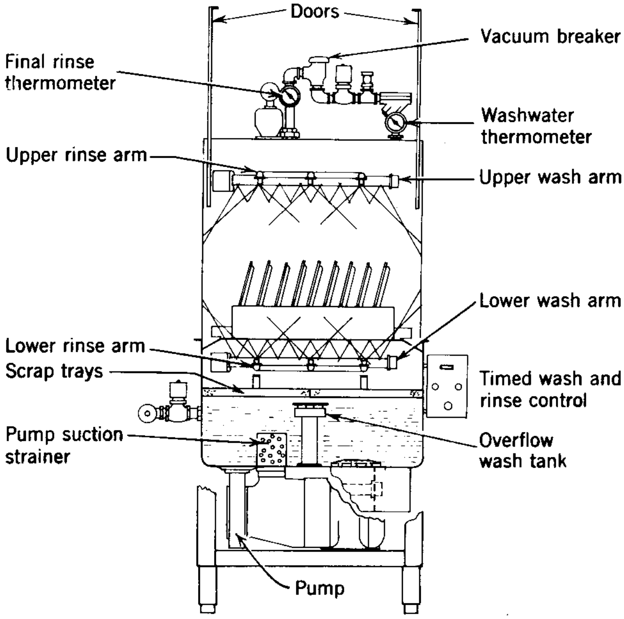


Figure 8-14 Stationary rack door-type machine. Illustrative only. (*Source: Food Service Equipment Standards,* NSF International, P.O. Box 130140, 789 N. Dixboro Road, Ann Arbor, MI 48113, September 1978, p. 88.)

1. Fluctuations in water pressure due to large demands and hydraulic friction losses will cause variations in the rate of flow. This is apparent from the basic hydraulic formula

$$Q = VA$$

where Q = rate of flow, cfs
V = velocity of the water, fps
A = area of the pipe, ft^2

But

$$V = \sqrt{2gh} \quad \text{and} \quad h = g/w$$

where g = 32.2 fps/sec
h = head of water, ft
p = water pressure, lb/ft^2
w = 62.4 lb/ft^3 for water

It can be seen therefore that a change in velocity, pipe diameter, or water pressure will cause a change in flow, and similarly a change in water flow

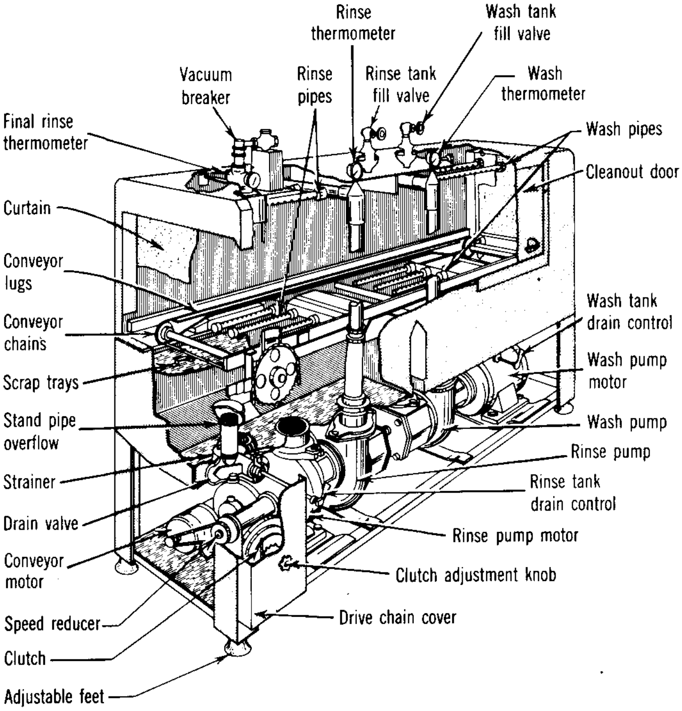


Figure 8-15 Single-tank conveyor-type machine. Illustrative only. (*Source: National Sanitation Foundation Standards,* Standard No. 3, "Commercial Spray-Type Dishwashing Machines," NSF International, P.O. Box 130140, 789 N. Dixboro Road, Ann Arbor, MI 48113, April 1965.)

will cause a change in velocity or pressure. It should be cautioned that many waters are hard or corrosive. Most hard waters contain minerals that form a scale on the inside of pipe when heated and corrosive waters erode the inside of pipe, both of which conditions increase the friction and, hence, reduce the flow of water to the dishwashing machine. The removal of hardness and control of corrosion are discussed in Chapter 3.

2. The provision of a pressure-reducing valve on the 180°F (82°C) rinse line at the machine will ensure that a larger volume of 180°F hot water will not be used by the machine than that for which the water heater was designed, or is needed, for proper functioning of the machine. The pressure-reducing valve should be set to maintain the water pressure at the machine preferably at 20 psi. If a larger volume of hot water is permitted to be used by the machine, due to a higher water pressure or manipulation of valves, the water heater will be overloaded beyond the design capacity, resulting in a higher water consumption and, hence, lower than 180°F water being delivered to the dishwashing machine.

3. On the other hand, if the water pressure in the rinse line is less than 15 psi under conditions of maximum use, there will be an inadequate volume of

180°F rinse water delivered to the dishwashing machine to do the intended rinsing and disinfection job. This would call for a hydraulic analysis and perhaps a booster pump. A pressure in excess of 25 psi will result in atomization or a fine-mist spray at the nozzles, which is not effective in rinsing. By maintaining the water pressure within the established limits, the hot-water rinse line of a known length, and the diameter usually not less than 1 in., it is possible to ensure the required rate of hot rinse-water flow. Hence, failure to deliver 180°F rinse water will immediately indicate an inadequate heater or heater and storage tank or, in an old installation, excessive friction in the water lines. There should be no shutoff valves or drawoffs between the heater and dishwashing machine. A partial closure of a valve on the line will result in a higher hot-water temperature or inadequate flow of rinse water. Drawoffs between the heater and dishwashing machine will reduce the water pressure in the line and the available volume of 180°F water to the machine.

The required size or capacity of the water heater to serve a dishwashing machine, kitchen fixtures, hand-washing sinks, and miscellaneous outlets can be estimated. Two design temperatures are used: 140 to 150°F (60–66°C) for general utility purposes and 180 to 200°F (82–93°C) for the dishwashing machine. The heating system must be designed to meet the estimated peak hot-water demands for its duration as well as normal hot-water needs. Several methods for computing hot-water requirements are given here. Low-temperature chemical-type machines may not remove encrusted or baked-on food particles from dishware at all times.

1. One method suggested by a manufacturer of heating equipment is based on the experience that the amount of hot water required per meal, including the peak hot-water demand, will average 1.8 gal.[109] This is divided as follows:

28 percent for food preparation, pot and pan washing, and so on, lasting 2 to $2\frac{1}{2}$ hr.

55 percent for dishwashing and related activities carried on at same time, lasting 1 hr or more; and

17 percent for utensil and equipment cleaning and general cleanup, lasting 1 to $1\frac{1}{2}$ hr.

An average usage of 1.8 gal per person per meal with a very similar distribution is suggested in the *Cornell Miscellaneous Bulletin*.[110] With a 1-hr dishwashing period, it is apparent that the maximum demand to be designed for is 55 percent of 1.8 gal or 1.0 gal/hr per meal served during the heaviest 1-hr feeding period. If the dishwashing period for the same number of dishes is extended over a 2-hr period, the rinse-water requirement would be at the rate of 0.5 gal/hr per meal. At restaurants serving light meals, the peak flow is estimated at 0.7 gal/hour per meal; at school lunchrooms and cafeterias, 0.7 to 0.8 gal; and 1.2 gal where elaborate meals are served.

2. Another method of estimating the hourly hot-water needs is to count the maximum number of dish racks to be washed and rinsed in 1 hr. Knowing the amount of rinse water used per rack from Table 8-17 or the manufacturer, it is a simple matter to compute the total amount of 180°F rinse water used per hour. Add to this the amount of water required to fill the dishwasher tank or tanks. For example, if 1.25 gal of 180°F (82°C) rinse water is used per 18 × 18-in. rack and a rack is washed every 50 sec, which is the maximum possible in a timed single-tank machine set to wash 40 sec and rinse 10 sec, then a maximum of 90 gal will be used in 1 hr. If the wash-water tank holds 20 gal, the total amount of water used in a maximum hour would be 110 gal. In practice, it is sometimes assumed that racks can be fed at a maximum rate of one per minute in a single-tank stationary-rack dishwasher, or 60 racks per hour, which would mean a water consumption of 75 gal/hr, with 18 × 18-in. racks, rather than 90 gal.

3. The American Gas Association suggests that 0.8 gal of 180°F water is used per meal in a single-tank dishwashing machine and 0.5 gal per meal in a two-tank dishwashing machine, in addition to 1.2 gal of 140°F (60°C) water per meal. It is assumed that eight dishes are used per meal.

4. *Design calculations*. The required heater capacity in Btu can be calculated from the formula

$$\text{Btu} = \frac{\text{gph} \times 8.3 \times \text{temperature rise}}{\text{overall efficiency}}$$

where Btu = required input rating of the heater
gph = gallons per hour of 180°F water required, usually heated to 190°F (88°C) when the heater is located some distance from the dishwasher
8.3 = weight of a gallon of water, lb
Temperature rise = temperature of water as it leaves the heater minus the temperature of the water entering the heater
Overall efficiency* = overall heating system efficiency of gas may be taken at 75 percent provided the heater and storage tank, if provided, are insulated.

Water heaters hold between 2 to 5 gal and 10 gal in the coils or surrounding heating tubes; this water is available to meet a momentary demand. The heat loss from long runs of pipe can be appreciable. Table 8-19 gives the heat loss from bare and insulated pipe.

*The thermal efficiency of electric heaters may be taken at 98 percent; gas heaters at 75 percent; steam boilers at 80 percent; oil heaters at 60 percent; and coal-fired heaters at 50 percent. One cubic foot of natural gas = 1050 Btu. See local utility company for other ratings. Btu ratings can be reduced 4 percent for each 1000 ft above sea level, higher than 2000 ft. One gallon of No. 2 fuel oil contains approximately 138,000 Btu.

TABLE 8-19 Heat Loss from Pipe Carrying Hot Water: Btu per Hour Heat Loss per Linear Foot of Horizontal Pipe in Still 70° F Air Carrying Hot Water at Temperature Stated[a]

Nominal Pipe Size (in.)	Bare Iron Pipe			Insulated Pipe, 85% Magnesia, 1-in.		
	120°F	150°F	180°F	120°F	150°F	180°F
$\frac{1}{2}$	27.2	45.8	66.6	8.2	13.3	18.5
$\frac{3}{4}$	33.0	55.2	80.2	9.3	15.0	20.9
1	39.5	66.3	96.6	10.5	17.1	23.8
$1\frac{1}{4}$	48.9	81.8	119.5	12.2	19.8	27.6
$1\frac{1}{2}$	54.5	92.0	134.1	13.3	21.5	30.0

[a]Does not include Btu needed to reheat water in pipes. For example, 10 ft of 1-in. pipe holds 1 gal and will require 415 Btu to raise its temperature 50°F, or wasting of water until 180°F water is obtained at the machine or outlet.

5. *Example*: A restaurant serves a maximum of 450 meals. Dishes are to be washed over a period of $1\frac{1}{2}$ hr. What type of dishwasher should be used? Several types of dishwashers are shown in Figures 8-14 through 8-16. What heater and storage tank capacities are needed if the temperature of the incoming water to the heater is 40°F (4°C)? If an average meal uses 6 pieces and a 20 × 20-in. rack is used that holds 24 pieces, each rack will hold the dishes from 4 meals. With dishes from 450 meals to be washed in $1\frac{1}{2}$ hr or 300 meals in 1 hr, a total of 300/4 = 75 racks are to be washed per hour. If 18 × 18-in. racks that hold 20 pieces are used, each rack will hold the dishes from 20/6, or 3.33, meals. With dishes from 300 meals to be washed in 1 hr, a total of 300/3.33 = 90 racks are to be washed per hour. The dishwashing machine that meets these requirements should be selected.

The machine selected may be a single-tank rack-conveyor dishwasher or a multiple-tank rack-conveyor dishwasher. Assume that a single-tank 18 × 18-in. rack-conveyor dishwasher is selected that uses 1.73 gal of 180°F (82°C) rinse water per rack of dishes. With 90 racks to be washed per hour, the hot rinse-water requirement would be 90 × 1.73 = 156 gph. (At the mechanical capacity, this machine would use 416 gph and process 240 racks.) To this should be added the water to fill the dishwashing machine wash tank, say 25 gal, making a total of 181 gph. If no storage is provided, the required gas heater capacity is

$$\frac{181 \times 8.3 \times (190 - 40)}{0.75} = 300{,}500 \text{ Btu/hr}$$

If an electric heater were designed for, its capacity would be

$$\frac{181 \times 8.3 \times (190 - 40)}{0.98} = 230{,}000 \text{ Btu/hr}$$

or, since 1 kW-hr = 3412 Btu, the electric heater would have a capacity of

$$\frac{230{,}000}{3{,}412} = 67.4 \text{ kW/hr}$$

It may be more practical to use an electric heater as a booster adjacent to the dishwashing machine to raise the rinse water from 140 to 180°F (60 to 82°C).

If a 120-gal storage tank is provided and the interval between meal periods is 4 hr, a lesser capacity heater would be required as follows: A 120-gal storage tank has an available storage of about 75 percent, or 90 gal, leaving 181 − 90, or 91, gph to be met instantaneously by the heater. The required gas heater capacity (adequate for $1\frac{1}{2}$ hr dishwashing period) under these circumstances would be

$$\frac{(\frac{90}{4} + 91) \times 8.3 \times (190 - 40)}{0.75} = 188{,}000 \text{ Btu/hr}$$

If a multiple-tank rack-conveyor dishwasher is used, say, 0.5 gal of 180°F rinse water is used per rack of dishes or equivalent. With 90 racks of dishes to be washed per hour, the hot rinse-water requirement would be 90 × 0.5 = 45 gph. Adding the water needed to fill the two dishwasher tanks of 60 gal (see manufacturer's catalog), a total of 105 gal must be designed for. If no storage tank is provided, the required heater capacity would be

$$\frac{105 \times 8.3 \times (190 - 40)}{0.75} = 174{,}000 \text{ Btu/hr}$$

If a 120-gal storage tank is provided (90 gal available) and the interval between meals is 4 hr, the required heater capacity would be

$$\frac{(\frac{90}{4} + 105 - 90) \times 8.3 \times (190 - 40)}{0.75} = 62{,}000 \text{ Btu/hr}$$

This is adequate for a dishwashing period of $1\frac{1}{3}$ hr, assuming 180°F water is used to fill the two dishwasher tanks. If it is considered that the 120-gal storage tank must be heated to obtain 90 gal, the required heater capacity would be

$$\frac{(\frac{120}{4} + 105 - 90) \times 8.3 \times (190 - 40)}{0.75} = 75{,}000 \text{ Btu/hr}$$

This would be adequate for a 2-hr dishwashing period.

6. Some designers add a factor of safety of 50 to 100 percent to the required heater capacity or, preferably, design for the mechanical capacity of the dishwashing machine. A common practice is the provision of a storage tank for the storage of all water at a temperature of 140°F. This tank supplies the 140°F needs and feeds the heater or booster supplying 180°F water. Several water heater flow diagrams are given in Figure 8-17.

7. For the problem given, in which dishes from 300 meals are washed, method 1 would call for 300 gal of 180°F water/hr; method 5 would require 181 gal; and method 3 would require 240 gal with a single-tank machine and 150 gal with a two-tank machine plus, if not included, water to fill the one or two tanks. In view of the possible variations, it is important that the most probable hot-water requirements peculiar to the establishment under consideration be carefully studied and the best possible estimate made for design purposes. Such factors as type of meals, number of dishes, equipment available, possibilities for hot-water waste, type of personnel and supervision, dishes to be washed per hour, water pressure, and type of dishwashing machine all have an effect on the hot-water requirements. National Sanitation Foundation Standard 5 gives sample calculations and graphs to simplify selection of gas and electric heaters for rinse water.

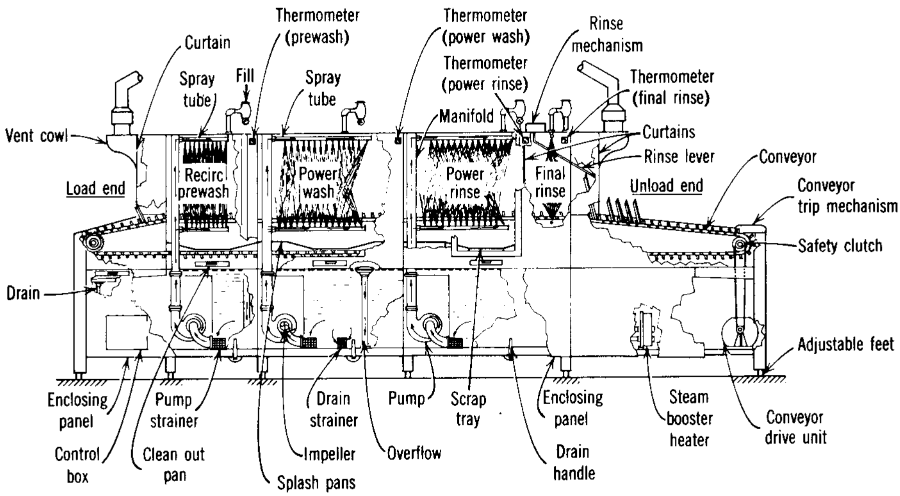


Figure 8-16 Multiple-tank rackless conveyor-type machine. Illustrative only. (*Source: National Sanitation Foundation Standards,* Standard No. 3, "Commercial Spray-Type Dishwashing Machines," NSF International, P.O. Box 130140, 789 N. Dixboro Road, Ann Arbor, MI 48113, April 1965.)

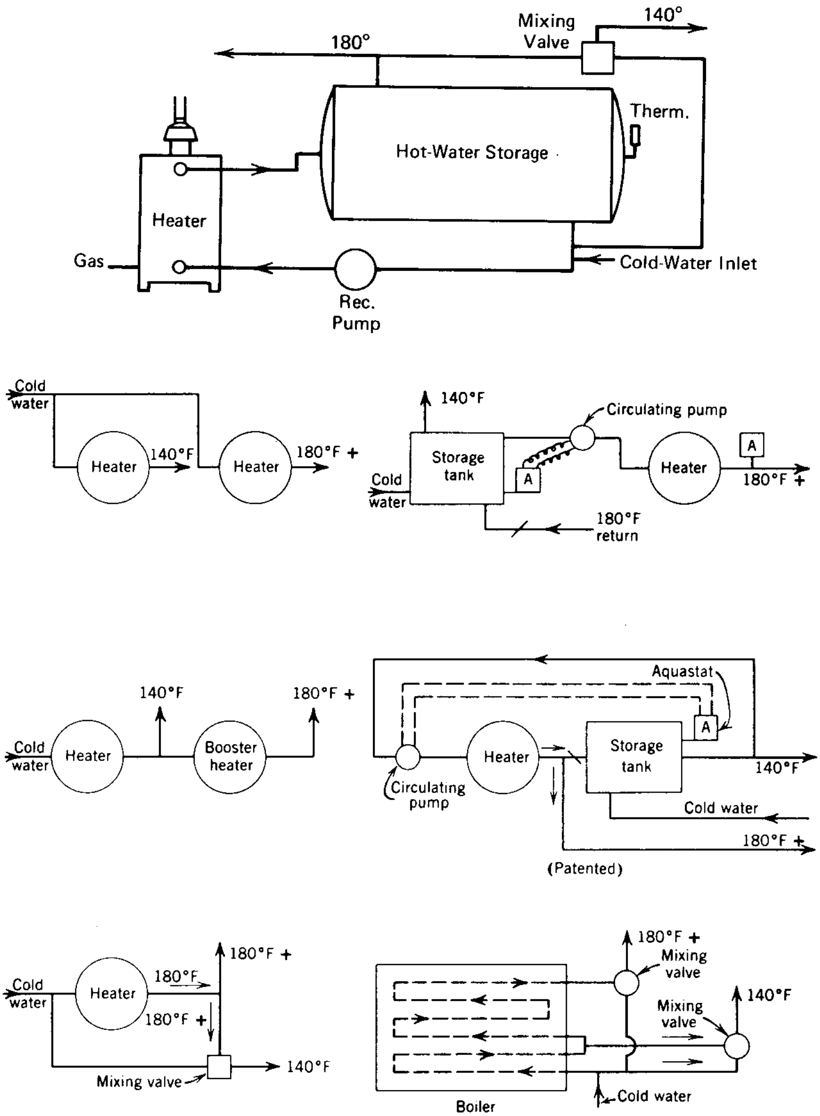


Figure 8-17 Water heater flow diagrams. The heater capacity must equal the requirements for 180°F (82°C) water plus 140°F (60°C) water over and above the available storage. A return circulating line is necessary on a heater located at a distance from a dishwashing machine. Thermometers, control valves, vacuum breakers, pressure-reducing flow control valves, strainer, and relief valves omitted from drawing. To supply 180°F (82°C) water to a dishwashing machine requires heating the water to about 190°F (88°C). Insulate heater, storage tank, and water lines.

Hot Water for General Utility Purposes

The hot-water requirements for general utility purposes include the needs for the hand washing of dishes, pots, pans, and utensils; for wall, floor, and equipment cleanup; for personal hygiene and toilet rooms; for food preparation; and for waste. One estimate for hand washing is 30 gal per sink per wash-up, with the dishwashing requirements broken down to prewash, 0.25 to 0.5 gal/meal served; detergent washing, 0.75 to 1.0 gal/meal served; and final rinsing, 0.5 to 1.5 gal/meal served. Total usage adds up to 1.5 to 3.0 gal/meal served. A factor of safety, an added 50 to 100 percent, is suggested, depending on the type of restaurant and seasonal demands. Water temperature of 120 to 140°F (49–60°C) is generally adequate for utility purposes. A temperature of 140 to 150°F (60–66°C) may cause scalding in 2 to 5 sec.

If it is assumed that 2 gal of 140°F water is used per meal, that 50 meals are served, and that hand dishwashing is completed in 1 hr, then the total hot-water demand per hour will be 100 gal, or 150 gal if a 50 percent factor of safety is added. This can be obtained from a water heater having a recovery rate to produce 150 gal of 140°F water in 1 hr. (A separate under sink booster is also required.) If a storage tank is provided capable of supplying the total demand and 3 hr are available to heat the water, then the heater recovery rate would be

$$\frac{1}{3} \times \frac{150}{0.75} = 67 \text{ gph}$$

The factor 0.75 represents 75 percent of the storage-tank capacity that may be withdrawn before the incoming cold water cools the remaining stored hot water below the desired temperature.

Another example might be the hot-water requirements of 260 gph in a kitchen plus that of three washbasins and two showers. The washbasins are used by 30 persons in 1 hr and the two showers by four persons in 1 hr. Say that it takes a person 3 min to wash at a basin and 10 min to take a shower. A basin faucet will flow at the rate of 3 gpm, of which 2 gpm can be taken as hot water. A shower head will flow at the rate of 5 gpm, of which $\frac{3}{4}$ or $3\frac{1}{2}$ gpm can be taken as hot water. Large variations can be expected depending on the usage, fixture, and water pressure. The required heater and storage-tank capacities can be obtained as follows:

$$\begin{aligned}
2 \text{ showers} &= 4 \text{ persons} \times 10 \text{ min} \times 3\tfrac{1}{2} \text{ gpm} = 180 \text{ gal} \\
3 \text{ basins} &= 30 \text{ persons} \times 3 \text{ min} \times 2 \text{ gpm} = 180 \text{ gal} \\
&\text{Kitchen usage} = 260 \text{ gal} \\
&\text{Total} = 620 \text{ gph}
\end{aligned}$$

If a storage tank is provided to supply 620 gal of hot water, it would have a capacity of 620/0.75 = 827 gal. With a heat-up period of 3 hr, the required heater would have a recovery rate of 827/3 = 276 gph. If a storage tank has a 450-gal capacity, of which 450 × 0.75 = 337 gal is available, the required heater would have a recovery capacity of 620 − 337 = 283 gph. At this recovery rate, the storage tank would be reheated in 450/283 = 1.6 hr.

In practice, the nearest standard-size storage tank and heater would be selected.

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No. 6, Dispensing Freezers

No. 7, Food Service Refrigerators and Storage Freezers

No. 8, Commercial Powered Food Preparation Equipment

No. 12, Automatic Ice Making Equipment

No. 18, Manual Food and Beverage Dispensing Equipment

No. 20, Commercial Bulk Milk Dispensing Equipment

No. 25, Vending Machines for Food and Beverages

No. 26, Pot, Pan, and Utensil Washers

No. 29, Detergent/Chemical Feeders for Commercial Spray-Type Dishwashing Machines

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9 Recreational Areas and Temporary Residences

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BEACH AND POOL STANDARDS AND REGULATIONS

The sanitation of bathing places is dictated by health and aesthetic standards. Few people would knowingly swim or water-ski in polluted water, and unsanitary surroundings are not conducive to the enjoyment of ''a day at the beach.'' People demand more and cleaner beaches and pools, and a camp, motel, hotel, club, or resort without a pool or beach is not nearly as popular as one so equipped.

Health Considerations

From our knowledge of disease transmission, it is known that certain illnesses, although uncommon, can be transmitted by improperly operated or located swimming pools and beaches through contact and ingestion of polluted water. Among these are typhoid fever, dysentery, infectious hepatitis, and other gastrointestinal illnesses; conjuctivitis, trachoma, leptospirosis, ringworm and other skin infections; schistosomiasis, or swimmer's itch; and upper respiratory tract diseases such as sinus infection, septic sore throat, and middle-ear infection. The repeated flushing of the mucous coatings of the eyes, ears, and throat and the excessive use of alum or lack of pH control expose the unprotected surfaces to possible inflammation, irritation, and infection. Contraction of the skin on immersion in water may make possible the direct entrance of contaminated water into the nose and eyes.

Twenty-six outbreaks with 1363 cases due to recreational water use were reported to the Centers for Disease Control and Prevention (CDC) from 1986 to 1988. Seven outbreaks involved hot tubs, four whirlpools, six lakes, four

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0-471-41813-7

pools, one creek, one pond, and one stream. Two of the outbreaks involved a hot tub and pool. The etiologic agent in the hot tub and whirlpool outbreaks was *Pseudomonas* and in one report *Legionella. Shigella sonnei* was the agent in three lake outbreaks, plus one Norwalk-like and one acute gastrointestinal illness (AGI). *Giardia,* AGI, and *Leptospira* accounted for the remainder of the outbreaks except for four, for which the etiologic agent was not determined.[1]

Bathing Beaches

Stevenson reported that "an appreciably higher over-all illness incidence may be expected in the swimming group over that in the nonswimming group regardless of the bathing water quality" (p. 12). It was further stated in his studies that "eye, ear, nose, and throat ailments may be expected to represent more than half of the over-all illness incidence, gastrointestinal disturbances up to one-fifth and skin irritations and other illnesses the balance."

Although based on limited data, swimming in lake water with an average coliform content of 2300/100 ml caused "a significant increase in illness incidence" and swimming in river water "having a median coliform density of 2700/100 ml appears to have caused a significant increase in such (gastrointestinal) illness" (ref. 2, p. 12). The study also showed the greatest amount of swimming was done by persons 5 to 19 years of age.

In a study of illness symptom rates among swimmers and nonswimmers at "barely acceptable" (BA) and "relatively unpolluted" (RU) beaches in New York City, Cabelli et al.[3] found a "statistically significant swimming-associated rate of gastrointestinal symptomatology at a 'barely acceptable' but not at a 'relatively unpolluted' beach" (p. 12). Gastrointestinal and respiratory symptoms were higher among swimmers than among nonswimmers. The geometric mean densities of total coliforms [most probable number (MPN) per 100 ml] were 1213 for the BA beach and 43.2 at the RU beach. The corresponding fecal coliforms were 565 and 28.4, respectively. Swimming in marine waters containing as few as 10 enterococci (streptococci) per 100 ml poses a gastrointestinal risk to bathers.[4]

A significant association between diarrheal illness and swimming in river water having a mean fecal coliform of 17,500 organisms per 100 ml was demonstrated by Rosenberg et al.[5] The same type *S. sonnei* was isolated from six swimmers and from the river water. A river-water sample collected from the swimming area one month after swimming was banned showed the presence of *S. sonnei*. Thirty-one of 45 cases of shigellosis were traced to swimming in the river at a location about 5 miles below the Dubuque, Iowa, sewage treatment plant, which was providing inadequate chlorination.[5]

In another study, conducted on Long Island, New York, saltwater beaches, no relationship was found between water quality and illness.[6] There are apparently no data correlating fecal coliform densities to enteric disease in bathing populations.[7] Other organisms proposed as possible indicators of bathing water quality are fecal streptococci and *Pseudomonas aeruginosa. Clostridium perfringens* and *P. aeruginosa* are more resistant than coliforms and, like enteric viruses, are primarily associated with human feces. *Clostridium perfringens* (*C. welchii*), shigellae, and *Salmonella* are also used in making special studies of bathing beach water quality.[3] Fecal streptococci and *C. perfringens* seem to be the best indicators.

Many other studies have been made to relate bathing water bacterial quality to disease transmission with inconclusive or negative results.[8]

British investigators have drawn the following general conclusions[9]:

(i) Bathing in sewage-polluted seawater carries only a negligible risk to health, even on beaches that are aesthetically very unsatisfactory.

(ii) The minimal risk attending such bathing is probably associated with chance contact with intact aggregates of faecal material that happen to have come from infected persons.

(iii) The isolation of pathogenic organisms from sewage-contaminated seawater is more important as evidence of an existing hazard in the populations from which the sewage is derived than as evidence of a further risk of infection in bathers.

(iv) Since a serious risk of contracting disease through bathing in sewage-polluted seawater is probably not incurred unless the water is so fouled as to be aesthetically revolting, public health requirements would seem to be reasonably met by a general policy of improving grossly insanitary bathing waters and of preventing so far as possible the pollution of bathing beaches with undisintegrated faecal matter during the bathing season.

The findings of the Public Health Activities Committee of the American Society of Civil Engineers (ASCE) Sanitary Engineering Division are summarized in the following abstract:[10]

> Coliform standards are a major public health factor in judging the sanitary quality of recreational waters. There is little, if any conclusive proof that disease hazards are directly associated with large numbers of coliform organisms. Comprehensive research is recommended to provide data for establishing sanitary standards for recreational waters on a more rational or sound public health basis. British investigations show that even finding typhoid organisms and other pathogens in recreational waters is not indicative of a health hazard to bathers but is only indicative of the presence of these diseases in the population producing the sewage. The Committee recommends that beaches not be closed and other decisive action not be taken because current microbiological standards are not met except when evidence of fresh sewage or epidemiological data would support such action.

A major contributing factor to the bacteriological quality of Milwaukee bathing beaches on Lake Michigan was found to be the rainfall intensity and the subsequent water drainage inflow pattern. Based on long-term beach water bacteriological history, it was possible to predict the number of hours that a beach should remain closed following the end of a 0.1- to 0.19-in. rainfall (12 hr) to 1.5 in. or more rainfall (96 hr).[11]

Diesch and McCulloch[12–14] and others summarized incidences of leptospirosis in persons swimming in waters contaminated by discharges of domestic and wild animals, including cattle, swine, sheep, foxes, raccoons, muskrats, and mice. Pathogenic leptospires were isolated from natural waters, confirming the inadvisability of swimming in streams and farm ponds receiving drainage from cattle or swine pastures.

A case–control study showed that seven children acquired leptospirosis after swimming in a creek that ran through a pasture. However, samples of creek water 4 weeks after the outbreak did not yield the organism and tested serum specimens from cattle did not implicate any herd. Common-source leptospirosis outbreaks have been frequently reported in Europe.[14] Schiemann[15] summarized 10 outbreaks of leptospirosis involving swimming in natural waters.

Joyce and Weiser[16] report that enteroviruses found in human or animal excreta, if introduced into a farm pond by drainage or direct flow, can constitute a serious public health hazard if used for recreational, drinking, or other domestic purposes.

Primary amebic meningoencephalitis (PAM), a rare disease that is generally fatal to humans, has been linked with swimming or bathing that involves *immersion* of the head in contaminated fresh and brackish water. Heated swimming pools, hot geothermal waters, and warm-water swimming areas associated with high ambient air temperatures have been associated with the disease. The causative agent is believed to be *Naegleria fowleri,* which is a free-living ameboflagellate. It is a common species in soil, decaying vegetation, and natural fresh water. The *Naegleria* cyst is reported to survive a temperature of 133°F (56°C) when suspended in water.[17–19] Optimum pH level is 7.4 to 7.8. *Acanthamoeba,* another free-living ameba, generally causes subacute or chronic infections less severe than PAM.[20] It probably gains entrance through a skin lesion with no history of swimming.[21]

Preventive PAM measures suggested at suspect warm-water pools include the diversion of surface-water drainage and the display of prominent warnings against diving, jumping, underwater swimming, or other activities likely to cause water to be driven up into the nose. In addition, the pool, spa, and hot tub water should be given complete treatment, including *continuous* recirculation, filtration, and free residual chlorination (at least 3.0 mg/l), whether the pool is heated or not. If a satisfactory level of free available residual chlorine cannot be maintained because of the temperature, presence of dissolved chemicals, or flow-through of water, the pool should be designated for bathing purposes only and should have a depth of not more than $2\frac{1}{2}$ ft. If the pool is an artificial one, it should be emptied at least daily and the bottom, sides, overflow gutters, and decks regularly scrubbed using a suitable disinfectant.[22]

In view of the available information, emphasis should also be placed on elimination of pollution sources (sewage, stormwater, land drainage), effective disinfection of treated wastewaters, and the proper interpretation of microbiological examinations of samples collected from representative locations. In a swimming pool, spa, and hot tub, it is necessary to eliminate cracks and crevices that can harbor the cysts and make them inaccessible to chlorine. *Naegleria* cysts are inactivated in 10 min. by 4 mg/l free chlorine at pH 7.2 or 7.3 and 86°F (25°C) and by 2 mg/l in 20 min.[23]

Swimming Pools In swimming pools, there is a possibility of direct or indirect transmission of eye, ear, respiratory tract, and skin infections and other illnesses from one bather to another, particularly if the water does not have an active disinfectant such as free available chlorine. However, data documenting pool-acquired illnesses is sparse and often only circumstantial. Skin infections caused by *Mycobacterium marinum* and leading to a granuloma have been reported following swimming in public pools. The organism was found to be resistant to free available chlorine in the 1.5-mg/l range.[24] Other bacterial and viral infections, including conjunctivitis and fever, have also been associated with swimming pools.[25]

Giardia lamblia was transmitted by the probable ingestion of swimming pool water contaminated by a child (carrier) who had a fecal accident. The pool had a rapid sand filter, 6 hr turnover, but no record of chlorine residual.[26] There was one outbreak of giardiasis related to a swimming pool reported in 1985.[27]

An accidentally fecally contaminated swimming pool was associated with an outbreak of cryptosporidiosis involving 44 persons in five separate swimming groups. The attack rate was 73 percent. The chlorine level was 2 ppm, but one of three diatomaceous earth filters was inoperative. Repair of the filtration system brought the outbreak under control. Since *Cryptosporidium* oocysts are resistant to normal chlorination treatment, the filtration system must be capable of removing the oocyst (4–6 μm size).[28]

Swimming pools receive not only body discharges such as mucus from the nose, saliva from the mouth, sweat, and traces of fecal matter, urine, and dead skin but also street and workplace soil that collects on the skin and various body lotions, oils, and creams—all of which can contribute to pollution of pool water.[29] In addition, outdoor pools receive dust, pollens, and other air pollutants. This emphasizes the importance of proper swimming pool design, including recirculation, filtration, and disinfection, and proper operation, as well as enforcement of the use of toilets and warm-water cleansing showers before entering the pool and after using the toilet, not only for health and hygienic reasons, but also for aesthetic reasons. Pool design and operation are discussed later in this chapter.

Whirlpools, Spas, and Hot Tubs Whirlpools, spas, and hot tubs are found at health spas, hospitals, and recreational facilities usually associated with swimming pools. Skin infections or rashes due to *P. aeruginosa* have been reported in several instances.[30,31] The relatively high water temperatures and agitation in whirlpools make maintenance of adequate free residual chlorine, the common disinfectant, difficult—hence the likely survival of pseudomonas and other pathogens. A study of eight whirlpool baths showed that *P. aeruginosa* can be recovered from whirlpool waters having 2 to 3 mg/l *total* residual chlorine. *Legionella pneumophila* has been isolated from whirlpools.[32] A free chlorine residual of 2 to 3 mg/l or greater appeared to be effective in inactivating the organism. The organism may be transmitted by aspiration of aerosol. The high concentration of total organic carbon, total Kjeldahl, and ammonia nitrogen, usually found present, would hinder maintenance of free available residual chlorine.[33] However, continuous recirculation and filtration with automatic chlorination and maintenance of 3.0 mg/l free residual chlorine should prevent infections.[31] Other disinfectants may be approved by the local health department. The water needs to be replaced at least weekly and superchlorinated when the water starts to become cloudy. The large evaporation associated with whirlpools, hot tubs, and spas results in cloudiness due to a buildup of total dissolved solids, which requires water dilution or replacement. In order to maintain disinfection efficiency, the water also needs to be superchlorinated when combined chlorine begins to form. A strong chlorine odor is probably indicative of the presence of chloramines. It is extremely important, before replacing the water, to thoroughly scrub and clean the walls and floors of whirlpools, spas, and hot tubs. This is necessary to remove adhering biofilm and slime that would harbor pseudomonas and other pathogens, which would be protected from the disinfectant.

A minimum of 2.5 mg/l free chlorine residual, a total alkalinity of 120 to 140 mg/l, and weekly cleaning including superchlorination at 10 mg/l for 10 hr have been recommended for redwood hot tubs.[34] Ozone or ultraviolet radiation may be used for supplemental treatment. Ultraviolet light plus hydrogen peroxide treatment shows promise. Destruction of *Giardia* cysts and *N. fowleri* is reported with 5 to 15 mg/l hydrogen peroxide, although 30 to 40 mg/l is recommended.[35]

The Consumer Product Safety Commission (CPSC) reported 10 deaths, apparently due to drowning, associated with the use of hot tubs.[36] Maintenance of water temperature at 100°F (38°C) for healthy adults and 98°F (37°C) for children under age 5 is advised, with a maximum allowable temperature of 102°F (39°C) for 15 min. Water temperatures above 102°F for persons with heart problems or with high blood alcohol level or for women who may be pregnant may be hazardous. Individuals under medical care should check with their doctor. A temperature of 100 to 102°F (38 to 39°C) is advised to minimize risk to the unwary user.

Inspection for possible electrical hazards, emergency shut-off switch next to the spa, antivortex drain, thermostatic controls, and an alarm system are recommended by the CPSC.[37] Detailed design, construction, safety, and operational standards are available.[38–42] Plans and specifications should be submitted and approved by the local health or other regulatory agency having jurisdiction before construction.

Proper operation is indicated by very low to negative total bacteria plate count, absence of coliform bacteria and *P. aeruginosa,* a total alkalinity as $CaCO_3$ of 80 to 120 mg/l, a free chlorine residual of 3.0 to 5.0 mg/l, a combined chlorine of zero, a pH of 7.5 to 7.6, and a water clarity of 0.5 nephelometric turbidity units (NTU) of less. The deepest part of the spa should be clearly visible from the side when still. The water should be turned over at least once every 30 min. Spas should provide 10 ft^2 per user.

Recreational White-Water Slides Guidelines for water slide flume design, operation, and maintenance to protect the health and safety of the user public have been prepared by the U.S. Public Health Service (PHS). The reader is referred to the publication for details.[43] A minimum plunge pool operating water depth of 3 ft and a filtration system capable of recirculating the total volume of the facility water in 1 hr or less is recommended.[44]

Adequate safety standards for the design and operation of recreational water slides, spas, hot tubs, and swimming pools should be adopted by state and local authorities.[45]

Regulations and Standards

Health departments generally require that swimming pools and bathing beaches be operated under permit. Usually, swimming pools are not to be constructed or altered until plans and specifications prepared by a licensed professional engineer or registered architect are submitted and approved by the commissioner of health. Regulations and standards cover water quality, design, construction, operation, maintenance, sanitary facilities, and related factors.[46]

Beaches Regulations governing the use of bathing beaches or natural, partly artificial pools, and evaluation of their suitability, are based on a sanitary survey of the drainage area to the beach or pool; the water quality, including meteorological factors; epidemiological data linking illnesses to the bathing area; and water circulation and dilution. Plans for the construction or modification of a public beach and facilities may be required by the regulatory agency in addition to plans for water supply and sewage treatment, refuse storage and disposal, food service facilities, and accident prevention.

The *sanitary survey* takes into consideration geographic factors and probable sources of pollution on the watershed tributary to the bathing beach. This includes sewage and industrial wastewater discharges, stormwater overflows, bird and animal populations, commercial and agricultural drainage, and their relationship to the beach. The location and volume of the pollution and its chemical, bacterial, and physical characteristics; the volume and quality of the diluting water; water depth; water surface area; tides and seasonal water levels; time of day and year; thermal and salinity stratification; confluence of tributaries; water currents; rainfall and storm events; and prevailing winds are all evaluated in interpreting water sampling data to determine the suitability of the water for bathing. Also important are biological hazards—excessive vegetation, infectious snails, and poisonous or dangerous aquatic organisms; safety hazards such as fast currents, strong tides, submerged objects, beach slope, and sharp drop-offs; and an uneven or unstable beach bottom in the wading area, the water depth in the diving area, and overhead electrical wires.

Bathing beach water quality standards vary throughout the country. They range from no standard to a permissible total coliform count of 50/100 ml to 2400/100 ml or higher; the preponderant number relates results to a sanitary survey of the bathing area, epidemiological data, and judgment. Interpretation of bacteriological results should take into consideration possibly associated illnesses, the sanitary survey, and meteorological factors such as rainfall, tidal currents, and prevailing winds as mentioned above.

Bathing beach standards usually refer to the MPN of the coliform group of organisms per 100 ml of sample (incubation at 35 × 0.5°C). This group includes *Escherichia coli,* which usually inhabits human and animal intestines, and *Aerobacter aerogenes* and *Aerobacter cloacae,* which are also frequently found in many types of vegetation as well as in pipe joint material, pipelines, and valves. The intermediate aerogenes–cloacae (IAC) subgroups are sometimes found in fecal discharges, but usually in smaller numbers than the *E. coli. Aerobacter aerogenes* and intermediate types of organisms are also commonly present in soil and waters polluted sometime in the past. It is apparent, therefore, that all surface waters can be expected to be polluted to a greater or lesser extent and that bathing in ‘‘unpolluted’’ water is a practical impossibility. It is also apparent that the total coliform test does not distinguish between the more hazardous recent human and animal pollution and the soil, vegetation, and old or past human and animal pollution. Enterococci provide the best correlation of mean densities to the incidence of swimming-associated gastroenteritis. *Escherichia coli* is second best, followed by fecal coliforms, total coliforms, *Aeromonas hydrophila, P. aeruginosa,* and *C. perfringens*[4,47] (see also ref. 4, pp. 1306–1314).

The coliform group of organisms includes the fecal coliforms (incubation at 35°C and then at 44.5 ± 2°C). The presence of fecal coliforms is thought to be more indicative of recent human and animal pollution and, hence, the presence of pathogenic organisms. The fecal coliforms may average 15 to 20 percent of the total coliforms in stream samples. (See also Chapter 3.) A recommended standard for water used for wading, swimming, water-skiing, and surfing states[48]:

> Fecal coliforms should be used as the indicator organism for evaluating the microbiological suitability of recreation waters. As determined by the multiple-

> tube fermentation or membrane filter procedures and based on a minimum of not less than five samples taken over not more than a 30-day period, the fecal coliform content of primary contact recreation waters shall not exceed a log mean of 200/100 ml (1000/100 ml total coliform), nor shall more than 10 percent of total samples during any 30-day period exceed 400/100 ml.[49]
>
> . . . the pH should be within the range of 6.5–8.3 except when due to natural causes and in no case shall be less than 5.0 nor more than 9.0.
>
> . . . the clarity should be such that a Secchi disc (20 cm in diameter divided into four quadrants painted alternating black and white) is visible at a minimum depth of 4 feet. In ''learn to swim'' areas the clarity should be such that a Secchi disc on the bottom is visible. In diving areas the clarity shall equal the minimum required by safety standards, depending on the height of the diving platform or board.

Water quality requirements for bathing waters adopted by the European Economic Community Council are shown in Table 9-1.

Swimming Pool Water Quality The sanitary quality of swimming pool water is determined by certain microbiological, chemical, and physical tests. Examinations are made in accordance with the analytical procedures described in *Standard Methods* by competent laboratory personnel.[50]

The American Public Health Association Public Health Joint Committee on Swimming Pools and Bathing Places, in *Public Swimming Pools,*[51] recommends the following:

pH	7.2–8.0*
Alkalinity (methyl orange, MO)	At least 50 mg/l total but not greater than 150
Clarity	6-in.- (15-cm-) diameter black and white disc readily visible at deepest point when viewed from side of pool† (not more than 0.5 NTU)
Plate count [(agar, 24 hr at 95°F (35°C)]	Not more than 15 percent of the samples over any 30-day period while pool is in use contain more than 200 colonies/ml. (A count of less than 100 colonies/ml can be maintained in a properly designed, constructed, and operated pool.)

* See also Swimming Pool Operation, this chapter.

† The National Spa and Pool Institute recommends that the deepest part of pool be visible. *ANSI/NSPI-1 1991 Standard for Public Swimming Pools,* National Spa and Pool Institute, Alexandria, VA.

TABLE 9-1 European Economic Community Quality Requirements for Bathing Waters

Parameter	G (Guide)	I (Mandatory)	Minimum Sampling Frequency
	Microbiological		
1. Total coliforms, 100 ml^{-1}	500	10,000	Every 2 weeks[a]
2. Fecal coliforms, 100 ml^{-1}	100	2,000	Every 2 weeks[a]
3. Fecal streptococci, 100 ml^{-1}	100	—	[b]
4. Salmonella, l^{-1}	—	0	[b]
5. Enteroviruses, PFU[c]/10 l	—	0	[b]
	Physicochemical		
6. pH	—	6–9 (0)	[b]
7. Color	—	No abnormal change in color (0)	Every 2 weeks[a]
	—	—	[b]
8. Mineral oils, mg/l	—	No film visible on surface of water and no odor	Every 2 weeks[a]
	0.3	—	[b]
9. Surface-active substances reacting with methylene blue, mg/l lauryl sulfate	—	No lasting foam	Every 2 weeks[a]
	0.3	—	[b]
10. Phenols (phenol indices), mg/l C_5H_5OH	—	No specific odor	Every 2 weeks[a]
	0.005	0.05	[b]
11. Transparency, m	2	1 (0)	Every 2 weeks[a]
12. Dissolved oxygen, % saturated O_2	80–120	—	[b]
13. Tarry residues and floating materials such as wood, plastic articles, bottles, containers of glass, plastic, rubber or any other substance, waste or splinters	Absence	—	Every 2 weeks[a]

Source: "Britainia Waives the Rules" *World Water,* June 1978, pp. 24–27. Adopted by the European Economic Community (EEC) Council December 8, 1975.

[a]When a sampling taken in previous years produced results that are appreciably better than those in this table, and when no new factor likely is lower the quality of the water has appeared, the competent authorities may reduce the sampling frequency by a factor of 2 (sampling every 2 weeks).

[b]Concentration to be checked by the competent authorities when an inspection in the bathing area shows that the substance may be present or that the quality of the water has deteriorated.

Coliform organisms (dechlorinated sample)	Not more than 15 percent of the samples over any 30-day period while pool is in use show positive (confirmed test) in any of the five 10-ml portions of a sample in multiple fermentation tube method or more than 1.0 coliform organisms per 50 ml in membrane fiber test.
Staphylococcal group (if made)	Not more than 50 organisms/100 ml

The Jackson candle turbidimeter is considered obsolete and impractical for routine swimming pool use and inaccurate below 25 Jackson turbidity units (JTU). The nephelometric turbidimeter has replaced the Jackson candle turbidimeter. It should be noted that the water clarity standard for a natural body of water uses the 8-in. (20-cm) Secchi disc, whereas the swimming pool standard uses a 6-in. (15-cm) disc. There is no direct relationship between NTU and Secchi transparency readings.[52] The near absence of turbidity ensures the effectiveness of disinfection.

Cloudy pool water may be due to improper filtration (unclean sand and cracks in bed, need for alum with sand filter, improper precoat in diatomite filter, or high alkalinity). Reddish brown color may be due to iron, brownish black color due to manganese, and blue green color due to copper corrosion. Algae growths may cause slime and green or brown coloring of the water. These problems and their solution are discussed in Chapter 3 and in this chapter.

Other Recreation Water For surface waters for general recreational use, not involving significant risk of ingestion and in the absence of local epidemiological evidence to the contrary, a standard of ''an average not to exceed 2000 fecal coliforms per 100 ml and a maximum of 4000 per 100 ml, except in specified mixing zones adjacent to outfalls'' are suggested.[48]

''For waters where the probability of ingesting appreciable quantities is minimal, the fecal coliform content, as determined by either the multiple-tube fermentation or membrane filter technique, should not exceed a log mean of 1000/100 ml and should not equal or exceed 2000/100 ml in more than 10 percent of the samples.''[48]

Sample Collection Water samples should be collected in wide-mouth bottles by plunging the bottle downward and then forward until filled while the bathing area or swimming pool is in use. The sampling points should be in the bathing area of a beach or near the pool outlet or outlets and at such representative points as will indicate the quality of the bathing water. A sample per 300 ft of beach in about a 2-ft depth of water is suggested. Samples of chlorinated water must be collected in sodium-thiosulfate-treated bottles so as to dechlorinate the sample and thus give a true indication of the quality of the water at the time of collection. Sodium thiosulfate should not be flushed out. In any case, the sample should be returned to the laboratory for examination as soon as possible after collection.

Accident Prevention and Life Saving

According to the CPSC National Electronic Injury Surveillance System,* an estimated 118,000 persons required emergency room treatment in 1982 for injuries associated with swimming pools, swimming pool slides, and diving boards. Most accidents were due to slippery walkways and decks, falls from diving boards and ladders, hitting protrusions, striking the bottom or sides of a pool because of inadequate depth for diving or sliding, and drowning when swimming alone or without adult supervision.

In a study made by Van Dusen and Fraser (ref. 25, p. 5), it was reported that there were 8100 deaths due to drowning in 1975 in the United States. Of this number, approximately 3100 were associated with swimming and 5000 with other water-based recreation. Of the 3100 swimming pool drownings, approximately 600 occurred in residential pools (19 percent). The other deaths occurred at motel–hotel pools (10 percent), apartment or condominium pools (10 percent), public pools (20 percent), and pools under sponsorship of schools, voluntary organizations, and private groups such as country clubs (41 percent). Swimming pool diving boards and water slides were a significant source of injuries. Children under 4 years of age are at highest risk at residential pools. It is reported that 50 children per day drown or come close to drowning in summer months, with most in California, Texas, and Florida. Double fencing and water safety education of parents and children are suggested. The CDC reported that in 1986 there were 2062 drownings involving children 19 years of age or younger. Alcohol use was associated with an estimated 40 to 50 percent of the events. Drownings were most common among children 4 years of age or less and males aged 15 to 19 years. Up to 90 percent of drownings in children 4 years of age or less occurred in residential swimming pools.[53]

In a special study[54] of 72 swimming pool injury cases, 52 "retrospective" cases (in which injuries were sustained before January 1, 1976) and 20 "prospective" cases (injuries after January 1, 1976), although not representative of the 65,000 annual pool-related accidents, the findings were informative. The major types of injury (57) were quadriplegic.† Diving and striking the head on the bottom was the primary cause of the injury—18 diving in inground pools with 4 ft or less water depth and 18 diving in above-ground

*Based on data collected from admissions to 119 selected hospital emergency departments for injury and consumer-product-associated injury. The hospitals represent a statistical sample from 5939 hospitals in the United States and its territories.

†Total care and wages loss estimated at $1 million during the average life span.

pools with 4 ft or less water depth. An additional eight accidents were due to water slides, six head-first entry in water of $3\frac{1}{2}$ ft or less depth. The remainder were miscellaneous injuries. In 54 of the injuries there was no designated person in charge at the time of the injury. Forty residential pools; 23 hotel, motel and apartment pools; 6 public school and city pools; and 2 private club pools were involved. Significantly, 32 of the pools were vinyl lined; hands slipped as individuals struck the bottom. Also, 38 of the pools were a concrete basin with variable depth and 20 were above-ground vinyl-lined pools 5 ft or less in depth; 46 did not have depth markers on the pool coping or interior walls; 43 had no warning signs posted in the pool area; 59 had no bottom markings in the pool; 51 occurred where water depth was 4 ft or less; and 15 where water depth was 5 ft, 1 in. or deeper. Shallow water, the absence of bottom markings, the lack of water depth markings, and the failure to post warning signs were the most prevalent conditions. Natural bodies of water are also involved in cervical spinal injuries; seven were reported in Wisconsin in 1988.[55]

Other studies show that a smooth nonslip bottom in the pool diving and upslope or run-out area will minimize possible head and neck injuries, that depth markings are often ignored, and that most injuries by far occur in the 13 or older age group. Injuries to the cervical spine can occur at impact speeds equal to or greater than 2 to 4 fps. There appears to be no practical way to build a pool deep enough or large enough to rely on hydrodynamic forces alone to slow a diver to a safe velocity.[54,56] A diving training and education program, in addition to proper pool depth, water depth marking, geometry, and construction, offers the best means for reducing diving-related accidents. In general, diving boards should be eliminated where diving cannot be supervised and where water depth is less than 5 ft. The depth of water under a deck-level diving board should be at least 9 ft, with the depth extending forward for at least 16 ft. Slides should terminate in at least 3 ft of water and be supervised. Slides must meet U.S. Consumer Product Safety Commission standards.

The elimination of tripping or slipping hazards in pools, runways, and decks and controlled area bathing with adequate lifeguard supervision will do much to prevent accidents and drownings. Attention to accident hazards and protection of life are musts at all public beaches and pools, including those at resorts, schools, clubs, associations, and so on. Failure to do so may cause serious injury and place the management in an untenable position in case of lawsuits.

The American Red Cross suggests that one trained guard may be sufficient for each 100 bathers, provided they are in a confined area.[57] On surf bathing beaches, one guard in a tower for every 100 yd of beach, a guard on patrol for every 100 ft of beach, and a guard in a boat for every 200 yd in the swimming area are recommended. Double this number may be needed on weekends and holidays. One lifeguard director for every 75 swimmers and one trained "life saver" for every 10 persons in the water have also been recommended at recreational camps and similar places. Bathing areas and pools should be marked with float lines for swimmers and nonswimmers. Standard life-saving equipment for bathing beaches includes lifeboats with anchors and bamboo or other light rigid poles 12 to 15 ft long, surfboards, torpedo buoys, heaving lines of $\frac{3}{16}$-in. manila line made up in coils containing 50 or 75 ft of line attached to 15- or 18-in.-outside-diameter ring buoys, and grappling irons.

Life-saving equipment per 2000 ft^2 of pool-water area should include a bamboo pole 12 to 15 ft long or shepherd's crook and a Coast Guard–approved ring 18 in. in diameter, with 50 ft of $\frac{1}{4}$-in. line, or a torpedo buoy or rescue tube with a 6-ft line attached. This equipment should be conspicuously distributed around the pool. An elevated lifeguard tower or chair should be required for a pool 2000 to 4000 ft^2, and an additional tower should be required for each additional 3000 ft^2. Where a lifeguard is not on duty, a sign in plain view should state in clear letters, at least 4-in. high, "Warning—No Lifeguard on Duty." Another sign should state, "Children Under Age Sixteen Should Not Use Pool Without An Adult in Attendance" and "Adults Should Not Swim Alone" (ref. 51, pp. 32, 33, 47, 50). Check state and local laws; many prohibit bathing at public beaches and pools unless a trained lifeguard is on duty. All pools should be fenced and kept locked when not under supervision. Public pools should be surrounded by a manproof fence or equivalent barrier. Semipublic or private swimming pools should be protected to prevent toddlers from accidentally falling into an unguarded pool. A fence at least 4 ft high with a self-closing door and latch handle at least 40 in. above grade is a minimum safeguard. Fence openings should not exceed 4 in. Childhood pool drowning and near-drowning rates at residential swimming pools are lower where fencing is required.[58] Bather supervision, fencing, water clarity, and lifeguards trained in cardiopulmonary resuscitation (CPR) were found to be associated with decreased pool drownings and near drownings.[59]

Where the water is not crystal clear at all times, as in natural ponds and dammed-up streams, it is especially important that bathing be carefully organized.

In any case, a system of checking such as "roll call" or "tag board" to determine who is in the water and who comes out, a "cap" system to distinguish nonswimmers, beginners, and swimmers, and a "buddy" system whereby bathers are paired according to their abilities are accepted and highly recommended safety practices. No one should be allowed to swim alone in a pool or natural body of water at any time.

A telephone should be readily accessible and the telephone numbers for respirators, ambulances, fire and rescue units, doctors, and hospitals conspicuously posted for use in case of emergency. Also needed are a safety plan, a 24-unit first-aid kit, spine board or carrying frame, cot and blankets, and a trained first-aid person. The lifeguard or other responsible person should be trained in CPR.

Artificial pools, lakes, streams, coastal beaches, and ponds may have holes, steep sloping bottoms, sudden drops, large rocks, stumps, heavy weed growths, tin cans, bedsprings, broken glass, and miscellaneous debris that can cause injury or drowning. These should, of course, be removed or, if not practical, carefully marked "Off Limits." The bottom should be gently sloping, clean, clear, and firm at least out to a depth of 5 ft. Silt, muck, or quicksand bottoms are not suitable. Where it is not feasible to remove the silt, muck, or mud and replace it with sand, a polyethylene sheet covered with 12 in. of sand or a paved bottom might be substituted, at least in the wading area. This will help keep the water clear and reduce the drowning hazard. Swimming should not be permitted where there are strong currents or undertow or high waves or in areas not specifically designated for swimming.

Electrical Hazards Electrical hazards at swimming pools have caused serious disability and death. Use of Underwriters Laboratories approved equipment (UL Label) and installation in accordance with the National Electrical Code* (1990) or its equivalent should greatly minimize, if not eliminate, the hazards. A ground-fault circuit breaker or interrupter that will immediately shut off the electric power at the source should be standard equipment on all electrical circuits in public, semipublic, and residential pool areas. This device is automatically activated when a defective wire, connection, or equipment (such as an electric motor, vacuum equipment, underwater light, electric panel box, light switch, radio wire, or ungrounded electric receptacle) permits current to flow or leak into the ground directly or indirectly. The power to an outlet or other connection is cut off when a preset amperage (5/1000 A, or 5 mA) is exceeded, which amperage is much less than that required to activate the usual fuse or circuit breaker. All wiring, pool equipment and accessories, including lights on metal poles, junction boxes, diving board stands and platforms and handrails, underwater and surface lights, step handrails, ladders, and other metal appurtenances are required to be properly bonded and grounded. Under no circumstances should electric wires or cables be permitted to pass overhead within a 20-ft horizontal distance of the pool.

SWIMMING POOL TYPES AND DESIGN

Swimming pools are generally classified as "artificial pools" and "partly artificial pools." Artificial pools are usually constructed of reinforced concrete or gunite, steel, aluminum, and fiberglass and have a vinyl lining. Pools are

*Published by the National Fire Protection Association, 1 Batterymarch Park, Quincy, MA.

designed and operated as recirculating pools with filtration and disinfection or, rarely and *if permitted,* with disinfection only, as fill-and-draw pools, or as flow-through pools. Saline-water swimming pools should meet the same requirements and standards as freshwater pools. The major concern is greater corrosion of metal piping and parts. An operation and maintenance manual and filter, pump, and motor design data should be provided with each swimming pool. Plans and specifications of the site, pool, whirlpool, spa, and recreational water slide, auxiliary structures, equipment, and facilities, including water supply, and wastewater disposal are usually required by the regulatory agencies before construction is started.

Recirculating Swimming Pool

In the typical recirculating-type swimming pool, a pump takes water out of the pool, passes it through a filter, chlorine is added, and the water is returned to the pool. Water lost by evaporation, splashing, and backwashing of the filters is replaced by fresh water. This type of pool permits use by a maximum number of bathers; a minimum amount of water is wasted, and fuel for heating the water, where desired, is saved because the filtered pool water is reused. If the filters are omitted or operated intermittently, the organic and dirt load cumulate, residual chlorine control is difficult, and frequent water change and cleaning are necessary. Filtration is provided by means of gravity rapid sand filters, pressure sand and anthracite filters, diatomaceous earth pressure and vacuum circular disc-, leaf-, and tube-type filters, and cartridge or high-permeability depth-type and surface-type filters. The pressure filters are most commonly used on swimming pools.

Fill-and-Draw Pool

The fill-and-draw pool is filled with fresh water, used for some period of time, then emptied, cleaned, and refilled. Such pools are nothing more than common bathtubs in which the pollution introduced is circulated among the bathers. Their use is generally prohibited.

Flow-Through Pool

The flow-through pool or pond is fed by a continuous supply of acceptable fresh water, without treatment, which causes an equal volume of pool water to overflow to waste. Although the bacterial pollution is reduced, it is not completely flushed out of the pool, as shown in Table 9-2. For example, a pool 60×20 ft holding 55,000 gal and provided with 166,500 gal of water per day to displace the pool water in 8 hr can, according to the formula $Q =$

TABLE 9-2 Effectiveness of Continuously Flowing Fresh Diluting Water in Removing Pollution from Swimming Pool in Absence of Disinfection

Number of Times Each 24 hr Water Is Displaced by Fresh Water (1)	Displacement Period, T (hr) (2)	Computed Quantity in Fresh Water per Bather, Q (3)	Percent of Pollution of Water Remaining in Pool (4)	Number of Days for Pollution to Reach Uniform Values Shown in Column 4 (5)
1	24	3,600	58	9
2	12	900	16	4
3	8	400	5	3
4	6	225	2	2

Source: New York State Department of Health, Bulletin 31, Albany, NY, 1950.

Note: Values given in columns 4 and 5 are in accordance with the "dilution law," $Q = 6.25T^2$. If the displacement period is 4 hr, only 0.3% pollution would remain (also known as the Becker formula). *Assumption:* Daily increment of pollution equals that initially present.

$6.25T^2$, accommodate 17 bathers per hour.* The quantity Q is the fresh water (no disinfectant) required per bather, which in this case is 400 gal, and T is the turnover period in hours, 8 in this example. On the other hand, this same pool would accommodate 48 bathers at any one time if the water were continuously chlorinated, filtered, and recirculated, the restriction being a desired pool area of 25 ft^2 per bather in the pool, maintenance of 0.6 mg/l free available chlorine, and water clarity. Flow-through pools require large controlled volumes of clean water and strict control of the number of bathers and microbiological water quality, which is not normally possible. A dilution of 500 gal per bather per day has also been used as a guide.

Partly Artificial Pool

The partly artificial pool is made by damming a stream, causing water to back up to form a small pond or lake. If the size of the artificial pool is small, the permissible number of bathers per hour would be governed largely by the dilution or volume of water entering the pool. But if a large lake is formed, so as to permit the natural laws of purification to operate, the permissible number of bathers would be governed by the results of bacteriological examination of a series of water samples collected during the bathing period and the sanitary survey.

* $\frac{166{,}500 \text{ gpd}}{24 \text{ hr}} = 6938$ gph; $\frac{6938 \text{ gph}}{400 \text{ gal}} = 17$ bathers per hour. Also, $Q = 6.25 \times 8^2 = 400$ gal.

Summary of Pool Design*

Site Selection and Layout

1. Accessible to users; space for parking, recreational, picnicking, bathhouse, and purification equipment.
2. Adequate and satisfactory water supply.
3. Adequate sanitary sewer or separate disposal system away from underground utilities.
4. Pool drainage and wastewater disposal proper. High water-table relief on main drain or pool bottom.
5. Site drained, gently sloping, 100 yd or more from roads, railroads, factories, and wooded areas.
6. Pool area enclosed with high wall or fence.
7. Deep end of pool away from entrance.

Pool Area and Depths

1. Provide for diving, swimming, and nonswimming areas. A minimum width of 20 ft and length of 60 ft and minimum water depth of 3 ft are suggested for public pools.

A water depth of at least 8 ft, 6 in. is suggested for a deck level to 2-ft-high diving board over water, 10 ft for a 3-ft, 3-in. (1-m) board, and 12 ft for a 10-ft (3-m) board. The minimum suggested length of a diving well, beyond the end of the board, is 12 ft for the 8-ft, 6-in. depth, 12 ft for the 10-ft depth, and 13 ft for the 12-ft depth. The suggested bottom run-out length from the end of the diving well to the 5-ft shallow end is 10 ft, 6 in. for the 8-ft, 6-in. depth, 15 ft for the 10-ft depth, and 21 ft for the 12-ft depth. The run-out is on a slope of at least 1 vertical to 3 horizontal to the 5-ft depth, and 1 vertical to 10 to 12 horizontal in the shallow area beyond the 5-ft depth.†

Diving boards should provide a clear height above the board of at least 13 ft extending at least 16 ft beyond, 8 ft behind and 8 ft to both sides of the end of the board. Follow manufacturer's directions if greater distance is recommended. Diving boards up to 3-ft, 3 in. (1 m) in height above the water level are located at least 10 ft from an adjacent diving board, center to center, and 10 ft from the pool sidewall. Boards higher than 3 ft, 3 in. (1 m) are located at least 10 ft from adjacent boards and 12 ft from pool sidewalls.[60]

*See state and local regulations.

†For more complete details see refs. 51 and 60. Recommended standards for Swimming Pools (ref. 60) states "these diving area dimensions do not meet the requirements of NCAA or AAU. Dimensions for diving pools shall be in accordance with the Standards of International Amateur Swimming and Diving Federation (FINA)," or the equivalent.

Because of the danger of an inexperienced person making a "perfect dive" and hitting the bottom of the pool at a dangerous velocity,[61] the installation of diving boards should in general be prohibited or discouraged unless special diving instruction and supervision can be provided.

2. Mark water depth on pool perimeter and sidewall above water surface, at 2-ft changes in water depth, and every 25 ft or less.

3. Use Table 9-3 as a guide in determining pool size, in the absence of state or local regulations.

4. Allow at least 10 ft^2 of deck space per bather and include a minimum 5-ft-wide strip around an indoor pool and 8 ft for outdoor pool, plus lounging space. Provide floor drain for at least each 400 ft^2. Pave deck space sloped $\frac{1}{4}$ to $\frac{3}{8}$ in./ft to drain; do not use grass or sand. Deck space at least three to four times pool-water area is preferred. Outdoor carpeting, if permitted, should contain no natural fibers, be resistant to rotting and attack by fungus, be well drained, and not hold water. The carpeting should also be resistant to fading and freezing temperature where this is applicable and meet National Sanitation Foundation standards or the equivalent.

Source of Fresh Water

1. Use municipal source if available or approved potable source.
2. Use an existing stream or lake or saline water for saltwater pool, if clean, to fill pool through the filters.
3. Develop a well or spring if necessary.

Recirculation System

1. Design to replace water in 6 to 8 hr.* For a private lightly loaded pool, 12 hr may be acceptable. For public spas and hot tubs, replace water every 30 min or less and in 1 hr or less for a residential unit. Check state and local regulations. Design should permit total recirculation from main drains, automatic surface skimmers, and perimeter overflow system.

2. Provide inlets preferably on four sides, at least 12 in. below water surface, not more than 15 to 20 ft apart, and one inlet within 5 ft from each corner; use directional inlets with gate valve or similar control. Provide two inlets with adjustable orifice at least 12 in. below water line for each 600 ft^2 of water surface or 15,000 gal of pool volume, whichever is greater. Include sidewall inlets in pools over 60 ft long and multiple inlets at shallow end if more than 20 ft wide. Maximum pipe velocity should be 6 fps in suction, 8

*A 3–4-hr turnover is recommended where pools are expected to be well used. (See *The Purification of the Water of Swimming Pools*, Department of the Environment, London, England, 1975, p. 29.)

TABLE 9-3 Swimming Pool Design Bathing Load Limits

	Area (ft^2)		
Authority	Diving	Swimming	Nonswimmers
APHA,[a] bathers in pool enclosure	3 ft 3 in. (1 m) board or less, 10 ft each side of board and 16 ft forward; for higher board, 12 ft each side of board and 20 ft forward; 10 persons per diving board	25	15
GLUMR Board,[b] bathers in pool enclosure	300 ft^2 around each diving board	25	10, 15 if pool depth 5 ft or less
National Spa and Pool Institute[c]	300 ft^2 per diving board	20	15
New York State, bathers in pool enclosure	300 ft^2 per diving board	25	15
Illinois, bathers actually in water[d]	—	30	15
Iowa State College	For cities under 30,000; maximum day = 5–10% of population and maximum day at any one time = one-third maximum day		
National Recreation Association	Provide swimming and bathing space for 3% of population; allow 15 ft^2 of water area per person		
Tile Council of America	600 ft^2 per 1000 for communities of 4000 people or less to 320 ft^2 per 1000 for communities up to 90,000 population		

Note: Adjust required pool area for class use as in schools and clubs and for special local conditions. The water area 5 ft or less in depth is considered nonswimming area, greater than 5 ft in depth is swimming area except for diving area.

[a] *Public Swimming Pools, Recommended Regulations for Design and Construction, Operation and Maintenance,* American Public Health Association, Washington, DC, 1981.

[b] *Recommended Standards for Swimming Pools,* Great Lakes–Upper Mississippi River Board of State Sanitary Engineers, Health Education Serivce, Albany, NY, 1977.

[c] *NSPI-I 1991 Standard for Public Swimming Pools,* National Spa and Pool Institute, Alexandria, VA, 1989. Swim and shallow areas per bather may be decreased if deck area is increased.

[d] Capacity may be increased by 3% in an outdoor pool if deck space is adequate. Post maximum pool and pool enclosure capacity.

fps in pressure lines, and 3 fps in gravity flow. Surface skimmer return inlet should provide at least 10 fps velocity. Provide vacuum cleaning system.

3. Pool drain(s) permits pool to be emptied, preferably in 4 hr or less. No direct connection to sewer.

4. Outlet opening or grating area is at least four times drain pipe width. Use multiple outlets if pool is more than 30 ft wide. Main drain grate velocity $1\frac{1}{2}$ to 2 fps maximum; grate openings not greater than 1 in. Antivortex cover.

5. Design for head loss of 5 to 7 psi in high-rate filter, 30 psi in diatomite filter, and 15 in. of mercury with vacuum diatomite filter. Add for piping head loss.

6. Select correct pump for type of filter, static head and head loss in filter, and recirculation piping and fittings. Pump to provide design pool turnover at an operating head of approximately 50 ft for pressure sand and 85 ft for pressure diatomite filter. See 5 above. Make *hydraulic analysis*.

Accessories

1. Water heater with automatic thermal control for indoor and some outdoor pools.*
2. Locate water heater, if provided, on water flowing from filters to pool. Use cold water for filter washing. Temperature of water entering pool not greater than 104°F (40°C). Provide thermometer on heater outlet and near pool inlet.
3. Hair and lint catcher. Provide spare on bypass, with valves. Area of strainer openings at least four times area of main recirculating line, openings no greater than $\frac{1}{8}$ in.
4. Vacuum cleaner connected to portable pump or recirculating pump suction line, with proper connections in pool sides at least 8 in. but not more than 12 in. below the pool-water surface.
5. Space heaters and ventilation for indoor pools for humidity control.
6. Residual chlorine and pH testing kits. Chlorine range 0.2 to 3.0; pH range 6.8 to 8.2, phenol red, most common. If cyanurates used, test kit should measure to 100 mg/l with increments of 25 mg/l.
7. Spare parts for chlorinator, including ammonia bottle and self-contained respirator or an approved-type gas mask where gas machine used. Self-contained pressure demand unit is recommended.
8. Hose bibs provided to hose down walks and floors.
9. Steps and ladders for pools more than 30 ft long.

*Ensure that the water heater (natural gas, propane, or No. 2 fuel oil) is supplied with adequate fresh air and that it is properly vented to the outside air to prevent the formation and buildup of carbon monoxide. Heaters and installation must comply with American National Standards Institute, federal, state, and Underwriters Laboratories requirements.

Disinfection—Chlorine

1. Chlorination is most common. Bromine and iodine are also used. Cyanuric acid–based chlorine may not be permitted since it is a possible carcinogen. Disinfectants used must be registered with the U.S. Environmental Protection Agency (EPA). Ozone and chlorine dioxide are also used in Europe. Sodium hypochlorite is recommended.

2. Chlorinator capacity adequate to dose indoor pool water at 5 mg/l and outdoor pool at 10 mg/l. Manufacturers recommend gas chlorinator capacity of 15 lb for 100,000 gal plus 10 lb for each additional 100,000 gal of pool volume. Another design basis is 1 lb of chlorine per 8 hr per 10,000 gal of water in the pool. Some agencies require that the chlorinator have a capacity to feed 10 mg/l for all public pools.

3. Gas chlorinator housed in separate room; can be mechanically ventilated with minimal danger to attendants, bathers, and adjoining areas. Provide self-contained breathing apparatus in a separate location for emergency use. (See Figure 9-6; also Chapter 3, Gas Chlorinator.) Use of hypochlorinator is recommended for safety reasons. Store sodium hypochlorite and other disinfectants in a cool, dry, well-ventilated, and secured place.

4. Compare first cost, operation, *safety,* and maintenance of positive-feed hypochlorinator versus solution feed gas chlorinator. If safety of gas chlorinator to bathers and public cannot be ensured because of topography, meteorology, and other factors, do not use.

5. Erosion feed chlorinators are also used but provide unstable dose rates when operated in a continuous-flow mode. Additional studies are needed.[62] They may be acceptable for pools less than 50,000-gal capacity, installed on suction side of pump.

Clarification of Swimming Pool Water

1. Pools require filtration equipment. See Table 9-4.

2. Provision made for batch treatment with alum, soda ash, or other chemical by means of solution feed pump or through the make-up water or surge tank. Ensure that several minutes of coagulation–flocculation can take place before water reaches filters.

3. Alkalinity adjustment by means of soda ash (sodium carbonate), added by dry chemical feeder, solution feeder, solution pot, or soda–ash briquets. Calcite or calcium carbonate graded sand may be used in filter. Sodium bicarbonate, $1\frac{1}{2}$ lb/10,000 gal, will increase alkalinity 10 mg/l. Add $1\frac{1}{2}$ pints of muriatic acid to lower alkalinity 10 mg/l.

4. Filter sand not less than 20 in. deep, clean and sharp, effective size 0.4 to 0.55 mm, uniformity coefficient not greater than 1.75, over at least 20 in. of gravel. Anthracite 0.6 to 0.8 mm size and 1.8 uniformity coefficient. Filters

TABLE 9-4 Swimming Pool Filtration and Capacity Data

Diatomite Filter Septa		Vertical Pressure Filters			
Diameter (in.)	Cylindrical Area (ft^2/ft of length)	Diameter (in.)	Surface Area (ft^2)	Inlet (in.)	Waste to Sewer (in.)
2	0.524	30	4.9	$1\frac{1}{2}$	2
3	0.785	36	7.1	2	$2\frac{1}{2}$
4	1.047	42	9.6	2	$2\frac{1}{2}$
5	1.309	48	12.6	$2\frac{1}{2}$	3
6	1.571	54	15.9	$2\frac{1}{2}$	3
		60	19.6	3	4
		66	23.8	3	4
		72	28.3	4	5
		78	33.2	4	5
		84	38.5	4	5
		90	44.2	4	5
		96	50.3	5	6
		102	56.8	5	6
		108	63.6	5	6
		114	70.9	5	6
		120	78.5	5	6

Notes:

Filter rate—2.0–3.0 gpm/ft^2 with sand or anthrafilt; 15 gpm/ft^2 high rate.
3.0 gpm/ft^2 for depth-type cartridge; 0.375 gpm/ft^2 for surface type.
1.0 to 2.0 gpm/ft^2 with diatomite, continuous feed.

Wash-water rate—15 gpm/ft^2 for sand filter; use 9 gpm/ft^2 when using anthrafilt since it has about one-half the density of sand. Water use should not exceed 2% of water filtered.

Recirculating pump maximum capacity (gpm) = total filter area in ft^2 × filter rate in gpm/ft^2.

$$\text{Hours for one pool turnover} = \frac{\text{pool capacity in gal}}{\text{recirculating pump capacity in gpm}} \times \frac{1}{60}.$$

Recirculating pump capacity = sum of flows from each recirculation inlet, which is made proportional to the volume of water in that part of the pool, and still provide design pool turnover.

provide at least 18-in. freeboard between top of sand and overflow. May use not less than 12 in. of sand for high-rate filter. Granular activated carbon is also used as a filter media.

5. Rate of filtration 2.0 to 3.0 gpm/ft^2 with sand or anthracite and 1.0 to 2.0 gpm with diatomite. The lower rates are recommended, but up to 2.5 gpm/ft^2 may be permitted in a diatomaceous earth filter with continuous body feed. Rates up to 15 gpm may be permitted for high-rate pressure sand filters. With cartridge filters, up to 3 gpm/ft^2 may be permitted for the depth type and up to 0.375 gpm/ft^2 for the surface type. Higher rates may be permitted for residential pools, spas, and hot tubs. Design for recirculation from main drains and perimeter overflow or surface skimmers.

6. Wash-water rate for sand filter, 15 gpm/ft^2. Use 9 gpm with anthracite.

7. Continuous feed of diatomite said to result in less diatomite use. Provide for precoat.

8. Provide on filter system a rate-of-flow indicator for recirculation and backwash measurement, air release valve on each filter shell at top, pressure gauges on influent and effluent lines and on either side of hair catcher, two baskets for hair catcher, and a sight glass on waste discharge line. Basket screens upstream of pump and filter.

Overflow Gutters and Skimmers

1. Overflow gutters within $\frac{1}{8}$ in. level completely around pool, except for steps; a 12- to 18-in. flat gutter sloping away from pool also used. See Figure 9-1. Overflows easily accessible for cleaning and inspection.

2. Surge capacity of 1 gal/ft^2 of pool area provided in special gutters, surge tank, or elsewhere for perimeter overflow. Gutters and skimmers have the hydraulic capacity to carry away the overflow water, without flooding, due to swimmers entering the pool. A swimmer displaces on the average 17 to 20 gal of water. Surge tank normally not required for small pools.

3. Outlet drains not less than $2\frac{1}{2}$ in., 15 ft on centers. Drainage to recirculating pump or balancing tank.

4. Pools less than 30 ft wide, with a surface area less than 1600 ft^2, may be provided with surface skimmers built into the side and corners of the pool to take the place of gutters if acceptable to the regulatory agency. Skimmer design and construction meets National Sanitation Foundation standards. (ref. 46, pp. 22–23). Minimum 2-in. line 12 in. below lip of skimmer to prevent air entering pump suction. Skimmers equipped with basket strainers.

5. At least 60 percent of recirculation from gutters or skimmers. Capacity of gutters 100 to 125 percent of pump recirculation. One skimmer for each 500 ft^2 of pool area, minimum of two; flow rate at least 30 gpm per skimmer and not less than 4.0 gpm per linear inch of weir. For residential pools, use one skimmer for each 800 ft^2, and for spas or hot tubs use one skimmer for each 100 ft^2.

No Connection with Potable Water Supply

1. Design does not provide opportunity for pool water to enter drinking water system. Backflow preventers on all potable water outlets in the pool area and on water lines to pool piping or equipment.

2. Introduce fresh water directly to the pool through an air break or into the suction side of the recirculation pump through a balancing tank or through

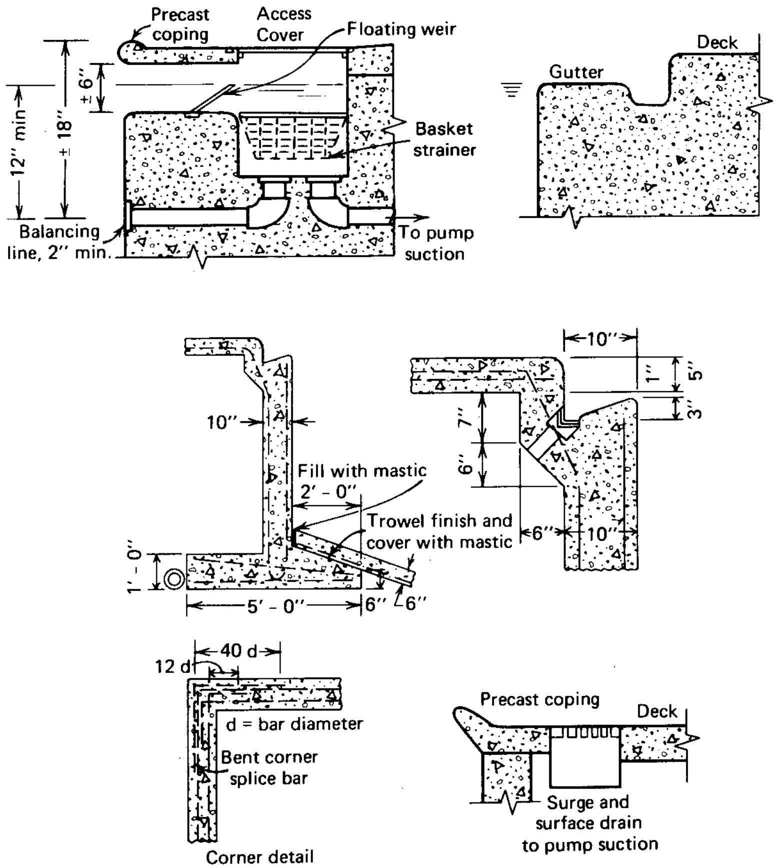


Figure 9-1 Swimming pool wall and gutter details. Prefabricated metal, precast gutters, and surface skimmers are available. The pool coping or edge of deck is sloped to drain away from the pool.

an approved backflow preventer. Pool drained through air break to sewer. No direct connection between pool deck drains and the sanitary sewer. See Figure 9-2.

Bathhouse

1. Facilities include separate dressing rooms, showers, toilets, and wash basins for each sex in proportion shown in Table 9-5. Showers have 95 to 105°F (35 to 41°C) water. See Figure 9-3.

2. Dressing rooms provide 7 ft^2 per female and 3.5 ft^2 per male patron expected at maximum periods. Well ventilated and lighted. Provide for direct

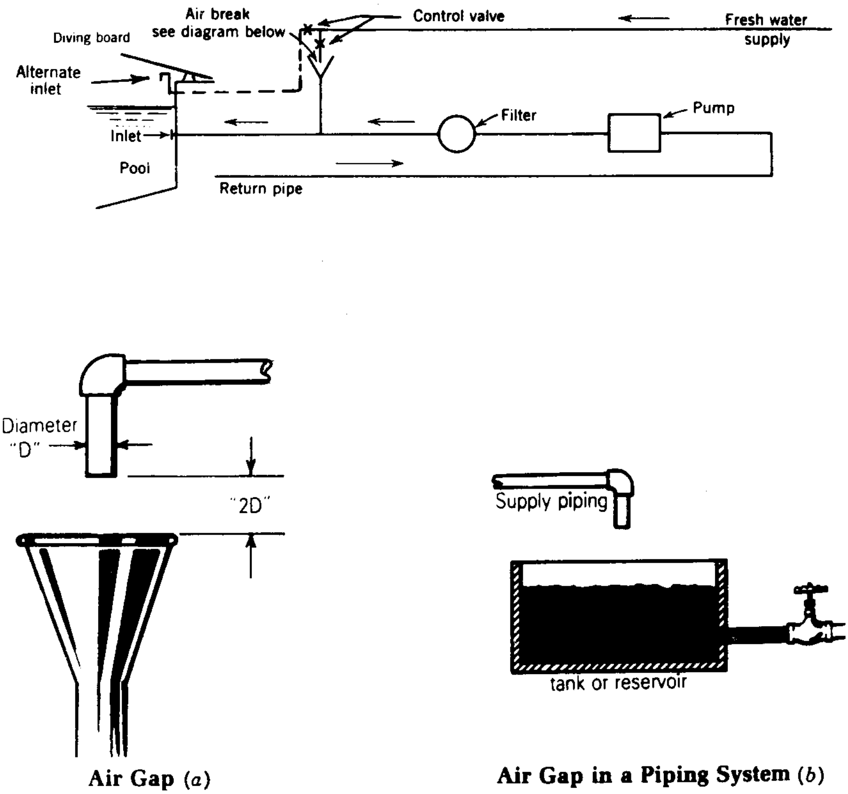


Figure 9-2 Acceptable means for adding fresh water to a pool and for draining wastewater. [*Source:* (*a, b*), *Cross-Connection Control Manual,* Environmental Protection Agency 570/9-89-007, U.S. EPA, Office of Water, Washington, DC, June 1989, p. 16.]

entrance of sunlight where possible; ordinary window glass and most transparent materials absorb the ultraviolet radiation.

3. Floor drains not more than 25 ft apart and floor sloped $\frac{1}{4}$ in./ft; $\frac{3}{4}$-in. hose bib for flushing. Floors smooth, nonslip.

4. Entrance and exit at shallow end of pool.

5. Bathers from dressing room must pass toilets and go through shower room before entering pool.

6. All electrical work, indoor and outdoor, shall be installed, comply with, and be maintained in accordance with the standards of the National Electrical Code or equal. See Accident Prevention and Life Saving, this chapter.

7. Dressing rooms, shower areas, and toilet rooms ventilated by mechanical or natural means to provide two air changes per hour.

TABLE 9-5 Plumbing Fixtures Recommended at Swimming Pools

	Number Men Served					Number Women Served				
Fixture	1	2	3	4	5	1	2	3	4	5
1 water closet	75	100	15	60	100	50	50	10	40	50
1 urinal	75	100	20	60	100	(if provided)			60	50
1 washbasin	100	100	15	60	100	100	100	10	60	50
1 shower	50	100	4	40	50	50	100	4	40	50
1 service sink	At least one					At least one				

Notes: For classes, the number of showers equals one-third the number of pupils in the maximum class. Provide at least one drinking fountain in pool area. Showers to provide 1.5–3 gpm; water temperature 95–105°F (35–40°C) through single control valve. At least two showers for each sex. See local regulations.

Column heads:

1. *Public Swimming Pools, Recommended Regulations for Design and Construction, Operation and Maintenance,* American Public Health Association, Washington, DC, 1981.
2. New York State Department of Health, State Sanitary Code, Part 6, Albany, NY, 1988.
3. Class in school, YMCA, and similar pool for 1-hr class. Multiply number of persons by $2\frac{1}{2}$ if class is of 2-hour duration.
4. *Swimming Pools,* Public Health Service, Department of Health, Education, and Welfare, Washington DC, June 1976, reprinted March 1983.
5. *ANSI/NSPI-1 1991 Standard for Public Swimming Pools.* Add one water closet, urinal, washbasin for each additional 200 males and one water closet and washbasin for each 100 females, plus 2 showers for each 50 males and females.

Small-Pool Design

To illustrate some of the design principles, a simple example is given below. Figure 9-4 shows a cross-section of the pool (see previous pages for design factors):

Size: 62 ft × 30 ft = 1860 ft^2.

Number of persons: 1860/25 = 75 people at any one time; 150 in pool enclosure.

Volume: $$\left[\frac{(3+5)}{2}\cdot 30+\frac{(5+9)}{2}\cdot 20+9\times 10\right]30\times 7.5=$$ 78,750 gal.

Recirculation period: assume 8 hrs.

Required capacity of recirculating pump = 78,750/8 × 60 = 164, say 175 gpm.

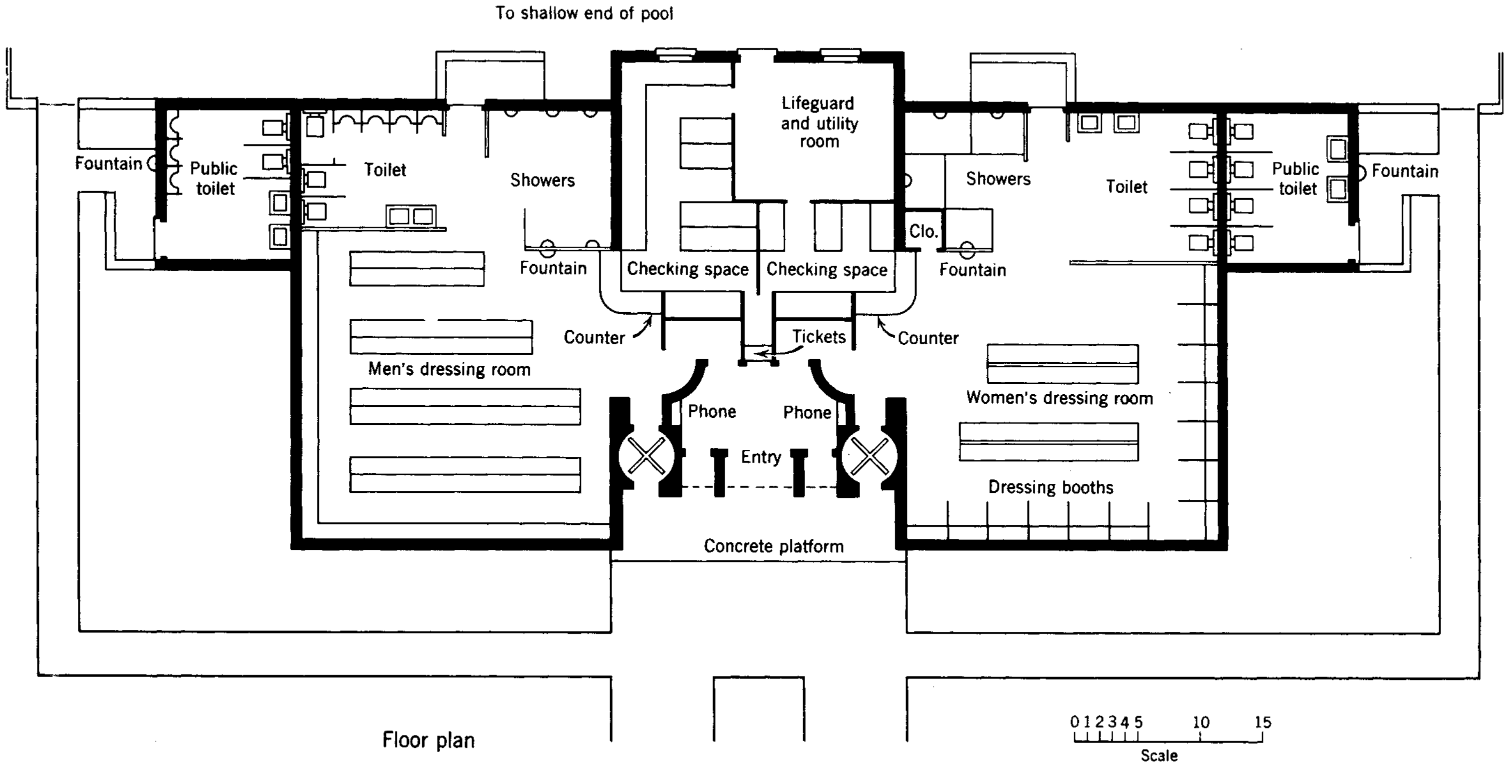


Figure 9-3 Suggested layout for a bathhouse for a 40 × 100 ft pool. Floor drains in all spaces.

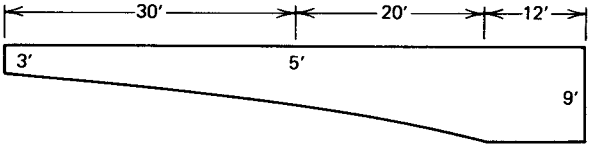


Figure 9-4 Typical summer resort swimming pool design, without diving board.

Required electric motor (1.750 rpm, with magnetic starter and under voltage protection)

$$= \frac{\text{gpm} \times \text{total head in ft*}}{3960 \times \text{pump and motor efficiency}}$$

$$= \frac{175 \times (16 \text{ ft in filter} + 16 \text{ ft in recirculation system})}{3960 \times 0.60 \times 0.80}$$

$= 2.95$, say, 3 hp with pressure sand filters

$$= \frac{175 \times (69 \text{ ft in filter} + 16 \text{ ft in recirculation system})}{3960 \times 0.60 \times 0.85}$$

$= 7.4$, say $7\frac{1}{2}$ hp with pressure diatomite filters (minimum)

Piping: Main lines to and from recirculating pump = 4 in.; lines to pool inlets = 2 in.; provide minimum of four pool inlets, more preferred. Locate inlets 18 to 24 in. below water surface. Provide 2-in. vacuum cleaner connections and flow measurement. All valves are gate valves. See Chapter 3, Design of Small Water Systems, for hydraulic analyses.

Hair catcher: 4 in.; coagulant feeder: one; soda ash feeder: one; one vacuum cleaner; and one flow indicator.

Chlorinator type: hypochlorinator, positive feed.

Filters: required area $= \frac{175}{3} = 58$ ft^2; three 5-ft-diameter filters $= 3 \times 19.6 = 58.8$ ft^2. Provide three 5-ft-diameter pressure sand filters; *or* one diatomite filter with total septum area of 88 ft^2, with air release at top of each filter shell consisting of $\frac{1}{2}$-in. line with globe valve, and pressure gauges on inlet and outlet lines.

Pool water heating:

*Make hydraulic analysis to calculate total head based on actual situation, filter type, piping sizes, fittings, and miscellaneous head losses, static head, operating pressures, etc. An average design head for a pressure sand system may be 50–60 ft, 80–85 ft for a pressure diatomaceous earth filter.

$$H = \text{heater size, Btu/hr}$$
$$Q = \text{volume of water in pool, gal}$$
$$T = \text{°F water temperature increased}$$
$$8.33 = \text{weight of 1 gal of water, lb}$$

Then

$$H = Q \times 8.3 \times T$$

A pool 30 × 62 ft in area and with a depth of 3 to 5 ft in the shallow area and up to 9 ft in the deep area holds approximately 92,000 gal of water (actually 91,555 gal). The temperature of the pool water is cooled to 58°F (14°C), and it is required that the temperature of this water be raised to 78°F (26°C). Determine required heater output:

$$H = 92{,}000 \times 8.3 \times 20$$
$$15{,}272{,}000 \text{ Btu/hr}$$
$$763{,}600 \text{ Btu/hr with a 20-hr pool heat-up time}$$

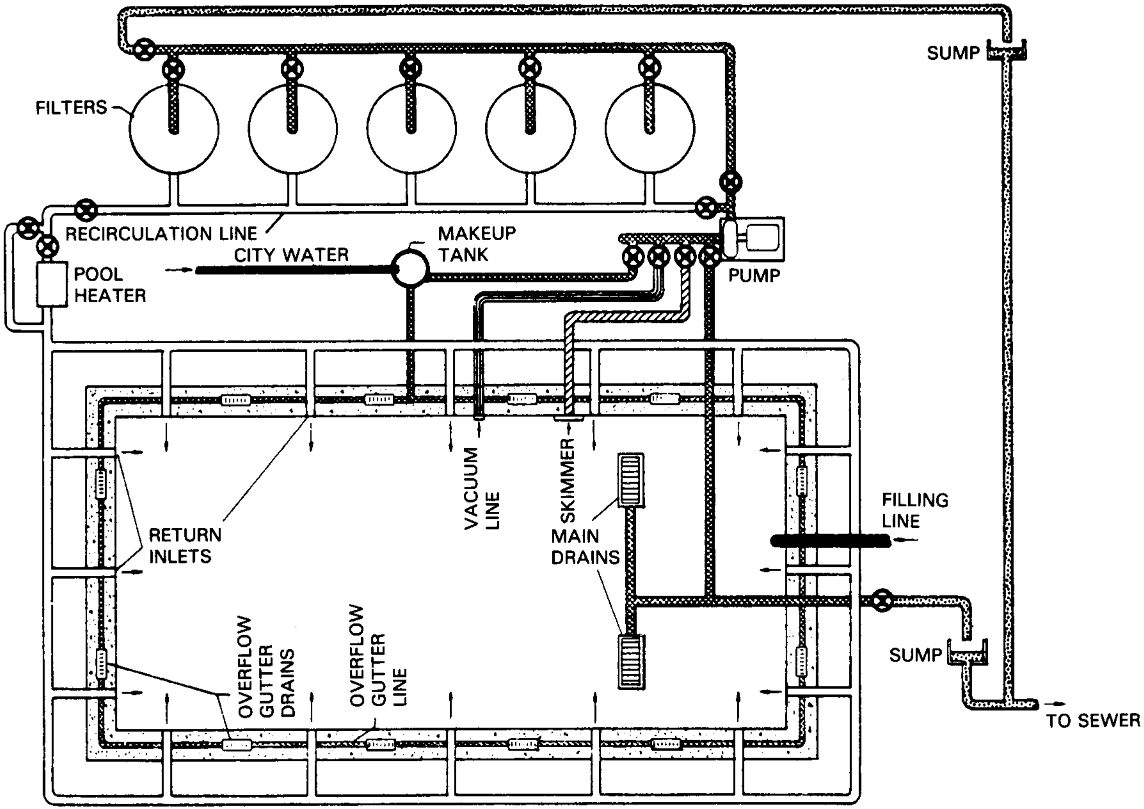
If the heat loss from the water surface is 14.3 Btu/ft^2 per hour per degree temperature difference, the average water temperature is 78°F (26°C), and the average air temperature is 58°F (14°C), the average water surface heat loss is

$$30 \times 62 \times 14.3 \times (78 - 58) = 531{,}960 \text{ Btu/hr}$$

Since the heater required will have an output of 763,600 Btu/hr and exceeds the water surface heat loss of 531,960 Btu/hr, it will be adequate for the example given to maintain the water temperature and allow for heat loss due to moderate ($3\frac{1}{2}$ mph) wind velocity. Add 25 percent if wind velocity is 5 mph. The pool heater must not discharge water above 104°F (40°C). The average air temperature and wind velocity are important factors. A pool cover over the water surface in the evening after the pool is closed will greatly minimize the water surface heat loss, speed up water temperature recovery, and save on heating costs—up to 50 percent reported. A solar heater may be used to supplement the heating.

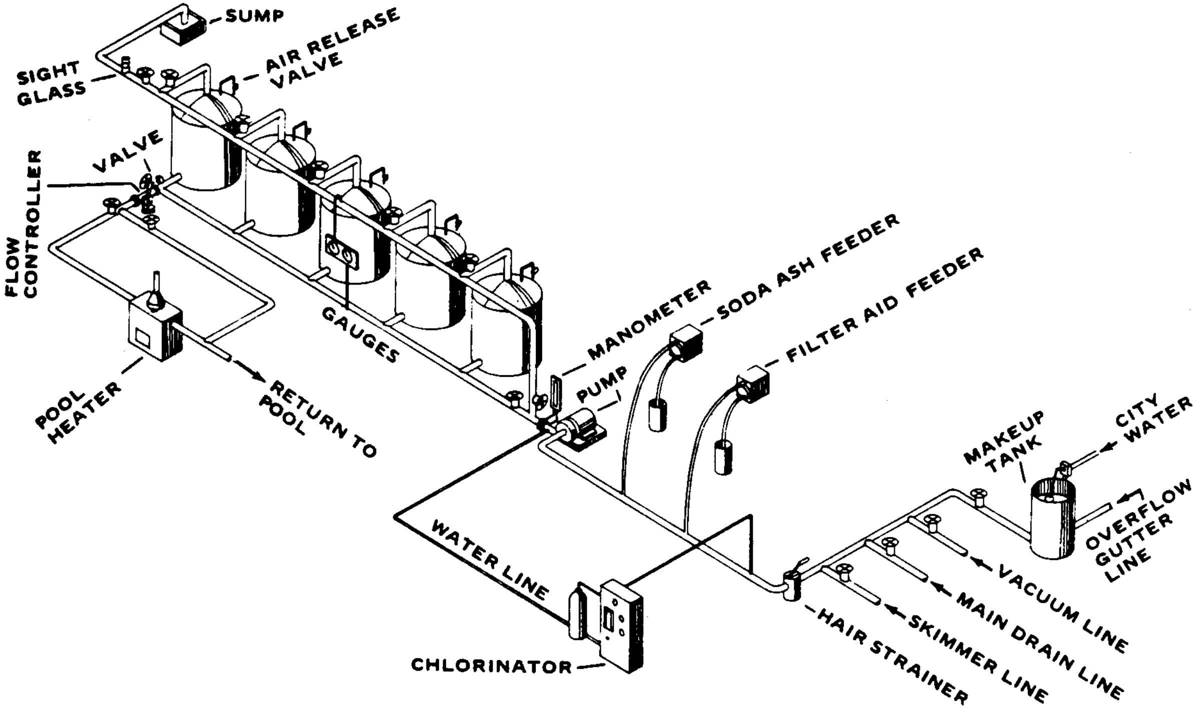
A filtering and disinfecting system for an indoor pool including surge tank for make-up water, water heating, and other appurtenances is illustrated in Figures 9-5 and 9-6.

It is important to ensure that all appliances and work comply with applicable regulatory agency codes and national standards.



(a)

Figure 9-5 (*a*) Swimming pool piping system; (*b*) Swimming pool filtration equipment. (*Source: Swimming Pools*, U.S. Department of Health and Human Services, Public Health Services, Centers for Disease Control and Prevention, Atlanta, GA, March 1983, pp. 14–15.)



(*b*)

Figure 9-5 (*Continued*)

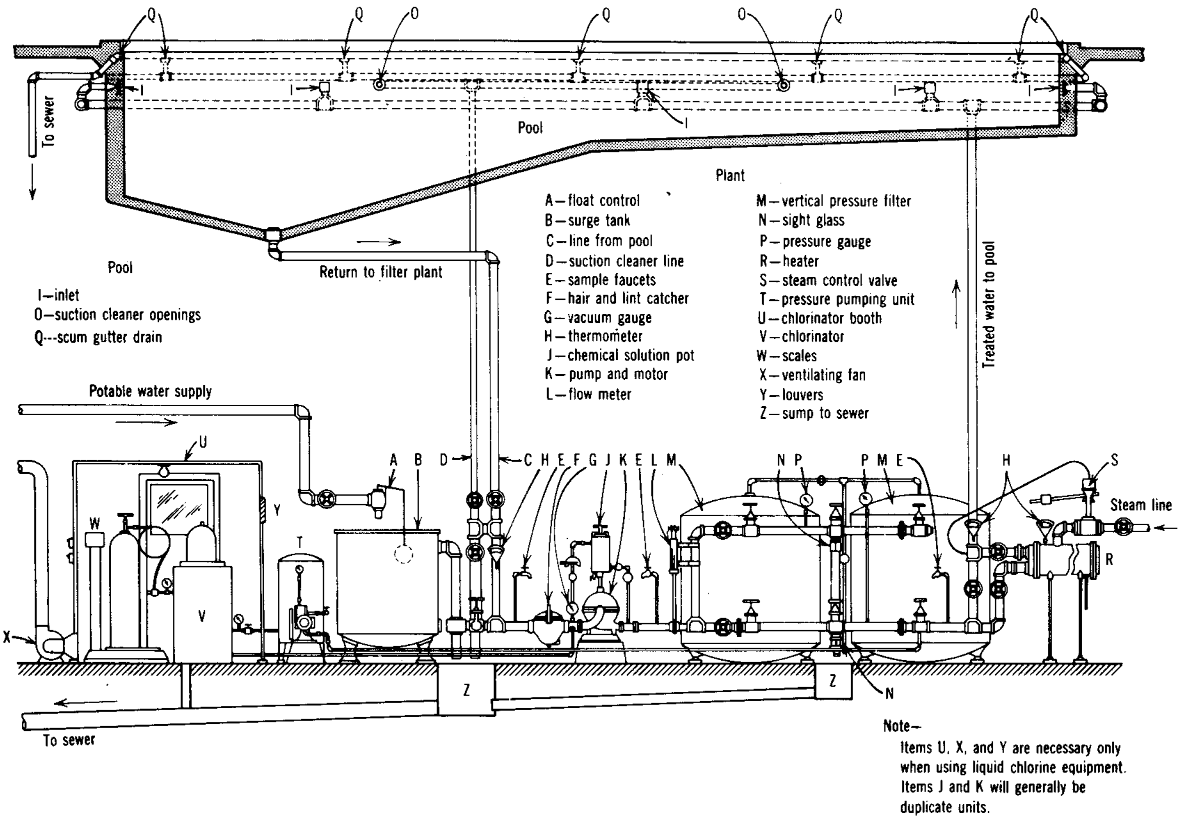


Figure 9-6 Complete pressure filter plant of recommended type, with simplified plumbing system. For purposes of illustration, only two filter units are shown instead of three or more units. No longer recommended by Michigan Department of Public Health. To upgrade, gutter water should be directed to the surge tank for filtration, with provision for discharge to waste. Pressure filters are high-rate sand filters (or diatomaceous earth or cartridge type). Sodium hypochlorite disinfection, or the equivalent, should replace gas chlorination; special approval required for gas (liquid chlorine). (*Source:* Michigan Department of Health, Bureau of Engineering, Bulletin No. 18, Lansing, MI, 1963.)

SWIMMING POOL OPERATION

Bacterial, Chemical, and Physical Water Quality

The bacterial quality of artificial swimming pool water approaches, and the clarity may exceed, that of the National Drinking Water Regulations. Maintenance of such water quality will be affected by many factors, many of which can be controlled by trained pool personnel. These include the following:

1. The operation and maintenance of purification equipment provided, such as strainers, pump, filters, chemical feed apparatus, and chlorinator.
2. The bathing load, or number of persons permitted to be in the pool at any one time and in any one day, based on the capacity of the purification equipment and pool area.
3. Pollution introduced by the bathers and enforcement of warm-water and soap-cleansing showers before entering or reentering the pool enclosure.
4. Supervision of pool personnel and bathers.
5. Maintenance of pool decks, general cleanliness, and separation of recreation and picnic areas from the pool and prohibition of food and spectators from pool enclosure.
6. Tests for residual chlorine and pH at least three times a day, water clarity (and cyanuric acid if used) measured daily, and tests made periodically for alkalinity, bacterial plate, and coliform counts. Keep daily operation record of all tests made and include number of bathers, peak bathing load, recirculation period, rate of flow, amounts of chemicals used (alum, soda ash, chlorine), filter head loss, volume of make-up water, and other maintenance. Also keep records of accidents, rescues, drownings, pool closure, and reason. Most health agencies have a standard form.

The accepted and effective method of maintaining satisfactory pool-water quality in a properly designed pool is by continuous recirculation, chlorination, and filtration over a 24-hr period. Attempts to economize by intermittent operation invariably lead to ineffective or nonuniform chlorination, algal growths, and reduced water clarity. This is particularly true at outdoor pools and pools subject to periodic heavy bathing loads. Proper water level must be maintained in a pool if the scum gutters and/or skimmers are to function as intended.

Where adequate laboratory facilities are available, samples should be collected at least once a week for bacterial analyses made at an approved laboratory near the pool, if possible, to reduce the time lapse between collection and examination of the samples. The tests made may include the total coliform and fecal coliform tests, which indicate the presence of intestinal-type organisms; the total bacteria plate 95°F (35°C) count, which indicates the concentration of bacteria in the pool water; and the test for enterococci (streptococci), which indicates the presence of organisms associated with respiratory illnesses. Other specific tests of interest are for staphylococci (*Staphylococcus aureus*), fecal streptococci (*Streptococcus faecalis*), *P. aeruginosa,* and *C. perfringens*. Of the tests mentioned, the coliform tests and the plate count are most valuable for general use, although the others give additional information. Staphylococci, streptococci, and adenoviruses found in pool waters are more resistant to chlorine than coliform bacteria. *Pseudomonas aeruginosa* is as sensitive to chlorine as *E. coli*.

As in other activities, the results of bacterial analyses must be interpreted in the light of a sanitary survey of the facility. Representative samples are an indicator or check on the effectiveness of pool operation at times of peak use. Deficiencies in equipment or operation usually become apparent before they become too serious. Hence, unsatisfactory results should be immediately investigated to eliminate their cause before any harm is done.

Disinfection

Chlorine, bromine, iodine, chlorinated cyanurates, and ultraviolet ray lamps have been used to disinfect swimming pool water. Chlorine and, to some extent, bromine are the chemicals of choice. Chlorinated cyanurates are not permitted by some health authorities. Ultraviolet ray lamps have distinct limitations; they do not leave a residual disinfectant and turbidity interferes with the rays' effectiveness. Iodine has not been used to any extent but is reported to be a satisfactory pool disinfectant and more stable than chlorine in outdoor pools. Ultraviolet light in combination with hydrogen peroxide has also been found effective for the disinfection of swimming pool water.[63] Bromine as bromine chloride reacts with water and ammonia to form bromamines, which are reported to be superior to chloramines against bacteria and viruses. Chlorine, however, has been the chemical of choice for swimming pool water disinfection. Chlorine used may be as a liquified compressed gas, as $5\frac{1}{4}$ or 12 to 15 percent sodium hypochlorite solution, as 35 percent granular lithium hypochlorite, or as 65 percent calcium hypochlorite granular powder or tablet.

The maintenance of at least 0.6 mg/l free available residual chlorine (without cyanurates) and a pH of 7.2 to 7.6 in pool water will produce consistently satisfactory bacteriological results. An operating free chlorine residual of 1.0 to 3.0 mg/l is usually required in practice. Free available chlorine is the sum of chlorine as hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). The HOCl component is the markedly superior disinfectant, but the proportion is largely dependent on the pH of the water and the water temperature. For example, at a pH of 7.2, 62 percent of the available chlorine is in the form of HOCl; at pH 7.4, 32 percent is available as HOCl; and at a pH of 8.0, 22 percent is available as HOCl, all at a temperature of 68°F (20°C). (See Table 3-17.)

Eye irritation may be caused by prolonged swimming in water with a pH below 7.4, combined residual chlorine (chloramines), or nitrogen trichloride in the water. A pH of 6.5 to 8.3 can be tolerated for a limited period of time because of the high buffering capacity of the lacrimal fluid.[64] With free residual chlorination, nitrogen trichloride, which is irritating to the mucous membranes as well as the eyes of bathers, starts to form as the pH of the water decreases below 7.8. At pH above 8.4, little disinfection will be accomplished by combined chlorine. A pH of 7.5 to 7.6 is probably optimal for minimal eye irritation, together with a free available chlorine residual of 0.6 mg/l for adequate disinfection. A pH above 7.6 would require 1.0 mg/l free available residual chlorine for equivalent disinfection. The pH of the pool water should be kept below 8.0 since the amount of active chlorine present decreases greatly with increasing pH, as noted above; only about 8 percent of the chlorine is HOCl at pH 8.5.

If the use of cyanuric acid with chlorination or chlorinated isocyanurates to stabilize the residual chlorine is *permitted,* the recommended minimum free available residual chlorine is 1.0 mg/l with a pH of 7.2 to 7.5, 1.25 with pH 7.6, 1.5 with pH 7.7, 1.75 with pH 7.8, 2.0 with pH 7.9, and 2.5 with pH 8.0. At a temperature above 86°F (30°C), the chlorine is not released; testing would show a low chlorine residual, and more isocyanurate would be added, resulting in a level far in excess of the 100-mg/l standard.[65] The cyanurate concentration should be maintained between 30 and 100 mg/l. Dilution or replacement water is necessary if the 100-mg/l concentration is exceeded, as the apparent free chlorine available is slower acting; however, it is more persistent than free chlorine in the presence of sunlight (ref. 51, p. 43). Cyanurates have been reported to cause liver and kidney changes in laboratory animals and eye irritation.

Ammonium alum or free ammonia should not be used as it will be impractical to maintain a free available chlorine in pool water because the ammonia would combine with the chlorine to form chloramines or combined chlorine. Combined residual chlorine is a slow-acting disinfectant and very ineffective as a bactericide in swimming pools, where it is important to immediately neutralize any contamination introduced by bathers. With continuous recirculation and adequate chlorination, this pollution can be neutralized by adding sufficient chlorine to maintain an adequate free available chlorine in pool water. When the combined residual chlorine (chloramine) reaches 0.2 mg/l, it should be neutralized by heavier chlorination beyond the breakpoint, as shown in Figure 3-16. The chlorine dosage should be at least 10 times the combined chlorine concentration. Chloramines also cause chlorinous odors in addition to eye irritation. Make provision, when superchlorinating, for adequate ventilation of the nitrogen trichloride formed, which is offensive and explosive indoors. Close the pool until the free chlorine is 3 mg/l or less.

The chlorination of water containing iron in solution will cause discoloration of the water and staining of pool walls. See Iron and Manganese Occurrence and Removal, Chapter 3.

When bromine is used as the disinfectant, to find the bromine residual with a chlorine comparator, multiply the residual chlorine reading by 2.25 to convert it to bromine (and by 3.6 to convert it to iodine). A bromine residual of

3.0 to 5.0 is recommended in a pool and 4.0 to 6.0 in a hot tub. Pure bromine at room temperature is a deep red color with a strong irritating odor. It fumes readily and is toxic and extremely corrosive. It is a very effective disinfectant. Bromine is commonly available as a slow-dissolving solid, which is safer to handle. Bromine, bromamine, and iodine react with diethyl-*p*-phenylenediamine (DPD) indicator and appear with free available chlorine.

Oxidation–reduction potential (ORP), or redox potential, recognized as an effective index of disinfection (usually chlorine or bromine) activity in pools and spas, is the oxidation or activity level of an oxidizing agent remaining in the water. It is measured in millivolts (mV) by means of an ORP meter. The ORP reading should be maintained at no less than 700 mV.* Studies in Europe and the United States show that ORP correlates very closely with bacteriological water quality. An ORP controller can be used to maintain the required ORP level by activating a chemical (chlorine solution) feeder. Routine residual chlorine or bromine testing required by the regulatory agency must still be made.

Do not mix an acid cleaner with hypochlorite powder or solution or bromine! Toxic chlorine or bromine gas is released.

Control of pH, Corrosion, and Scale

The chemical quality of pool water is generally measured by tests for the pH value and chlorine residual. Occasional laboratory determination of calcium hardness, alkalinity, free carbon dioxide, and total dissolved solids is desirable, but pH and residual chlorine tests should be made at least three times a day, before and during peak loads. The maintenance of a proper pH and alkalinity ratio is important for possible corrosion reasons and others. Pipe scaling is likely above pH 8.0. Water coagulation, disinfection with chlorine, and eye irritation are affected by the acidity–alkalinity balance. Dissolved solids in excess of 2000 mg/l may cause corrosion and reduce water clarity. Dilution with water low in dissolved solids is indicated. A Langelier index of 0.0×0.5 will help maintain a proper chemical and physical water quality. See Calculation of Saturation Index, this chapter.

pH Adjustment A sudden jump in pH may be due to algal growths as a result of inadequate or interrupted chlorination. Algal control is discussed below and in Chapter 3. Maintenance of a free chlorine residual in pool water at all times will prevent algal growth. In practice, the pH of pool water will drop rapidly, where chlorine gas is used. Alum, if used, also tends to lower the pH. If not corrected, the water may become corrosive and cause eye irritation. Alum may also appear in a pool as a floc if the pH of the water is not controlled. Its concentration in pool water should be less than 0.1 mg/l.

*650 to 750 mV usually quoted.

To raise the pH, it is common to add sodium carbonate, also known as soda ash, to pool water. This is done by means of a chemical solution feed machine that introduces the chemical, usually in the recirculating pump suction line, or by placing the soda ash briquets near the pool recirculation outlets. Sodium hydroxide, known as caustic soda or lye, will also produce the desired result, but this material can cause severe burns; hence, its use is not recommended unless competent and trained personnel are available and proper precautions are taken in handling hazardous chemicals. Sodium bicarbonate will also raise the pH, but its usual purpose is to raise total alkalinity.

If the pH gets too high, it may promote scale formation. It should be lowered by diluting with fresh water if its pH is lower. Acid such as hydrochloric acid, also called muriatic acid, or dilute sulfuric acid could be used. Sodium bisulfate is recommended as it is safer to use. Mix the powder in water, then sprinkle around the pool or add to pump suction. Handle acids with care. Never add water to acid; add acid solution slowly to water.*[65] The alkalinity will also be lowered upon the addition of acid. Adjustment of the alkalinity first to about 80 mg/l will simplify pH adjustment. Keep the pH from falling below 7.2; 7.5 to 7.6 is optimum.

Alkalinity Adjustment Chlorine as hypochlorous acid and hypochloric acid reacts with alkalinity in the water at a rate of 1 part chlorine to 1.2 parts alkalinity. This can be compensated for by adding 1.2 mg/l alkalinity as calcium carbonate. On the other hand, chlorination by means of sodium or calcium hypochlorite will add some alkalinity to pool water. To increase alkalinity as calcium carbonate by 10 mg/l, add $1\frac{1}{2}$ lb of sodium bicarbonate (soda ash or baking soda) per 10,000 gal of water. To lower total alkalinity by 10 mg/l, add 30 oz of sodium bisulfate or $1\frac{1}{2}$ pt of muriatic acid, in small amounts at any one time, to 10,000 gal of water. Also 1 lb of calcium chloride per 10,000 gal water will raise hardness as calcium carbonate about 11 mg/l (ref. 51, p. 60). Maintain the methyl-orange alkalinity between 80 and 120 mg/l, ideally at 100.

Scale Control Scale control ordinarily requires a balance between calcium hardness as calcium carbonate, total alkalinity as calcium carbonate, and pH for the prevailing water temperature. Calcium carbonate is the principal scale former. It will form a deposit on filter media, in piping, on pool accessories, and on pool walls. Sodium and calcium hypochlorite, soda ash, and caustic soda tend to support scale formation unless otherwise controlled. Once formed, scale is difficult to remove. Sand paper and power tools or professional help may be needed. The goal is a calcium carbonate saturation that results in a stabilized water with neither corrosion nor precipitation of calcium

*Also, add solid to water, *never* water to solid.

carbonate. Several methods for determining the approximate level of calcium carbonate stability are discussed in Chapter 3 under Corrosion Cause and Control and in standard publications dealing with water supply and treatment. *Public Swimming Pools* (ref. 51, pp. 59–62) gives examples for calculating the Langelier index or saturation index to determine if a water tends to be corrosive or scale forming. An example is given below. Scale control is simplified by maintaining control over the pool water pH.

Calculation of the Saturation Index[66] Saturation index (SI) is equal to the pH plus a temperature factor (TF) plus a calcium hardness factor (CF) plus an alkalinity factor (AF) minus the constant 12.1:

$$SI = pH + TF + CF + AF - 12.1$$

The optimum saturation index is zero. Tolerance limits are ± 0.5. If the index is positive, the water is supersaturated with $CaCO_3$ and may deposit a protective coating or scale in the pipeline, particularly metal filters, valves, and pumps.

If the index is negative, water will dissolve $CaCO_3$ and may be corrosive.

Temperature						
°F	°C	TF	Calcium Hardness	CF	Total Alkalinity	AF
32	0	0.0	5	0.3	5	0.7
37	3	0.1	25	1.0	25	1.4
46	8	0.2	50	1.3	50	1.7
53	12	0.3	75	1.5	75	1.9
60	16	0.4	100	1.6	100	2.0
66	19	0.5	150	1.8	150	2.2
76	24	0.6	200	1.9	200	2.3
84	29	0.7	300	2.1	300	2.5
94	34	0.8	400	2.2	400	2.6
105	41	0.9	800	2.5	800	2.9
128	53	1.0	1000	2.6	1000	3.0

Example: Given temperature 68°F, total hardness 200 mg/l, total alkalinity 20 mg/l, $CaCO_3$, and pH 7.8,

$$SI = pH + TF + CF + AF - 12.1 \quad (CF = 0.70 \times 200 = 140 \text{ mg/l})$$

$$7.8 + 0.52 + 1.76 + 1.22 - 12.1 = -0.8$$

Therefore, the water is corrosive.

Note: The saturation index must be maintained slightly on the positive side within the tolerance limits.

Normal control levels:

pH 7.4–7.8	Free chlorine 0.6 (minimum)
Temperature 78–80°F (indoor)	Saturation Index − 0.5 to +0.5
Total alkalinity 80–120 mg/l	Calcium hardness 180–250 mg/l

To increase alkalinity control, $1\frac{1}{2}$ lb of sodium bicarbonate ($NaHCO_3$, baking soda) will raise the alkalinity of 10,000 gal of water by 10 mg/l.

To lower alkalinity control, add muriatic acid; no more than 1 pt ($\frac{1}{8}$ gal) per 5000 gal of pool water will lower alkalinity by 12 mg/l. (Or, add 1.25 lb of sodium bisulfate.)

To increase pH control, use soda ash.

To decrease pH control, add muriatic acid or sodium bisulfate.

Hardness control (Note): Calcium hardness is assumed to be 70 percent of total hardness. To increase, 1 lb of calcium chloride will raise the calcium hardness of 10,000 gal of water by 11 mg/l. It should be added in small amounts. To lower, dilute with soft water.

Clarity

The physical quality of the water (its appearance and clarity) is determined by sight tests previously described. The clarity of artificial swimming pool water is maintained by continuous filtration. Where sand or anthrafilt filters are used, alum is the chemical usually used to coagulate and trap the suspended matter and color in the water. For best results, in addition to pH control previously discussed, the alum must be fed in small controlled quantities, be well mixed with the recirculated water, and then be allowed to flocculate before it reaches the filter. One way in which this is done is to add filter alum (aluminum sulfate) into a reaction or makeup tank and then introduce the alum into the suction side of the pump, where it is thoroughly mixed with the water in passing through the pump and flocculated before reaching the filters. A dosage of 3 to 4 lb of alum per 10,000 gal of pool water is normally used. At some pools, excellent results are obtained by slowly adding a small quantity of alum immediately following backwash of the filters to replace the flocculent mat on top of the sand bed, following which the chemical feed is stopped. Diatomite filters use 0.10 to 0.15 lb/ft^2 of diatomaceous earth for precoat plus continuous feed to maintain porosity of filter. See Swimming Pool Water Quality, this chapter. As a rule-of-thumb, the drain at the deepest end of the pool should be clearly visible from the pool deck.

Iron and Manganese If iron or manganese is in the water used to fill the pool or in the make-up water, it will cause the water to darken, with possible staining of pool walls, when chlorine is added. Check this *before* using the water. Add 1 oz of 5 percent sodium hypochlorite to a quart of the water. If it darkens in an hour or two, iron and/or manganese is present. Professional assistance is needed to treat the water. See Chapter 3.

Swimming Pool Water Temperature

At indoor pools, it is desirable to control the temperature of the pool water and air. An air temperature about 5°F (3°C) warmer than the temperature of the water in the pool is recommended. The water temperature suggested for general use is 80°F (27°C); 74 to 76°F (23–24°C) is comfortable; 78 to 82°F (26–28°C) is ideal. Outdoor pools in hot climates may require water replacement or the addition of large quantities of ice to keep the water from getting too warm. Spray aeration of recirculated water to the pool can lower the water temperature 5 to 10°F (3–6°C). Cold-water make-up water, heat exchange equipment, a shade structure designed to withstand wind, and a cooling tower can also be used. The water temperature should not exceed 85°F (29°C). Swimming or bathing in water above this temperature for any length of time has a temporary debilitating effect. Swimming in 40°F (4°C) water causes fatigue and breathing difficulty in a short time, 10 min or less.

Condensation Control

In indoor pools, condensation and mildew can be a serious problem if ventilation and humidity control are inadequate. Unit heaters, which are combination fans and heaters, offer a practical relief, but serious problems require professional consultation.

Testing for Free Available Chlorine and pH

The residual chlorine test and the test for pH of swimming pool water require a special procedure and technique to give better accuracy. Combined chlorine is of little value as a disinfectant in swimming pool water and can produce a false sense of security.

The DPD method developed by A. T. Palin is the preferred method for the free residual chlorine test. Commercial test kits for field use are available that permit simple comparison with a color standard to accurately determine free, combined, and total residual chlorine.* The DPD test compensates for interference by copper and dissolved oxygen. It is not affected by nitrite nitrogen up to 5 mg/l. If present, oxidized manganese can interfere with the color reading, but a procedure to correct for this is available (ref. 29, pp. 12–13).

*Test kits for measuring pH, residual chlorine, and cyanuric acid should comply with National Sanitation Foundation Standard No. 38 or the equivalent.

Monochlorine and dichloramine can also be measured. A free residual chlorine of 1.0 mg/l is considered adequate. See Testing for Residual Chlorine, Chapter 3.

When high free available chlorine is maintained in pool water, the chlorine will bleach the pH color indicator, giving an improper reading. If the free available chlorine is first removed, a proper reading can be obtained. This can be done by adding one drop of $\frac{1}{4}$ percent sodium thiosulfate solution to the pool water sample. This will destroy the free available chlorine present without appreciable effect on the pH value. The glassware used must be clean and the sample must not be contaminated by lime, alum, or other soil. Phenol red (range 6.8–8.2) as the indicator and a color comparator are used in the field. The optimum pH is 7.5 to 7.6. The residual chlorine test kit should have a range of at least 0.2 to 3.0 mg/l. The DPD test for free residual chlorine should be made rapidly to minimize obtaining a false measurement due to interfering substances, particularly chloramines.

Algae Control

Algae development in a pool causes a slimy growth on the walls and bottom (concrete is more susceptible), reduced water clarity, increased chlorine consumption, unpleasant odors, and a rapid rise in the pH of the pool water in one day. The wall and bottom growths penetrate into cracks and crevices, making them difficult to remove once they become attached. The suspended or floating type are more easily treated. However, the best and simplest control method is to prevent the algae from developing, and this can be accomplished by maintaining a free chlorine residual of at least 0.6 mg/l in the pool water at all times. This cannot be accomplished by intermittent recirculation and chlorination.

If algae difficulties are experienced, several control measures can be tried. These include heavy chlorination, copper sulfate treatment, quaternary ammonium treatment, emptying the pool and scrubbing the walls and bottom with a stainless steel or nylon brush and strong chlorine, caustic soda, or copper sulfate solution and combinations of these methods. Caustic soda can cause severe burns; its use by a lay person is not recommended.

Heavy chlorination, or superchlorination, is the preferred treatment. Dosage of the pool water to maintain a free chlorine residual of 0.6 to 2 mg/l, together with recirculation and filtration, should be effective in preventing and destroying the algae growths normally found in a pool. Hand application of 7 gal of 14 percent sodium hypochlorite to a 100,000-gal pool will speed up the treatment.* Other forms of chlorine, such as 25 or 70 percent calcium hypochlo-

*$\frac{7 \text{ gal} \times 8.34 \text{ lb} \times 0.14}{100{,}000 \text{ gal} \times 8.34 \text{ lb}} = \frac{X}{1{,}000{,}000}$; $X = 9.7$ mg/l dosage Hazardous nitrogen trichloride may be formed. Ventilation is required.

rite, can of course also be made up into 10 to 15 percent solution and the clear supernatant evenly distributed in the pool water. Bathers should not be permitted to use the pool until the residual chlorine drops to less than 4 mg/l. Iron, manganese, and hydrogen sulfide if present will precipitate out of solution in the presence of free chlorine. Check a pool sample before treatment.

Copper sulfate has long been known for its ability to control algal growths. Most algae are destroyed by a dosage of 5 lb/10^6 gal, but practically all forms are killed at a dosage of 2 mg/l or 16.6 lb of copper sulfate per million gallons of water. The copper sulfate crystals can be easily dissolved in pool water by dragging the required amount, placed in a burlap bag, around the pool. There are dangers in the use of copper sulfate with certain waters. If the pool water has a high alkalinity, a milky precipitate will be formed that also interferes with the action of the copper ion, and waters high in sulfur or hydrogen sulfide will react and produce a black coloration upon the addition of copper sulfate. If in doubt, try dosing a batch of the water in a barrel or pail. Too high a concentration of copper sulfate will tend to discolor one's hair or bathing suit; hence, pool water that has been overdosed should be diluted.

Quaternary ammonium compounds have been suggested for algae control, and some satisfactory results have been reported, but free residual chlorination is made difficult. Care must be used not to overdose because foaming will be produced.

Prevention of Ringworm and Other Skin Infections

The prevention and control of ringworm infections, including floor treatment, are discussed in Chapter 1.

At one time, the provision of a footbath containing a strong solution of chlorine or other fungicide at the entrances to a pool and in gym shower rooms was required by health officials. Experience has shown, however, that footbath solutions were rarely properly maintained, with the result that they became, in fact, incubators and spreaders of the infection rather than inhibitors. The contact time between the feet and fungicide solution was too brief to do much good. The fungus on the feet is usually so imbedded in the skin that the solution could not penetrate to the spores.

Where footbaths are built into the floor, they can serve the very valuable purpose of preventing the tracking of dust, sand, and dirt into the pool. They must, however, be provided with a continuously running spray and an open drain.

Rented towels and bathing suits used at public pools can also be the means whereby ringworm and other infections are spread. Therefore, it is essential that towels and suits be carefully laundered and sanitized after each use. This can probably be done best by a public laundry. If sanitization is done at the pool, equipment and supervision must be provided to ensure that towels and suits will be washed in hot water and suitable soap or detergent, rinsed in clean water, and then dried for at least 30 min by artificial heat at a temperature above 175°F (79°C), which will destroy bacteria and the fungus spores. A water temperature of 160°F (71°C) for 25 min will kill nearly all microorganisms other than spores. Chemical disinfection may also be effective, although heat treatment is believed to be more reliable. Woolens, silks, nylons, and elasticized materials will require special handling. Cold-water disinfection can be accomplished by soaking suits 5 min in a 1:1000 dilution of alkyl-dimethyl-benzyl-ammonium chloride or other quaternary ammonium compound. This is reported to show "no adverse effect on dyes or materials commonly used in swimming suits." Temperatures above 110°F (43°C) will shrink most woolens.

Personnel

As in most other instances, the designation of one competent person who is responsible for satisfactory operation of the entire swimming pool is a basic necessity. Only in this way can safe, clean, and economic operation be ensured. In large pools, this person would be the manager, supervising the bathhouse attendants, lifeguards, and water purification plant operator. A competent manager should be a good administrator who is familiar with all phases of pool operation, including the water treatment plant, collection of water samples, making routine control tests, and keeping operation reports. At summer resorts, camps, and similar places, the senior lifeguard may be given the overall responsibility for pool operation for reasons of economy. This does not usually prove to be satisfactory unless the lifeguard can be trained before the summer season in the fundamentals of pool operation.

Most states have laws or sanitary codes regulating the operation of swimming pools and bathing beaches. The owner has a legal responsibility to comply with these laws and rules. Failure to do so would make the owner liable to prosecution for negligence. It is to the owner's interest and protection that such records be kept to show proper operation of the swimming pool purification equipment, clarity of pool water, lifeguards on duty, elimination of accident hazards, and any other measures taken to protect the users of the pool. Swimming pool operation report forms are available from most health departments. To be of value, these reports must be carefully and accurately filled out each day. Analysis of reports will indicate occurrences of failure and the need for new equipment. The operator should be provided with a residual chlorine test kit having a range of 0.2 to 3.0 mg/l and a pH test kit having a range between 6.8 and 8.4.

Pool Regulations

Regulations should be as logical and concise as possible. The following are samples:

1. Urinating, spitting, or blowing the nose in the pool can spread disease to other bathers. Use the overflow gutter for expectoration and toilet facilities to help keep your pool clean.
2. Persons having skin disease, running sores, a cold, or other infection endanger the health of their fellow bathers; hence, they cannot be permitted to use the pool until well.
3. Spectators carry dirt on their feet that would be tracked into the pool. This lowers the quality of the pool water; therefore, spectators are not permitted inside the pool enclosure. Pets, except a seeing eye dog with a blind person, should be excluded.
4. A pool is a common bathtub in which the water is kept clean by continuous purification and replacement of the water. Dirt and bacteria may build up in the pool faster than the purification equipment can take it out if bathers do not remove perspiration, dirt, and dust from their bodies. Therefore, take a warm-water and soap shower before entering the pool and after using the toilet. Bathers with long hair are required to wear a bathing cap.
5. The maintenance of order is necessary to prevent accidents and drownings and permit maximum enjoyment of the facilities. Obey the lifeguard and attendants promptly. There shall be no swimming in the absence of an attendant.

SWIMMING POOL MAINTENANCE

Recirculating Pump

1. Inspect and service regularly.
2. Check motor bearings for lateral and vertical wear. Brushes and commutators should wear evenly; clean commutator with fine sandpaper when placing in operation and turn down commutator if uneven.
3. Pump impeller has little end play or slippage; check suction and pressure produced by pump, lubrication, and stability of pump mounting. No entrance of air in suction. Slight leakage from packing gland is permissible.
4. Check pump capacity against operating head.
5. Compute backwashing, recirculating rate, and pool turnover against design. A new pump may be needed.
6. Determine water clarity, uniformity of chlorination, and bacteriological quality of pool water.
7. If repairs are needed, call in competent pump person or electrician at beginning of season or during closed periods. Check all fuses, switches, connections; bearings, pump shafts, operation, and cavitation.

8. Drain pump casing, cover pump and motor with canvas, and remove fuses from switch boxes at end of season. If subject to flooding, remove.

Hair Catcher

1. Maintain a regular daily cleaning schedule.
2. Keep a replacement basket strainer on hand. A hair catcher in parallel with proper valves is very desirable.

Filters

1. Open air valve at top of each filter shell to release air. If problem recurs frequently, find and eliminate cause. Check tightness of valves, packings, fittings, and gaskets.
2. At end of each season after backwashing, drain each filter, open manhole, and inspect sand. The sand should be level, without dirt, hair, holes, or cracks. Open inlet valve to filter to slowly admit water. If sand comes up unevenly or boils in spots, sand may have to be cleaned or replaced or the underdrain system may be partially clogged.
3. Sample of sand at depth of 6 to 8 in. should be clean.
4. If backwash rate is not adequate to clean sand bed, anthracite may be substituted, which requires only about two-thirds the backwash rate for sand.
5. Deep raking of sand surface may permit washing out of mud and dirt.
6. Sodium hydroxide treatment may be used to clean sand bed. Add 1 to 2 lb/ft^2 of filter area to 12 in. of water over the sand. Lower the water level to just above the sand surface; let stand 12 hr, drain out solution, and repeat. Backwash and observe condition of sand as explained in 2. A strong solution of chlorine, sulfur dioxide (sulfuric acid), salt, or detergent may also be used to remove organic matter.
7. Excessive use of soda ash and alum with a hard water may cause cementation of sand grains and improper water filtration. Break up incrustations or replace sand. Use of a metaphosphate with a hypochlorinator may prevent this difficulty.
8. Failure to use a filter aid with a diatomite filter or pretreatment of water high in iron or manganese will cause clogging of the filter tubes. Check head loss every few weeks; remove and clean tubes whenever necessary—soak in 8 percent solution of sodium hexametaphosphate for 2 hr and scrub; replace damaged tubes; and use a new gasket for filter shell head when it is opened.
9. Backwash and drain filters at end of summer season to prevent freezing. Check for needed repairs. Also drain skimmers and recirculation lines and traps. Plug open lines.

10. See that valves operate easily and properly. Grease stems and lubricate moving parts. Check packing and repack if necessary. Drain and inspect all piping and fittings at end of each season.

Chemical Feed Equipment

1. Dismantle at least once a year; inspect and replace worn parts. Special attention should be given to gaskets, check valves, shut-off valves and seats, tubing and piping, diaphragms, pistons, and special gears.
2. Rinse with clear water and drain before storing.
3. Coat metal parts subject to corrosion with petroleum jelly, plastic, or paint.
4. Check oil level and lubricant cups in accordance with manufacturer's instructions.
5. Do not store chemicals near electric motors and switches. Ventilate rooms.

Pool Structure

1. Overflow troughs, drains, walls, floors, walks, lockers, shower rooms, toilets, and fixtures kept clean and in good repair.
2. At least one person is delegated responsibility for cleanup twice a day. Proper equipment and cleaning compounds provided.
3. Depressions in walks leveled; broken or cracked floors repaired.
4. Vacuum cleaning equipment provided and used. Pool walls and floors clean, without growths, smooth but not slippery.
5. Winter protection of a pool includes drainage of all equipment, piping, tanks, floor drains, and fixture traps. Trapped floor drains should be sealed watertight. If pool is designed to withstand ice pressure due to freezing water, the pool need not be drained. Pool walls with an outward batter of 1 to $1\frac{1}{2}$ in. per foot of height will permit ice to expand and raise. A pool cover is essential.

WADING POOLS

Definitions of wading pools vary. All are meant to be shallow, up to 24 in. maximum depth, and specifically for the use of children. They are usually included with the design of a swimming pool as an independent structure.

Public health and recreational agencies have recognized for some time that wading pools can actually be the cause of more illness than swimming pools if not properly operated and maintained as noted below. The irresponsible child may relieve itself in the pool and drink the same water with innocent abandon. Dirt, sand, grass, food, and other debris are carried into the wading pool in such quantity as to make purification of the wading pool water a special problem.

Types

Wading pools have been constructed and operated as spray showers with open drain so as not to collect water, as flow-through types, as recirculation and filtration with chlorination types, and as fill-and-draw pools. The fill-and-draw wading pool cumulates pollution and is rarely kept clean; it should not be used at public places. The recirculation, with continuous chlorination, type of pool may be suitable if the pollution load is not too great and careful supervision can be given to the operation. The recirculation should include filtration and the addition of sufficient chlorine to maintain at least 0.6 mg/l free residual chlorine in the pool water. Because of the heavy pollution, the wading pool should not be connected with the swimming pool recirculation system. A 1- to 2-hr turnover and 10 ft^2 per child is recommended. Of all the types of wading pools mentioned, the spray type with an open drain is the safest and cleanest. Children seem to enjoy the sprays immensely; the danger of drowning and infection from polluted water is eliminated. Existing wading pools can easily be converted to spray-type pools in which there is no standing water.

The design details of a wading pool are shown in Figure 9-7. A gently sloping floor, say 6 in. in 10 ft, a drain provided with a sand trap, and a drained concrete apron at least 10 ft wide completely around the pool are elements common to all wading pools. A 6-in. drain is adequate for most wading pools; it must be so graded to make the backing up of sewage impossible. Where a sand play area is provided, and this is very desirable, constant maintenance will be needed. This would include frequent raking to remove foreign matter and turnover of the sand to prevent the development of odors, particularly where the sand tends to remain wet and is in the shade. An underdrain system in such cases is necessary. Disinfection of the sand by sprinkling with a chlorine solution, followed by fresh water spraying from a garden hose may be found periodically desirable. Toilet facilities should be convenient to the wading pool users to help reduce pollution of the wading pool and sand play area.

BATHING BEACHES

The location of bathing beaches, sanitary surveys, bacterial standards, health considerations, safety, and accident prevention were previously discussed. A suggested camp waterfront layout that includes numerous safety features is shown in Figure 9-8.

Where bottom conditions are hazardous or unstable or the water depth is excessive, consideration might be given to construction of a ‘‘floating pool’’

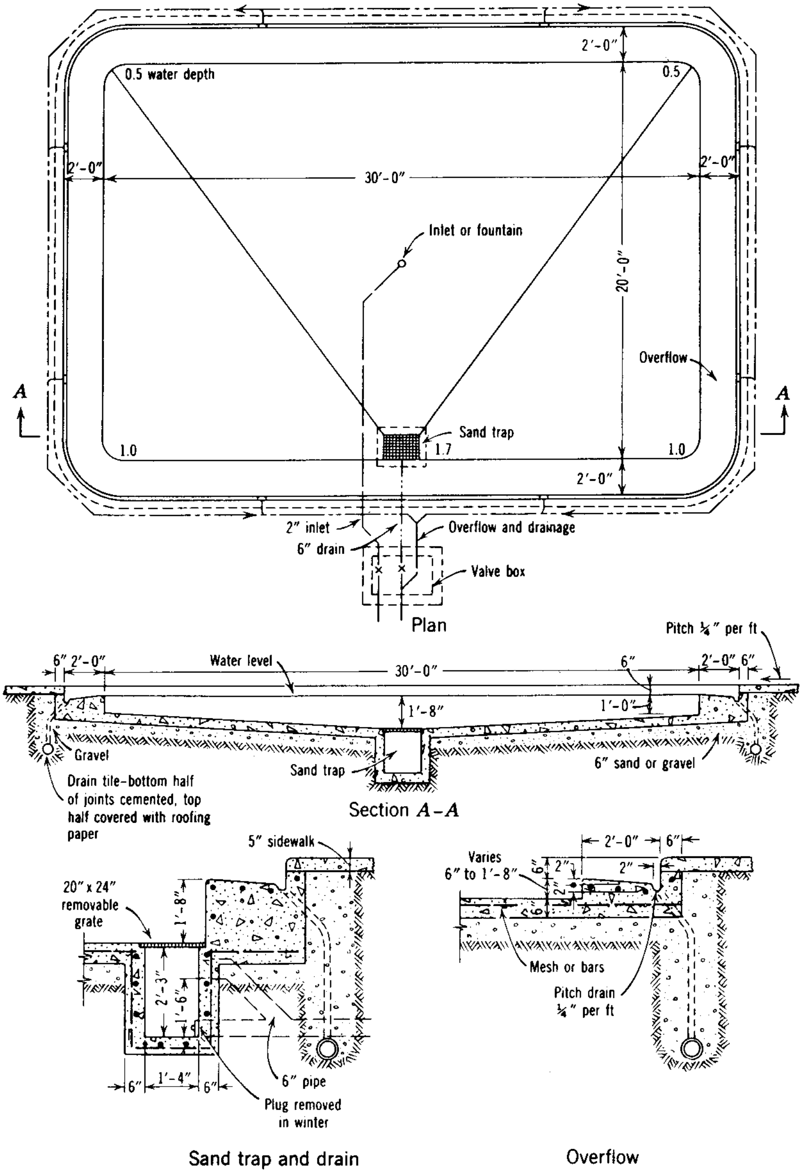


Figure 9-7 Suggested design for wading pool.

on the shore. The pool would have a solid bottom and sides that permit the free movement of water in and out, also an ample deck space.[67] In any case, diving areas are expected to be cleared of stumps, rocks, and other obstacles and have minimum water depths and areas meeting those specified for swimming pool diving boards or platforms. The bottom should be firm with a slope not greater than 1 in 10 horizontal for depths up to 4 ft and not to exceed 1

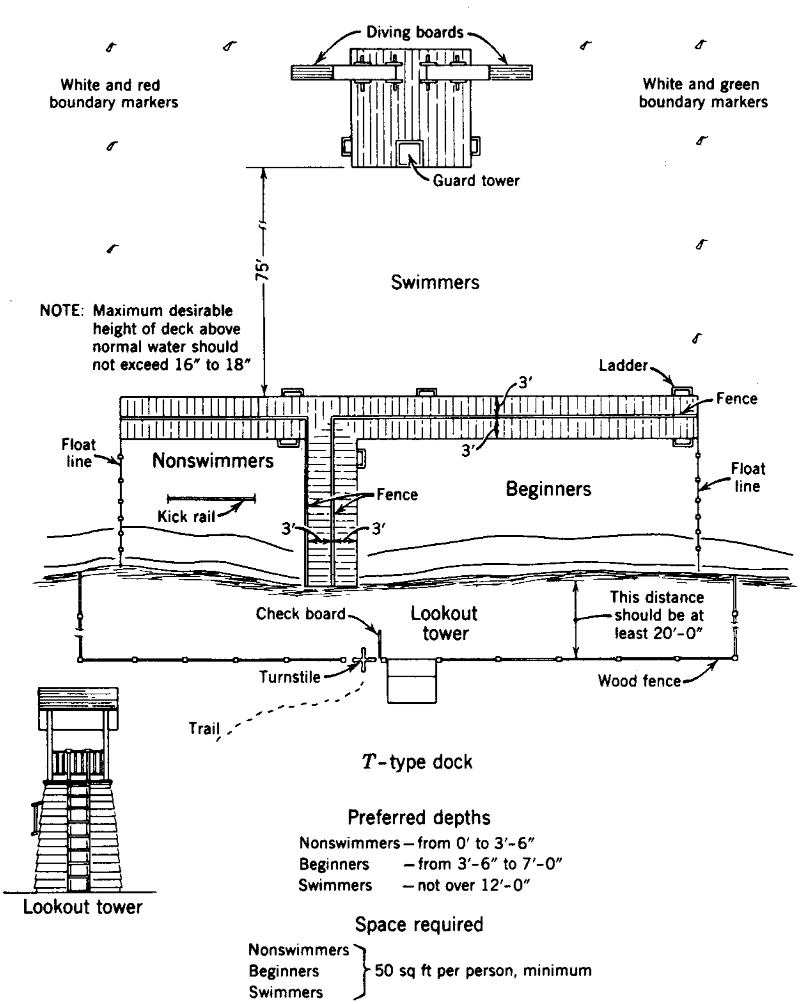


Figure 9-8 Suggested waterfront layout. Drawing not to scale. (*Source:* Boy Scouts of America, Division of Program, Engineering Service.)

in 3 for greater depths. The bathing area should provide at least 25 ft^2 per bather and the swimming area, over 4 ft deep, 75 ft^2 per bather.

Public beaches usually attract large numbers of people for extended periods of time. Toilet facilities are a necessity. Table 9-6 suggests the number of plumbing fixtures to be provided. A beach area of 200 ft^2 per person would be ideal; 50 ft^2 per person should be the minimum.

Disinfection and Water Quality

Unsatisfactory laboratory reports on bathing beach water call for a sanitary survey and evaluation to determine their cause and significance. If a beach is

TABLE 9-6 Plumbing Fixtures Required for Natural Bathing Places

	Commodes				
Number of Fixtures	Male	Female	Urinals (Males)	Lavatory Per Sex	Showers Per Sex
1	1–199	1–99	1–199	1–199	1–199
2	200–399	100–199	200–399	200–399	100–199
3	400–600	200–399	400–600	400–750	200–299
4		400–600			
		Over 600, one fixture for each additional 300 persons	Over 600, one fixture for each 300 males	Over 750, one for each additional 500 persons	Over 299, one for each additional 100 persons

Source: Environmental Health Practice in Recreational Areas, Public Health Service, Department of Health, Education, and Welfare, Washington, DC, January 1978, p. 49.

Note: The trend is to increase the ratio of fixtures to users by 50% or more. Two commodes for the first 100 females, with an equal number of fixtures for both sexes.

being excessively polluted by sewage or other wastes, the obvious solution is reduction of the pollution at the source, to the point at which it does not adversely affect the water quality. The importance of a sanitary survey and its intelligent interpretation in such cases are of major significance. When the remaining pollution reaching the bathing area or introduced by the bathers is small, or when the dilution provided (as determined by the dilution formula $Q = 6.25T^2$, where Q is the quantity of water per bather per day in gallons and T is the replacement period in hours) is not adequate to meet bacteriological standards, disinfection of the water may be possible.

The method for applying chlorine is determined by such factors as the type of beach, water current, size, and facilities available. If a sewer outfall is the culprit and it cannot be removed, the simplest emergency procedure might be heavy chlorination, thorough mixing, and 15- to 30-min retention of the disinfected sewage before discharge to the receiving body of water. Chlorine can also be added to the bathing area at one time to treat a given volume of water several times a day; it can be added directly and continuously to the bathing water by means of submerged orifices, or the chlorine can be added in high concentration to water recirculated back to the bathing area. Each method has its limitations and requires careful planning and supervision. Prohibition of bathing may be indicated, but the actual health risk and social implications of such action during a hot summer, for example, should also be taken into consideration. See Health Considerations earlier in this chapter.

The batch treatment or continuous treatment of a given volume of water is a special problem in each case. The chlorine solution, up to 10 or 14 percent, can be added before each bathing period from a motorboat or rowboat as a spray or by means of a belt-driven solution feeder that traverses the bathing area. Since a large quantity of organic matter will be present to absorb the chlorine, a sufficient quantity of chlorine solution will have to be added to satisfy, at least partially, the initial chlorine demand. One might start with a dosage of 5 mg/l and be guided by the results of residual chlorine and bacteriological tests. It will be exceedingly difficult to maintain a residual chlorine for any extended period of time.

The continuous addition of chlorine, using a gas solution feed machine through an underwater distribution system with orifices, has been tried with partial success. Rubber or plastic piping should be used. If there is a current, the perforated chlorine distribution piping system would, of course, be located upstream. Where a small stream is dammed up and there is a measurable flow through the bathing area, chlorine can be added by means of one or more improvised drip chlorinators strategically located.

Good results can be obtained by continuous chlorination and recirculation of the water in the bathing area. The capacity of the pump or pumps, number and location of inlets and outlets, and capacity of the chlorinator must be determined to fit individual cases. See Gas Chlorination, Chapter 3, for safety precautions.

The effectiveness of chlorination will be readily apparent by observing the clarity of the water and the presence or absence of algae. The algae may appear as a green coloring in the water resembling pea soup, as a green scum, or as a dark flaky deposit. Experience has repeatedly shown that when a free residual chlorine is maintained in the water at all times, the bathing water is attractive and relatively clear of algal growths. In all cases, technical control over the treatment, including the maintenance of adequate daily operation reports, is necessary.

Control of Algae

The control of algae is discussed in some detail in Chapter 3.

Under average conditions in recreational areas, a copper sulfate dosage of 5 lb/10^6 gal evenly applied at intervals of 2 to 4 weeks will prevent the development of most microorganisms but may result in some fish kill. In the eastern part of the United States, the treatment should start in April or, if microscopic examinations are made of the water, when more than 300 organisms, or areal standard units, per milliliter of sample are reported.

Chlorination treatment can also be effective in a partly artificial pool, such as that formed by damming up a small stream. However, to be effective, it must be under good technical control and at least 0.6 mg/l free residual chlorine maintained in the water at all times. This will not only prevent the growth of most algae but also help keep the water cleaner looking and relatively clear.

Control of Aquatic Weeds

Aquatic weeds are objectionable in bathing areas. They become entwined around the legs and arms of bathers, interfere with swimming, and provide harborage for snails. The weeds bind up phosphorus and nitrates.

One of the simplest ways of controlling the growth of aquatic weeds is lowering the water level sufficiently during the winter months to cause the plants to freeze, dry out, and die. If this is followed by burning and removal of the remaining debris, reasonably good control will result. The physical cutting and removal of the weeds are also temporarily effective. Where aquatic weeds grow above the water surface, chemical control by the use of weed killers is possible.

Sodium arsenite as AS_2O_3 at a rate of 4 to 7.5 mg/l has been very effective in controlling submerged rooted or anchored aquatic weeds, but its use is no longer advised. The chemical is very toxic to humans and dangerous to the applicator. Other chemicals such as Endothall, Acrolein, Diquat, and 2,4-D granules or pellets may be used *if approved* by the control agency. Diquat, 2,4-D low-volatile esters, or Amitrol-T may be permitted for floating weeds. The manufacturer's directions should be carefully followed, and when the water is located on a water supply watershed, permission must first be obtained from the water supply officials. Sodium arsenite is not usually allowed. Endothall and Diquat are permitted by the EPA if applied according to directions.

The health, agriculture, and conservation departments should also be consulted because some of the chemicals available are toxic to humans and fish. In many instances, knowledge regarding persistence and effect on the ecology may be limited. A permit to apply chemicals to public waters is usually required. Only approved chemicals should be used and only when necessary. See also Chapter 10.

Control of Swimmer's Itch

Swimmer's itch is a nonhuman form of schistosomiasis known as schistosome dermatitis. The larvae of certain schistosomes are found in lakes and saltwater beaches in many parts of the world, including North America. Migratory fowl, small mammals, and other birds carry and distribute the nonhuman schistosomes. Droppings containing the eggs fall in water. The eggs hatch and the larvae (mircadia) must enter an appropriate species of snail* within 36 hr or die. The organism develops in the snail to the larval form, which is released in the water to produce the fork-tailed schistosome cercariae. The cercariae may infect the natural hosts, or bore into the bather's skin where they die, causing a rash and severe itching if not rubbed off with a rough towel *before* the water film dries on the skin surface. An immediate freshwater shower after leaving the water and vigorous towel drying are also effective. These schistosomes do not mature in humans. However, *S. mansoni* and *S. haematobium* do mature in humans and are released in the stool and urine.[68]

Elimination of the snail, which is necessary to the life cycle of schistosomes, will break the life chain and prevent schistosome dermatitis. The control of debris and aquatic growths in shallow water, to which snails become attached, will reduce snail harborage. A water velocity of about 2 fps or more in canals will prevent upstream migration of snails. But actual destruction of the snail offers the best protection. The application of copper sulfate, sodium pentachlorophenate, copper pentachlorophenate, or copper carbonate to provide a dosage of 10 mg/l to the water will kill snails in the water (but not the eggs), as well as the free-swimming cercariae, if the water can be impounded for 48 hr.[69] Mackenthun[70] reports that the application of a mixture of 2 lb of granular copper sulfate and 1 lb of copper carbonate for each 1000 ft^2 of bottom to be treated will control the snails for a season or two in lake waters with a total methyl orange alkalinity of 50 mg/l of greater. With a lesser alkalinity, 2 lb of copper carbonate is successful.[70] A solution may be applied to the bottom being treated by means of a hose dragged behind a boat. The optimum time in the north central U.S. lake states is between mid-June and July 4. It must be remembered that the dosages mentioned here will kill fish life and perhaps bleach swimming suits; hence, special precautions

***Stagnicola emarginata* and *Physa parkeri* beach snails, and *Lymnaea stagnalis* and *Stagnicola palustris* swamp snails.

should be taken. Under certain circumstances, acidity control of the water might be possible. In such cases, maintenance of a pH of 7.0 or less will discourage snail growth. Copper is most effective at pH 7.0.[71] Regular drainage and drying of areas with exposure to sunlight will kill the snails and eggs. Chlorination to provide a residual of 0.5 mg/l for 20 min in a lake bathing area will kill the cercariae. If snail control is not possible, swimming or wading in endemic areas should be prohibited. Heating drinking water or bathing water to 122°F (50°C) will kill the cercariae.[68]

The cost of chemical treatment to control *schistosomiasis-causing snails* including *Biomphalaria* and *Bulinus* species, found in many parts of the world,* is high and requires repeated application based on field observation and testing. It is better to first prevent and minimize the conditions favorable to the snail growth and aquatic growths that promote schistosomiasis. The ampullarid snail *Marisa cornuarietis* is reported to control *Biomphalaria glabrata* snail populations and prevent schistosomes from infecting *B. glabrata* under suitable conditions of water temperature, vegetation, and reservoir level fluctuation. The cercariae survives only 48 hr in water. It is also removed by filtration.[72] Proposed impoundments such as dams, as well as canals and irrigation ditches, should first be evaluated for possible deleterious effects and their prevention.

The molluscicides of choice are niclosamide and *N*-tritylmorpholine, and yurimin in Japan. Benzene hexachloride and calcium arsenate have been used in China.[73] Granular bayluscide has also been found effective in killing snails. To prevent and control snails, divert water from canals and ditches and scrape and clean them of all snails and vegetation. Straighten canals and ditches. Bury snails $3\frac{1}{2}$ ft (1 m) and burn vegetation. See also Schistosomiasis, Chapter 1.

Evaluation of Bathing Beach Safety and the Impact of Closing a Beach

The obvious action to protect the public from a ''polluted'' beach is to prohibit bathing. Enforcement of such a determination is not always simple and may pose serious problems. Many factors determine the suitability of natural waters for bathing purposes, and their importance varies. Therefore, strict standards for water quality and safety must be interpreted in the light of

1. a sanitary survey of the area to identify pollution sources, patterns of water circulation and sources of dilution, effects of various rainfall intensities, the potential for self-purification, and related factors;
2. the microbiological, physical, and chemical quality of the water;

*Africa (Lake Volta in Ghana, Lake Kariba on the Zambesi River, and Lake Nasser in Egypt), the Arabian peninsula, northeastern and eastern South America, the Caribbean area, the Middle East, parts of India, and the Orient. The disease-causing schistosomes are not indigenous to North America.

3. epidemiological data indicating a significant incidence of related illnesses; and
4. economic and social, including psychological, impact.

Items 1, 2, and 3 have been discussed earlier in this chapter under (a) Health Considerations and (b) Regulations and Standards. The social and economic impact of closing a beach can be far reaching and should also be carefully weighed in interpreting the scientific data available in view of the inconclusive disease transmission evidence available. Nevertheless, it is considered unwise to use waters known to be grossly polluted for bathing or swimming, as a relationship and hence potential hazard exist.

Closing of a beach could have serious economic consequences. Businesses such as restaurants, hotels, motels, gas stations, and suppliers and employment dependent on the visitors would suffer immediate and possibly long-term substantial loss. Vacationers and tourists would patronize other areas, and survival of the resort area could be jeopardized. Public safety and fire services would also have to be placed on alert with consequent increased municipal costs. The closing of a beach, especially during a hot summer, could trigger rioting, looting, and property damage, not to mention possible injuries and deaths. It is apparent that the closing of a beach cannot be taken lightly. A careful evaluation must be made of the public health, safety, social, and economic risks and benefits before a decision is made.

TEMPORARY RESIDENCES

Operation of Temporary Residences

Camp, motel, hotel, and resort management is a very specialized field, requiring more than just the ability to provide an entertaining program for children and adults. There are more than 11,000 children's camps and an unknown number of summer family camp colonies, dude ranches, hostels, boarding houses, motels, hotels, and campgrounds scattered throughout the United States. In many cases, these places are communities unto themselves, with their own utilities and services. The operational problems approach those of small villages; some have a capacity of more than 1000 persons.

Camp leadership training courses usually include study of programming, nature lore, arts and crafts, counselor leadership, camping and woodcraft, fishing, aquatics, music, and related activities. The provision of basic sanitary and safety services and facilities and an environment conducive to good health is frequently overlooked, underemphasized, or taken for granted. Every camp director should have the basic knowledge to understand the significance of the multiple health and sanitation problems that may arise. Camp directors should know the resources available and be able to decide promptly the proper steps that may have to be taken to satisfactorily solve the problems. The health departments are anxious to help. They too are desirous of seeing that the health of the campers and guests is protected. Consult with the local and state health departments and seek their advice in health and sanitation matters.

The fundamentals and problems associated with disease transmission; location and planning; water supply; sewage and solid waste disposal; swimming pools and bathing beaches; food, including milk; insects; rodents; noxious weeds; and housing are described elsewhere in this text and should be referred to for more detailed information. Although the discussion that immediately follows concentrates on children's camps, the same principles apply to other types of temporary residences.

Camps

It has been estimated that 4 million children between the ages of 6 to 16 in the United States attend 7200 overnight and 4000 day camps each year.[74] Probably an equal number of adults visit resort hotels and camps. The importance of maintaining minimum standards of sanitation, health, and safety at these establishments is recognized by federal guidelines[75] and state and local health department laws. Camps include overnight, summer day, and traveling day camps. A permit is usually required to operate a camp.

The development of children and the extension of their education through planned and supervised activities are major objectives of many camps. The camping philosophy followed should be determined and understood before interpreting compliance and the satisfactoriness of camp operation, maintenance, and supplied facilities.

A typical inspection report form is shown in Figure 9-9. Many variations and more detailed versions are used to help determine if an establishment is in compliance with the intent of existing regulations. Actually, trained judgment is necessary to determine what is adequate or satisfactory under the particular conditions of operation. A more detailed explanation of the items can be found in the text under the appropriate headings. Each permitting authority has specific regulations to be complied with. State and local laws, ordinances, and regulations dealing with building, fire, electrical, and recreational safety, in addition to sanitation and hygiene, must be met. The more common items in Figure 9-9 are briefly explained here to guide and help obtain better understanding of the intent of the laws and regulations.

Compliance Guide[75–84]

1. *Permit* A current permit signed by the health officer and displayed in a prominent place would indicate compliance with the sanitary code at the time of issuance. The person to whom the permit is issued is required to comply with the provisions of the permit.

2. *Competent Sanitation Supervision* At least one competent person who is very familiar with all sanitary facilities at the camp and who is charged with the responsibility of keeping the grounds and buildings clean, the water

NEW YORK STATE DEPARTMENT OF HEALTH
Children's Camp Program

Children's Camp Inspection Report

A Review of Compliance with Subpart 7-2 of the New York State Sanitary Code

CAMP'S NAME		INSPECTION TIME	START	FINISH
STREET ADDRESS	TOWN, VILLAGE OR CITY	COUNTY		
LOCATION CODE AND NUMBER: COUNTY / FACILITY CODE / MO. DAY YEAR / NO. OF CAMPERS	INSPECTION TYPE: ☐ Preseason ☐ Operation ☐ Preseason Reinspection ☐ Operational Reinspection			

Section	Item	No.
PUBLIC HEALTH HAZARDS	Adequate Supervision - Staff Qualifications, Ratios, Camp Safety Plan Requirements	01
	Adequate Water Supply - Protection	02
	No Failing Sewage System - No Human Exposure	03
	Adequate Food Source or Protection	04
	Medical Plan and Medication Administered by Qualified Staff	05
	Camp Vehicle Transportation - Adequate Protection/Supervision	06
	Waterfront/Bathing Facilities - Adequate Protection/Supervision	07
	Riflery/Archery - Adequate Range/Supervision	08
	Horseback Riding - Adequate Equipment/Supervision	09
	Fire Safety - Overcrowding, Adequate: Exits; Alarm System; Fire Fighting Equipment	10
	Adequate Installation of Heat Producing Equipment or Storage of Flammable or Toxic Substances	11
	Other	12
	PERMIT Date Issued MO. DAY YEAR	13
PERSONNEL	Counselor-to-Camper, Supervision, Ratio	14
	Director, Counselors, Waterfront, Riflery, Lifeguard, Other	15
	Personnel Records, Resumes on File	16
	Communicable Disease Carrier	17
	Written Camp Safety Plan: On File, Updated, Implemented, Training, Verification	18
WATER SOURCES	Source Uncontaminated, Treated, Compliance with Part 5	19
	Records Maintained, Submitted	20
	Treatment Continuous, Sources/and Treatment Maintained	21
	Sources Protected, Located and Maintained	22
	Cross Connections, Backflow	23
	Common Utensil, Drinking Fountain	24
	Cl Residual ________ppm	25
SEWAGE	Facilities Provided, Maintained, No Sewage on Ground	26
MEDICAL	Written Plan, Updated, Implemented, History, Log Injuries/Illness, Modified Diets	27
	Infirmary, Holding Area, Supplies	28
	First Aid, CPR, Ratio	29
SHOWERS TOILETS	Privy, Toilet, Lavatory, Ratio, Special Fixtures, Maintained	30
	Showers, Tempered Water, Ratio, Maintained	31
WATER SAFTEY	Part 6 Compliance GEN 130 Used? 1 = YES 2 = NO	32
	Safety Equipment, Markings, Float Lines, Area Divided, Authorized Area	33
	Controlled Access, Pool Fenced, Gates Self-closing, Locked, Illuminated	34
	Supervision, Checking Bathers, Buddy System, Off-site	35
	Lifejackets, Watercraft, Waterskiers, Supervised Small Craft Usage	36
	Equipment Functioning, pH ______, Cl/Br ______ppm Records	37

Section	Item	No.
RECREATIONAL SAFETY	Riflery - Location, Instruction, Camper Age, Firing and Ready Lines, Backstop, Signs, Flags, Rifles, Instructor, Assistant, Ratio, Equipment Maintained, Stored	38
	Archery Range Location, Marked, Clearances, Firing, Ready Line, Instructors, Ratio, Equipment Stored	39
	Horseback Riding - Ratio, Headgear, Shoes, Instruction; Animals - Disease Free, Compliance with DEC, A & M Laws	40
	Equipment - Personal Weapons Restricted, Playground Equipment, Activities Handicapped Accessible, Off-Site Trips, Ratios	41
HOUSING	Maintenance - Safe Adequate Size, Cleanable, Watertight Roof, Sides, Adequate Light, Ventilation, Winter Building Heated	42
	Mattresses and Linen Clean, Good Condition, Linen Laundered Weekly, Clearance: Above Bed; Between Heads; Beds; Two Levels or Less	43
	Floor Area, Overcrowding, Wall, Ceiling Height, Ramps, Adult Counselors each Level, Non-Ambulatory Ground Floor	44
CONSTRUCTION, ELECTRICAL & FIRE SAFETY	Construction Notice: State and Local Laws Compliance Statement	45
	Building Standards, Electrical Safety	46
	Fire Alarm System, Drills, Equipment Inspected, Fire Safety Plan: On File; Updated; Implemented; Fires Reported	47
	Exits: Obstructed, Unprotected, Number, Dead Ends, Assembly Areas	48
	Exit Direction Signs, Emergency Lighting	49
	Heating - Sources: Installed; Maintained	50
	Flammable Liquids: Labeled; Stored	51
	Tents Flame Retardant	52
	Fire Fighting Equipment; Acceptable, Provided, Inspected, Placement, Maintained	53
FOOD	Part 14 Compliance (Use DOH 192 for Overnight Camps)	54
	Transported Food Protected	55
	Quantity, Quality	56
	Storage, Display, Dispensing, Handling, Protection	57
	Dishes, Food Utensils: Clean; Cleanable; Sanitized; Stored	58
	Approved Source, Labeled	59
	Potentially Hazardous, Temperature, Reserved, Frozen Desserts	60
	Personnel, Infections, Hygienic Practices	61
	Handwashing Facilities, Tempered Water, Tiolet	62
	Floors, Walls, Ceilings	63
	Lighting, Ventilation, Heat, Odors, Condensation	64
GENERAL	Surface Drainage, Storage, Labeling: Pesticides; Toxic Chemicals, Paths Appropriate Surfaces	65
	Insect, Rodent, Weed Control	66
	Refuse Storage, Handling, Disposal, Maintained	67
	Transportation, Truck Cab, Counselor, Driver, Inspection	68
	Reinspection Required 1 = YES 2 = NO	

INSPECTION BY: (Signature)	REPORT RECEIVED BY:	DATE:

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Figure 9-9 Children's camp inspection report. Coding: 1. No violations observed; 2. Part or parts of the item in violation; 3. Item not reviewed, evaluated, observed; 5. Item in violation corrected at time of inspection.

supply, swimming pool, and sewerage systems working properly, and the hot-water systems, refrigerators, and dishwashing facilities functioning should be available at all times the property is open for use. At hotels and motels, a record should also be kept of guests' names, addresses, and car license numbers.

3. *Medical and Nursing Supervision* There should be at least a registered professional resident nurse in attendance at all camps where children are not physically normal. At all camps there should be a licensed physician on call and a physician's assistant, a licensed or practical nurse, or a person at the camp trained in first aid acceptable to the permit-issuing official, an equipped first-aid cabinet, and telephone. An infirmary, including hot and cold running water, examining room, isolation and convalescent space, and bathroom with flush toilets, is practically essential at the larger camps. In the smaller camps, a tent with a fly and mosquito netting and floor are the minimum facilities. See Figure 9-10. A medical log of all illnesses and injuries treated should be kept.

Every person attending camp should have on file in the dispensary an immunization record, including a dated history of live measles (Rubeola) vaccination at or after 12 months of age or a physician-documented history of the disease[85] as well as diphtheria, mumps, polio, Rubella, and tetanus.

An indication of the need for nursing supervision and the application of preventive principles is shown in a study of illnesses and injuries in a summer

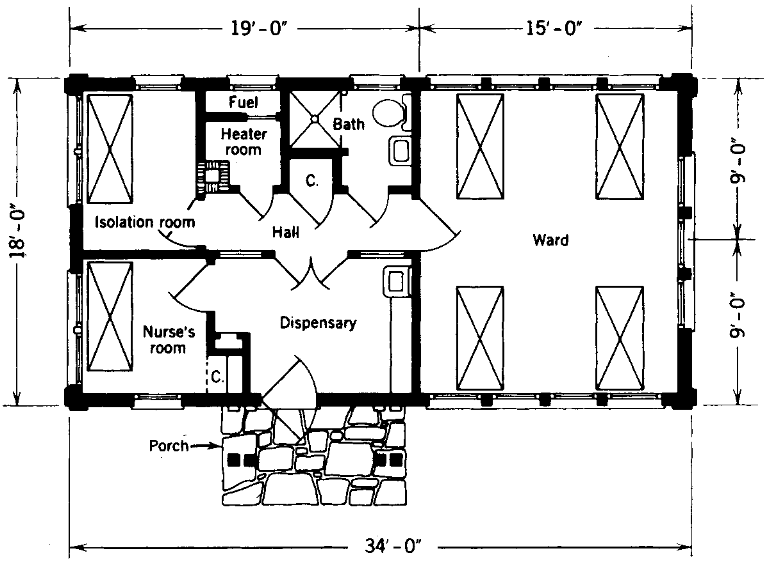


Figure 9-10 Typical summer camp, health lodge. (*Source: Organized Camp Facilities*, National Park Service, U.S. Department of the Interior, Washington, DC, reprint from *Park and Recreation Structures*.)

camp.[86] Of 8873 visits to the infirmary by 320 campers and 92 staff members during an eight-week season, 40 percent were for the administration of drugs. The majority of the visits involved the upper respiratory tract, the skin, the skeletal-muscular system, the central nervous system, the ears, and the lower respiratory tract.[85]

In 1974, the PHS/CDC had a record of 25 deaths, 1448 injuries, and 1223 serious illnesses among children while at camp. But these figures are acknowledged to be low, being based on news clippings and questionnaires.[87]

4. *Adult Supervision* A competent camp director, or director's assistant, should be available at all times at camps accommodating children under 16 years of age, in addition to other adult supervision as may be needed. It is common to have one counselor for every six to eight campers, depending on camper age, plus a service and activities staff. At least one counselor should be present during sleeping hours on every level of a building used for sleeping. The camping philosophy will govern. In any case, the director or deputy should assume personal responsibility to make daily inspections of all environmental factors, including the cleanliness of foodhandlers, food servers, refrigeration, water supply treatment, sewage and refuse collection and disposal, sleeping quarters, swimming and bathing areas, firefighting facilities, and accident hazards. The director's competence should include good character and practical and educational experience; he or she should be a college graduate, at least 25 years of age, with at least 3 years experience in camping, including administration. The counselors should be at least 18 years old.

The supervisor of specialized activities such as aquatics, mountain climbing, horseback riding, and scuba diving must be qualified by specialized training and experience. Where a rifle or archery range is established or a craft shop is available, ensure that its use is permitted only under competent supervision and that established precautions are taken.

Campers must not be permitted in open trucks. All camp vehicles and vehicles used for transportation of campers must be maintained in safe operating condition. Drivers must possess the required license and have at least one year's experience.

5. *Surface Drainage* If surface water is not carried away or readily absorbed by the soil or if groundwater, rock, or clay is close to the surface, making the subsurface disposal of sewage and other liquid wastes impractical, surface drainage would be considered unsatisfactory unless special provisions are made. The grounds should be kept reasonably dry. The Soil Conservation Service may be of assistance on drainage problems.

6. *General Conditions Sanitary and Safe* Where papers, tin cans, bottles, garbage, or other refuse are strewn about in buildings or on the ground, where numerous flies are present, where building interiors or exteriors are not clean looking, or where there is sewage or other liquid waste overflow, conditions are not considered to be sanitary.

This is also interpreted to mean that poison ivy, oak, or sumac and ragweed, mosquitoes, ticks, chiggers, mice, rats, or other insects and rodents that may transmit disease or cause injury should be effectively controlled or eliminated. Pesticides must be stored in a locked cabinet and used only by qualified persons. The control of insects, rodents, and noxious weeds is discussed in Chapter 10. Power equipment protection, watercraft, and vehicles must meet federal and state regulations. Open wells or pits must be closed and steep cliffs barricaded. Gasoline, fuel oil, and bottled gas are stored away from habitation and in a protected area. Electrical wiring, including swimming pool and area installations, must comply with the latest edition of the National Electrical Code. Ask for a certificate from the Board of Fire Underwriters or licensed electrician. See also (a) Accident Prevention and Life Saving, (b) Swimming Pool Types and Design, and (c) Bathing Beaches, this chapter. For camp safety guidelines, see ref. 75.

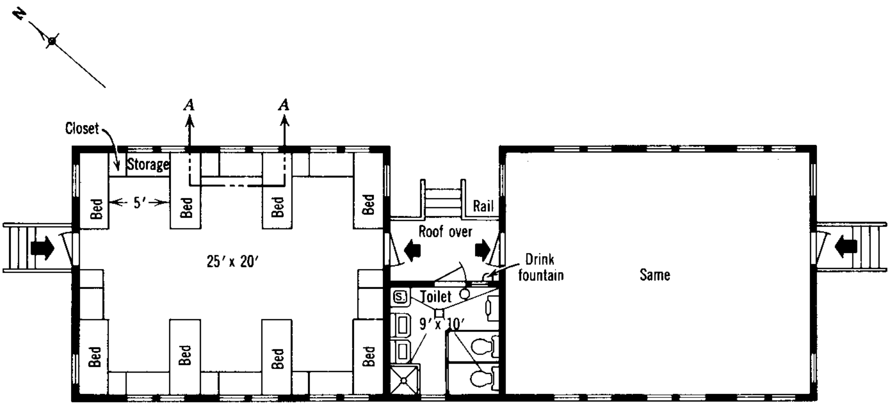
7. *Structurally Safe* A building is considered structurally safe when it is capable of supporting $2\frac{1}{2}$ to 4 times the loads and stresses to which it is or may be subjected and complies with applicable state and local building codes. The piers, foundations, girders, beams, flooring, and stairways must be sound and sturdy. Stairways and balconies should include handrails and balusters. The floors should not give significantly when stamped on. A licensed professional engineer or registered architect is qualified to determine the structural safety of a building. Existing building codes must be met.

8. *Adequate Size* Adequacy depends on the use to which the building is put. For example, sleeping quarters should provide at least 40 ft^2 of floor area per bed, including about 10 ft^2 for a footlocker and clothes closet, as shown in Figure 9-11, with a ceiling height of 7 ft over at least 80 percent of the floor area. Kitchens should provide sufficient space for storage and avoid overcrowding and confusion. Dining rooms should allow $1\frac{1}{2}$ to 3 ft around tables for serving and free movement of chairs and benches. The provision of 20 to 25 ft^2 per person in recreational and assembly rooms, 12 to 15 ft^2 per person in mess halls, and 7 to 9 ft^2 per person in kitchen areas, including storage and dishwashing, has been found adequate, with the smaller areas being more suitable for camps accommodating more than 100 and the larger areas for camps of 100 or less. See Figures 9-11, 9-12 and 9-13.

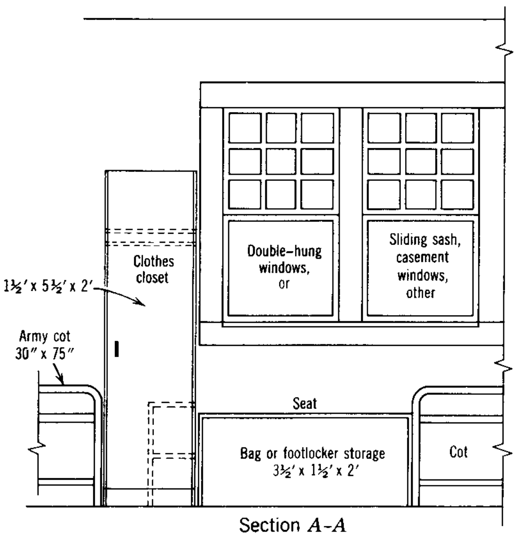
9. *Easy to Keep Clean* Smooth, washable finishes that are light colored, readily drained, and well lighted are easier to keep clean. More detailed information on floor and wall construction and lighting is given in Chapter 8 and in the following paragraphs.

10. *Watertight Roof and Sides* Dormitories, cabins, tents, dining halls, and similar structures should have watertight roofs and sides protected by overhanging eaves, storm canopies, or windows to keep out the rain. Floors should be so constructed as to remain dry and free of dampness. To accomplish this objective, the floors, including joists, are raised above the ground with the space beneath ventilated. Masonry floors built on the ground require damp-proofing.

11. *Lean-tos Exclude Rain* Lean-tos are short-term shelters; nevertheless, where provided they should be constructed to keep regularly used spaces relatively dry.



Floor plan



Section *A-A*

Figure 9-11 A double-cabin housing plan with connecting toilet. Notes: (1) All dimensions are approximate. (2) Closets and cabinets are built in place. (3) Roof eaves overhang about 24 in. (4) Cabins are built 2 to 3 ft above ground. (5) Cabin floors are tight, first-grade wood or cement, composition, or equal material. (6) All doors are self-closing. (7) All windows, louvres, and doors are screened. Windows provide a glass area equal to not less than 15 percent of the floor area. (8) Toilet floors, including shower stalls, are cement, tile, or terrazzo with sanitary cove base integral with floor. (9) Toilet stalls are open at bottom. (10) Louvres are provided in roof. (11) Ceilings have a height of 8 ft, not including peak. (12) Bathroom includes utility sink, wastepaper basket, 2 flush toilets, 2 wash basins, 1 urinal, 1 shower, paper towels, and soap or soap dispensers.

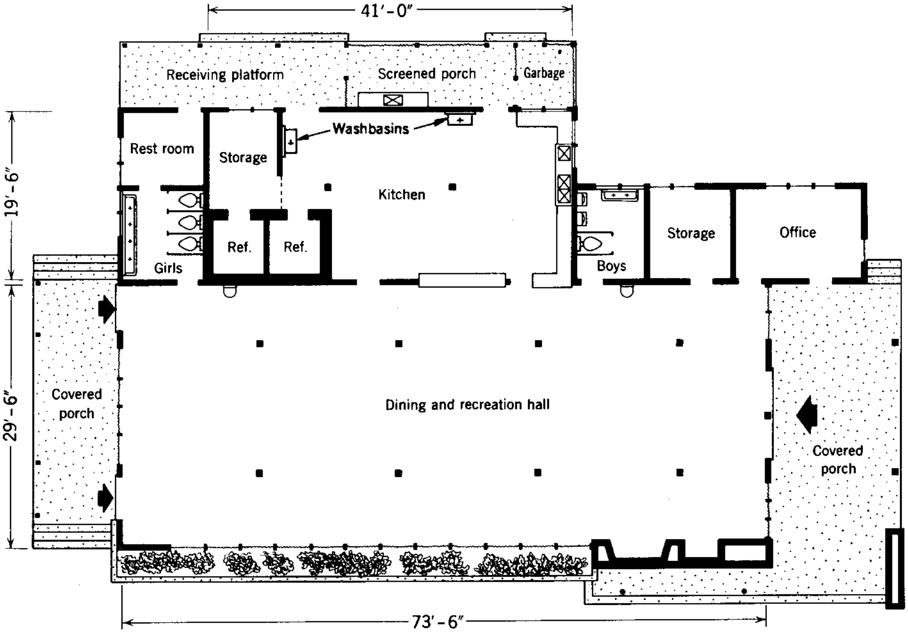


Figure 9-12 Plan of Cornell central camp building. (*Source: Cornell Miscellaneous Bull.* 14, New York State Colleges of Agriculture and Home Economics, Cornell University, Ithaca, NY, March 1953. See also Figures 8-11 and 8-12.)

12. *Cleanable Floors Provided* Where floors are frequently wet, hard acid brick or quarry tile laid with full $\frac{1}{16}$-in. Portland cement or equal hard joints, sloped to a drain, make good floors. Where floors are wet infrequently, top-grade maple wood floors, well laid, are preferred. Other types of floor materials and coverings that do not entrain dust, grease, or other soil and that can be kept clean are satisfactory. All corners should be rounded and a sanitary flush cove base provided around the floor at the walls. See Chapter 8.

13. *Stoves Fire Protected and Vented* Heating stoves and baking ovens should rest at least 4 in. above a "stove board" or fire-resistant floor. In existing buildings, the equipment can be placed on a built-up fire-resistant floor consisting of 22-gauge sheet metal and 4 in. of masonry, all extending about 24 in. in all directions beyond the stove. Clearance from combustible walls will vary, from 18 in. for a circulating-type wood stove having a double wall with air vents top and bottom to 36 in. for a radiant type. Stove pipes are at least 18 in. from the ceiling. Lesser spacing is permitted with suitable fire protection. (See National Fire Protection Association No. 89M, Quincy, MA, 1971.) Portable stoves should be prohibited. All water heaters, furnaces, and space heaters should be properly vented to the outside air and provision made for adequate dilution air and backdraft protection. Stoves burning wood, coal, gas, or oil must be properly vented to the outside air. Fuel-burning water

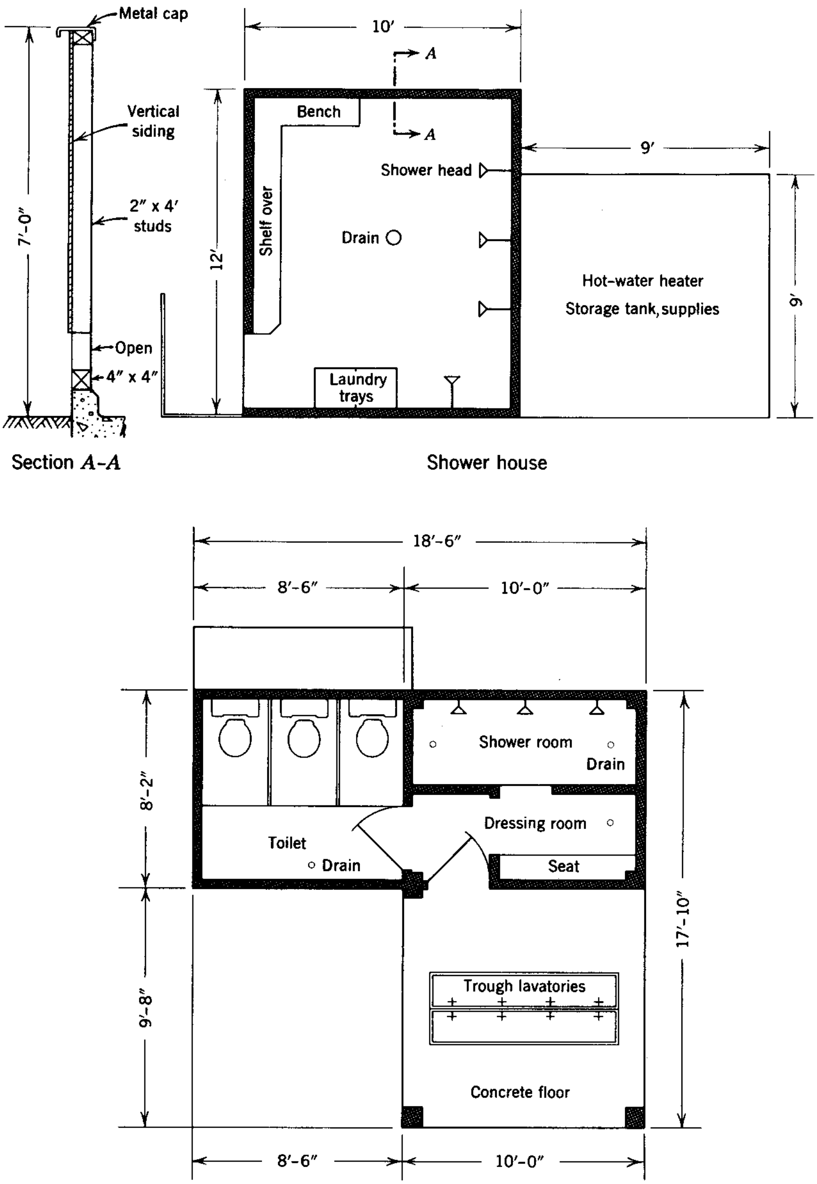


Figure 9-13 Latrine and shower-house floor plans. (Unit latrine from *Organized Camp Facilities,* U.S. Department of Interior, Washington, DC, 1977.)

heaters should not be allowed in sleeping rooms and the use of kerosene cooking and heating stoves should be prohibited. Follow National Fire Protection Association and building department standards and specifications. Get expert advice.

Hoods over kitchen ranges should provide at least a 9-in. space between the hood and combustible material. Vents should extend to a properly constructed lined masonry chimney or an exterior stack extending at least 2 ft out from the building and 2 ft above the roof in such a manner that no danger can occur if grease in the hood and vent should catch fire. Horizontal runs should be not longer than 20 ft, slope up at least in./ft, and be provided with a backdraft diverter; the connection made to the chimney should terminate flush with the interior of the chimney lining. Use a proper thimble. Terra cotta clay pipe lining is standard for chimneys. Hoods, exhaust ducts, vents, fans, and filters require regular cleaning. A spark screen should be installed on chimney caps where a solid fuel is used. See also Chapter 11.

14. *Fire Prevention* There should be a plan and periodic fire drills for both campers and staff. Flammable and hazardous materials should be stored under lock and key away from activity centers and other buildings.

Suitable fire extinguishers should be readily available at all times.* Foam, carbon dioxide, dry chemical types, and halogenenated types are recommended for fires in flammable liquids, oils, greases, oil-based paints, and flammable gases (class B fires). The carbon dioxide and dry-chemical-type extinguishers are recommended for electrical fires (class C). The water-type extinguisher is suitable for wood, paper, textile, rubber, and rubbish fires (class A); do not use on grease, oil, or electrical fires. Water extinguishers can be protected from freezing by adding calcium chloride containing a corrosion inhibitor. Five pounds to 9 qt of water will protect to 10°F (–12°C). Eight pounds six ounces of calcium chloride to 2 gal of water will protect to −20°F (−29°C), and 10 lb will protect to −40°F (−40°C).

One $2\frac{1}{2}$- or two $1\frac{1}{2}$-gal fire extinguishers per 1000 ft^2 of floor space accessible within 75 ft is recommended. Provide one additional $2\frac{1}{2}$-gal or two $1\frac{1}{2}$-gal extinguishers for each additional 2000 ft^2. For each transformer or power generator, provide one 4-lb carbon dioxide extinguisher; in each kitchen or other area where flammable grease or liquids are used, stored, or dispensed, provide one 12-lb carbon dioxide or dry chemical extinguisher. In any case, *be guided by local fire and building department regulations,* where they exist, and the National Fire Protection Association suggestions.

At small camps, it is also good practice to have available 50 to 100 ft of 1-in. garden hose with nozzle and convenient hose-bib water outlets within reach of all structures. Adequate water volume and pressure are of course

*See *NFPA 10, Portable Fire Extinguishers,* National Fire Protection Association, Quincy, MA, 1990. Extinguishers provided for the protection of cooking grease fires shall be only of the sodium carbonate or potassium bicarbonate dry chemical type.

essential. At large camps, a community-type water system as described in Chapter 3 should be provided. All extinguishers require annual inspection. The soda and acid type and foam type should be discharged, refilled, and tagged. The water-tank type should be operated to ensure it is not clogged and refilled. Other types of extinguishers should be weighed, refilled if necessary, and tagged. Do not overlook the usefulness of such simple devices as a covered water bucket in tent and cabin areas, fire shovel, ground-fire beater, stirrup pump near streams, and back pump.

All tents or canopies should be fiber impregnated and flame retardant and no plastic tents of any type are allowed. Liquid petroleum gas and oil storage tanks should be protected and located at least 25 ft from any building.

15. *Buildings and Grounds Clean* Trash, weeds, brush, poison ivy, or manure should not be permitted to accumulate. Barns, stables, and picket lines, for example, should be kept clean. Existing structures should be kept in repair or torn down.

16. *Fire Escapes and Exits Provided* In general, there should be more than one exit from each floor of a building with doors hung to swing in the direction of egress. When rooms are provided above the ground floor, at least two separate, unobstructed exits should be indicated that are accessible from all rooms through approaches 3 ft or more in width. Stair halls, stairs, or passages connecting the entrance or first story with the second story should be separated by means of a self-closing fire-resistant door. Exits should be plainly marked. Buildings with more than two floors should not be used unless special approved fire protection and escape facilities are provided, including outside iron stairways or enclosed fire-resistant stairways with self-closing doors. Also provide automatic fire or smoke detection devices in all buildings used for sleeping. In addition, fire alarm systems and a horn or siren should be provided in buildings sleeping more than 50 persons and in all multistory buildings. Have a fire plan for emergency (including drill), and determine and comply with state and local regulations. Dormitories should be spaced at least 40 ft from other buildings, 25 ft back from the access road curb, and with one side at least 60 ft from any other building. In any case, *conform with state and local fire protection regulations*.

17. *Sleeping Quarters Adequate* Beds that are spaced 5 ft apart, with an allowance of at least 50 ft^2 of floor space per bed, prevent overcrowding and provide for clothing storage. Where this is not possible, at least 40 ft^2 per person and head-to-foot sleeping should be used, with provision for aisle space, ready exit in case of fire, and clothing storage. If a minimum spacing between beds of 3 ft cannot be obtained, temporary housing, such as under fiber-impregnated flame-retardant canvas, should be furnished to alleviate overcrowding. Sleeping quarters should provide at least 400 to 600 ft^3 of air space per bed and a window area equal to not less than 10 to 15 percent of the floor area. In special cases, a lesser volume than 400 ft^3 may be permitted. Double-decker beds are considered two beds; they are not recommended since

an accident hazard is introduced and the spread of upper respiratory diseases is facilitated. A smoke detector at the ceiling of each sleeping unit is required.

18. *Buildings Adequately Ventilated* This is accomplished when the accumulation of body odors is prevented, usually when an air change of 10 ft^3 minimum is provided per person. The necessary air change is frequently secured in the summer by opening windows and by air leakage or seepage through the walls, ceilings, floor, windows, and doors. An area of window glass equal to 10 to 15 percent of the floor area preferably divided between opposite walls, with one-half of the area openable, is desirable. Toilet rooms should have openable screened windows (which are used) or separate forced-air or gravity ventilation providing four to six air changes per hour. See Ventilation, Chapter 11.

19. *Kitchens and Dining Rooms Separate from Dormitory and Toilet* This is meant to prohibit sleeping in the kitchen and dining room and provide a separation between the kitchen and toilet room. A hand-washing vestibule ahead of the toilet compartment accomplishes this objective.

20. *Screening Adequate* Rooms in which food is prepared or served should have all usable windows and other openings equipped with full-length 16-mesh wire screening during the fly season. Sleeping rooms, dining rooms, recreational halls, and theaters are frequently screened for protection against mosquitoes and other insect pests. In endemic insectborne disease areas, screening is necessary. The number of flies and mosquitoes actually present, the control measures used, and the effectiveness of residual insecticides applied also determine the need for screening.

21. *Equipment Adequate for Food Preparation* Utensils, tables, cutlery, dispensers, sinks, stoves, and so on, used in the preparation of food should be sufficient in number and smooth and seamless or with flush seams. Stainless steel is highly recommended. Tables should have nonabsorbent tops; spatulas, scoops, butter forks, tongs, relish jars, mustard jars, and ketchup bottles should be adequate and easily cleanable. See Chapter 8 and National Sanitation Foundation standards. Stoves and ovens should be large enough to prepare the food for a usual meal.

22. *Floors, Walls, Ceilings Clean* The walls, floors, and ceilings of kitchens, dining rooms, and workrooms should be so constructed as to permit them to be readily cleaned, and they should be kept clean and in good repair. Light colors, tightness, and smoothness facilitate cleanliness. A concrete, tile, or composition floor that is badly cracked; a wooden floor that is slivered, warped, or poorly laid so as to leave spaces between strips where dirt and water could collect; or a floor covering that is cracked and with holes worn through would not be satisfactory. The floor should be well drained, even, smooth (but not slippery), tight, and water-repellent without cracks, holes, or slivers. Walls should be washable to splash height.

Equipment placed 18 in. away from the walls or other stationary equipment and 8 in. above the floor will simplify cleaning.

Proper lighting simplifies the working and cleaning operations and reduces accident hazards. Lighting should meet the recommendations tabulated in Chapter 8. A more efficient design results when considerations are given to the spacing of light sources, elimination of glare, shielding, control of outside light, lightness of work surfaces, walls, ceilings, fixtures, trim, and floors.

23. *Ventilation Adequate* Ventilation is adequate when cooking fumes and odors are readily removed and when excessive heat and condensation are prevented. This will require windows that can be opened both from the top and bottom and, in most cases, ducts that will induce ventilation. Hoods with exhaust fans should be provided over ranges, ovens, deep-fat fryers, rendering vats, steam kettles, and any other equipment that will give off large amounts of steam or soot.

24. *Water Supply Safe* A water supply is considered safe when a complete sanitary survey of the water system shows that the water is obtained from a source adequately purified by natural agencies or adequately protected by artificial treatment. The water supply system should also be free from sanitary defects and health hazards. In addition, water samples collected from representative points on the distribution system and examined by an approved water laboratory should consistently show the absence of coliform microorganisms. The physical and chemical characteristics of the water should not be objectionable.

The explanations and sketches given in Chapter 3 describe in greater detail what is satisfactory and what is good construction.

If ice is used for beverages, only that which is obtained from an approved source and which is distributed in a clean manner should be used. Tongs, scoops, or an automatic ice dispenser, not the hands, should be used for the serving of ice.

Water available at any public establishment at any tap, faucet, or hose is assumed to be, and should be, safe to drink unless it is made inaccessible.

The provision made to secure water on hikes or camping trips should be investigated. Iodine or chlorine water purification tablets should be available and their use understood.

25. *Adequate Quantity of Hot and Cold Water* The quantity of water should be ample for drinking, handwashing, cooking, and dishwashing, for flush toilets if provided, and for bathing and laundry purposes. This total will probably vary from 30 to 75 or more gallons per person per day, depending on the number of plumbing fixtures, water pressure, type of establishment and guests, location, water usage, and other variables. A water outlet should be available within 100 ft of any structure or recreational area. Hot water for handwashing and showers should be maintained at 95 to 105°F (35–41°C).

Computation of the probable total water demand, storage, pipe sizes, and pump sizes is discussed in Chapter 3. The design of the hot-water supply and demand for kitchen and general utility purposes is discussed in Chapter 8. It should be remembered that peak water demands may be 5 to 10 times average demands and that pneumatic water storage tanks can make available only about 20 percent of the tank volume.

Some suggested hot-water storage tank and heater sizes suitable for camps are shown in Table 9-7 for comparison and reference purposes. Various rule-of-thumb guides are given in providing hot water. At camps, a minimum of 3 to 5 gal per person per day is suggested for showers alone. Another value used is 5 to 7 gal per person for all purposes with 40 to 70 percent in storage and about 30 percent provided by the heater per hour. (See also Table 11-9.) Coin-operated, *electrically activated* shower controls require a ground-fault interrupter between the power source and the shower head approved by a recognized testing agency such as the Fire Underwriters.[88]

26. *Operation Reports Satisfactory* Where a water supply is treated, accurate and complete daily reports on the operation of the treatment plant must be kept and submitted monthly to the health department. A special form that includes the desired specific information is usually provided by the health department. The report will show whether the resort owner or manager is doing his or her job properly; it also serves as evidence that reasonable care has been taken to treat the water. To be of value, however, all entries must be accurate. The same principles apply to sewage treatment and swimming pool operation reports.

27. *Sources of Water Protected* See Chapter 3.

28. *No Cross-Connections or Backflow Permitted* This subject is illustrated and discussed in greater detail in Chapter 3 and in Chapter 11 under Plumbing.

TABLE 9-7 Hot-Water Storage Tank and Heater Sizes

Facility	Capacity (persons)	Approximate Tank Capacity[a] (gal)	Heater Size (Btu/hr)
Central kitchen	125–150	225	150,000[b]
	200–300	500	190,000[c]
Central showers	125–150	250	60,000[d]
	200–300	400	90,000[d]
Health lodge	—	30	Home size

Source: Camp Sites and Facilities, Boy Scouts of America, New Brunswick, NJ, 1950.

[a]Use nearest commercial size; specify minimum working pressure of 85 psi for galvanized steel tank, with standard tappings. Insulate tank. Also insulate hot-water delivery lines.

[b]Rated to raise 140 gal/hr 90°F (32°C) for hand-type dishwashing. Add booster heater to deliver 180°F (82°C) water to disinfecting rinse sink and an immersion or under-sink heater to keep water at about 200°F (93°C).

[c]Rated to raise 200 gal/hr 90°F (32°C) for general purposes and as a booster to furnish 180–200°F water to spray-type dishwashing machine with circulator.

[d]Provide mixing valve, inaccessible to campers, to limit water temperature at shower heads to 95–105°F maximum (35–41°C). A hot-water temperature of 135°F (57°C) can cause third-degree burns in 10–15 sec.

29. *Water Storage Protected* Proper construction and protection are discussed in Chapter 3.

30. *Common Drinking Cup Prohibited* A glass or cup should not be left near a water faucet whereby anyone may use it. Provide paper cups in sanitary dispensers or sanitary drinking fountains in the ratio of one to 50 to 75 persons.

31. *Drinking Fountains Satisfactory* A satisfactory drinking fountain is one having a protected nozzle extending above the rim of the bowl in which the nozzle throws an inclined, uniform jet of water. Wastewater should be drained away to a disposal system or seepage pit to prevent the collection of pools of water. Use American National Standards Institute (ANSI) standard Z4.2 for sanitary drinking fountain.

32. *Separate Toilet Facilities Provided* Separate toilet facilities for campers and visitors are required for each sex. These may be flush toilets or sanitary privies.

33. *Toilets Convenient and Adequate* Toilets provided should be near the sleeping quarters and centers of activities and not further away than 150 ft. Flush toilets for foodhandlers and kitchen help should adjoin the kitchen. Washbasins with warm running water, soap, and paper or other type of sanitary towels are essential for foodhandlers in the kitchen.

Table 9-8 shows the minimum recommended number of plumbing fixtures to provide at residential camps, with hot and cold running water at showers, washbasins, service sinks, and laundry tubs.

The height of water closets and washbasins should be adjusted to the age of the children served. Suggested heights are given below:

	Height to Rim of Fixture	
Age	Washbasin	Water Closet
Up to 6	19	10
7–9	21	10
9–12	23	10
Over 12	26	12

The walks and toilet rooms or latrines should be clear, well marked, and lighted at night. See Figure 9-14.

34. *Privy Location, Construction, and Maintenance Satisfactory* Privies should be located not less than 100 ft from any well, stream, or lake and 50 ft from any sleeping area; also at least 200 ft from places where food is prepared or served and convenient to the users (within 200 ft). The pit should be at least 2 ft above seasonal high groundwater. Other types of privies and toilets and details concerning location, construction, and maintenance are given in Chapter 4. Privies that are properly constructed, located, and kept clean are relatively inoffensive and satisfactory sanitary devices.

TABLE 9-8 Plumbing Fixtures Recommended for Residential Childrens Camps

Individuals of Each Sex to Be Served	Toilet		Urinals, Male	Handwashing Facilities, Male or Female	Shower Heads, Male or Female
	Male	Female			
1–10	1	1	—	1	1
11–18	1	2	1	2	2
19–33	2	2	1	3	2
34–48	2	3	2	3	3
49–63	3	4	2	4	4
64–79	3	5	3	4	5
80–95	4	6	3	5	6

Source: Youth Camp Safety & Health, Public Health Service, Department of Health, Education, and Welfare, Atlanta, GA, May 1975, pp. 14–15.

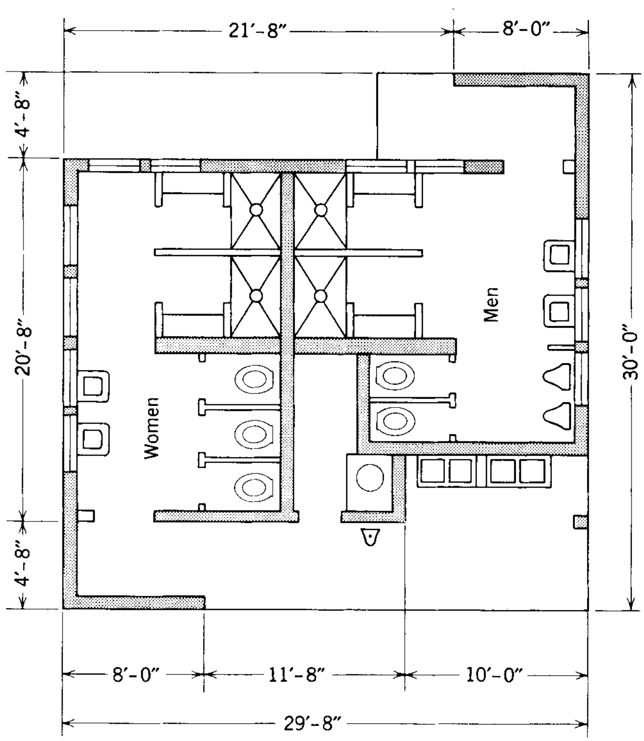


Figure 9-14 Layout of a permanent type of comfort station. (*Source: Environmental Health Practice in Recreational Areas,* PHS Pub. No. 1195, Department of Health, Education, and Welfare, Washington, DC, 1977.)

35. *Disposal Systems Satisfactory* Sewage disposal systems are considered to be satisfactory when the overflow or exposure of inadequately treated sewage, including bath, sink, and laundry wastes, on the surface of the ground is prevented and when surface and groundwater pollution is prevented. When there is an overflow or when an overflow is imminent, immediate steps should be taken to correct this dangerous condition.

To protect the owner and comply with the requirements of most sanitary codes, a licensed professional engineer or architect competent in matters of sewage disposal and treatment should be engaged to prepare plans for an adequate system. The plans should be comprehensive, with construction details of existing and proposed work, including structures served, water system, sewerage system, bathing area, roads, topography, soil profiles, and any other features necessary for proper design and review of the plans. Following examination and approval of the plans by the health department sanitary engineer, the job can be released for competitive bids. Construction of the sewage disposal or treatment system should be under the supervision of the designing engineer or architect to ensure compliance with the approved plans.

Most camp sewerage systems include one or more septic tanks, which should be preceded by a grease trap on the kitchen waste line, if designed to receive kitchen wastes. Septic tanks should be inspected each year before the camping season and cleaned when the sludge or scum approaches the depth given in Table 4-11. Grease traps require frequent cleaning, depending on the size and type. Under-sink grease traps are not advised. Outside septic-tank-type grease traps should be cleaned at least once a month. More frequent inspections should be made to determine the cleaning schedule for each establishment if the carryover of grease and clogging of sewers is to be prevented. Where other more elaborate treatment systems are provided, each unit should be maintained in proper working order so as not to lower the overall efficiency of the treatment process and to prolong the useful life of the system.

36. *Location of Sewage Disposal or Treatment System Satisfactory* Sewage disposal systems are satisfactorily located when they are at least 100 and preferably 200 ft from sources of water supply and 100 ft from lakes, streams, or swamps. Many other factors, as explained in Chapters 3 and 4, must be taken into consideration.

37. *Pasteurized Milk Used* Only pasteurized milk, cream, cottage cheese, or other dairy products obtained from an inspected and approved source should be used.

38. *Refrigeration Adequate* Refrigeration is adequate when it is possible to store and maintain all perishable foods at the proper temperature over weekends, without packing or crowding. The box should be relatively dry and permit air to circulate freely. There is never too much refrigeration space provided at camps.

Refrigerator sizes, temperatures, food storage, and maintenance are discussed in Chapter 8. Camps should provide at least $2\frac{1}{2}$ ft^3 of refrigeration space per person accommodated; 3 ft^3 is better.

39. *Food Storage Satisfactory* If perishable fresh or prepared foods are left standing outside of refrigerators, food storage is unsatisfactory. If food is packed or disorganized in refrigerators, stored on the floor, or uncovered, the storage is not satisfactory. (Foods are packed in freezers.) Storerooms and storage spaces should be provided that are rodent-, insect-, and dampproof or food and dry stores should be kept in containers providing this protection. Food and drink should be wholesome. Details are given in Chapter 8.

40. *Food Handling Satisfactory* Tongs, ladles, spatulas, or forks should be used in place of the hands to handle food whenever possible, and clean practices must be the rule if food poisonings and infections are to be prevented. Frozen meat, poultry, and other frozen foods, except vegetables and chops, should be thawed slowly in the refrigerator and not thawed by letting them stand overnight in a warm kitchen. Prepared foods should be served immediately, kept on a warming table maintained at a temperature above 140°F (60°C), or refrigerated in pans to a depth of 2 to 3 in. at or below 45°F (7°C). See Chapter 8.

Foodhandlers are expected to have clean hygienic habits, wash their hands thoroughly with soap and warm water after soiling them and after visiting the latrine, wear clean clothing, bathe daily, and be free from communicable diseases.

Milk is one food that is particularly susceptible to contamination. Satisfactory handling and protection of milk can be obtained by serving it in quart, pint, or half-pint prepackaged containers. Bulk-milk dispensers in which a special can with sanitary outlet is cleansed, disinfected, filled, and sealed at the pasteurizing plant and eliminates the use of the dipper and bulk milk are available. A prior understanding is necessary before the pasteurizing plant will agree to handle this equipment. The dispenser must be an approved type. Leftover food including milk returned from the dining room must not be reused. It should be thrown away.

Other precautions to prevent food poisoning and infection are given in Chapters 1 and 8. Pesticides should be carefully stored and used. See Chapter 10.

41. *Dishes Washed, Cleansed, and Disinfected* The dishwashing operation and equipment are discussed in considerable detail in Chapter 8. Dishes and utensils should look and feel clean.

42. *Garbage Storage Satisfactory* There should be available an adequate number of covered metal receptacles to store all the garbage and other soiled refuse from one meal. See Chapter 5.

All the liquid wastes should be discharged to a properly designed disposal system through a grease trap.

43. *Garbage Disposal Satisfactory* Probably the most satisfactory method for the disposal of garbage is to make arrangements for the use of a municipal incinerator or sanitary fill. When this is not practical, all refuse, including garbage, kitchen wastes, tin cans, bottles, ashes, and rubbish should

be disposed of in a camp or resort-operated sanitary fill. A description of the sanitary fill operation is given in Chapter 5.

An open dump invariably encourages fires and the breeding of rats and flies. It is always unsatisfactory. Selling garbage for hog feeding encourages the spread of trichinosis. It should be discontinued in the interest of public health unless provision is made by the collector to first boil all garbage 30 min.

44. *Shower Facilities Provided* Bathing facilities consisting of showers supplied with hot and cold running water, preferably with tempered water, are satisfactory. Floors should be nonskid and graded to a trapped drain and the walls constructed of impervious material to splash height. Shower facilities convenient to kitchen personnel are a major consideration to help ensure cleanliness. The availability of a swimming pool or bathing beach is not a substitute for warm-water and soap-cleansing showers but is further reason to provide warm-water showers to prevent greater pollution of the swimming pool. In tick-infested areas, daily showers should be encouraged. Common wash pans should be discarded as they are just as much disease spreaders as common drinking cups or common bath and dish towels. See Figure 9-13. Adjust shower water temperature to 95 to 105°F (35 to 41°C).

45. *Bathing Areas Conform with Sanitary Code* Pools and bathing beaches are operated and maintained in conformity with sanitary code regulations. No bathing should be permitted at any time unless under the supervision of a competent person trained in life-saving procedures.* Construction of pools and bathing beaches, the life-saving procedures established, records kept, operation, and maintenance are covered earlier in this chapter. The importance of ensuring that effective safety and life-saving plans are actually being practiced cannot be sufficiently emphasized. Pools should be fenced in. See this chapter for details. Bathing areas should be marked for swimming ability.

46. *Reports of Communicable Diseases* Persons in charge of a camp must report cases of diseases that are presumably communicable. It is a duty of the person in charge of a camp and the doctor who may be in attendance to immediately report to the health officer the name and address of any individual in the camp known to have or suspected of having a communicable disease. Strict isolation shall be maintained until official action has been taken. The method of isolation should be approved by the health officer. The person in charge should not allow such individual to leave or be removed without permission of the health officer.

Whenever a water-, food-, air-, or arthropodborne outbreak or contact illness outbreak is suspected or an unusual prevalence of any illness in which

*Should be over 21, have American Red Cross water safety instructor's and CPR certificates or the equivalent, and be assisted by a certified senior lifesaver for each 25 swimmers. One counselor to eight bathers.

fever, diarrhea, sore throat, vomiting, or jaundice is a prominent symptom, it is the obligation of the person in charge of a camp to immediately report by telephone, by telegram, or in person the existence of such illness to the health officer having jurisdiction. Health officers are required to investigate such outbreaks or the unusual prevalence of disease to determine the cause and prevent its repetition or spread. See Chapter 1, Investigation of Water and Foodborne Disease Outbreaks.

47. *Duty to Enforce Regulations* It is the responsibility of the person operating a camp or the person to whom a permit is issued to ensure that all regulations are faithfully observed at all times.

Travel-Trailer Parks

A travel trailer is "a vehicular, portable structure built on a chassis, designed as a temporary dwelling for travel, recreation and vacation, having body width not exceeding 8 ft and its body length does not exceed 32 ft."[89]

There has been a great increase in vacation travel by trailer and motor home in the United States and abroad. The more than 2000 privately owned parks and 1200 national and state parks and campgrounds are frequently overtaxed during the vacationing season. Proper planning, designing, operation, and maintenance of trailer parks and campgrounds are essential. Most states recognize the potential hazards involved where unsanitary conditions are permitted to exist and have adopted regulations to protect the users. Accepted standards to promote good sanitary practices at travel-trailer parks are summarized below for easy reference.[89]

Site Adequate size, well drained, no water accumulations or breeding places for insects or rodents, relatively free of dust, smoke, soot, noise, and odors. If possible, select site accessible to public water and sewerage systems, main highways, and service areas. Comply with zoning, building, health department, and other regulations. See Chapter 2.

Roads and Parking Areas Roads should be at least 18 ft wide (12 ft wide if serving less than 25 trailers), continuous, and dust controlled. Make roads 24 ft wide if two-way and 34 ft wide if cars parked on both sides. Provide space for off-street parking and maneuvering. See Figures 9-15 and 9-16.

Trailer Space Not more than 25 trailer spaces per acre; at least 10 ft from other trailer or structure. Add recreational area of not less than 8 percent of the gross area of the site, not less than 2500 ft^2.

Plans Submit plans to health and zoning or planning agencies for approval. Show to scale the location and area of the trailer park; topography; location of coach spaces, roads, service buildings, and other structures; water lines;

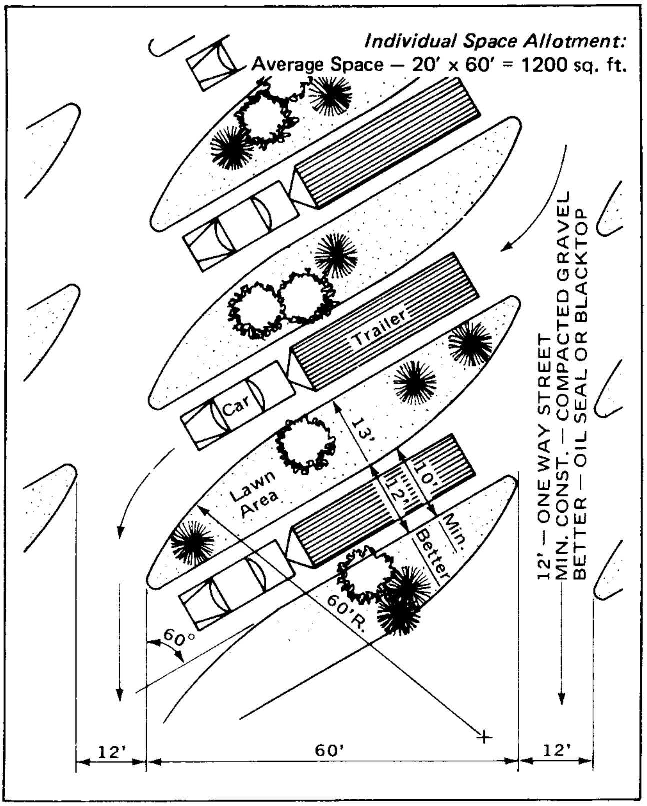


Figure 9-15 Typical transient (overnight) recreational vehicle park. (*Source: Environmental Health Practice in Recreational Areas*, PHS Pub. No. 1195, Department of Health, Education, and Welfare, Washington, DC, 1977, p. 53.)

Recommended facilities for overnight parks:
(1) Absolute minimum—central recreational vehicle sanitary and water stations and toilets. (2) Fair—individual electrical outlets, central recreational vehicle sanitary and water stations, and toilets. (3) Good—individual electrical outlets; central recreational vehicle sanitary and water stations, toilets, and showers. (4) Better—individual electrical and water outlets; several individual sewer connections, one or more central recreational vehicle sanitary stations, toilets, showers, and coin-operated laundry. (5) Best—individual electrical, water, and sewer connections, toilets, and showers, coin-operated laundry; and picnic tables.

fire hydrants; sanitary sewers; stormwater drains; catch basins; refuse storage racks; private wells; and sewage disposal or treatment systems. Include service building floor plan and fixtures, details of the water system and sewage disposal or treatment works, trailer water, electric and sewer connections, cold- and hot-water storage, and heater capacity.

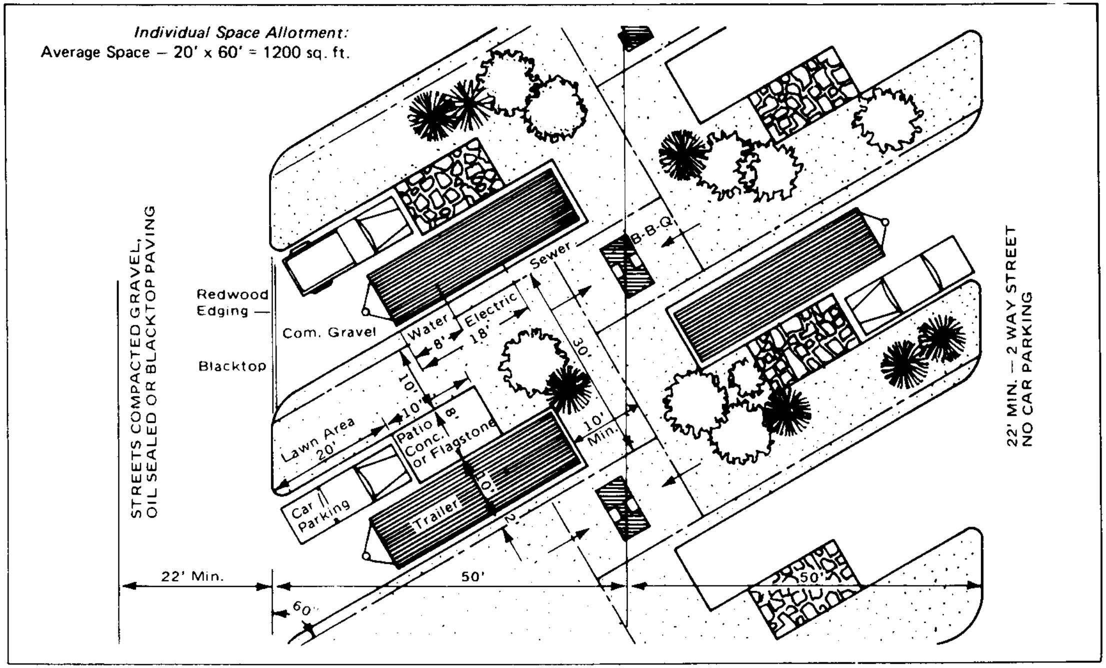


Figure 9-16 Typical resort (destination) recreational vehicle parking area. (*Source: Environmental Health Practice in Recreational Areas*, PHS Pub. No. 1195, Department of Health, Education, and Welfare, Washington, DC, 1971, p. 53.)

Recommended facilities for destination parks:

(1) Absolute minimum—back-in parking, individual electrical outlets, central recreational vehicle sanitary and water stations, and toilets and showers. (2) Fair—back-in parking, individual electrical and water connections, central recreational vehicle sanitary stations, and toilets and showers. (3) Good—drive-through parking, individual electrical and water connections, central recreational vehicle sanitary stations, toilets, showers, coin-operated laundry, and picnic tables. (4) Better—drive-through parking, individual electrical, water and sewer connections, toilets, showers, coin-operated laundry, picnic tables, and grocery. Also, barbecue, bottled gas, recreational vehicle parts for sale, plus bait and other fishing and sport accessories. Recreational building and swimming pool may be on a "pay-as-you-go" basis.

Service Building Provide at least one. Access walks surfaced and lighted with at least 5 foot candles of illumination. Building within 300 ft of spaces served. Construction cleanable; floors drained to sewerage system; maintained clean, screened, ventilated, windows as high as practicable, providing at least 10 percent of floor area; laundry room and mirrored areas have 40 foot candles of illumination, heated to 70°F (21°C) in cold weather; separate men's and women's toilet rooms; hot and cold water for every lavatory, sink, tub, shower, and clothes washer. A floor plan is shown in Figure 9-17.

Minimum plumbing facilities are discussed earlier in this chapter. The number may be reduced if trailer-park use is limited to only self-contained trailers.

Water Supply At each trailer space and service building, connect a public water supply if available or an approved private supply that provides an adequate volume of water. The source should provide at least 100 gal per trailer

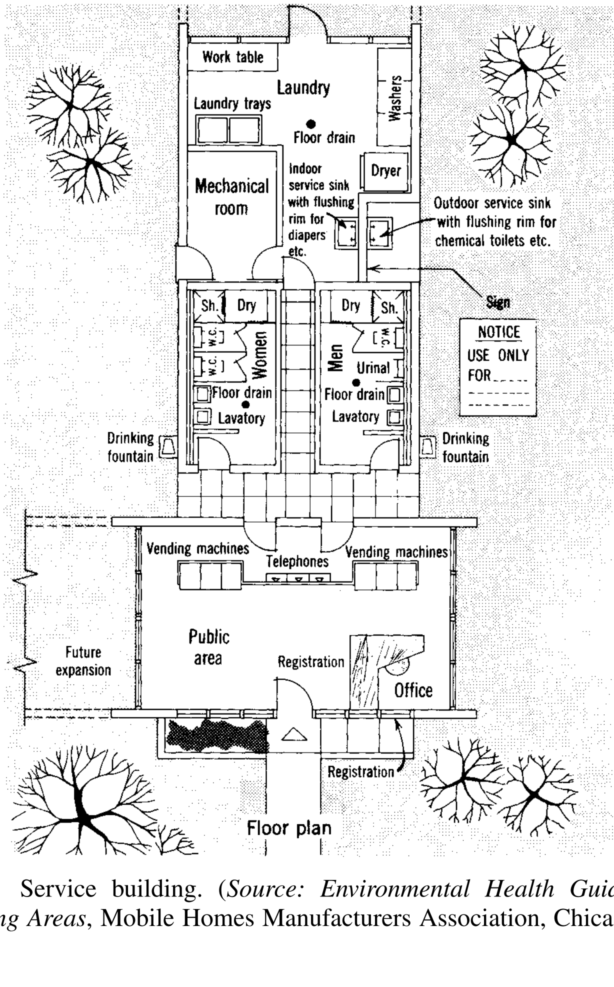


Figure 9-17 Service building. (*Source: Environmental Health Guide for Travel Trailer Parking Areas*, Mobile Homes Manufacturers Association, Chicago, IL, 1966.)

space per day for individual connections and 50 gal per space per day without connections. The distribution system, including storage and pumping equipment, should be designed for a maximum momentary water demand based on Table 9-9.

A special water supply outlet, as shown in Figure 9-18, in the ratio of 1 to each 100 spaces is needed for filling trailer water storage tanks. A flexible hose, shut-off valve, and backflow preventer are provided.

A trailer water supply connection extending at least 4 in. above the ground with a $\frac{3}{4}$-in. valved outlet is needed at each space capable of supplying water at a minimum pressure of 20 $lb/in.^2$ See Figure 9-19. Sanitary-type drinking fountains should be provided at service building and recreational areas. Surface water or questionable groundwater supplies should not be used unless use and treatment have been approved by health authorities. Maintenance of daily records are required.

See Chapter 3 for water supply design, storage, construction, and protection details.

Sewerage System Plumbing complies with state and local regulations. Special attention is given to possibility of backsiphonage; no connection permitted where possibility exists. Provide a 4-in. sewer connection extending 4 in. above ground surface and trapped below frost for each trailer space, as illustrated in Figure 9-20. No wastewater shall discharge to the ground surface.

Sewer lines are 10 ft from water lines and are designed for 2 fps velocity when flowing full. See Chapter 4. Joints are watertight, infiltration minimum, and surface water excluded. Manholes not more than 400 ft apart, at juncture of two or more sewers and at change in direction. Capped cleanouts with plugs to grade are permitted on 4- and 6-in. lines in place of manholes if at least 100 ft apart. Vents are needed on airtight system. Minimum 6-in. sewers are recommended.

TABLE 9-9 Estimated Maximum Water Demand for Travel-Trailer and Mobile-Home Park

	Demand Load (gpm)	
Number of Spaces	Travel[a]	Home[b]
25	42	65
50	65	115
75	85	155
100	115	180
150	150	235
200	180	285
250	215	325
300	230	370

[a]Travel-trailer park at 4 fixture units per space.
[b]Mobile-home park at 8 fixture units per provided space.

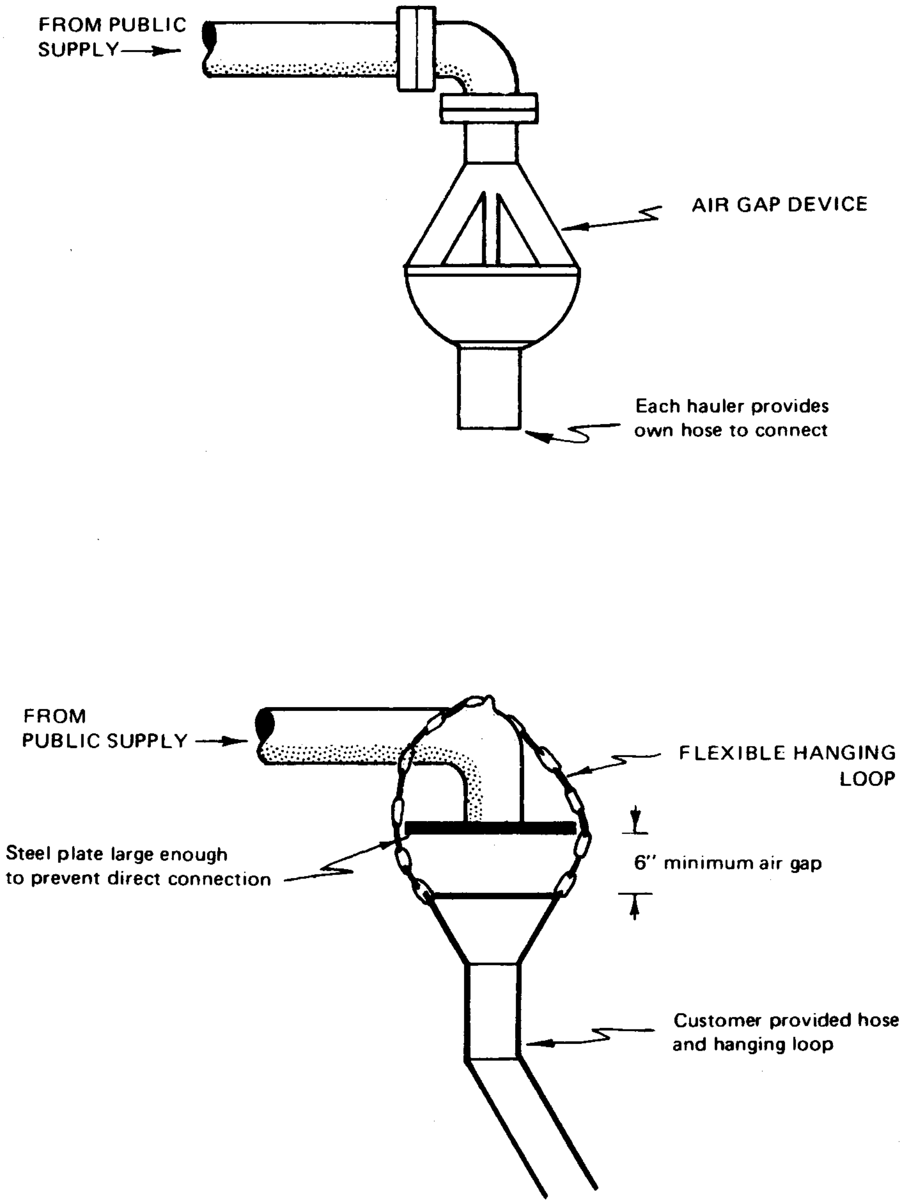


Figure 9-18 Acceptable water loading station devices. (*Source: Recommended Standards for Water Works,* A Report of the Committee of the Great Lakes–Upper Mississippi River Board of State Public Health and Environmental Managers, Health Research, Health Education Services Division, Albany, NY, 1987.)

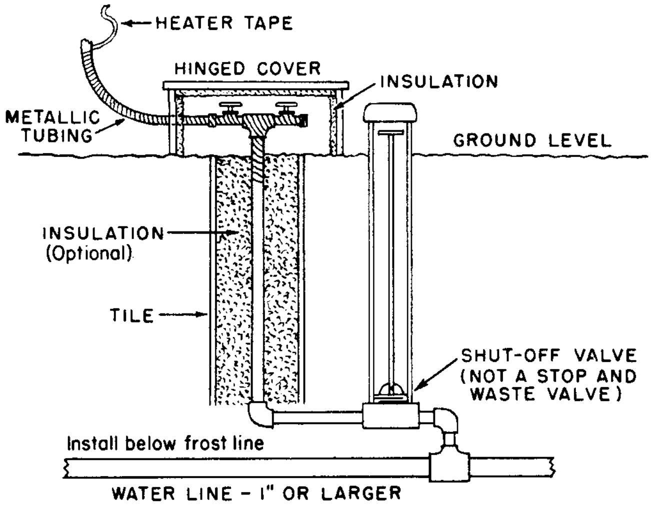


Figure 9-19 Typical water supply connection showing a method of winter protection. Terminate riser 12 to 18 in. above ground surface and equip with antisiphon backflow preventer. (*Source: Environmental Health Practice in Recreational Areas*, PHS Pub. No. 1195, Department of Health, Education, and Welfare, Washington, DC, 1977, p. 54.)

Connect to public sewer. If this is not possible, design the treatment plant for a minimum flow of 100 gal per trailer space per day, to prevent a health hazard or nuisance. Design of plant must meet state and local requirements. See Chapter 4 for design and construction details. Separate provision should be made for storm- and surface-water drainage.

Refuse Handling Tightly covered containers providing 30-gal capacity per trailer space should be adequate. Bulk containers can also be used. Can storage rack is cleanable and located within 150 ft of any trailer. See Chapter 5 for acceptable disposal methods if municipal or contract service is not available.

Insect and Rodent Control Mosquitoes, flies, roaches, rats, mice, and so on, are eliminated or kept under control. See Chapter 10.

Miscellaneous Electrical wiring and apparatus complies with local codes and National Electrical Code.[90] Fuel oil and bottled gas tanks are protected and securely connected to stoves or heaters by means of metallic tubing.[91] Take fire prevention and protection precautions. Include smoke detectors and fire extinguishers.[92] Make alterations, repairs, and additions in conformance with good practices. Keep pets under control and conditions sanitary. Maintain a register of occupants and vehicles. Eating and drinking establishments

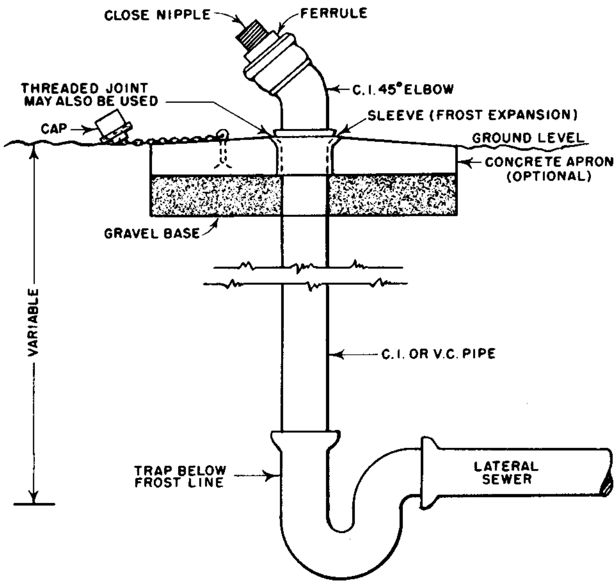


Figure 9-20 Typical sewer connection. Use 4-in. riser and minimum 3-in. sewer connection extending at least 4 in. above ground surface. Concrete apron or curb 3 in. thick and 12 in. from riser. (*Source: Environmental Health Practice in Recreational Areas*, PHS Pub. No. 1195, Department of Health, Education, and Welfare, Washington, DC, 1977, p. 54.)

should be constructed and maintained in compliance with PHS, state, and local ordinances. See Chapter 8. Tiedowns will minimize overturning during windstorms.

Campgrounds*

Privately owned, national, and state campgrounds serve hikers and all types of recreational vehicles (RVs) involving millions of campers. Recreational vehicles include travel trailers, campers, motor homes and vans, tent trailers, and truck-mounted shells. The amenities provided with the vehicle vary widely from self-sufficient and luxurious accommodations to merely sleeping and storage spaces providing shelter.

Site Selection Environmental factors to be considered in site selection and planning are discussed in Chapter 2.

*See ref. 84, pp. 22–24, 54–57.

Location The location of the campground should relate to the highway system. A location within 2 miles of a main highway interchange and on a road leading to it is suggested.

A traffic count of campers and tourists traveling the nearest main highway, along with interviews, will give an indication of the number and type of users that might be expected. A location near a population center is more popular.

The site must have a relatively high degree of privacy. Areas adjacent to commercial and industrial sites may encounter problems of noise, air pollution, odors, and other nuisances that will seriously detract from the attractiveness of the site and the comfort of its residents. Vacationers using camps and other recreational facilities are interested in benefiting from outdoor living, and the resources of the area should be such that they contribute to this experience.

Area Requirements The land area required will depend upon the type of establishment, construction, topography, usable area, population to be served, and many other factors. An investment analysis and traffic count as noted above would give an indication of the potential users and the area needed. This is a good procedure to follow, but it is not always done.

A minimum number of tent sites, recreational vehicle spaces, and perhaps motel units or cabin units is needed to produce a reasonable return on an investment, and in estimating this number, the anticipated extent of usage must be taken into account. For example, 100 tent sites may justify running a camping ground as a full-time summer activity. This number, the type of construction, and the facilities to be provided will give an indication of the land area required. Land area requirements can obviously vary widely, depending on the type of camping site. However, some guidelines can be given based on what experience has shown to be good practice.

A committee of experts on public health considered it advisable to limit the size of a camping site to 25 acres with a capacity of not more than 2000 persons. In addition, the density should not exceed 60 tent or RV sites or 80 persons per acre. This would correspond to a gross area of 540 ft^2 per person or 1800 ft^2 per site with an average of 3.3 persons per site.

Another guideline[93] for planning vacation-type camping grounds suggests an area of about 2500 ft^2 per site, with 5000 ft^2 as being more desirable. For overnight sites, a minimum of 1500 ft^2 is suggested. These areas would include space for car and RV parking. For level areas, 12 sites per acre is considered optimum and would include roads.

The area requirements for other types of tourist accommodation and recreational areas could be quite variable, depending on the type of facility and construction. A summary of some area guidelines is given in Table 9-10.

Plumbing Fixtures Adequate numbers of plumbing fixtures should be provided. Lack of facilities will result in misuse of the area, the practice of undesirable health habits, difficulties in maintaining the area in a sanitary

TABLE 9-10 Area Guidelines for Camp and Recreation Places

Camping site density including roads	12–24 per acre
Population density including roads	50–80 persons per acre
Camping site area, overnight	1200–1500 ft^2
Camping site area, family vacation, or travel-trailer	1800–5000 ft^2

Source: J. A. Salvato, *Guide to Sanitation in Tourist Establishments,* World Health Organization, Geneva, 1976, p. 24.

Note: Where local standards are more stringent, they shall apply. Recommended areas are intended to be usable areas.

condition, and adverse criticism by campers. Without the cooperation of campers and supervision by the management, the maintenance of a healthy and pleasant environment is practically impossible.

Commercially available fixtures are generally made with smooth, impervious, easily cleaned surfaces and no concealed crevices. Plastic is being introduced to a limited degree, especially for bathtubs and showers, and the use of precast concrete for laundry tub units and shower bases is not uncommon. Bathtubs are not suitable for camping and recreational areas. Rough usage may be expected and an effort should be made to select the strongest types of fixture. The use of heavy-duty institutional-type fixtures securely anchored will minimize problems of vandalism.

Fixtures should be installed in such a way that cleaning presents no problem. Piping should be buried or kept as far above the floor as possible and run to the nearest wall to minimize the amount of exposed piping. Wall-hung closet bowls, for example, simplify floor cleaning procedures. Water closet seats should be of smooth nonabsorbent material of the open-front type. The elongated type of water closet bowl with a greater surface area of water is preferred since it is less likely to become soiled. Urinals should be of the individual wall-hung type with open trapways (no strainers) and visible water seals. Trough and wall urinals are difficult to maintain in a sanitary condition unless regularly flushed, cleaned, and washed down together with the adjoining walls and floor.

Hot water should be supplied to all laundry tubs, kitchen sinks, hand washbasins or troughs, and showers through mixing-type faucets that permit the temperature of the water to be adjusted to suit the user. A controlled temperature of 95 to 105°F (35–41°C) is practical and safe for showers and hand basins. Water heaters and hot-water storage tanks should have an adequate capacity to meet the anticipated demand.

Comfort Stations Central facilities (comfort stations or service buildings) are essential in camping and similar recreational areas. The facilities should be of permanent construction provided with an interior finish of moisture-resistant materials that will withstand heavy use, frequent washing, and cleaning. With floor drains and concrete floors, the entire area can be hosed down rapidly and easily. The use of ceramic tile floors and wainscot reduces maintenance costs and is believed to discourage vandalism. Partitions should terminate about 1 ft above the floor. Adequate lighting, both natural and artificial, and ventilation are essential. Windows should be located above eye level for privacy and should be screened with 1.5-millimeter (16-mesh) screen during the insect season. All doors should open outward and be self-closing. Separate facilities should be provided for men and women. Savings in construction costs can be made by grouping the facilities for both sexes under one roof. If this is done, clearly marked separate entrances, preferably at opposite ends of the building, should be provided (see Figures 9-14 and 9-17). The interior wall separating the facilities must be of durable soundproof construction. There is some advantage in having a double dividing wall so that the interior space can be used as a pipe chase where all piping is readily available for maintenance.

The accessibility of toilet facilities is most important; if they are too far from tents, trailers, or camping areas, improper practices will occur, resulting in nuisances and health hazards. It is recommended that no camping, tent, or trailer area be located more than 300 ft from a comfort station. This distance may be rather excessive during the night for young children and older people. In such cases, individual ''portable toilet units'' might be used in emergencies and a separate facility consisting of a flush-rim service sink should be provided in an enclosure attached to the comfort station for disposing of wastes and cleaning the portable unit.

Mirrors, shelves, and power outlets for electric shavers are also required. Shaver outlets should be provided at the rate of one outlet for every 20 camp sites, but to avoid congestion in washrooms, they should not be located above hand washbasins. Toilet paper and/or paper holders, soap dispensers, and paper towels should be available at all times. Special marked containers are needed for the disposal of paper towels, sanitary napkins, and disposable diapers to help in preventing water closet blockages. This waste should be disposed of along with other refuse. Cotton or linen roller towels with an automatic rewind mechanism for the soiled portion or hot air blowers are sometimes provided for hand drying, but paper towels are preferred.

Recommended ratios of users to fixtures are shown in Table 9-11 as a guide for design purposes. A comfort station with well-balanced facilities should contain at least two water closets, two hand washbasins, and one urinal for males; three water closets and two hand washbasins for females; one flush-rim service sink; and one laundry sink. Piped hot and cold water should be provided to all fixtures. The use of coin-operated laundry machines and dryers in comfort stations is gaining acceptance; the machines are installed in a room separate from the toilet facilities. Where washing machines are not provided, laundry trays and wringers in the recommended ratio (see Table 9-11, footnote c) and a protected clothes drying area should be available for the use of visitors.

TABLE 9-11 Minimum Number of Plumbing Fixtures for Various Types of Tourist Accommodations

Type of Occupany	Number of Sites	Water Closets M	Water Closets F	Urinals M[a]	Hand Washbasins M	Hand Washbasins F	Showers M	Showers F
Picnic areas[b]	1–40	1	2	1	1	1	—	—
	41–80	2	4	2	2	2	—	—
	81–120	3	6	3	3	3	—	—
	Over 120, add 1 fixture for the additional number of sites shown in parentheses	1 (60)	1 (60)	1 (100)	1 (100)	1 (100)	—	—
Camping areas[b,c]	1–20	1	1	1	1	1	1	1
	21–30	1	2	1	2	2	1	1
	31–40	2	2	1	3	3	1	1
	41–50	2	3	2	3	3	2	2
	51–75	3	4	2	4	4	2	2
	76–100	3	4	2	4	4	3	3
	Over 100, add 1 fixture for the additional number of sites shown in parentheses	1 (40)	1 (40)	1 (100)	1 (40)	1 (40)	1 (50)	1 (50)
Caravan or trailer camps[b,c] (one service sink with flushing rim should be provided for disposal of liquid wastes; where camps permit only self-contained caravans, it is only necessary to provide one flush toilet and 1 hand washbasin for each sex per 100 spaces or every fraction of 100)	1–15	1	1	1	1	1	1	1
	16–30	1	2	1	2	2	1	1
	31–45	2	2	1	3	3	1	1
	46–60	2	3	2	3	3	2	2
	61–80	3	4	2	4	4	2	2
	81–100	3	4	2	4	4	3	3
	Over 100, add 1 fixture for the additional number of sites shown in parentheses	1 (30)	1 (30)	1 (100)	1 (30)	1 (30)	1 (40)	1 (40)

Boarding and lodging houses, tourist homes, hotels, dormitories without private bath[b,c]	One fixture for the number of persons shown in parentheses	1 (10)	1 (8)	1 (25) for over 150 men 1 (50)	1 (8)	1 (8)	1 (8) for over 150 persons 1 (20)	1 (8)

Source: J. A. Salvato, Jr., *Guide to Sanitation in Tourist Establishments,* World Health Organization, Geneva, 1976, p. 56.

Note: M = males; F = females.

[a]The use of special urinals for women is being recommended for recreational and similar areas. Where they are used, the same number should be provided as for men, and the number of water closets reduced proportionately.

[b]Provide one sanitary drinking fountain outside each toilet room or for every 50 persons; for beaches, provide one for every 100 ft 930 m) of beach.

[c]Provide one laundry tray or clothes washing machine and a kitchen sink or dishwashing trough with piped hot and cold water for every 30 sites or 60 persons. A foot shower is also useful in camping areas.

Other Water supply, sewage and other wastewater disposal, solid waste storage and disposal, food protection, and vector control factors applicable to campground design and operation are also discussed in Chapters 3 to 5, 8, and 10.

Migrant-Labor Camps

The problems associated with recruitment, labor relations, minimum wages, housing, sanitation, unemployment compensation, health and welfare, child labor, and education at migrant-labor camps have received nationwide and international[94] study. Many of the problems are related to economic exploitation, poor housing and facilities, exposure to pesticides, safety hazards, infectious and parasitic diseases, poor sanitation, malaria (in some countries), mental health, nutritional deficiencies, drug abuse, and institutional arrangements; other related problems are deficiencies in water supply, wastewater disposal, refuse storage and disposal, toilet and shower facilities, personal hygiene, and food storage, refrigeration, and preparation. In one study, migrants who did not have access to water and sanitation facilities in the field had a clinic utilization rate for diarrhea 20 times higher than that of the urban poor.[95] It was found ''that lack of drinking water and toilets causes the spread of contagion, bladder disease, and heat prostration among farm workers.''[96] A federal appeals court ruled in 1987 that toilets, drinking water, and other sanitation facilities be provided for field workers. Litigation had been ongoing since 1972.[96] The problems are difficult but not impossible to ameliorate. This area of work will tax the ingenuity and patience of the most dedicated people in public health as well as those in other official and voluntary agencies having an interest in improving the lot of the migrant worker.

An indication of the attitude of some enforcement officials and operators of farm-labor camps is obtained from the following comments relating to environmental sanitation:

If bathing facilities are provided at farm-labor camps, the people will not use them; the tubs will be used to store and collect trash.

Do not provide showers—the soil is too tight. Sewage will overflow onto the ground surface and create a more dangerous public health hazard.

Farm laborers do not expect bathing facilities. They never had any where they came from anyway.

A galvanized iron tub is provided, which is perfectly adequate for taking a sponge bath. That's what we used when we were kids.

A washbasin and pitcher of water is all you need to keep clean.

The water supply is inadequate now—how can we provide laundry tubs and showers with running water?

The health department should first prove that our well-water supply is adequate before asking us to put in showers.

Showers are too expensive; we cannot afford to put them in.

The growers will not go along with the health department.

Political influence will be used to prevent the health department from carrying on a progressive farm-labor program.

The local health department will be voted out of existence.

You will not get the support of your own staff.

There is no health hazard involved in the failure to provide showers.

The opposition expressed by these statements is really no different from what one would expect when embarking on any new environmental sanitation program. The half-truths must be attacked with education, painstaking health and engineering investigation, conferences, sound advice, and patience. When this is coordinated with a long-range plan to improve the environmental sanitation conditions and the work of other agencies, a successful program will result. The ultimate solution of the problems rests on elimination of the migrant-labor camp system, as the very system itself exposes the migrant to increased health risks and exploitation.

Specific items relating to health and sanitation at farm-labor camps are similar to those discussed previously in this chapter under Temporary Residences and under the various headings in the remainder of the text. Good information, including inspection reports and compliance guides, is also available from most state health departments, extension services, the PHS, and the Department of Labor. Some construction and facilities guides are given in Table 9-12. Labor camps are under the jurisdiction of the U.S. Department of Labor and state agencies. (A five-year enforcement program is graphically illustrated in Figure 12-2.) The Department of Labor issued field sanitation standards in 1987 requiring that employers of 11 or more farm field workers provide potable drinking water, handwashing facilities, and toilets in the ratio of one to 20 workers, located within $\frac{1}{4}$ mile of the work area. This is intended to protect workers against communicable intestinal diseases, heat-related illness, urinary tract infections, and pesticide exposures. Pesticides must be handled, used, and disposed of with extreme care. Workers must be advised and protected, wear protective clothing, wash and change field clothing, and wash hands and sprayed foods before eating. The enforcement responsibility rests with the Occupational Safety and Health Administration (OSHA).

Mass Gatherings

The assemblage of large numbers of people in a limited area requires that certain minimum facilities be provided for the protection of their health, safety, and welfare. The gatherings can vary from several thousand to several hundred thousand with and without overnight accommodations and facilities. The types of events may include fairs, jamborees, auto races, music festivals,

TABLE 9-12 Some Construction Guides and Facilities at Farm-Labor Camps

Use	Area, Number, or Volume Recommended
Kitchen area	8 ft^2/person including service counter, storage shelves, refrigerator, sink with hot and cold water, cook stove
Dining area	10–12 ft^2/person
Sleeping area	50 ft^2/person plus storage space; beds spaced 36 in.; double-deck bunks spaced 48 in.
Showers and washbasins, with 95–105°F (35–41°C) water	3–5 gal/person; 30% minimum provided per hour by heater and 2 gal/person in storage
Kitchen—hot water	3:4 to 1 gal/person per hour
Water closet or privy seat	1:15 men and 1:15 women
Urinal	1:20 men
Shower	1:10 persons
Washbasin	1:16 persons with hot and cold water
Laundry tub or machine	1:30 persons; minimum of one tub
Sleeping and cooking rooms	100 ft^2/person
Common stove	1:10 persons or 2 families per stove
Water supply	35 gal/person per day for cooking, bathing, and laundry at peak rate of $2\frac{1}{2}$ times average hourly demand
Light and ventilation	Windows not less than $\frac{1}{10}$ floor area, $\frac{1}{2}$ openable, screened; 30 foot candles in kitchen and living areas, 20 elsewhere
Building heating	Equipment capable to maintain 68°F (20°C) in cold weather

carnivals, and similar "happenings" held in open areas. The magnitude of such events can completely overwhelm all but the largest communities unless the highways, space, communication, sanitation, security, and related facilities are designed, operated, and maintained to handle the mass of people likely to descend upon the site. Such events should require a permit from the health department or other designated authority to indicate that adequate preparations have been made.

Some guidelines and information needed to assist in the preparation for mass gatherings follow*:

*Adapted from "Guidelines for Preparation of Engineering Report to Accompany Application for Permit to Conduct a Mass Gathering in New York State," New York State Department of Health, Albany, NY, June 30, 1970, and "A Resolution to License and Regulate Persons Engaged Within the Boundaries of the County, but Outside the Limits of the City, Villages and Incorporated Towns, in the Business of Providing Entertainment or Recreation, or Providing for the Lodging of Transients," adopted September 13, 1949, as amended, County Board of Supervisors of Jackson County, IL, February 1970.

1. Estimated maximum attendance and area reached by advertising.
2. Expected opening and closing date.
3. Name, owner, and location of property.
4. Name of operating "person."
5. Statement from state department of transportation giving capacity of connecting highways.
6. Statement from state and local police that traffic control plan is adequate to serve 20,000 persons per hour.
7. Statement from local emergency management director approving plans for the assemblage and its evacuation.
8. Statement from local fire authority approving the fire protection plan.
9. Emergency medical plan, including medical personnel, first-aid, hospital, and ambulance arrangements, and emergency evacuation facilities such as a helicopter.
10. Plan showing area of site and location in relation to adjoining towns within 20 miles.
11. Statement certifying all required construction, facilities, services, utilities, and operational plans are functional and approved 48 hr before assemblage time.
12. Security plan acceptable to state police ensuring crowd control, security enforcement, and narcotics and drug control.
13. Plan for site showing boundaries, roads, toilet facilities, water supply, assemblage areas, first-aid stations, food service areas, refuse storage and disposal, drainage, sewage and wastewater disposal, water storage tanks, lakes, ponds, streams, wells, electric service, telephones, radio communications, emergency access and egress roads, parking areas, lighting, and other services and facilities necessary for operation.
14. *Space:* 50 ft^2 per person in assembly areas, 250 ft^2 per person in campground area.
15. *Water supply:* 1 pt/person/hr; source, distribution, quality, and quantity comply with state health department standards.
16. *Toilet facilities* (*for each sex*): One seat per 100 persons and one lavatory per 100 persons; 40 percent of required seats for men should be urinals. Where portable toilets are used, obtain adequate cleanup and servicing schedule, including permit for waste disposal. Adjust for duration of event, time of year, beverages available, and sexes. The normal frequency of use is 4 hr; average time per use: 54 sec for male, 75 sec for female; unit tank capacity 350 uses.[97]
17. *Refuse storage and disposal:* Provide in areas of assemblage 25 ft^3 of storage receptacle per 100 persons per day (24 hr), including policing and approval of disposal site.

18. *Food service:* Provide detailed plan for food service, including food sources, menu, mandatory use of single-service dishes and utensils, *refrigeration facilities,* food handling.
19. *Vector control:* Where mosquito and biting fly populations are in excess of 15 specimens per trap per night or other potential disease vectors are found, vector populations shall be reduced to a satisfactory level 48 hr before people assemble and shall be maintained for duration of the event.
20. Noxious weeds such as poison ivy or poison oak shall be removed from accessible areas.
21. *Signs:* Show, to the extent needed, location of all facilities, including roads, toilet facilities, first-aid stations, firefighting equipment, parking areas, camping sites, eating places, and exits.
22. *Drinking fountains:* One sanitary-type drinking fountain, including waste disposal facility, per 500 persons.
23. *Sewage and other wastewater disposal:* Complies with health department standards and permit obtained for collection system and disposal.
24. *Bathing areas:* Show location and safety measures; permit from health department.
25. *Lighting:* Illuminate public areas of site at all times with no reflection beyond boundary of site.
26. *Noise control:* Sound level not to exceed 70 dBA at perimeter of site.
27. *Parking:* Provide usable space at the rate of 100 passenger cars per acre and 30 buses per acre located off public roadways.
28. Public liability and property damage insurance as needed and reasonable in relation to the potential risks and hazards involved.
29. *Performance bond:* Provide security sufficient to execute plans submitted and cover reasonable contingencies.
30. *Communication center:* At least one for operator and one for permit-issuing official.
31. *Operation and maintenance:* Adequate staff, equipment, facilities, and spare parts, as well as communications and security.

There is a special need for the permit-issuing official to ensure coordination and cooperation between state and local agencies. The agencies having a responsibility and role in any mass gathering include the local government, state and local police, health, fire, transportation, and civil defense. Each should clearly understand in advance its particular responsibilities and plan accordingly. One individual should be in charge and serve as liaison officer, with the permit-issuing official having overall responsibility.

Highway Rest Areas

Rest areas on superhighways may be simple or elaborate. They may include parking areas, restrooms, water, and sheltered picnic areas with provisions for outdoor cooking, restaurant, fast-food service, tourist information, dog trails, scenic views and trails, and gasoline stations. Toilet facilities may vary from privies to flush toilets with washbasins, drinking fountains, and heat. It is apparent that the water supply must be safe and adequate; the food service safe; the sewage and excreta disposal sanitary; the refuse storage and disposal proper; flies, mosquitoes, ticks, and noxious weeds controlled; and cooking spaces, tables, and benches adequate. The U.S. Department of Transportation, Federal Highway Administration, and state agencies have guidelines for the design, operation, and maintenance of highway rest areas.

Marinas and Marine Sanitation*

The Problem Expansion of interest in tourism and recreational activities generally has involved increased use of pleasure boats and land-based boat servicing facilities—for example, public and private marinas, yacht clubs, sleeping and eating facilities, and boat launching sites. As is usual when large numbers of people congregate (whether on land or water), increased public health hazards are associated with the growing popularity of boating, sailing, and cruising. Therefore, agencies concerned with health, water pollution control, conservation, and recreation, along with boat owners, resort managements, and those providing on-shore services, are responsible to ensure that problems connected with boating are minimized or prevented.

Boats and ships of all kinds (recreational, commercial, industrial, and government owned) contribute to the water pollution problem. Pollutants may be discharged not only into the water but also into the air or on land:

1. Water pollutants include gasoline, oil, and lead compounds; human wastes; galley wastes; wastewater from toilets, sinks, and showers (all considered as sewage); garbage, cans and bottles, and other solid wastes; bilge and ballast water; grease; chemicals; and accidental cargo spillages. Galley, sink, and shower wastes are referred to as gray water.
2. Air pollutants include fuel hydrocarbons; oxides of carbon and other gases; soot and lead compounds discharged below water level; gaseous, particulate, and thermal emissions from marine sewage incinerating devices; and unpleasant odors and noise.
3. Land pollutants include oil residues, grease, garbage, and miscellaneous debris stranded along shorelines, which not only cause economic loss but also make the area unattractive to both residents and visitors. Also included in this category are wastewater and solid wastes deposited on land where servicing facilities for water craft are not provided.

In addition, depending on whether the boating activities take place on the sea, an estuary, a river, or a lake, drinking water supplies, fishing grounds,

*See ref. 84, pp. 113–117.

and recreational areas may be polluted and fish, including shellfish, contaminated. Serious health hazards are associated with the ingestion of contaminated drinking water and shellfish. Contact with polluted water during bathing, skin diving, and water skiing activities should be avoided.

The pollution problem associated with watercraft can be especially acute at marinas, popular fishing sites, and sheltered inlets providing attractive mooring places for weekends and holidays; at regattas and similar events; and at bathing beaches where large numbers of watercraft congregate. Since privately owned recreational watercraft in the United States are estimated to carry an average of 3.1 to 3.6 persons, the amount of sewage discharged at these places may be equivalent to that produced by a sizable community. The magnitude of the problem is indicated by the report of the EPA for 1973, which stated that enforcement of its standards would affect some 600,000 U.S. vessels, including about 550,000 recreational craft, as well as a large number of foreign ships using U.S. national waters.[98]

Control of Pollution from Watercraft The EPA sets performance standards for marine waste disposal. The U.S. Coast Guard enforces federal regulations and is authorized to certify treatment and disposal devices in U.S. waters. Control of small vessels (65 ft or less) should be a state and local responsibility. Maceration plus chlorination prior to discharge of wastes is generally accepted by the EPA, but states may require more complete treatment of ‘‘no discharge’’ when greater environmental protection is shown to be necessary and for houseboats used as residences.

The control of pollution at marinas and from watercraft should be based on the general principles given in this text, but regulations should also cover the following points:

1. Installation and operation of marine toilets, preferably with no discharge to the water. Secondary treatment, including the treatment of gray water should be required as a minimum if permitted. Devices available for watercraft include portable toilets, recirculating toilets (manual and electrical) with an integral or separate holding tank, and incinerating toilets. Wastewater treatment systems with discharge to the water include maceration/disinfection units and physicochemical treatment systems. Approval of such devices, if given, should be for certain large vessels only and should be based on certification from a recognized national testing laboratory that there is no cross-connection with a potable water supply and that the construction, safety, and operating procedures are in accordance with the requirements of the regulating agency. Enforcement of discharge standards is difficult, if not impracticable, except when vessels are berthed at marinas or moored in confined bodies of water. Flow-through systems should be considered inadequate in the vicinity of water supply intakes, shellfish beds, fishing grounds, and bathing waters. Notices and buoys are required to mark restricted discharge areas.

2. On-shore pump-out stations for emptying boats' holding tanks and toilets and providing for the proper disposal of wastewater to a municipal or private collecting and treatment system or on-shore storage. The provision of pump-out facilities should be encouraged; septic tank and cesspool pump-out vehicles might be adapted for this purpose. Prior approval of the arrangement should be obtained from the regulating agency. Pump-out units may be stationary or portable and mechanically, manually, or electrically (coin-in-the-slot) operated. A positive displacement pump is generally used. Motors, electrical connections, and switches should be explosion proof. Special pump-out fittings, flush deck flanges and caps, and hose connections are needed to pump out boats' holding tanks and toilets.

3. Watercraft engines that emit only minimum permissible amounts of air and water pollutants. Two-stroke outboard motors that discharge crankcase drainage, raw fuel, or other pollutants to the receiving waters should be phased out.

4. Proper disposal of bilge, grease, ballast waters, and cleaning chemicals.

5. The use only of new or thoroughly cleaned drums for the flotation of docks, floats, houseboats, and similar structures in order to prevent possible leakage of polluting chemicals.

Present-day knowledge and experience shows that the on-board holding tank, which can be pumped out to a municipal or other shore-based collection and treatment system, is the best method of controlling sewage and other wastewater disposal from watercraft. This concept is particularly applicable to inland fresh waters and coastal waters. However, adequate pump-out facilities must be made available, and the requirement of an on-board holding tank needs to be enforced.

Shore-Based Support Facilities Suggested services and facilities requiring supervision may include the following (see Figure 9-21):

1. Marinas (for boat docking, mooring, storage, leasing, servicing, toilet recharge chemicals, provisioning), boat launching ramps, and pump-out facilities. Hoses for pumping out boats' holding tanks and toilets should be distinctly labeled and colored; brown is a suitable color. Special hoses are also needed for rinsing out holding tanks; they should also be clearly marked and distinctively colored and equipped with approved backflow prevention devices. These hoses should not be used for any other purpose. Marinas may be required to obtain an annual license or permit for purposes of regulation and to ensure compliance with established standards. Holding tank waste may disrupt treatment plant.
2. Public toilets with a service sink for emptying portable toilets and a proper wastewater disposal system. Public toilets should include water

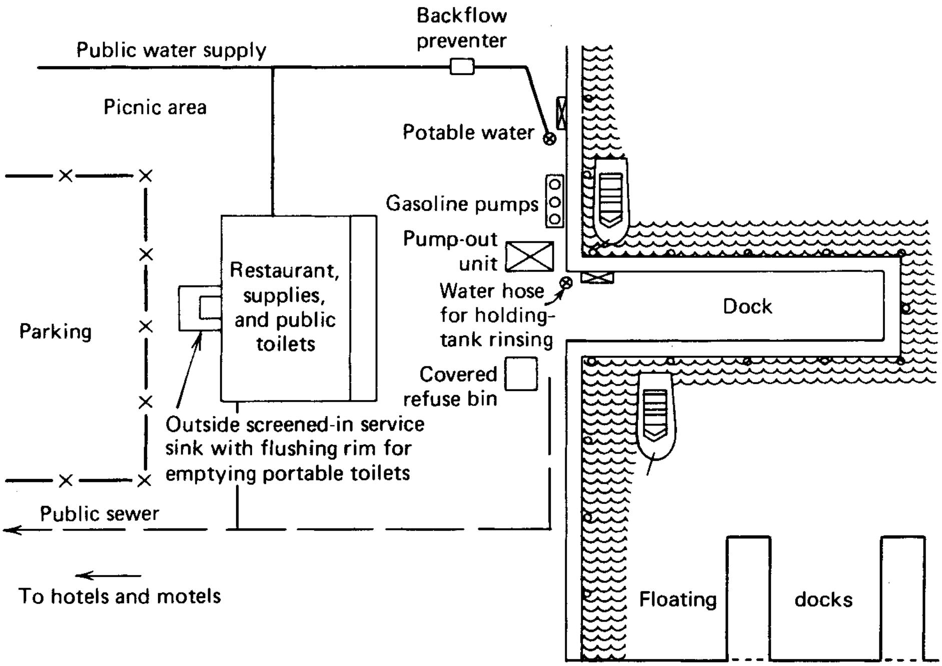


Figure 9-21 Marine with pump-out unit and other facilities. (*Source:* J. A. Salvato, Jr., *Guide to Sanitation in Tourist Establishments*, World Health Organization, Geneva, 1976, p. 116.)

closets and urinals, washbasins, and showers supplied with hot and cold water and clothes washers in separate enclosures, the number of these facilities being based on the number of moorings or boat slips, docking and boat servicing facilities, restaurants, picnic areas, and estimated use.

3. Potable water supply outlets equipped with approved backflow prevention devices. Hoses should be distinctly labeled and colored; blue is a suitable color. Hose nozzles should be protected from contamination and stored in a special cabinet when not in use.
4. Refuse collection receptacles or bins and a refuse disposal service.
5. Food service, catering, and provisioning facilities.
6. Parking areas.
7. Picnic areas and fish cleaning facilities.
8. Hotels and motels.
9. Bathing beaches.
10. Club houses and other recreational facilities.

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10 Residential and Institutional Environment

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The World Health Organization (WHO) Expert Committee on the Public Health Aspects of Housing defined housing (residential environment) as

> the physical structure that man uses for shelter and the environs of that structure including all necessary services, facilities, equipment and devices needed or desired for the physical and mental health and social well-being of the family and individual.[1]

Every family and individual has a basic right to a *decent home* and a *suitable living environment*. However, large segments of the population in urban and rural areas throughout the world do not enjoy one or both of these fundamental needs. Therefore, housing must be considered within the context of and relative to the total environment in which it is situated, together with the structure, supplied facilities and services, and conditions of occupancy.

The realization of a decent home in a suitable living environment requires clean air, pure water and food, adequate shelter, and unpolluted land. Also required are freedom from excessive noise and odors, adequate recreational and neighborhood facilities, and convenient community services in an environment that provides safety, comfort, and privacy. These objectives are not achieved by accident but require careful planning of new communities and conservation, maintenance, and redevelopment of existing communities to ensure that the public does not inherit conditions that are impossible or very costly to correct. In so doing, that which is good or sound, be it a structure or a natural condition, should be retained, restored, and reused.

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0-471-41813-7

SUBSTANDARD HOUSING AND ITS EFFECTS

Growth of the Problem

Practically all urban and rural areas contain substandard, slum, and blighted areas.* The causes are numerous; they are not easily detected in the early stages or, for that matter, easily controlled.

In the United States there has been a rapid growth in population in the suburbs. Many of the older cities have not enlarged their boundaries and are no longer experiencing a population increase.† Many have shown a decline. The population trend graphs (see Figure 10-1) of the city of Buffalo and Erie County, New York, are typical of population shifts in older cities and metropolitan areas.

Between 1800 and 1910 a very rapid growth took place in the cities of the United States due to the mass movement of people from rural to urban areas and heavy immigration. Many of the newer immigrants sought out their relatives and compatriots, who usually lived in cities, thereby straining the available housing resources.

With the movement of large numbers of people to cities, urban areas became congested; desirable housing became unobtainable. Inadequate facilities for transporting people rapidly and cheaply to and from work made it necessary for many people to accept less desirable housing in the cities, close to their work. The inability of the ordinary wage earner to economically afford satisfactory housing left little choice but to accept what housing was available. Some landlords and speculators took advantage of the situation by breaking

* Substandard housing is said to exist when there are 1.51 or more persons per room in a dwelling unit, when the dwelling unit has no private bath or is dilapidated, or when the dwelling unit has no running water. Other bases used are described under Appraisal of Quality of Living, this chapter. An extensive definition of substandard buildings is given in the *Uniform Housing Code* (International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, CA 90601, 1997 edition, pp. 22–24).

A slum is "a highly congested, usually urban, residential area characterized by deteriorated unsanitary buildings, poverty, and social disorganization" (*Webster's Third International Dictionary*, 1966). A slum is a neighborhood in which dwellings lack private inside toilet and bath facilities, hot and cold running water, adequate light, heat, ventilation, quiet, clean air, and space for the number of persons housed. It is also a heavily populated area in which housing and other living conditions are extremely poor.

To blight is to "prevent the growth and fertility of; hence to ruin; frustrate" (*Webster's*). A blighted area is an area of no growth in which buildings are permitted to deteriorate.

† The 1980 U.S. Census of Housing showed a general population increase in the "Sun Belt" states in the South and the Southwest but a decline or stabilizing in many other states. The U.S. Department of Commerce, Bureau of the Census, in *Patterns of Metropolitan Area and County Population Growth: 1980 to 1987*, shows continuation of this trend in the South and West but a stabilization or decline in the northeast and midwest regions. Between 1950 and 1986, the percent of the total population in the suburbs outside metropolitan statistical areas increased from 23.30 to 45.05. See Table 2-4 in this book. *Environmental Quality*, 21st Annual Report, U.S. Government Printing Office, Washington, DC, p. 266.

		Population	
Year	Buffalo	Erie Co.	Total
1900	352,387	81,399	433,686
1910	423,715		
1920	506,775	127,913	634,688
1930	573,076	189,332	762,408
1940	575,901	222,476	798,377
1950	580,132	319,106	899,238
1960	532,759	530,931	1,064,688
1970	462,768	650,723	1,113,491
1980	357,381	657,545	1,014,926
1990	328,123	640,409	968,532

Figure 10-1 Population trends in city of Buffalo and in Erie County, NY.

up large apartments into smaller dwelling units, by minimizing maintenance, and by constructing "cheap" housing.

Unfortunately, assistance or leadership from local government units to control potential problems is slow; there is usually a lag between the creation of housing evils and the enactment of suitable corrective legislation and enforcement. For example, the Tenement House Law applicable to New York City was passed by the New York State legislature in 1867. However, subsequent amendments and discretionary powers vested in the board of health resulted in nullifying the law to a large extent. A new Tenement House Law of 1901 was made mandatory for New York City and Buffalo. But many amendments were made to the law within the next 10 years, as a result of powerful pressure from corporate property owners, which practically defeated the original intent of the law. The experience in New York City and Buffalo shows the wisdom of having an informed public opinion to support legislation for the public good and combat the pressures of vested interests. It also shows the practical dangers of discretionary powers. In 1912, the legislature strengthened the law. The Tenement House Law applied only to dwellings with three or more families who did their own cooking on the premises. A Multiple Dwelling Law with wider coverage became effective in New York City in 1929, replacing the Tenement House Law. It became effective in Buffalo in 1949. It is to be noted that between 1867 and 1912 the existent laws were of doubtful effectiveness, yet in the 32-year period between 1880 and 1912 the New York City population increased from about 2 million to 5 million and that of Buffalo from 155,000 to 425,000.

Obsolescence is another factor that causes the growth of slums. Land and property used for purposes for which they may have been well suited in the first place may no longer be suitable for that purpose. An example is the slum frequently found on the rim of a central business area, originally a good residential district convenient to work and business. This may start with the expansion or spill-over of business into the contiguous residential areas, thereby making the housing less desirable. People next door or in the same building, desiring quiet and privacy, move. Owners are hesitant to continue maintenance work, causing buildings to deteriorate. The landlord, to maintain income, must either convert the entire building to commercial use or lower rents to attract lower income tenants. If the landlord converts, more people leave. If the landlord lowers the rents, maintenance of the building is reduced still further and overcrowding of apartments frequently follows. The progressive degradation from blight to slum is almost inevitable. As blight spreads, so does crime, delinquency, disease, fire, housing decay, and welfare payments.

There are areas that are slums from the start. The absence of or failure to enforce suitable zoning, building, sanitary, and health regulations leads to the development of ‘‘shanty towns’’ or poor housing areas. Add to this small lots and cheap, new, and converted dwellings and tenements that are poorly located, designed, and constructed, just barely meeting what minimum requirements may exist, and a basis for future slums is assured.

An indifferent or uninformed public can permit the slums to develop. The absence of immediate and long-range planning and zoning, lack of parks and playgrounds, poor street layout, weak laws, inadequately trained personnel to enforce laws, pressure groups, lack of leadership from public officials and local key citizens, and poor support from the courts and press make the development of slums and other social problems only a matter of time.

Population growth has been taking place outside the major older cities (Figure 10-1), but the rate of housing construction and rehabilitation has not kept pace with its growing needs. Federal grants and loans encouraging low-cost housing and rehabilitation of sound housing; the high cost of new housing, facilities, and services; and the high cost of gasoline have slowed down the migration of people from the cities to the suburbs. The loss of housing due to obsolescence, abandonment, decay, vandalism, and demolition further compounds the problem. The National Association of Home Builders estimated that more than 2 million new housing units were needed each year in the 1980s, but costs are high and construction is not keeping pace.

According to a 1974 housing survey, lack of plumbing, leaking roofs, inadequate heating, and generally bad housing repair—common problems in the late 40s—have almost been eliminated. In 1987, only 2.4 percent of the housing units lacked complete, private plumbing, compared to 45 percent in 1940.[2] Generally, however, low-income families still occupy homes with defects, and housing and neighborhoods in some sections of U.S. cities show obvious signs of deterioration.[3] In 1983, 8.9 percent of all occupied housing units were considered physically substandard.[4]

It is apparent that unless the rate of new home construction is accelerated, the rehabilitation of sound substandard dwelling units strongly encouraged, and the conservation and maintenance of existing housing required, a decent home for every American family will never be realized. Added to this is the continued need to provide public housing and financial assistance to the low-income family.

Critical Period

There comes a time in the ownership of income property, particularly multiple dwellings, when the return begins to drop off. This may be due to obsolescence and reduced rents or an increase in operation and maintenance costs, including utilities, fuel, and taxes. At this point, the property may be sold (unloaded); repairs may be made to prevent further deterioration of the property; the property may be abandoned, sold, or demolished for a more appropriate use; or a minimum of repairs may be made consistent with a maximum return and tax payments delayed. This is a critical time and will determine the subsequent character of a neighborhood. In situations where repairs are not made or where a property is sold and repairs are not made and taxes are not paid, the annual rental from substandard property may equal or exceed the assessed valuation of the property. A complete return on one's investment in five to seven years is not considered unusual in view of the so-called risks involved. Because of this, housing ordinances should be diligently enforced and owners required to reinvest a reasonable part of the income from a property in its conservation and rehabilitation, *at the first signs of deterioration*. This would tend to prevent rapid deterioration, the ''milking'' of a property, and nonpayment of taxes. The burden on the community to acquire and demolish a worthless structure for nonpayment of taxes or maintain an eyesore and fire and accident hazard would be lessened. Shortening the time, from the usual five years to one or two years, required for the initiation of *in rem** proceedings to foreclose for real estate tax delinquencies, while the property still has value, would reduce abandonment if coupled with firm but reasonable code enforcement. Cause for further property devaluation and extension of the blighting influence would also be reduced. See Figures 10-2 and 10-3. In New York City, *in rem* proceedings on one- and two-family dwellings can be taken only after three years, but after one year for multiple dwellings. An owner can redeem a building after four months and may, at the city's discretion, within two years if all back taxes and repair costs are repaid.[5]

It is an unfortunate practical fact, because of the complexity of the problem, that effective code enforcement for housing conservation and rehabilitation is in many places not being accomplished. Efforts suffer from frustration and lack of support, aided and abetted by government apathy or sympathy and marginal financial assistance through welfare payments. A greater return can be realized by giving greater assistance to those communities and property owners demonstrating a sincere desire to conserve and renew basically sound areas. Evidence of actual maintenance and improvement of the existing hous-

*Legal actions or judgments to seize property.

Figure 10-2 Run-down, filthy, vermin-infested backyards present many real health hazards.

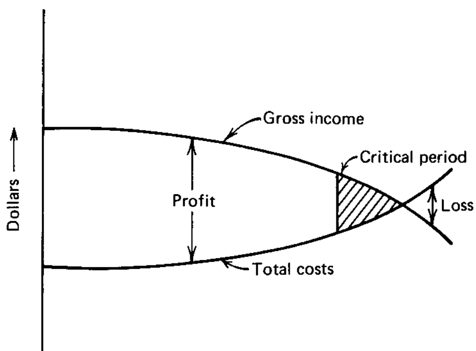


Figure 10-3 Rental housing gross income versus total costs with time, showing critical period. Gross income tends to go down and total costs up as property ages.

ing supply, code enforcement, encouragement of private building, low-interest mortgages, and provision of low- and middle-income housing are some of the facts that should guide the extent and amount of assistance a community receives.

Rent controls, however, can place the owners of rental properties in poor neighborhoods in a financially untenable position. An inadequate return on an investment usually leads to reduced services and maintenance and to property deterioration. Since a significant number of renters in poor neighborhoods may be on welfare, it would appear sound to provide higher welfare rent allowances and rent subsidies tied to property maintenance and housing code compliance. But an adequate return or profit may be distorted by the sale and resale of property by speculators to dummy corporations at increasing cost. Hence, fairness and caution are necessary.

Another factor may add to the housing problem. When there is a shortage of dwelling units and rentals are high, there is a pressure to purchase rather than rent. There is also an incentive to purchase since an income tax deduction can be taken as a home owner, which is not available to a renter. However, there is likely to be a concurrent rise in property values when this occurs because of the shortage of rental units at a moderate price. These factors favor the conversion of existing multifamily units to condominiums and construction of new condominiums, thereby excluding from the housing market many who are poor or not sufficiently affluent and those on fixed incomes who cannot afford the higher cost of a condominium. If not protected, those displaced may be forced into less desirable housing and possible exploitation, thus contributing to the spread of slums.

Health, Economic, and Social Effects

The interrelationship of housing and health is complex and not subject to exact statistical analysis. For example, poverty, malnutrition, and lack of education and medical care also have important effects on health. These may mean long hours of work with resultant fatigue, improper food, and lack of knowledge relating to disease prevention, sanitation, and personal hygiene. The problem is compounded by poor job and income opportunities and by the slum itself, through the feelings of inferiority and resentment of the residents against others who are in a better position. In addition, slums are characterized as having high delinquency, prostitution, broken homes, and other social problems. Who can say if people are sick because they are poor or poor because they are sick. Although a real association is perceived to exist between poor health and substandard housing, it has not been possible to definitely incriminate housing as *the* cause of a specific illness. Many factors contribute to the physical and mental health and social well-being of the family and individual, of which housing or the housing environment is one.[6,7] Studies show that as a matter of practical fact many factors associated with substandard housing are profoundly detrimental to the life, health, and welfare of a community. The results of a few studies and reports are summarized in Table 10-1.

The higher morbidity and mortality rates and the lower life expectancy associated with bad housing are also believed to be the cumulative effect or result of continual pressures on the human body. Dubos[8] points out in a related discussion that many medical problems have their origin in the biological and mental adaptive responses that allowed a person earlier in life to cope with environmental threats.

He adds:

> The delayed results of tolerance to air pollutants symbolize the indirect dangers inherent in many forms of adaptation, encompassing adaptation to toxic substances, microbial pathogens, the various forms of malnutrition, noise, or other excessive stimuli, crowding or isolation, the tensions of competitive life, the disturbances of physiological cycles, and all other uncontrolled deleterious agencies typical of urbanized and technicized societies. Under normal circumstances, the modern environment rarely destroys human life, but frequently it spoils its later years.

Emphasis must be on preventive sanitation, medicine, architecture, and engineering to avoid some of the contributory causes of early and late disability and premature death. This avoidance includes the insidious, cumulative, long-term insults to the human body and spirit as well as maintenance and improvement of those factors in the environment that enhance the well-being and aspirations of people.

Although this discussion concentrates on the environmental health aspects of housing, it is extremely important that concurrent emphasis be placed on the elimination of poverty and on improved education for those living in poor housing and neighborhoods. It is essential that the causes of poverty and low income be attacked at the source, that usable skills be taught, and that educational levels be raised. In this way, more individuals can become more productive and self-sufficient and develop greater pride in themselves and their communities.

APPRAISAL OF QUALITY OF LIVING

APHA Appraisal Method

The American Public Health Association (APHA) appraisal method for measuring the quality of housing was developed by the Committee on the Hygiene of Housing between 1944 and 1950. This method attempts to eliminate or minimize individual opinion to arrive at a numerical value of the quality of housing that may be compared with results in other cities and may be reproduced in the same city by different evaluators using the same system. It is also of value to measure the quality of housing in a selected area, say at five-

TABLE 10-1 Effects Associated with Substandard Housing

Diseases	Tuberculosis	Health and Other	Police	City Costs
CD rate 65% higher, VD rate 13 times higher, CD death rate as high as 50 years ago[a]	Half of cases from one-fourth of population[a]	Source of 40% of mentally ill in state institutions[a]	Juvenile delinquency twice as high[a]	20% of area in city brings in 6% of real estate tax[f]
Intestinal disease rate 100% higher in homes lacking priv. flush toilet[b]	Tuberculosis rate 8 times higher[b]	Infant death rate 5 times higher[a]	20% of area in city accounts for 50% of arrests, 45% of major crimes, 50% of juvenile delinquency[f]	Contributes $5\frac{1}{2}$% of realestate tax but takes 53% of city service[f]
Meningococcis rate $5\frac{1}{2}$ times higher[c]	Secondary attack rate 200%[e]	Infant mortality as high as 50 years ago[a]	2.6 times more arrests, 1.9 times more police calls, 2.9 times more criminal ases, 3.7 times more juvenile delinquents[i]	Slums cost $88 more per person than they yield; good areas yield $108[j]
Infective and parasitic disease death rate 6.6 times higher[d]	Death rate 8.6 times higher[c]	Life expectancy 6.7 years less[d]	50% of murders, 60% of manslaughters, 49% of robberies[g]	20% of area in city accounts for 45% of city service costs, 35% of fires[f]
Pneumonia and influenza death rate 2 times higher[c]	20% of area in city accounts for 60% of cases[f]	64% of out-of-wedlock cases[g]		1.5 times more fires, 15.7 times more families on welfare, 4 times more nursing visits[i]
Lead poisoning in children higher.		Interest rate for mortgages higher in blighted areas		Account for most of the welfare benefits.
(Rat and roach infestation higher.)		Fire insurance rates higher		Slums yielded one-half of cost of serices required[k]
Carbon monoxide poisoning.		Accidental death rate 2.3 times higher[d]		
		Injuries, burns, and accidental poisoning 5–8 times the national average[h]		

[a] Release by Dr. L. Scheele, Surgeon General, PHS Pub. 27, 1949, regarding six cities having slums.
[b] National Health Survey by U.S. Health Service, 1935–1936.
[c] B. Blum, *J. Am. Pub. Health Assoc.,* **39,** 1571–1577 (December 1949).
[d] Erie County Health Department, NY, 1953 Annual Report.
[e] Paper on housing and progress in public health by W. P. Dearing, M.D., presented at the University of North Carolina, April 16, 1950.
[f] Miscellaneous city studies.
[g] The Twenty-seventh Annual Report of the Buffalo Urban League, Inc., NY.
[h] A. H. Stevenson, Airlie House Conference, Department of Health, Education, and Welfare, Washington, DC, March 17–19, 1970.
[i] Report from City of Louisville, KY.
[j] R. M. Foley, "To Eradicate our Vast Slum Blight," *New York Times*, Magazine section, November 27, 1949.
[k] J. P. Callahan, "Local Units Fight Problem of Slums," *New York Times,* July 22, 1956.

year intervals, and to evaluate the effects of an enforcement program or lack of an enforcement program. The appraisal method measures the quality of the dwellings and dwelling units as well as the environment in which they are located.

The items included in the APHA dwelling appraisal (see Tables 10-2 and 10-3) are grouped under ''Facilities,'' ''Maintenance,'' and ''Occupancy.'' Additional information obtained includes rent, income of family, number of lodgers, race, type of structure, number of dwelling units, and commercial or business use. The environmental survey (see Table 10-4) reflects the proximity and effects of industry, heavy traffic, recreational facilities, schools, churches, business and shopping centers, smoke, noise, dust, and other factors that determine the suitability of an area for residential use.

The rating of housing quality is based on a penalty scoring system, shown in Table 10-2. A theoretical maximum penalty score is 600. The practical maximum is 300; the median is around 75. A score of zero would indicate all standards are met. An interpretation of the dwelling and environmental scores is shown in Table 10-5. It is apparent, therefore, according to this scoring system, that either the sum of dwelling and environmental scores or a dwelling or environmental score of 200 or greater would classify the housing as unfit.

Application of the APHA appraisal method requires trained personnel and experienced supervision.* The survey staff should be divorced from other routine work to concentrate on the job at hand and produce information that can be put to use before it becomes out of date. In practice, it is desirable to select a limited area(s) for pilot study. The information thus obtained can be used as a basis for determining the need for extension of the survey, need for new or revised minimum housing standards, extent of the housing problem, development of coordination between existing official and voluntary agencies, the part private enterprise and public works can play, public information needs, and so on.

Census Data

Much valuable information is collected and summarized by the U.S. Bureau of the Census. The census data† include the number of one family and multifamily dwelling units, trailers and mobile homes, and condominiums; the population per owner- and renter-occupied unit‡; the number of dwelling units with private bath, including hot and cold piped water as well as flush toilet and bathtub or shower and the number lacking some or all these facilities;

* A trained sanitarian can inspect about 10 dwelling units per day. For every four inspectors, there should be one trained field supervisor, three office clerks, and one office supervisor.

† The latest published census data are *Census 2000.*

‡ The average number of persons per housing unit was 3.28 in 1940, 3.33 in 1960, 3.14 in 1970, 2.76 in 1980, 2.69 in 1985, and 2.62 in 1989.

TABLE 10-2 Appraisal Items and Maximum Standard Penalty Scores (APHA)

Item	Maximum Score	Item	Maximum Score
A. Facilities		16. Rooms lacking installed heat[a]	20
Structure:		17. Rooms lacking window[a]	30
1. Main access[a]	6	18. Rooms lacking closet	8
2. Water supply[a] (source)	25	19. Rooms of substandard area	10
3. Sewer connection[a]	25	20. Combined room facilities[c]	
4. Daylight obstruction	20	***B. Maintenance***	
5. Stairs and fire escapes	30	21. Toilet condition index	12
6. Public hall lighting	18	22. Deterioration index[a] (structure, unit)[b]	50
Unit:		23. Infestation index (structure, unit)[d]	15
7. Location in structure	8	24. Sanitary index (structure, unit)[d]	30
8. Kitchen facilities	24	25. Basement condition index	13
9. Toilet[a] (location, type, sharing)[b]	45	***C. Occupancy***	
10. Bath[a] (location, type, sharing)[b]	20	26. Room crowding: persons per room[a]	30
11. Water supply[a] (location and type)	15	27. Room crowding: persons per sleeping room[a]	25
12. Washing facilities	8	28. Area crowding: sleeping area per person[a]	30
13. Dual egress[a]	30	29. Area crowding: nonsleeping area per person	25
14. Electric lighting[a]	15	30. Doubling of basic families	10
15. Central heating	3		

Source: An Appraisal Method for Measuring the Quality of Housing, Part II, Vol. A, "Appraisal of Dwelling Conditions," American Public Health Association, Washington, DC, 1946. Copyright by the American Public Health Association. Reprinted with permission.

Notes: (1) Maximum theoretical total dwelling score is 600, broken down as facilities, 360; maintenance, 120; and occupancy, 120. (2) Housing total = dwelling total + environmental total.

[a] Condition constituting a basic deficiency.

[b] Item score is total of subscores for location, type, and sharing of toilet or bath facilities.

[c] Item score is total of scores for items 16–19, inclusive. This duplicate score is not included in the total for a dwelling but is recorded for analysis.

[d] Item score is total of subscores for structure and unit.

TABLE 10-3 Basic Deficiencies of Dwellings (APHA)

Item[a]	Condition Constituting a Basic Deficiency[b]
	A. Facilities
2.	Source of water supply specifically disapproved by local health department
3.	Means of sewage disposal specifically disapproved by local health department
9.	Toilet shared with other dwelling unit, outside structure, or of disapproved type (flush hopper or nonstandard privy)
10.	Installed bath lacking, shared with other dwelling unit, or outside structure
11.	Water supply outside dwelling unit
13.	Dual egress from unit lacking
14.	No electric lighting installed in unit
16.	Three-fourths or more of rooms in unit lacking installed heater[c]
17.	Outside window lacking in any room unit[c]
	B. Maintenance
22.	Deterioration of class 2 or 3 (penalty score, by composite index, of 15 points or over)
	C. Occupancy
26.	Room crowding: over 1.5 persons/room
27.	Room crowding: number of occupants equals or exceeds 2 times the number of sleeping rooms plus 2
28.	Area crowding: less than 40 ft^2 of sleeping area/person

Source: An Appraisal Method for Measuring the Quality of Housing, Part II, "Appraisal of Dwelling Conditions," American Public Health Association, Washington, DC, 1946. Copyright by the American Public Health Association. Reprinted with permission.

Note: Some authorities include as a basic deficiency unvented gas space heater, unvented gas hot-water heater, open gas burner for heating, and lack of hot and cold running water.

[a] Numbers refer to items in Table 11-2.

[b] Of the 13 defects that can be designated basic deficiencies, 11 are so classified when the item penalty score equals or exceeds 10 points. Bath (item 10) becomes a basic deficiency at 8 ponts for reasons involving comparability to the U.S. Housing Census, deterioration (item 22) at 15 points for reasons internal to that item.

[c] The criterion of basic deficiency for this item is adjusted for number of rooms in unit.

the number of dwelling units occupied by persons of Spanish/Hispanic origin or descent; the number of rooms and bedrooms per dwelling unit; the number on public water supply, drilled well, dug well, spring or other; the number on public sewerage, septic tank or cesspool, or other system; the type of heating and fuel used; size of plot; information on occupation and income; the monthly rental; and the value or sale price of owner-occupied one-family homes. Other statistics on selected population characteristics for areas with 2500 or more inhabitants and for counties are available. This information, if not too old, can be used as additional criteria to supplement reasons for

TABLE 10-4 Environmental Survey—Standard Penalty Scores (APHA)

Item		Maximum[a] Penalty Score
	A. Land Crowding	
1.	Coverage by structures—70% or more of block area covered	24
2.	Residential building density—ratio of residential floor area to total = 4 or more	20
3.	Population density—gross residential floor area per person 150 ft^2 or less	10
4.	Residential yard areas—less than 20 ft wide and 625 ft^2 in 70% of residences	16
	B. Nonresidential Land Areas	
5.	Areal incidence of nonresidential land use—50% or more nonresidential	13
6.	Linear incidence of nonresidential land use—50% or more nonresidential	13
7.	Specific nonresidential nuisances and hazards—noise and vibration, objectionable odors, fire or explosion, vermin, rodents, insects, smoke or dust, night glare, dilapidated structure, unsanitary lot	30
8.	Hazards to morals and the public peace—poolrooms, gambling places, bars, prostitution, liquor stores, nightclubs	10
9.	Smoke incidence—industries, docks, railroad yards, soft coal use[b]	6
	C. Hazards and Nuisances from Transportation System	
10.	Street traffic—type of traffic, dwelling setback, width of streets	20
11.	Railroads or switchyards—amount of noise, vibration, smoke, trains	24
12.	Airports or airlines—location of dwelling with respect to runways and approaches	20
	D. Hazards and Nuisances from Natural Causes	
13.	Surface flooding—rivers, streams, tide, groundwater, drainage, annual or more	20
14.	Swamps or marshes—within 1000 yd, malarial mosquitoes	24
15.	Topography—pits, rock outcrops, steep slopes, slides	16
	E. Inadequate Utilities and Sanitation	
16.	Sanitary sewage system—available (within 300 ft), adequate	24
17.	Public water supply—available, adequate pressure and quantity	20
18.	Streets and walks—grade, pavement, curbs, grass, sidewalks	10
	F. Inadequate Basic Community Facilities	
19.	Elementary public schools—beyond $\frac{2}{3}$ mi, 3 or more dangerous crossings	10
20.	Public playgrounds—less than 0.75 acres/1000 persons	8
21.	Public playfields—less than 1.25 acres/1000 persons	4
22.	Other public parks—less than 1.00 acres/1000 persons	8
23.	Public transportation—beyond $\frac{2}{3}$ mi, less than 2 buses/hr	12
24.	Food stores—dairy, vegetable, meat, grocery, bread, more than $\frac{1}{3}$ mi	6

Source: An Appraisal Method for Measuring the Quality of Housing, Part III, "Appraisal of Neighborhood Environment," American Public Health Association, Washington, DC, 1950. Copyright by the American Public Health Association. Reprinted with permission.

[a] Maximum environment total = 368.

[b] Include other sources of air pollution.

TABLE 10-5 Housing Quality Scores (APHA)

Factor	Good (A)	Acceptable (B)	Borderline (C)	Substandard (D)	Unfit (E)
Dwelling score	0–29	30–59	60–89	90–119	120 or greater
Environmental score	0–19	20–39	40–59	60–79	80 or greater
Sum of dwelling and environmental scores	0–49	50–99	100–149	150–199	200 or greater

Source: An Appraisal Method for Measuring the Quality of Housing, Part III, "Appraisal of Neighborhood Environment," American Public Health Association, Washington, DC, 1950. Copyright by the American Public Health Association. Reprinted with permission.

specific program planning. Plotting the data on maps or overlays will show concentrations sometimes not discernible by other means.

The accuracy of census data for measuring housing quality has been questioned and, hence, should be checked locally, particularly if it is to be used for appraisal or redevelopment purposes. Nevertheless, it is a good tool in the absence of a better one.

Health, Economic, and Social Factors

It is frequently possible to obtain morbidity and mortality data for specific diseases or causes by census tracts or selected areas. Also available may be the location of cases of juvenile delinquency, public and private assistance, and probation cases. Sources of fires, nuisances, and rodent infestation and areas of social unrest give additional information. Health, fire, police, and welfare departments and social agencies should have this information readily available. See Table 10-1. Tabulation and plotting of these data and overlays will be useful in establishing priorities for action programs.

Planning

The location of existing and proposed recreational areas, business districts, shopping centers, churches, schools, parkways and thruways, housing projects, residential areas, zoning restrictions, redevelopment areas, airports, railroads, industries, lakes, rivers, and other natural boundaries help to determine the best usage of property. Where planning agencies are established and are active, maps giving this as well as additional information are usually well developed. Analysis and comprehensive planning on a continuing basis are essential to the proper development of cities, villages, towns, counties, and metropolitan areas. The availability of state and federal aid for community-wide planning should be investigated. Plans for urban development, housing code enforcement, rehabilitation, and conservation should be carefully integrated with other community and state plans before decisions are made. These subjects are discussed in greater detail in Chapter 2.

Environmental Sanitation and Hygiene Indices

Most modern city and county health departments can carry on a housing inspection program based on minimum housing standards, provided competent personnel is assigned. Where housing inspections are made on a routine basis and records are kept on a computer, data processing punch-card system, visible card file, or by combination methods, problem streets and areas can be detected with little difficulty. A survey and follow-up form based on a modern housing ordinance are shown in Figure 10-4. It should list recommendations for correction based on what is practical from field observation so as to serve as the basis for an accurate confirmatory letter to the owner. The type of deficiencies found, such as the lack of a private bath and toilet, dwelling in disrepair, or lack of hot and cold running water, can give a wealth of information to guide program planning. Usually the origin of complaints, which if plotted on a map will give a visual picture of the heavy workload areas, can be added to the survey. Reliable cost estimates for complete rehabilitation of selected buildings and a simple foot survey should be made to confirm administrative judgment and decisions before any major action is taken. Many apparently well-thought-out plans have fallen down under this simple test. For example, deterioration may have proceeded to the point where rehabilitation is no longer economically or structurally feasible under existing market conditions. Other criteria are tax delinquency, welfare clients, vandalism, age, ownership turnover, housing vacancy, property value, illnesses, rodent and insect infestation, and the amount of housing demolished.

Other Survey Methods

These include aerial surveys, external ground-level surveys, and the Public Health Service Neighborhood Environmental Evaluation and Decision System (NEEDS).[9] The selection of a small number of significant environmental variables can also provide a basis for a rapid survey if checked against a more comprehensive survey system.

NEEDS This is a five-stage systems technique designed to provide a rapid and reliable measure of neighborhood environmental quality. The data collected are adapted for electronic data processing to reduce the time lapse between data collection, analysis, program planning, and implementation.

Stage I An exterior sidewalk survey is made of 10 to 20 blocks in each problem neighborhood of a city to determine those in greatest need of upgrading. The conditions analyzed include structural overcrowding, population crowding, premises conditions, structural condition of hous-

Dates inspected ____________

Address ____________ Type of Structure and Occupancy ____________
(frame, stucco, brick veneer, solid brick; residential, factory, store)

Owner and Address ____________

No.	Item	Yes	No	CM
1.	Water supply in each apt. satisfact. quality and quantity (no X-conn).			
2.	Private in each apt.			
	(*a*) water closet			
	(*b*) washbasin			
	(*c*) shower/tub			
	(*d*) kitchen sink			
	(*e*) cabinets and counter			
	(*f*) refrig. and stove			
3.	Piped hot water for			
	(*a*) washbasin			
	(*b*) shower/tub			
	(*c*) kitchen			
4.	Plumbing, heating, electricity, and fixtures properly installed and maintained.			
5.	Water-repellent floor and base in toilet room and bathroom.			
6.	Window $\frac{1}{10}$ floor area in every room; openable, adequate light and air or induced ventilation for bath.			
7.	Dwelling unit provides 150 ft^2 for one and 100 ft^2 area for each additional occupant.			
8.	Dwelling can be heated to 68°F.			
9.	Sleeping rooms provide 70 ft^2 for one person and 50 ft^2 for each additional person.			
10.	Every habitable room has 2 electric outlets; bathroom, w.c. stall, laundry, and hall have a min. 10ft-c on floor.			
11.	Occupant keeps dwelling unit and fixtures clean and sanitary.			
12.	Space and water heaters adequate, properly connected, and vented to outer air; backdraft guard; smoke alarm.			
13.	Premises free of rodent and vermin infestation; rodentproof.			
14.	Refuse, garbage, and trash storage proper and adequate.			
15.	One or more apartments above 2nd floor have 2 means of egress.			
16.	Public halls and stairs lighted, daylight and artificial in MD.			
17.	Property and dwelling properly drained and sewered.			
18.	Owner keeps public areas of building and premises clean.			
19.	Living in cellar prohibited.			
20.	Dwelling in good repair, safe, sanitary, and weatherproof (handrails, stairs, walls, wiring, floors, siding, doors, frames, plaster, porch, eaves, roof, foundation beams firm and sound).			
21.	Lodging house has one washbasin, shower or tub, and water closet per 6 persons.			
22.	Lodging house supplies clean linen and towels prior to letting and weekly.			
23.	Cooking in lodging house done in approved and lawful kitchen or kitchenette only.			

NOTE: Explain each "No" item on back by item number and follow with recommendation for correction. "CM" is checked or dated when correction is made. "MD" denotes three or more dwelling units.

Floor	Apt.	Total Hab. Area	Total Hab. Rooms	Bedrooms		Persons	Shelter monthly rental
				No.	Area		

Remarks: (tenant names, agent, change in ownership)

Inspected by: ____________

EH-49,5

Figure 10-4 Dwelling survey.

ing and other buildings, environmental stresses, condition of streets and utilities, natural deficiencies, public transportation, natural hazards and deficiencies, shopping facilities, parks and playgrounds, and airport noise. (Time: 1 person-hour per block.)

Stage II The neighborhood(s) selected are surveyed in some depth to determine the physical and social environmental problems facing the residents. About 300 dwelling units and families are sampled in the study area. This phase includes interviews to determine demographic characteristics, health problems, health services, interior housing conditions, and resident attitudes.

Stage III The data collected in stage II are computer processed and analyzed with local government and community leaders. Problems are identified and priorities for action are established.

Stage IV Programs are developed to carry out the decisions made in stage III. The community participates and is kept aware of the study results and action proposed.

Stage V The decisions made and programs developed are implemented. Federal fiscal assistance is also solicited, and the information and support made possible by this technique are used to strengthen applications for grants.[9]

Health Principles

The APHA Committee on the Hygiene of Housing has listed the criteria to be met for the promotion of physical, mental, and social health. Thirty basic principles, with specific requirements and suggested methods of attainment for each, are reported in *Basic Principles of Healthful Housing,* originally published by the APHA in 1938. These are still valid.

The "basic principles" have been expanded to reflect progress made and present-day aspirations of people to help achieve total health goals such as defined by the WHO. The APHA Program Area Committee on Housing and Health prepared a comprehensive statement of principles available to guide public policy and goal formulation.[10] These can also serve as a basis for performance standards to replace specification standards for building construction, living conditions, and community development. The major headings, or objectives, of the committee report are quoted below. The reader is referred to the committee report for further explanation of the items listed.

Basic Health Principles of Housing and Its Environment*

I. *Living Unit and Structure*

"Housing" includes the living unit for man and family, the immediate surroundings, and the related community services and facilities; the total is referred

*From *Housing: Basic Health Principles & Recommended Ordinance* (ref. 10). Copyright by the American Public Health Association. Reprinted with permission.

to as the "residential environment." The following are basic health principles for the residential environment, together with summaries of factors that relate to the importance and applicability of each principle.

A. Human Factors
   1. Shelter against the elements.
   2. Maintenance of a thermal environment that will avoid undue but permit adequate heat loss from the human body.
   3. Indoor air of acceptable quality.
   4. Daylight, sunlight, and artificial illumination.
   5. In family units, facilities for sanitary storage, refrigeration, preparation, and service of nutritional and satisfactory foods and meals.
   6. Adequate space, privacy, and facilities for the individual and arrangement and separation for normal family living.
   7. Opportunities and facilities for home recreational and social life.
   8. Protection from noise from without, other units, and certain other rooms and control of reverberation noises within housing structures.
   9. Design, materials, and equipment that facilitate performance of household tasks and functions without undue physical and mental fatigue.
   10. Design, facilities, surroundings, and maintenance to produce a sense of mental wellbeing.
   11. Control of health aspects of materials.

B. Sanitation and Maintenance
   1. Design, materials, and equipment to facilitate clean, orderly, and sanitary maintenance of the dwelling and personal hygiene of the occupants.
   2. Water piping of approved, safe materials with installed and supplied fixtures that avoid introducing contamination.
   3. Adequate private sanitary toilet facilities within family units.
   4. Plumbing and drainage system designed, installed, and maintained to protect against leakage, stoppage, or overflow and escape of odors.
   5. Facilities for sanitary disposal of food waste, storage of refuse, and sanitary maintenance of premises to reduce the hazard of vermin and nuisances.
   6. Design and arrangement to properly drain roofs, yards, and premises and conduct such drainage from the buildings and premises.
   7. Design and maintenance to exclude and facilitate control of rodents and insects.
   8. Facilities for the suitable storage of belongings.
   9. Program to ensure maintenance of the structure, facilities, and premises in good repair and in a safe and sanitary condition.

C. Safety and Injury Prevention
   1. Construction, design, and materials of a quality necessary to withstand all anticipated forces that affect structural stability.
   2. Construction, installation materials, arrangement, facilities, and maintenance to minimize danger of explosions and fires or their spread.
   3. Design, arrangement, and maintenance to facilitate ready escape in case of fire or other emergency.
   4. Protection against all electrical hazards, including shocks and burns.

5. Design, installation, and maintenance of fuel-burning and heating equipment to minimize exposure to hazardous or undesirable products of combustion, fires, or explosions and to protect persons against being burned.
6. Design, maintenance, and arrangement of facilities, including lighting, to minimize hazards of falls, slipping, and tripping.
7. Facilities for safe and proper storage of drugs, insecticides, poisons, detergents, and deleterious substances.
8. Facilities and arrangements to promote security of the person and belongings.

II. *Residential Environment*

The community facilities and services and the environment in which the living unit is located are essential elements in healthy housing and are part of the total residential environment.

A. Community or Individual Facilities
1. An approved community water supply or, where not possible, an approved individual water supply system.
2. An approved sanitary sewerage system or, where not possible, an approved individual sewage disposal system.
3. An approved community refuse collection and disposal system or, where not possible, arrangements for its sanitary storage and disposal.
4. Avoidance of building on land subject to periodic flooding and adequate provision for surface drainage to protect against flooding and prevent mosquito breeding.
5. Provision for vehicular and pedestrian circulation for freedom of movement and contact with community residents while adequately separating pedestrians from vehicular traffic.
6. Street and through-highway location and traffic arrangements to minimize accidents, noise, and air pollution.
7. Provision of such other services and facilities as may be applicable to the particular area, including public transportation, schools, police, fire protection, and electric power, health, community, and emergency services.
8. Community housekeeping and maintenance services, like street cleaning, tree and parkway maintenance, weed and rubbish control, and other services requisite to a clean and aesthetically satisfactory environment.

B. Quality of the Environment
1. Development controls and incentives to protect and enhance the residential environment.
2. Arrangement, orientation, and spacing of buildings to provide for adequate light, ventilation, and admission of sunlight.
3. Provision of conveniently located space and facilities for off-street storage of vehicles.
4. Provision of useful, well-designed, properly located space for play, relaxation, and community activities for daytime and evening use in all seasons.
5. Provision for grass and trees.

6. Improved streets, gutters, walks, and access ways.
7. Suitable lighting facilities for streets, walks, and public areas.

C. Environmental Control Programs

Maintenance of a healthy environment necessitates an educational and enforcement program to accomplish the following.

1. Control sources of air and water pollution and local sources of ionizing radiation.
2. Control rodent and insect propagation, pests, domestic animals, and livestock.
3. Inspect, educate, and enforce so that premises and structures are maintained in such condition and appearance as not to be a blighting influence on the neighborhood.
4. Community noise control and abatement.
5. Building and development regulations.

In an article based on a working paper prepared for the WHO consultation on housing and implications for health, Schaefer[11] listed the following principles of health need and action to be taken to increase the health potential of housing internationally:

Principles of Health Needs

1. Communicable diseases can be reduced if housing provides for safe water supply, sanitary excreta and garbage disposal, adequate drainage of surface waters, and necessary facilities for domestic hygiene and safe food storage and preparation.
2. Housing should protect against avoidable injuries, poisonings, and exposure that contributes to chronic diseases and malignancies.
3. Housing may promote mental well-being; since prehistoric times, the home has been a place of refuge from danger and stress.
4. The neighborhood and community, as well as the dwelling itself, affect health.
5. Health depends also on how residents use their housing.
6. The dwelling conditions of certain groups put them at special health risk, leaving them especially vulnerable to multiple health hazards.

Principles of Health Action

1. Health advocacy in housing decisions should be strongly emphasized by health authorities, in alliance with other concerned groups, at all levels of administration and through multiple channels and media.
2. In the government sphere, health advocacy should be directed at a broad range of policies.
3. To implement socially desirable policies, health advocacy should be intersectoral in its orientation; moreover, it should be integrated into the

technical and social processes that countries use to develop and maintain community resources.

4. For policies and standards to be effective, extensive public and professional education is required to promote the provision and use of housing in ways that improve health status.
5. Finally and emphatically, community involvement at all levels should support self-help, neighbor-help, and communal cooperative action in dealing with the needs and problems of the human habitat.

Minimum Standards Housing Ordinance

Building divisions of local governments have traditional responsibility over the construction of new buildings and their structural, fire, and other safety provisions as specified in a building code. Fire departments have responsibility for fire safety. The health department and such other agencies with an interest and responsibility are concerned with the supplied utilities and facilities, their maintenance, and the occupancy of dwellings and dwelling units for more healthy living. This latter responsibility is best carried out by the adoption and enforcement of a housing ordinance.

In an enforcement program, major problems of structural safety or alterations involving structural changes for which plans are required would be referred to the building division. Serious problems of fire safety would be referred to the fire department. Interdepartmental agreements and understanding can be mutually beneficial and make possible the best use of the available expertise. This requires competent staffing and day-to-day cooperation.

Housing and Health APHA-CDC Recommended Minimum Housing Standards has been prepared for local adoption.[12] Other model ordinances are also available.[13] The standards should apply to *all* existing, altered, and new housing. The contents of the APHA–Centers for Disease Control and Prevention (CDC) standards are as follows:

Foreword

Introduction

1. General Provisions
2. Definitions
3. Responsibilities of Owners and Occupants of Dwellings and Dwelling Units or of Premises
4. Basic Equipment and Facilities
5. Fire Safety and Personal Security
6. Lighting and Ventilation
7. Heating and Thermal Requirements
8. Sanitation and Safety Requirements
9. Space Requirements

10. Rooming Houses and Rooming Units
11. Inspections: Powers and Duties of the (Appropriate Authority)
12. Licensing of the Operation of Multiple Dwellings and Rooming Houses
13. Rules and Regulations
14. Notice of Violation
15. Penalties
16. Corrective Actions
17. Collection and Dissemination of Information
18. Appeals
19. Emergencies
20. Conflict of Ordinances: Effect of Partial Invalidity
21. Effective Date

These standards give the conditions to be complied with before and during occupancy. They are minimum standards and in many instances should be exceeded. An agency having or contemplating a housing program should maintain a copy of this publication and the *Uniform Housing Code*[13] in its reference file.

A housing code or ordinance should reflect the need for safety devices and the hazards associated with new construction materials. Provision should also be made for compliance assistance and enforcement flexibility.

Smoke detectors have been found to be effective safety devices that belong in all dwellings and dwelling units. These devices afford major protection to life and property, particularly when coupled with alarms and sprinklers in multiple dwellings.

Energy conservation concerns have emphasized the importance of insulation materials to prevent heat losses from buildings. It is necessary to ensure that such materials are not flammable and do not release toxic fumes or materials when installed or subjected to high temperatures.

The administrative section of a housing code should permit the phased improvement of sound dwellings and dwelling units first in selected areas having identifiable grossly substandard living conditions. The expected level of compliance would be consistent with the intent of the housing code regulations and the achievable environmental quality of the neighborhood. Low-interest loans, fiscal and technical guidance, limited grants, craftsmen and labor assistance, tax relief, and other inducements are essential to encourage rehabilitation, stem the tide of deterioration and blight, and make possible compliance with the housing code. Concurrently, community services and facilities would need to be improved and maintained at an adequate level.

HOUSING PROGRAM

Approach

Housing can be a complex human, social, and economic problem that awakens the emotions and interests of a multitude of agencies and people within a community. Government agencies must decide in what way they can most effectively produce action; that is, whether in addition to their own efforts it is necessary to give leadership, encouragement, and support to other agencies that also have a job to do in housing.

Resolution of the housing problem involves just about all official and nonofficial groups or agencies. Organization begins with the housing coordinator, as representative of the mayor or community executive officer. The groups involved include an interagency coordinating committee; citizens advisory committee; health, building, public works, law, and fire departments; urban development agency; housing authority; financing clinic; planning board; air pollution control agency; office of community relations; public library; rent control office; universities and technical institutes; welfare department; council of social agencies; neighborhood and community improvement associations; banking institutions; real estate groups; consulting engineers and architects; general contractors; builders and subcontractors; press; and service organizations.

Components of a Good Housing Program

Good housing does not just happen. It is the result of far-sighted thinking by individuals in many walks of life. In some cases, a few houses are built here and there and areas grow with no apparent thought given to the future pattern being established. This is typical of small subdivisions of land and developments where there is no planning. In other instances, typical of large-scale developments, construction proceeds in accordance with a well-defined plan. The growth of existing communities, the quality of service and facilities provided, and the condition in which they are maintained usually depend on the leadership and coordination provided by the chief executive officer and legislative body and the controls or guides followed. The more common support activities are described below.

Planning Board A planning board can define the area under control and, by means of maps, locate existing facilities and utilities. Included, for example, are highways, railroads, streams, recreational areas, schools, churches, shopping centers, residential areas, commercial areas, industrial areas, water lines, and sewer lines. In addition, plans are made for future revisions or expansion for maximum benefit to the community. A zoning plan is needed to delineate and enforce the use to which land will be put, such as for residential, farm, industrial, and commercial purposes. This also provides for protection of land values. Subdivision regulations defining the minimum size of lots, width and grading of roads, drainage, and utilities to be provided may also be adopted. New roads or developments would not be accepted unless in compliance with the subdivision standards. The planning board, if supported, can guide community changes and, if established early, can direct the growth of a community, all in the best interest of the people.

Department of Public Works A public works department usually has jurisdiction over building, water, sewers, streets, refuse, and, if not a separate department, fire prevention and protection.

The building division's traditional responsibility is regulation of all types of building construction through the enforcement of a building code. A building code includes regulations pertaining to structural and architectural features, plumbing, heating, ventilation and air conditioning, electricity, elevators, sprinklers, and related items. Fire structural regulations are usually incorporated in a building code, although a separate or supplementary fire prevention code may also be prepared. Certain health and sanitary regulations, such as minimum room sizes, plumbing fixtures, and hot- and cold-water connections, should of course be an integral part of a building code; this ensures that new construction and alterations will comply with the health department's housing code minimum standards regulating occupancy, maintenance, and supplied facilities.

The water and sewer division would have the fundamental responsibility of making available and maintaining public water supply and sewerage services where these sanitary facilities are accessible. In new subdivisions of land, the provision of these facilities, particularly when located outside the corporate limits of a city or village, is usually the responsibility of the developer.

The division of streets would maintain streets, including snowplowing, cleaning, rebuilding old roads, and ensuring the proper drainage of surface water. In unincorporated communities the highway department assumes these functions. New roads would not be maintained unless dedicated to the city, village, or township and of acceptable design and construction.

Refuse collection would include garbage, rubbish, and trash. This function may be handled by the municipality, by contract, or by the individual.

Public Housing and Urban Development In existing urban communities, the housing authority is generally responsible for the construction and operation of dwellings for low-income families and for the rehousing of families displaced by slum clearance. The urban development agency assembles and clears land for reuse in the best interest of the community and rehouses persons displaced as a result of its actions. In basically good neighborhoods, unsalvable housing is demolished, good housing is protected, and sound substandard housing is rehabilitated. In general, large-scale demolition involving the destruction of viable neighborhoods having structurally sound housing should be avoided.

Health Department State and local health departments have the fundamental responsibility of protecting the life, health, and welfare of the people. Although most cities have health departments, many areas outside of cities do not have the services of a completely staffed county or city–county health department. However, where provided, the health department responsibilities are given in a public health law and sanitary code. In addition to communicable disease control, maternal and child health care, clinics, nursing services, and environmental sanitation, the health department should have supervision over housing occupancy, maintenance and facilities, food sanitation, water supply, sewage and solid waste disposal, pollution abatement, air pollution control, recreation, sanitation, control, radiation hazards, and the sanitary engineering phases of land subdivision. The environmental sanitation activities, being related to the planning, public works, housing, and redevelopment activities, should be integrated with the other municipal functions. For maximum effectiveness and in the interest of the people, it is also equally proper that the services and talents available in the modern health department be consulted and utilized by the other municipal and private agencies.

Health departments have the ideal opportunity to redirect and guide nuisance and complaint investigations; lead-poisoning elimination; carbon monoxide poisoning prevention; and insect, rodent, and refuse control activities into a planned and systematic community sanitation and housing hygiene program. By coordination with nursing, medical care, and epidemiological activities, as well as with those of other agencies, the department is in a position to constructively participate in the elimination of the causes contributing to the conditions associated with slums and substandard housing. The health department should also assist in the training of building, sanitation, welfare, and fire inspectors and others who have a responsibility or interest in the maintenance and improvement of living conditions.

Private Construction New construction and rehabilitation of housing in accordance with a good building and housing code are essential to meet the normal needs of people. Private construction and rehabilitation of sound structures should be encouraged and controlled to meet community goals and objectives in accordance with an adopted plan. In complete rehabilitation of a sound structure, the supporting walls, facade, and floor beams are preserved and new kitchens, bathrooms, bedrooms, living rooms, public areas, and utilities are installed. The availability of streets, water, sewers, and other utilities minimizes the total cost of providing "new" rental units, particularly if supported by some federal grant and low-interest loans. This could be accompanied by the establishment of cooperative ownership by qualified families and by self-help programs (Habitat for Humanity).

Rehabilitation is sometimes discouraged by contractors and architects because it can be full of surprises, depending on the extent of the preliminary investigation and the completeness of plans and specifications.

Loan Insurance Mortgage loan insurance by the government to stimulate homeownership has been fundamental to the construction and preservation of good housing. However, private financial institutions also have a major function and obligation. The reluctance or refusal of some lending institutions to make loans in certain urban areas for housing rehabilitation or purchase, known as "redlining," and the similar practice by insurance companies for fire and property insurance,[14] confound efforts to upgrade neighborhoods. Such practices should be reviewed.

Outline of a Housing Program

Several approaches have been suggested and used in the development of a housing program. They all have several things in common and generally include most of the following steps.[15]

1. Establishment of a committee or committees with representation from official agencies, voluntary groups, the business community, and outstanding individuals as previously described.
2. Identification of the problem—the physical, social, and economic aspects and development of a plan to attack each.
3. Informing the community of survey results, housing needs, and the recommended action.
4. Designation of a board or commission to coordinate and delegate specific functions to be carried out by the appropriate agency—for example, urban renewal, redevelopment, public housing, code enforcement, rehousing, rehabilitation, and refinancing.
5. Appropriation of adequate funds to support staffing and training of personnel.
6. Appraisal of housing and neighborhoods and designation of urban, suburban, and rural areas for (a) clearance and redevelopment, (b) rehabilitation, and (c) conservation and maintenance. This involves identification of structures and sites selected for preservation, interim code enforcement, rehabilitation of basically sound structures not up to code standards, spot clearance, provision or upgrading of public facilities and services, and land-use control.
7. Preparation and adoption of an enforceable housing code and other regulations that will upgrade the living conditions and provide a decent home in a suitable living environment.
8. Institution of a systematic and planned code enforcement program, including education of tenants and landlords, *prompt* encouragement

and *requirement* of housing maintenance, improvement, and rehabilitation where indicated.
9. Concurrent provision and upgrading of public facilities and services where needed.
10. Provision of new and rehabilitated housing units through public housing, private enterprise, nonprofit organizations, individual owners, and other means.[16]
11. Aid in securing financial and technical assistance for homeowners.
12. Liaison with federal, state, and local housing agencies, associations, and organizations.
13. Requirement that payments to welfare recipients not be used to subsidize housing that does not meet minimum health standards.
14. Evaluation of progress made and continual adjustment of methods and techniques as may be indicated to achieve the housing program goals and objectives.

These efforts need to be supplemented by control of new building construction, land subdivision, and mobile home parks. Also to be included are migrant-labor camps, camp and resort housing, commercial properties, and housing for the aged, chronically ill, handicapped, and those on public assistance.

Solutions to the Problem

The more obvious solutions to the housing problem are production of new housing, rehabilitation of sound housing, redevelopment, slum clearance, and public housing for low-income families. Increasing emphasis is being placed on cooperative ownership and on the conservation and rehabilitation of existing sound housing to prevent or slow down blight.* It is probably the most economical way of providing additional, healthier dwelling units and at the same time protecting the existing surrounding supply of good housing. Privately financed housing, redevelopment, and public housing cannot reach their full usefulness unless the neighborhood in which they are carried out is also brought up to a satisfactory minimum standard and is protected against degradation.

Federal, state, and local governments have an essential role in providing leadership and support. Federal programs usually make assistance available to finance housing for low- and moderate-income families, for urban development of programs including rehabilitation and conservation, and for redevelopment of urban communities. The federal programs include community

*Careful analysis is advised as the hidden costs and problems associated with major building rehabilitation cannot as a rule be fully anticipated. (M. Federman, "Building Rehabilitation: The Last Resort," *Civil Eng., ASCE,* July 1, 1981, pp. 72–73.)

development block grants, urban development action grants, low income housing assistance, loan guarantees, and rehabilitation loans to eligible communities. Their implementation varies with the availability of federal funds. A local legally constituted agency is necessary to represent the municipality.

For example, eligibility for urban redevelopment funds may require formulation of a program to effectively deal with the problem of urban slums and blight within the community and to establish and preserve a well-planned community with well-organized residential neighborhoods of decent homes and suitable living environment for family life. The program can also make a municipality eligible for assistance for concentrated code enforcement, special help to blighted areas, demolition grants, rehabilitation grants and loans, and neighborhood facilities improvement and development. A workable program would require the following:

1. Adoption of adequate minimum standards of health, sanitation, and safety through a comprehensive system of codes and ordinances effectively enforced.
2. Formulation of a "comprehensive community plan" or a "general plan"—implying long-range concepts—and including land use, thoroughfare, and community facilities plans; a public improvement program; and zoning and subdivision regulations. See Chapter 2.
3. Identification of blighted neighborhoods and analysis for extent and intensity of blight and causes of deterioration to aid in delineation for clearance or other remedial action.
4. Establishment of an adequate administrative organization, including legal authority, to carry on the urban renewal program.
5. Development of means for meeting the financial obligations and requirements for carrying out the program.
6. Provision of decent, sanitary housing for all families displaced by urban renewal or other government activities.
7. Development of active citizen support and understanding of the urban renewal program.

The restoration of a substandard housing area in an otherwise sound and healthy neighborhood must include removal of the blighting influences to the extent feasible and where indicated. These include heavy traffic, air pollution, poor streets, lack of parks and trees, poor lighting, dirty streets and spaces, inadequate refuse storage and collection, inadequate water supply and sewerage, unpainted buildings, noisy businesses and industries, and tax increases for housing maintenance and improvement.

Further explanations and specifics to carry out some of the above program functions are given in the sections that follow.

Selection of Work Areas

A housing program must keep in proper perspective community short- and long-term plans, special surveys and reports, area studies, pilot block enforcement, and the routine inspection work to enforce a minimum standards housing ordinance. Continual evaluation of the program is necessary to ensure that the control of blight and deterioration of buildings and neighborhoods, as well as the rehabilitation of substandard dwellings, is being carried out where encountered. When indicated and possible, such action should be carried out on a planned block or area basis. This makes accomplishments more apparent and also awakens community pride, which can become "infectious." A blighted block does not always have a neon sign at the head of the street. The very insidiousness of blight makes it difficult to recognize and will have to be deliberately sought out and attacked. It may be only one or two houses in a block, which are recognized by a dilapidated outward appearance, by the inspector's intimate knowledge of the neighborhood and people, by office records showing a history of violations, or by routine survey reports. Signs of deterioration and dilapidation should be attacked immediately before decay and blight take over and incentive to make and support repairs becomes an almost impossible task.

The selection of conservation, rehabilitation, clearance, and redevelopment areas should take into consideration and adapt the following criteria:

1. The grading of socioeconomic areas using a weighted composite consisting of overcrowding, lack of or dilapidated private bath, lack of running water, and other measurable factors reported by the Bureau of the Census, including income and education.
2. The grading of areas using health indices and mortality and morbidity data.
3. The grading of areas on the basis of social problems, juvenile delinquency, welfare and private agency case load, adult probation, early venereal diseases, social unrest, and so on.
4. The areas having the high, average, and low assessed valuation, dilapidation, and overcrowding.
5. The grading of neighborhoods using the APHA or equal appraisal system, health and building department surveys, and plotted data. A sampling of 20 percent of the dwellings can give fairly good information.
6. Results of surveys and plans made by planning boards, housing authorities, and redevelopment boards.
7. Selection of work areas with reference to these criteria as well as existing and planned housing projects, parks, redevelopment areas, parkways or thruways, railroads, and industrial or commercial areas; also existing barriers such as streams or lakes, good housing areas, swamps, and mountains.

8. Health department environmental sanitation and nursing division office records and personal knowledge of staff.
9. Visual foot surveys and combinations of items 1 through 8.

The superimposition of map overlays showing the above characteristics will bring out areas having the most problems.

Enforcement Program

Enforcement of a housing conservation and rehabilitation ordinance involves use of the same procedures and techniques that have been effective in carrying out other environmental sanitation programs. The development of a proper attitude and philosophy of the intent of the law and its fair enforcement should be the fundamental theme in a continuing in-service training program. A housing enforcement program can proceed along the following lines:

1. Inspection of a pilot area to develop and perfect inspection techniques and learn of problems and practical solutions to obtain rehabilitation of substandard areas.
2. Routine inspection of all hotels and rooming and boarding houses for compliance with minimum standards housing ordinance. A satisfactory report may be made a condition to the issuance of a permit and a license to operate.
3. Routine inspection of multiple dwellings. An initial inspection on a two- or three-year plan will reveal places requiring reinspection.
4. Inspections throughout a city, village, or town on an individual structure, block, and area basis to obtain rehabilitation and conservation of sound housing or demolition of unsalvable structures. This may be made a requirement by local ordinance before a dwelling or multiple dwelling can be resold. It could also apply before rerental.
5. Concentration of inspection in and around salvable areas to spread the border of improved housing so that it will merge with a satisfactory area.
6. Redirection of complaint inspections to complete housing surveys when practical. This can make available a large reservoir of personnel for more productive work.
7. Continuing in-service training with emphasis on law enforcement through education and persuasion, alteration and reconstruction, letter reporting, and financing to obtain substantial rehabilitation, not patchwork.
8. Close liaison with all city departments, especially city planning and building divisions, urban renewal agency, welfare, and the courts.

9. Continuing public education, including involvement of community and neighborhood organizations, to support the housing program and help or guide owners to conserve and rehabilitate their homes.

The enforcement program should take into consideration the problems, attitudes, and behavior of the people living in the dwelling units and the changes that need to be effected with the help of other agencies. The enforcement program must also recognize that, to be effective, subsidies and other forms of assistance to low-income families will usually be necessary to support needed alterations and rehabilitation.

Staffing Patterns Various staffing patterns have been suggested to administer a housing code enforcement program. One basis is a program director supported by one assistant to supervise up to eight inspectors, each making an estimated 1000 inspections per year. Slavet and Levin suggest the following ratios[17]:

1. One inspector per 10,000 population or one inspector per 1000 substandard dwelling units (this assumes inspection and reinspection to secure compliance at an average of 200 substandard dwelling units per year over a five-year period);
2. one inspector per 3000 standard dwelling units, assuming inspection of 600 units per year over a five-year period, in addition to the staff needed to handle complaints;
3. one financial specialist for every three or four housing inspectors;
4. one community relations specialist for every three or four housing inspectors;
5. one rehabilitation specialist for every two or three inspectors;
6. one clerk for every three or four inspectors;
7. one supervisor for every six to eight inspectors;

Some Contradictions An enforcement program will reveal many contradictory facts relating to human nature. These only serve to emphasize that the housing problem is a complex one. The social scientist and anthropologist could study the problems and assist in their solution provided he or she works in the field with the sanitarians and engineers:

1. For example, it has been found that a person or family living in a substandard housing area may be very reluctant to move away from friends and relatives to a good housing area where the customs, religion, race, and very environment are different.

2. A housing survey may show that a structure is not worth repairing, and the expert construction engineer or architect may be able to easily prove that conclusion. But the owner of a one-, two-, or three-family building will rarely agree. He will go on to make certain minimum repairs or even extensive repairs to approach the standards established in the housing ordinance, leaving you wondering if there really is any such thing as a nonsalvable dwelling.

3. There is the not-infrequent situation where two old structures are located on the same lot, one facing the street and the other on the rear-lot line. If one structure is demolished, another cannot be built on the same lot because zoning ordinances usually prohibit such intensive lot usage by new structures. Therefore, the owner, rather than lose the vested right due to prior existence of the structure, with respect to the zoning ordinance, may choose to practically rebuild the dwelling at great cost rather than tear it down.

4. Another common occurrence is the tendency for some landlords to seize upon health or building department letters recommending improvements to bring the building into compliance with the housing ordinance as the opportunity to evict tenants and charge higher rentals. This is not to say that the owner is not entitled to a fair return on an investment, but the intent is that no one should profit from human misery. (A fair return on one's investment has been given as 10 percent of the assessed valuation or purchase price of the property.) Since the department's objective is to improve the living conditions of the people, it should not become a party to such actions. As a matter of fact, it is the unusual situation where needed housing improvements cannot be made with the tenant living in the dwelling unit, even though some temporary inconvenience may result. Hence, in such situations, it is proper for the department to state that it is its opinion that the needed repairs can be made without evicting tenants, thereby leaving the final determination in the exceptional cases with the owner and the courts.

5. A rather unexpected development may be the situation where an owner agrees to make repairs and improvements, such as new kitchen sink and provision of a three-piece bath with hot as well as cold water under pressure, only to be refused admittance by the tenant. For the tenant knows that the rent may be increased and suddenly decides that a new bathroom is a luxury he or she can get along without. In such case, the courts have granted eviction orders and have sanctioned the reasonable increase in rent.

6. Rent control makes possible affordable housing for many families, but inadequate rents (income) discourage maintenance and promote decay and eventual building abandonment. See Figure 11-3. A fair balance must be reached.

Fiscal Aspects The financing of improvements is sometimes an insurmountable obstacle to the lay person. As an aid to the people affected by a housing enforcement program, a "financing clinic" can be formed to advise homeowners in difficult cases. The clinic may be a committee consisting of a banker, an architect, a general contractor, a plumbing contractor, and a representative of the building division, redevelopment board, federal agencies, and community. The department representative would help the owner present the problem. If the homeowner is instructed to submit estimates of cost from two or three reliable contractors, a sounder basis for assistance is established.

An enforcement program must recognize that many investors use the criterion that a dwelling is not worth purchasing unless it yields a gross annual income equal to one-quarter to one-fifth of the selling price. Another rule of thumb, for rehabilitation of a dwelling, is that the cost of alteration plus selling or purchase price shall not be more than five times the gross annual income, or an individual's income shall be at least 25 to 28 percent of the cost of the dwelling unit (taxes, mortgage, maintenance).

Getting Started The report that appeared in *The New York Times* is an excellent example of a sound approach to initiate housing conservation and rehabilitation. It is quoted below (October 6, 1957):

> Home owners whose properties are in Milwaukee's first "conservation" area are not likely to complain to the Mayor when their houses are inspected in the door-to-door canvass being made by the city. Mayor Frank Zeidler's home is in the area, too.
>
> The inspections are planned to find out whether the district's middle-aged homes meet housing code standards. Although the courts can enforce compliance with the code, the drive is aimed primarily at informing owners of dangerous deterioration, with the expectation that they will correct the conditions within a reasonable time.
>
> Mayor Zeidler told his neighbors that "this is in the nature of getting free advice." According to the National Association of Housing and Redevelopment Officials, the drive can save a neighborhood from becoming a slum which, experience shows, costs taxpayers more than it repays in tax revenues.

Enforcement Procedures

The fair and reasonable enforcement of the *intent* of a minimum standards housing ordinance requires the exercise of trained judgment by the administrators, supervisors, and field inspectors. Continuing in-service training of the housing staff is essential to carry out the purpose of the housing ordinance in an effective manner.[18] A trained educator can offer valuable assistance and guidance in planning the training sessions and in interpreting the program to the public and legislators. Health department sanitarians are admirably suited to carry out the housing program because of their broad knowledge in the basic sciences and their ability to deal effectively with the public.

The enforcement measures and procedures can be summarized as follows.

1. Preparation of a housing operating manual giving a background of the housing program, guides for conduct, inspection report form based on the housing ordinance, interpretation of sections of the ordinance need-

ing clarification for field application, suggested form paragraphs for routine letters, including typical violations and recommendations for their correction, follow-up form letters, building construction details, and related information. A few form paragraphs and architectural details are included in the text to suggest the type of material that can be included in a housing manual to obtain a certain amount of uniformity and organization in a housing enforcement program.

2. Complete inspection of all types of premises and dwelling units occupied as living units. A comprehensive checklist or survey form based on the housing ordinance similar to Figure 10-4 could be used.
3. Preparation of a complete rough-draft letter by the sanitarian based on field inspection, listing what was found wrong, together with recommendations for correction.
4. Review of the inspection report and suggested letter by a supervising sanitarian for completeness and accuracy. The letter is signed by the supervisor and a tickler date confirmed for a follow-up inspection. See Figure 10-5.
5. Maintenance of a visible card-index file or computer entry on each multiple dwelling, boarding house, rooming house, and hotel, in addition to a file on each dwelling, including one- and two-family structures.
6. A reinspection letter based on the findings reported in the first letter and remaining uncorrected. This may take the form of an abridged original letter listing what remains to be done, a letter calling for an informal hearing, a letter giving 30 days in which to show substantial progress, or a special letter. See Figure 10-6.
7. In some instances substantial improvements are requested that justify a reasonable rent adjustment. This should be brought out at the time of informal hearings when financial hardship is pleaded. Informal administrative hearings are very useful.
8. Office consultation with owners to investigate long-range improvement programs within the limits of the law and the federal, state, and private assistance available.
9. Maintenance of a list of competent contractors who perform alteration work.
10. Review of cost estimates with the owner for completeness.
11. Arranging for expert consultation to finance improvements, including a hearing before a ‘‘financing and construction clinic,’’ which should have representation from the lending institutions as well as from the contractors, architects, and engineers.
12. In recalcitrant cases, a letter from the chief city judge or justice providing for a pretrial hearing to show cause why a summons should not be issued, followed by the hearing. A similar procedure could be fol-

COUNTY DEPARTMENT OF HEALTH

Division of Environmental Sanitation

Re:

C. , New York

Dear

The City of recently adopted a minimum standards housing ordinance to assist in the conservation and rehabilitation of existing housing. In this connection Mr. of this Department made a survey of dwellings in your neighborhood on Listed below are the conditions found at your building which were in need of improvement or correction.

We shall be glad to discuss any questions or difficulties you may have in complying with the minimum housing standards. Would you please advise this office in writing within 10 days of the action you propose to take?*

Your cooperation will help prevent the deterioration of property values in your neighborhood and help make a more healthful place in which to live.

Very truly yours,

J. A. Salvato, Jr., P.E.,

Chief, Bureau of General Sanitation

By...

* This letter is not to be construed as reason for removal of tenants, unless specifically stated therein.

Alterations or additions must be made in accordance with all applicable laws. Consult with the Division of Buildings, Room 325, City Hall for a permit to perform building, plumbing or electrical work required here. A building unlawfully occupied or with an increased number of living units must be brought into compliance, or if this is not permitted by law, it must revert to its original use.

JAS/er (1) 9/54:1000

Figure 10-5 Form letter to confirm findings at time of first inspection.

COUNTY OF
HEALTH DEPARTMENT

Re:
C. , New York

Dear

This department notified you by letter on of the housing deficiencies existing on your premises and the need for making corrections. However, a reinspection showed that no substantial progress had been made, and to date we have received no reply from you.

Inasmuch as the conditions enumerated in our letters to you are violations of the Minimum Housing Standards Ordinance, it is imperative that the needed improvements be made. Your failure to reply must be interpreted as an indication of lack of good faith or misunderstanding of the intent of our letters.

Under the circumstances, you are requested to appear in Room , City Hall, at to show cause why legal action should not be started. It is hoped that you will come prepared with an itemized report, indicating when the needed improvements will be completed, so as to make unnecessary further action by this department.

We wish to emphasize that it is our intention and obligation to follow up on violations of the Minimum Housing Standards Ordinance until such time as all work is done. It is only in this way that existing housing in the City of can be conserved and rehabilitated.

Very truly yours,

J. A. Salvato, Jr., P. E.,

Chief, Bureau of General Sanitation

By...

JAS/er(3)
9/54:500

Figure 10-6 Administrative hearing letter.

lowed by the corporation counsel or county attorney. The courts could also establish a special session to hear housing cases.

13. Issuance of a summons by the corporation counsel at the request of the enforcement agency when other measures have failed, if authorized by local law. A record of appearances and results should be kept.
14. Issuance of a summons by an authorized member of the enforcement agency in emergencies, if authorized by local law.

15. Cooperation with the press with a view toward obtaining occasional special reports, feature articles, and community support.
16. Cooperation and liaison with all private and public agencies having an interest in housing.
17. Notification of the welfare department when public assistance is being given for rental because payment for housing should be made only when the facilities and conditions of maintenance and occupancy meet minimum standards.
18. Education of the legal department to obtain an aggressive, trained, and competent attorney who can become experienced in housing problems and be able to guide the legal enforcement phase of housing work.
19. Stimulate resurgence of neighborhood pride in the rehabilitation and conservation of all buildings on a block or area basis. Information releases and bulletins explaining what community groups and individuals can do to improve their housing is an excellent approach.
20. Discourage profit at the expense of human misery by making it possible through state law to file a lien in the county clerk's office against a property that is in violation of health ordinances, for the information of all interested and affected persons.
21. Notification of the mortgage holders and insurance carriers of existing conditions.
22. Legislation requiring those who purchase city-owned property at public auctions to first list all the property they have owned in the past five years, properties they own with delinquent city taxes, the name and address of all major stockholders if a corporation, whether the purchaser owns vacant or abandoned buildings, and whether the city had ever taken title to the purchaser's property for back taxes.
23. In the case of corporate ownership, legislation requiring that name, address, and the number or percentage of shares owned in the corporation be filed in the county clerk's office.
24. Registration and periodic reregistration of current ownership to facilitate the service of notices and enforcement. Require an in-state agent for receipt of legal notices.
25. Requirement of a certificate of occupancy each time an apartment is rented to a new tenant.
26. Legislation authorizing payment of rent into an escrow account to correct code violations, after which the account is turned over to the owner.
27. A municipal emergency repair program funded through attachment of rents or a property lien.
28. Low-interest loans and grants to make repairs.
29. Legislation permitting tax foreclosure proceedings within two years or less to permit acquisition of property while it still has value, before it

has deteriorated beyond hope of economic rehabilitation, with safeguards for the sincere resident owner who is temporarily in financial difficulty. This requires a systematic inspection system, early identification of deficiencies, prompt and vigorous enforcement, or foreclosure, where indicated.

The enforcement procedure generally includes news releases and information bulletins, inspection, notification, reinspection, second notification, third notification, informal hearings, administrative hearings, pretrial hearings, and summonses. In brief, therefore, the enforcement procedure consists of education and persuasion, with legal action being a last resort.

Not to be forgotten is stimulation of the possible role of nongovernment agencies having a direct or indirect interest and concern in the maintenance of good housing and in housing rehabilitation. The role could consist of seminars and individual assistance for home improvement given by banks, material supply companies, builder and contractor organizations, community colleges, urban development and redevelopment agencies, and fire insurance companies. The assistance could include financing methods for improvements; available federal (and state) grants and loans; filing of applications for assistance; owner–contractor relations; value of architectural services; and information on materials, supplies, and equipment for home repairs and improvements, their advantages, disadvantages, and costs.

HOUSING FORM PARAGRAPHS FOR LETTERS

It is necessary to have some reasonable uniformity and accuracy when writing letters or reports to housing code violators. This becomes particularly important when a housing code enforcement unit has a large staff and when court action is taken. By using a dwelling inspection form such as Figure 10-4, and the form paragraphs listed below, it should be possible for the inspector to readily prepare a draft of a suitable letter for review by that inspector's supervisor. The form paragraphs can and should be modified as needed to reflect more precisely the unsatisfactory conditions actually observed and practical suggestions for their correction. Reference to the pages that follow will be helpful in describing violations for use in the form letter (Figure 10-5). All construction must comply with the local or state building and fire prevention code.

Structural Safety

To be considered structurally safe, a building must be able to support two and a half to four times the loads and stresses to which it is or may be subjected.

Certain conditions that may be deemed dangerous or unsafe need explanation. For example, a 12-in. beam that has sagged or slanted more than one-quarter out of the horizontal plane of the depth of floor structural members in any 10-ft distance would be more than 3 in. out of level in 10 ft and, hence, unsafe. An interior wall consisting of 2 × 4-in. studs or 4-in. terracotta tile blocks more than one-half out of the vertical plane of the thickness of those members between any two floors would be more than 2 in. out of plumb and, hence, unsafe. See Figure 10-7.

A stair, stairway, or approach is safe to use when it is free of holes, grooves, and cracks that are large enough to constitute a possible accident hazard. Rails and balustrades are expected to be firmly fastened and maintained in good condition. Stairs or approaches should not have rotting or deteriorating supports, and stairs that have settled more than 1 in. or pulled away from the supporting or adjacent structure may be dangerous. Stair treads must be of uniform height and sound and securely fastened in position. Every approach should have a sound floor and every tread should be strong enough to bear a concentrated load of at least 400 lb without danger of breaking through. See Figure 10-8.

Incomplete Bathroom

The (*first floor rear apartment*) *did not have a tub or shower.* A complete bathroom including a water closet, tub or shower, and washbasin connected with hot and cold running water is required to serve each family. See Figures 10-9 and 10-10. The bathroom shall have a window or skylight not less than 10 percent of the floor area, with at least 45 percent openable, providing adequate light and ventilation. A water-repellent floor with a sanitary cove base or its equivalent is necessary. A ventilation system may be approved in lieu of a window or skylight.

No Hot Water

There was no piped hot water in the (*kitchen of the first floor-front apartment*). This apartment shall be provided with hot water or water-heating facilities of adequate capacity, properly installed and vented. The heater shall be capable of heating water to permit water to be drawn at every required kitchen sink, lavatory basin, bathtub, or shower at a temperature of approximately 110°F (43°C).

Leaking Water Closet

The water-closet bowl in the (*describe location*) *apartment was* (*loose*) (*leaking*) *at the floor.* (*When the toilet is flushed, the water drains onto the floor and seeps through the ceiling to the lower apartment.*) The water closet should

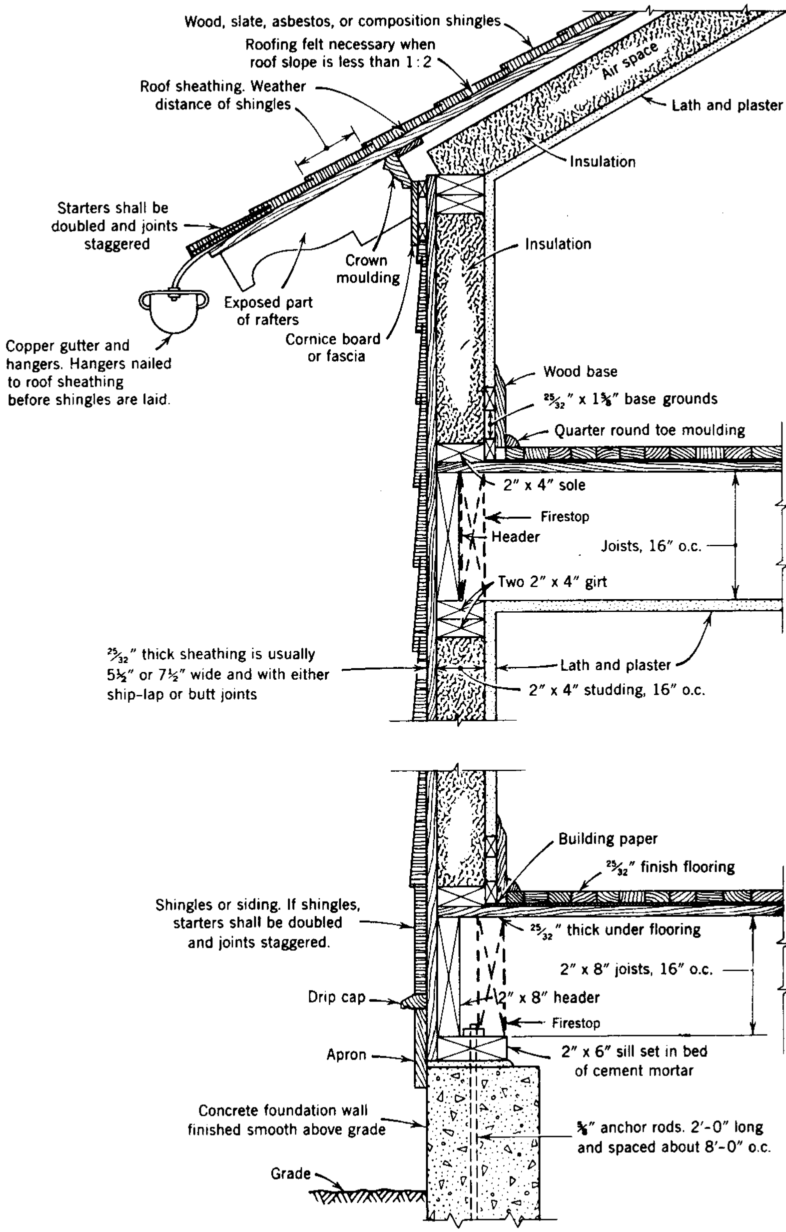


Figure 10-7 Wall construction.

be securely fastened to the floor, floor flange, and soil pipe so that it will be firm and not leak when flushed. (It will also be necessary to repair the loose ceiling plaster in the lower floor and repaint or repaper as needed.)

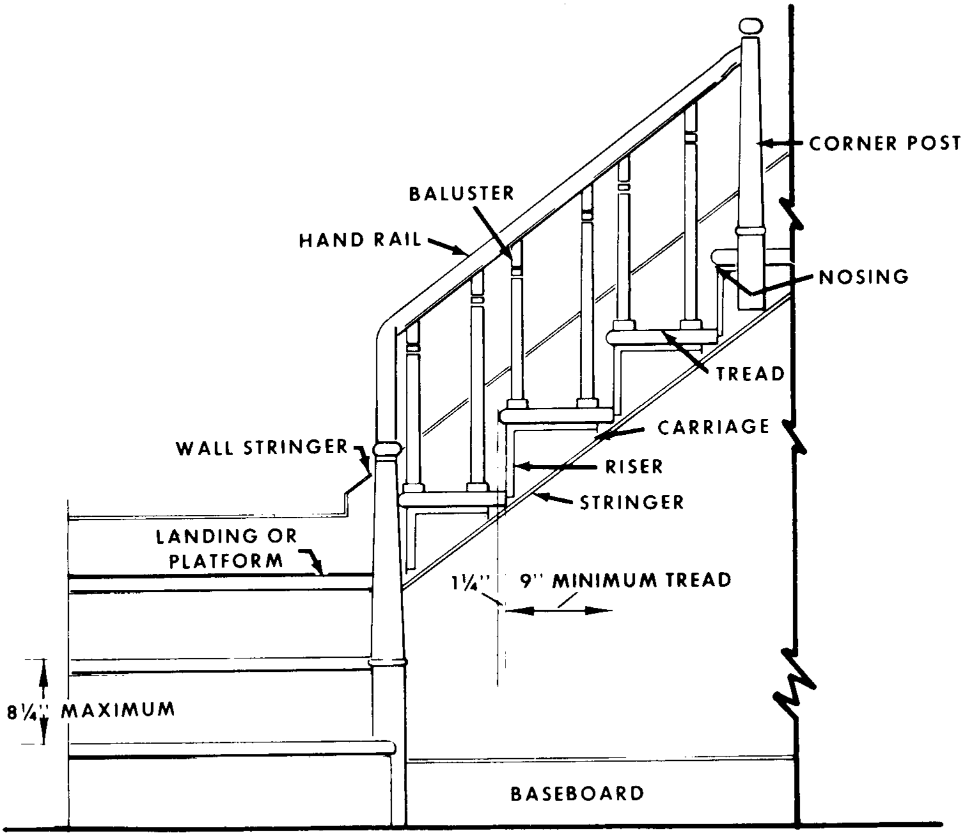


Figure 10-8 Stairway details. [*Source: Basic Housing Inspection*, DHEW Pub. (CDC) 80–8315, U.S. Government Printing Office, Washington, DC, p. 38.]

Floors Not Water Repellent

The bathroom (*water-closet compartment*) (*floor covering*) *was* (*worn through*) (*broken*) (*bare wood with open joints*). The floor should be (repaired) (made reasonably watertight), and the floor covering should extend about 6 in. up the wall to provide a sanitary cove base. Satisfactory material for the floor covering is inlaid vinyl, rubber or composition tile, smooth cement concrete, tile, terrazzo, and dense wood with tightly fitted joints covered with varnish or other similar coating providing a surface that is reasonably impervious to water and easily cleaned.

Exterior Paint Needed

The exterior paint has (*peeled, worn off*), *exposing the bare wood, rusting the nails, causing splitting and warping of the siding.* This will lead to the

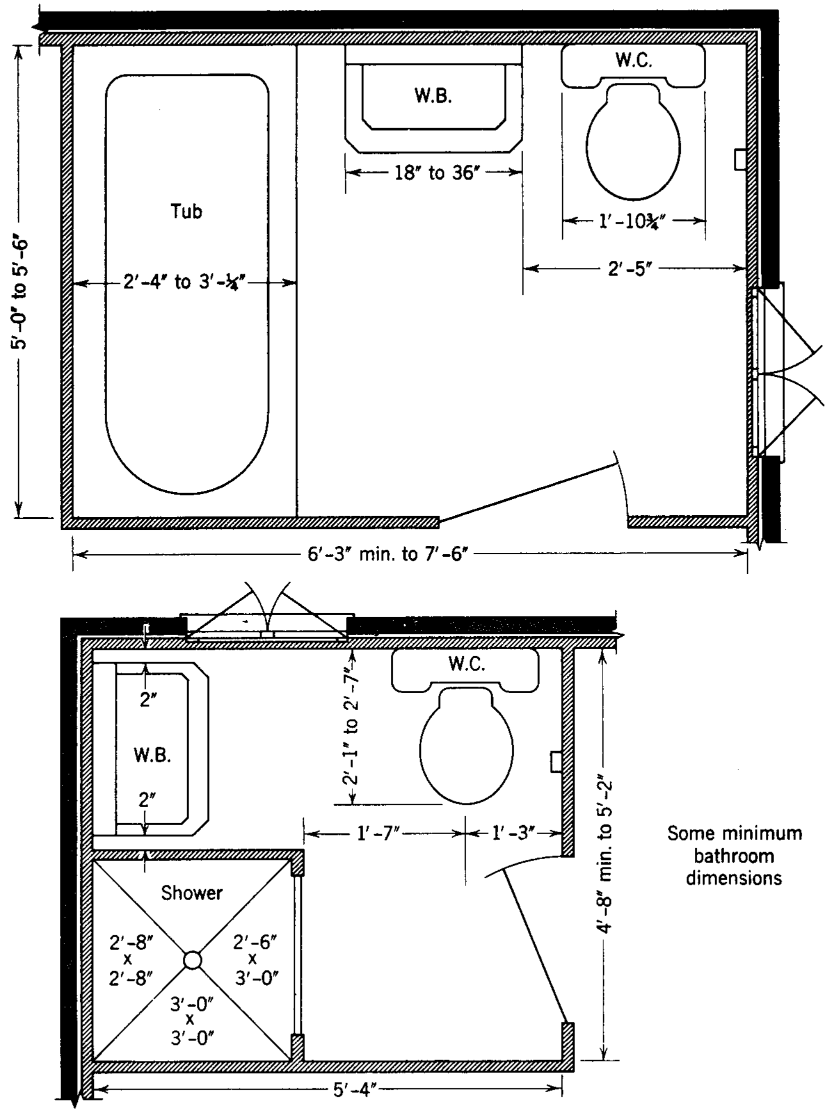


Figure 10-9 Three-piece bathroom showing minimum dimensions.

entrance of rainwater, rotting of the siding, sheathing, and studs, as well as inside dampness and falling of the plaster. You are urged to immediately investigate this condition and make the necessary repairs, including painting or other weather- and decay-resistant treatment of the house, to prevent major repairs and expenses in the future.

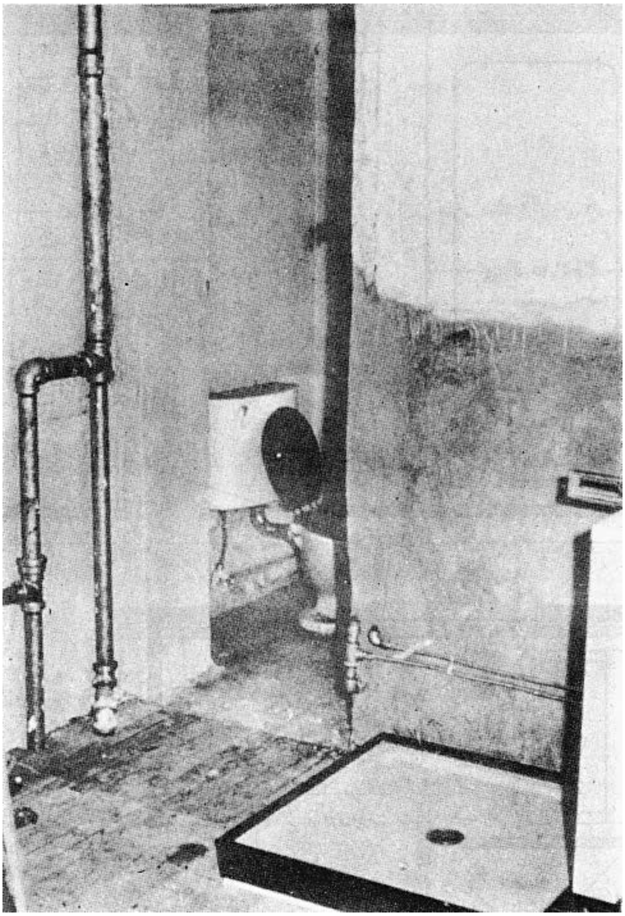


Figure 10-10 Alteration for shower and washbasin addition.

Rotted and Missing Siding

The (*shingles, siding, apron, cornice, exposed rafters*) (*on the north side of the house at the second-floor windows and foundation*) *is* (*are*) (*rotted and missing*). Decayed material should of course all be removed, the sheathing repaired wherever necessary, and the shingles, siding, and so on, replaced. Following the carpentry work, all unpainted or unprotected material exposed to the elements should be treated to prolong its life.

Sagging Wall

The (*door frames and window frames*) *in the* (*location*) *are out of level, making complete closure of the doors and windows impossible.* Outside light could be easily seen through the openings around the (window rails and door jambs). The supporting beams, girders, posts, and studs should be carefully inspected as there was evidence that some of these members were rotted, causing the outside wall to sag. The building should be shored and made level wherever necessary. The unsound material should be replaced, and the improperly fitting doors, windows, and framing repaired to fit and open properly. See Figures 10-7 and 10-11.

Loose Plaster

The plaster is (*loose*) (*and buckled*) (*and has fallen*) *from the living room ceiling and walls in the* (*name apartment or other location*) *over an area of approximately* (*10 ft*^{2}). All loose plaster should be removed and the wall replastered; following curing, it should be painted or papered to produce a cleanable, smooth, and tight surface.

Leaking Roof

There is evidence of the roof leaking over or near the (*kitchen, living room, etc., in the tenant apartment*). *The* (*paint, paper*) *was stained and peeling.* It is essential that the leak be found and repaired, not only to prevent the en-

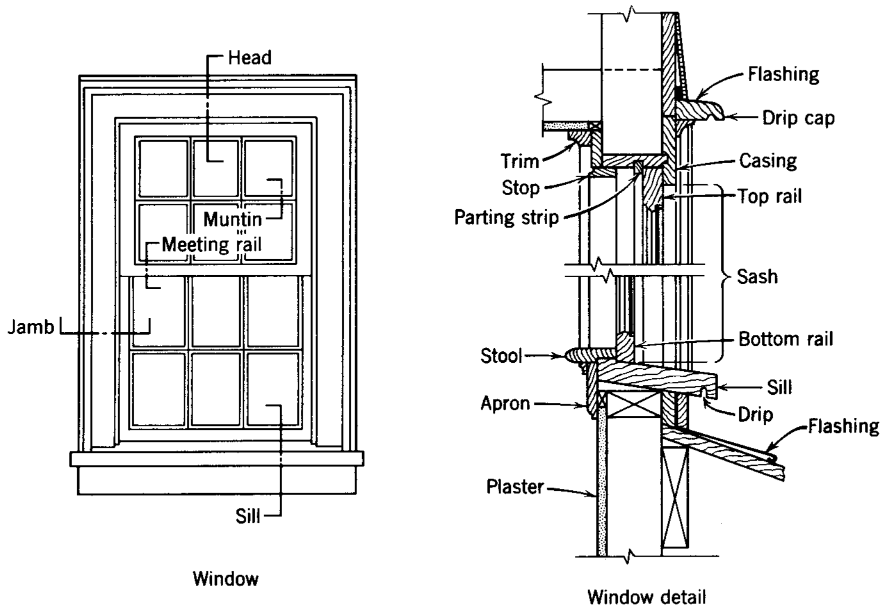


Figure 10-11 Window details.

trance of water and moisture in the apartment but also to prevent loosening of the plaster, rotting of the timbers, and extension of the damage to your property.

No Gutters or Rain Leaders

There are no gutters or rain leaders on this building. Gutters and rain leaders should be placed where needed and connected to the sewer if permitted to ensure proper drainage of rainwater. This will also make rotting and seepage of water through siding and window frames and entrance of water into the basement less likely.

No Handrails

There are no handrails in the stairway between the (*first and second floors at the rear*). This is a common cause of preventable serious accidents. Handrails should be provided and securely fastened at a height of 30 to 32 in., measured above the stair tread.

Lead Paint

Children living in apartment (*10B*) *have been screened for lead and were found to have high levels of lead in their blood.* Lead is a cumulative poison that causes mental retardation, behavioral changes, anemia, and other impairments. Lead-based paint found on window and door frames in the apartment had flaked and peeled. Lead-based paint must be removed, but it requires special precautions to protect children and adults from the paint dust. Use a contractor who has been licensed to do this type of work.

Refuse in Attic

There are (*rags, refuse, paper, and trash*) *in the attic.* These materials are a fire hazard and provide harborage for mice and other vermin. All rags, paper, and trash must be removed from the attic, and the attic maintained in a clean and sanitary condition at all times.

Water-Closet Flush Tank Not Operating Correctly

The (*water runs continuously*) *in the water-closet flush tank in the* (*John Jones's apartment*)*; OR the water closet in the* (*John Jones's apartment*) canot be flushed. The broken, worn, or missing ball-cock valve, ball-cock float, flush-valve ball, flush lever, or flush handle should be repaired or replaced to permit proper flushing of the water closet. See Figure 10-12.

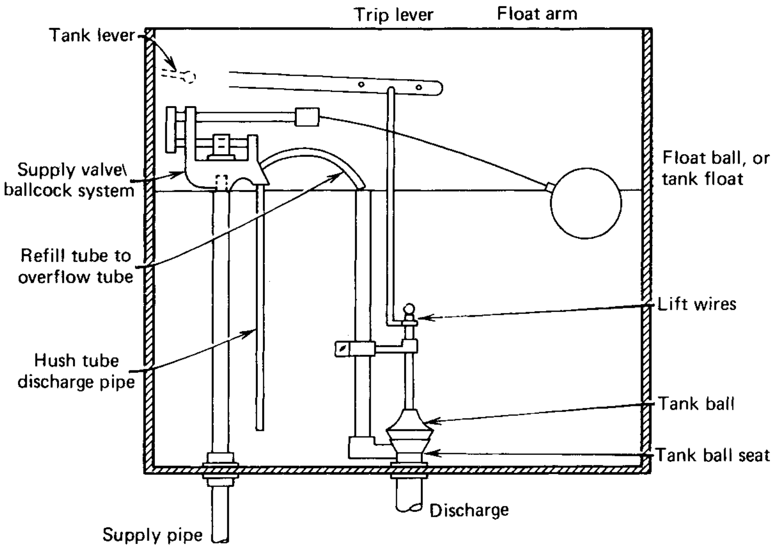


Figure 10-12 Water-closet tank. (Flapper valve can replace tank ball. Unvented supply valve requires backflow preventer.)

Garbage Stored in Paper Box or Bag

Garbage is being stored in (*open, uncovered baskets*) (*paper bags*) (*paper boxes*) (*in the rear yard*). This encourages rodent, fly, and vermin breeding. All garbage should be drained, wrapped, and properly stored in tightly covered containers. It will be necessary for you to procure needed receptacles for the proper storage of all garbage until collected.

Dilapidated Garbage Shed

The garbage shed in the (*specify location*) *is in a dilapidated, rotted, and unsanitary condition.* Garbage sheds tend to accumulate garbage and encourage rodent, fly, and vermin breeding. This dilapidated garbage shed should be removed and the premises cleaned. Store the garbage cans on an elevated rack or concrete platform. (Enclose pamphlet showing some suggested storage racks.)

Debris in Yard or Vacant Lot

The vacant lot located at (*specify location*) *was found littered with* (*old lumber, tin cans, and rubbish*). This is unsightly and may serve as rat harborage and as an invitation to dump on the property. It is requested that you make a personal investigation of the conditions reported and arrange to have the lot cleared and cleaned. It is also recommended that you post a "No Dumping" sign to discourage future littering of the property.

Dirty Apartment

The apartment on the (*second floor*) *is in a very unsanitary condition.* (*Describe.*) All occupants are expected to keep their apartment and the premises they control in a clean and sanitary condition at all times. (Give a copy of the letter to the tenant.)

Overcrowded Sleeping Room

The bedroom(*s*) *in the* (*specify location*) are overcrowded. There are (*three*) *persons in a room having an area of* (*80*) ft^2 and (four) persons in a room (85) ft^2. Every room occupied for sleeping purposes shall contain at least 70 ft^2 of floor space for one person and 50 ft^2 for each additional person. (Suggest correction.) This apartment should not be rerented for occupancy by more persons than can be accommodated in accordance with this standard.

No Window in Habitable Room

No window to the outside air is provided in the (*living room, kitchen, bedroom*). Every room used or intended to be used as a living room, kitchen, or bedroom is required to have a total unobstructed window area of at least 10 percent of the floor area. Consideration should be given to the possibility of cutting in a new window or providing a skylight if the room is to be continued in use as a bedroom, living room, or kitchen.

Unlawful Third-Floor Occupancy

The third floor of this building had been converted and was occupied for living purposes. The conversion or alteration of a third floor or attic in a frame building for living or sleeping purposes is prohibited by Chapter X of the city ordinances. This is a major hazard in case of fire. Discontinue the use of the third floor immediately. (Refer a copy of the letter to division of buildings.)

Unlawful Cellar Occupancy

The cellar is being used for (*sleeping, living, purposes*). A cellar may not be used for living purposes; hence, this space must be permanently vacated. (The housing ordinance defines a cellar as "a room or groups of rooms totally below ground level and usually under a building.")

Clogged Sewer

The (*soil stack, building drain, or sewer*) *is apparently clogged, for sewage from the upper apartment*(*s*) *backs into the* (*kitchen sink, water closet*) *in the* (*first-floor front apartment*). The clogged sewer must be cleared and, if necessary, repaired to eliminate cause for future complaint.

Unvented Heater

The gas water heater(*s*) (*burning carbonaceous fuel*) *in the* (*name room or space and locate*) *is* (*are*) *not vented.* Unvented heaters in bathrooms and sleeping rooms have been the cause of asphyxiation, carbon monoxide poisoning, and death. These heaters must be properly vented to the chimney or outside air, supplied with sufficient air to continuously support combustion of the fuel, and be protected to prevent fires and minimize accidental burns. See Venting of Heating Units, this chapter.

Furnace Flue Defective

The furnace flue has rusted through in several places (*and the connection to the chimney is loose*), *causing waste gases to escape into the basement.* Since such gases rise and seep into the upper apartment(s) and have been known to cause asphyxiation, it is imperative that the flue be repaired and the collar sealed to prevent leakage of any waste gases. This should also improve the efficiency of the furnace.

Rubber-Hose Gas Connection

The gas heater(*s*) *in the* (*tenant apartment*) *has* (*have*) (*plastic pipe, rubber hose*) *connection*(*s*). Such materials eventually leak and may cause death in the household. It will be necessary to replace all plastic and rubber-hose connections with rigid, metal pipe.

Rat Infestation

There is evidence of a very bad rat condition existing in this building as indicated by (*explain condition*). All holes in the foundation (floors) should be sealed with cement mortar and openings around wood framing closed with metal flashing or with cement mortar where possible. Traps and repeated use of a rodenticide such as warfarin are suggested to kill rats inside the building. All sources of food and harborages must be eliminated. Such control measures should be continuous for at least two or three weeks to be effective. (Enclose pamphlet giving additional details dealing with accepted control measures.)

Roach Infestation

The apartment is apparently infested with roaches, as indicated by the roachy odor and roaches observed hiding under the sink, baseboard, moldings (*stains in the kitchen cabinet, pellets of excrement in the dish cabinet*). Roaches are sometimes brought in with boxes of food, baskets, or bags; dirt and filth encourage their reproduction in large numbers. Thorough cleaning, filling of cracks around frames with plaster or plastic wood, followed by the proper application of an insecticide in selected places and in accordance with the manufacturer's directions should bring the problem under control. (Enclose pamphlet that gives additional detailed information.)

Overflowing Sewage Disposal System

The sewage disposal system serving the dwelling is (*seeping out onto the surface*) (*discharging into the ditch in front of your home*). This is a health hazard not only to those living there but also to neighbors and pets. Immediate steps should be taken to determine the cause and make corrections. (See Chapter 4 for more details.)

Improperly Protected Well-Water Supply

A sanitary survey of the well-water supply shows it to be subject to contamination. The well (*is uncapped*) (*has a hole around the casing where surface water can drain down and into the well*) (*does not have a tight seal at the point where the pump line*(*s*) *pass into the casing as noted by drippage observable from looking into the well*). The necessary repairs should be made to prevent contamination of the water supply and then the well should be disinfected as explained in (enclosed) instructions. (See Chapter 3 for more details.)

Major Repairs

In view of the major repairs and improvements needed, only some of which have been reported above, plans prepared by a registered architect should be submitted showing the existing conditions and all proposed alterations for approval by this Department and the Division of Buildings, before any work is done. This procedure makes possible the receipt of comparable bids from several contractors and usually results in more orderly prosecution of the work at a minimum cost.

Minor Repairs

In view of the repairs and improvements needed, a sketch drawn to scale should be prepared showing existing and proposed work to ensure that the work can be done as intended. The sketch should be submitted to and approved by the Division of Buildings and this Department before any work is done. This procedure makes possible the receipt of comparable bids from several contractors and usually results in more orderly prosecution of the work at a minimum cost.

Obtain at Least Three Estimates

We urge you to obtain at least three estimates from reputable contractors before having any work done. Written bids should be requested and assurance obtained from the contractor that the estimate is all inclusive.

PLUMBING

Plumbing Code

Sanitary plumbing principles that are based on the latest scientific studies should be fundamentally similar but will be varied in application depending on the local conditions. Some plumbing designs and standards currently in existence are based on an unsound old rule of thumb or prejudice. They could be reviewed with profit in the light of present-day knowledge.

The *National Plumbing Code,*[19] the *Uniform Plumbing Code,*[20] and the *Standard Plumbing Code* (also called the *Southern Code*)[21] are the three major plumbing codes currently being used in the United States. Public Health Service Pub. 1038[22] is also a comprehensive standard code of minimum requirements for use. Some of the major codes have combined to form the *International Plumbing Code.*[23] The interested person would do well to have copies in a reference file. The sizing of water supply, drainage, vent, and storm-drain piping is concisely covered.

In addition to the major codes, different parts of the country frequently have their local plumbing codes (state, county, or city level). These local code requirements must be checked before doing any plumbing work.

One term used frequently is *plumbing fixture*. This term includes installed receptacles, devices, or appliances either supplied with water or receiving on discharge liquids or liquidborne wastes or both. The bathtub, sink, water closet, dishwasher, and drinking fountain are examples of plumbing fixtures. In practice, the probable flow is estimated based on the fixture unit. A *fixture unit* is the load-producing flow effect for comparing different plumbing fixtures. One water supply fixture unit (wsfu) is usually taken as $7\frac{1}{2}$ gpm. The drainage fixture unit (dfu) for different fixtures can also be found in most plumbing codes.

Approval of plans for plumbing systems must usually be obtained before construction is started. Health departments can accomplish more in the interest of public health by seeing that proper standards of plumbing exist and are enforced than by actually doing the plumbing inspection. For example, the health department can see to it that plumbing and building codes prohibit dangerous cross-connections and interconnections and require a private three-piece bathroom and kitchen sink served by hot and cold water in every new dwelling unit. This is fundamental to the prevention of disease, the promotion of personal hygiene, and sanitation. Plumbing codes should prohibit the use of lead piping for water distribution and the use of tin–lead (50:50 and 60:40) solder for joining copper piping. See Lead in Chapter 3.

Plumbing codes should specify an adequate number of fixtures for private, public, and industrial use, all properly supplied, trapped, vented, and sewered, as noted in Tables 10-6 through 10-9. Water connections with unsafe or questionable water supplies would be prevented, and connections or conditions whereby used or unsafe water could flow back into the potable water system would be prohibited. Of course, a safe water supply and proper sewage disposal should be ensured.

Housing codes would be expected to make reference to a modern plumbing code. Housing codes would be of little value unless they were applicable to all new, altered, and existing one-, two-, or multifamily dwellings, hotels, boarding houses, and rooming houses.

The health department should serve as a consultant to the building, plumbing, water, and sewer divisions. Any new or revised codes or regulations should first be reviewed and approved by the health department before being considered for adoption to ensure that the fundamental principles of public health and sanitary engineering are not violated.

Tables 10-6 through 10-9 respectively give the minimum number of plumbing fixtures for different building occupancies, the minimum sizes of fixture supply and drain, maximum distance of fixture trap from vent, and hot-water demands for different types of buildings. Some plumbing details, with particular emphasis on backflow prevention, recommended minimum number of plumbing fixtures, the application of indirect waste piping, and other details are discussed below.

Backflow Prevention[24,25]

The backflow of polluted or contaminated water or other fluid or substance into a water distribution piping system through backpressure or backsiphonage is a very real possibility. The best way to eliminate the danger is to prohibit any connections between the water system and any other system, fixture, vat, or tank containing polluted or questionable water. This can be accomplished by terminating the water supply inlet or faucet a safe distance above the flood-level rim of the fixture. The distance, referred to as the air gap, is 1 in. for a $\frac{1}{2}$-in.-or-smaller-diameter faucet or inlet pipe, $1\frac{1}{2}$-in. for a $\frac{3}{4}$-in.-diameter faucet, 2 in. for a 1-in.-diameter faucet, and twice the effective opening (cross-sectional area at point of water supply discharge) when its diameter is greater than 1 in. When the inside edge of the faucet or pipe is close to a wall, that is, within three or four times the diameter of the effective opening, the air gap should be increased by 50 percent.

Sometimes, as with water closets and urinals equipped with flushometer valves, it is not possible or practical to provide an air gap. Under such circumstances, where the water connection is not subject to backpressure, an

TABLE 10-6 Minimum Number of Plumbing Fixtures

Type of Building Occupancy	Water Closets	Urinals	Lavatories	Bathtubs/Showers	Drinking Fountains	Other
Assembly—places of worship	1 for 150 women 1 for 300 men	1 for 300 men[a]	1	—	1	—
Assembly—other than places of worship (auditoriums, theaters, convention halls)	1 for 1–100 persons 2 for 101–200 persons 3 for 201–400 persons Over 400, add 1 fixture for each additional 500 men and 1 for each 300 women	1 for 1–200 persons 2 for 201–400 persons 3 for 401–600 persons Over 600, add 1 fixture for each 300 men[a]	1 for 1–200 persons 2 for 201–400 persons 3 for 401–750 persons Over 750, add 1 fixture for each 500 persons	—	1 for each 300 persons	1 slop sink
Dormitories—school or labor, also institutional	Men: 1 for each 10 persons Women: 1 for each 8 persons	1 for each 25 men. Over 150, add 1 fixture for each 50 men[a]	1 for each 12 persons (separate dental lavatories should be provided in community toilet rooms; a ratio of 1 dental lavatory to each 50 persons recommended)	1 for each 8 persons; for women's dormitories, additional bathtubs should be installed at ratio of 1 for each 30 women; over 150 persons add 1 fixture for each 20 persons	1 for each 75 persons	Laundry trays, 1 for each 50 persons; slop sinks, 1 for each 100 persons

Dwellings—one and two-family	1 for each dwelling unit	—	1 for each dwelling unit	1 for each dwelling unit	—	Kitchen sink, 1 for each dwelling unit
Dwellings—multiple or apartment	1 for each dwelling unit or apartment	—	1 for each dwelling unit or apartment	1 for each dwelling unit or apartment	—	Kitchen sink, 1 for each dwelling unit or apartment[b]
Industrial—factories, warehouses, foundries, and similar establishments	1 for 1–10[a] 2 for 11–25[c] 3 for 26–50[c] 4 for 51–75[c] 5 for 76–100[a] 1 fixture for each additional 30 employees	1 for 11–30 men 2 for 31–80 men 3 for 81–160 men 4 for 161–240 men	1–10 for 1–100 persons 1–15 for over 100 persons	1 shower for each 15 persons exposed to excessive heat or to occupational hazard from poisonous, infectious, or irritating material	1 for each 75 persons	
Institutional—other than hospitals or penal institutions (on each occupied story)	1 for each 25 men 1 for each 20 women	1 for each 50 men[a]	1 for each 10 persons	1 for each 10 persons	1 for each 50 persons	
Hospitals Individual room	1	—	1	1	—	1 slop sink per floor
Wards	1 for 8 patients	—	1 for each 10 patients	1 for each 20 patients	1 for each 100 patients	

TABLE 10-6 (*Continued*)

Type of Building Occupancy	Water Closets	Urinals	Lavatories	Bathtubs/Showers	Drinking Fountains	Other
Waiting rooms	1	—	1	—	—	
Employees	Same as public	Same as public	Same as public	—	Same as public	
Penal institutions	1 in each cell	1 in each exercise room	1 in each cell	1 on each cell block floor	1 on each cell block floor	1 slop sink per floor
Prisoners	1 in each exercise room	—	1 in each exercise area	—	1 in each exercise area	
Employees	Same as public	Same as public	Same as public	—	Same as public	
Public buildings, offices; business, mercantile, storage, and institutional employees	1 for 1–15[c] 2 for 16–35[c] 3 for 36–55[c] 4 for 56–80[c] 5 for 81–110[c] 6 for 111–150[c] 1 fixture for each additional 40 employees	Urinals may be provided in men's[a] toilet rooms in lieu of water closets but for not more than $\frac{1}{3}$ of the required number of water closets	1 for 1–15 employees 2 for 16–35 employees 3 for 31–60 employees 4 for 61–90 employees 5 for 91–125 employees 1 fixture for each additional 45 persons	—	1 for each 75 persons	1 slop sink per floor

Schools						
Elementary	1 for each 40 boys, 1 for each 35 girls	1 for each 30 boys	1 for each 50 pupils	In gym or pool shower rooms, $\frac{1}{5}$ pupils of a class	1 for each 100 pupils but at least 1 per floor	Slop sinks, 1 on each floor
Secondary	1 for each 40 boys, 1 for each 45 girls	1 for each 30 boys	1 for each 50 pupils			
Working men, temporary facilities	1 for each 30 working men	1 for each 30 working men	1 for each 30 working men	—	1 fixture or equivalent for each 100 working men	

Source: Report of Public Health Service Technical Committee on Plumbing Standards, September 1962, PHS Pub. No. 1038, Department of Health, Education, and Welfare, Washington, DC, 1963.

[a] Where urinals are provided for the women, the same number shall be provided as for men.

[b] For apartments or multiple dwelling units in excess of 10 apartments or units, 1 double laundry tray for each 10 units or 1 automatic laundry washing machine for each 20 units.

[c] Number of each sex.

TABLE 10-7 Minimum Sizes of Fixture Supply and Drain

Type of Fixture/Device	Pipe Size (in.) Supply	Drain
Bathtubs	$\frac{1}{2}$	$1\frac{1}{2}$
Combination sink and tray	$\frac{1}{2}$	$1\frac{1}{2}$
Drinking fountain	$\frac{3}{8}$	1
Dishwasher, domestic	$\frac{1}{2}$	$1\frac{1}{2}$
Kitchen sink		
Residential	$\frac{1}{2}$	$1\frac{1}{2}$
Commercial	$\frac{3}{4}$	$1\frac{1}{2}$
Lavatory	$\frac{3}{8}$	$1\frac{1}{4}$
Laundry tray, 1 or 2 compartments	$\frac{1}{2}$	$1\frac{1}{2}$
Shower, single head	$\frac{1}{2}$	$1\frac{1}{2}$
Sink, service, P trap	$\frac{1}{2}$	2
Sink, service, floor trap	$\frac{3}{4}$	3
Urinal, flush tank, wall	$\frac{1}{2}$	$1\frac{1}{2}$
Urinal, direct, flush valve	$\frac{3}{4}$	2
Urinal, pedestal, flush valve	1	3
Water closet, tank-type	$\frac{3}{8}$	3
Water closet, flush valve type	1	3
Hose bibbs	$\frac{1}{2}$	—
Wall hydrant	$\frac{1}{2}$	—

Source: PHS Pub. No. 1038, Department of Health, Education, and Welfare, Washington, DC See also Chapter 4 for trap sizes and fixture unit ratings.

Note: The minimum water pressure at the outlet, at times of maximum demand, shall not be less than 8 psi, except for direct flush valves, where 15 psi is required, and where special equipment requires other pressure.

approved non-pressure-type backflow preventer, such as that shown in Figure 10-13, may be used to prevent backsiphonage. The backflow preventer must be installed on the outlet side of the control valve, at a distance not less than four times the nominal diameter of the inlet, measured from the control valve to the flood-level rim of the fixture, and in no cases less than 4 in.

A pressure-type vacuum breaker (see Figure 10-14) is installed on a pressurized system and will function only when a vacuum occurs. It should not

TABLE 10-8 Distance of Fixture Trap from Vent

Size of Fixture Drain (in.)	Maximum Distance (ft)
$1\frac{1}{4}$	$2\frac{1}{2}$
$1\frac{1}{2}$	$3\frac{1}{2}$
2	5
3	6
4	10

TABLE 10-9 Hot Water Demands and Use for Various Types of Buildings

Type of Building	Maximum Hour	Maximum Day	Average Day
Men's dormitories	3.8 gal/student	22.0 gal/student	13.1 gal/student
Women's dormitories	5.0 gal/student	26.5 gal/student	12.3 gal/student
Motels: number of units			
20 or less	6.0 gal/unit	35.0 gal/unit	20.0 gal/unit
60	5.0 gal/unit	25.0 gal/unit	14.0 gal/unit
100 or more	4.0 gal/unit	15.0 gal/unit	10.0 gal/unit
Nursing homes	4.5 gal/bed	30.0 gal/bed	18.4 gal/bed
Office buildings	0.4 gal/person	2.0 gal/person	1.0 gal/person
Food service establishments			
Type A, full-meal restaurants and cafeterias	1.5 gal/max. meals/hr	11.0 gal/max. meals/hr	2.4 gal/avg. meals/day[a]
Type B, drive-ins, grilles, luncheonettes, sandwich and snack shops	0.7 gal/max. meals/hr	6.0 gal/max. meals/hr	0.7 gal/avg. meals/day[a]
Apartment houses			
20 or less	12.0 gal/apt.	80.0 gal/apt.	42.0 gal/apt.
50 apartments	10.0 gal/apt.	73.0 gal/apt.	40.0 gal/apt.
75 apartments	8.5 gal/apt.	66.0 gal/apt.	38.0 gal/apt.
100 apartments	7.0 gal/apt.	60.0 gal/apt.	37.0 gal/apt.
130 apartments or more	5.0 gal/apt.	50.0 gal/apt.	35.0 gal/apt.
Elementary schools	0.6 gal/student	1.5 gal/student	0.6 gal/student[a]
Junior and senior high schools	1.0 gal/student	3.6 gal/student	1.8 gal/student[a]

Source: ASHRAE Guide and Data Book, Atlanta, GA, 1970. Copyright by the American Society of Heating, Refrigerating and Air Conditioning Engineers. Inc. Reprinted with permission.

Note: The table remains unchanged in the latest ASHRAE publication—*1999 ASHRAE Handbook: HVAC Applications*. Heaters should be preset to deliver water at 130°F (54°C). The Consumer Product Safety Commission (CPSC) recommends a maximum of 120°F (49°C).

[a] Per day of operation

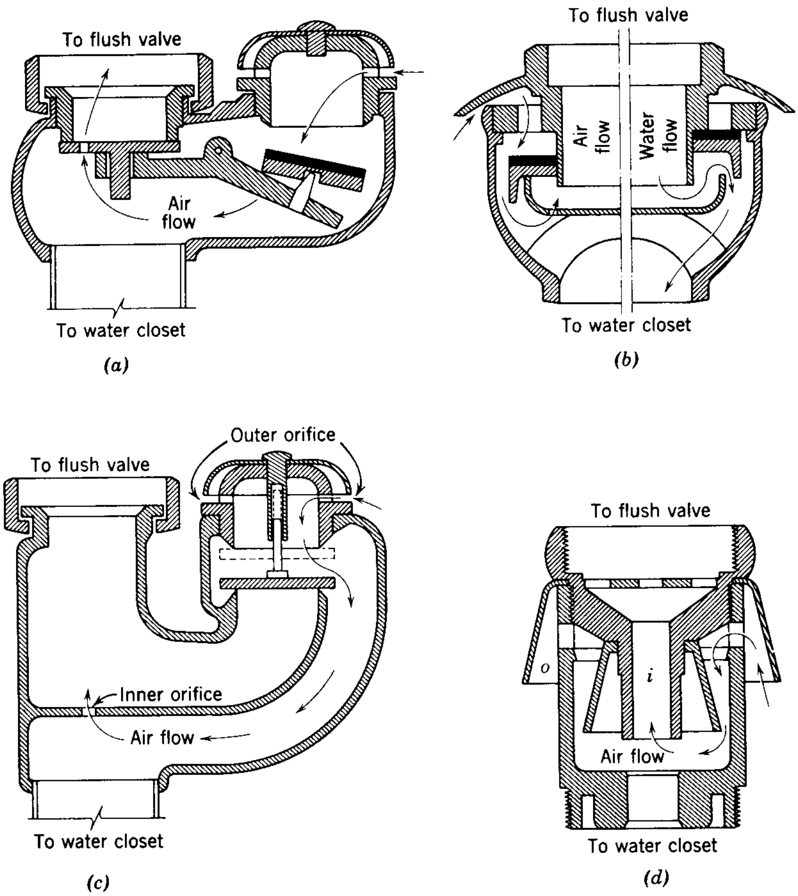
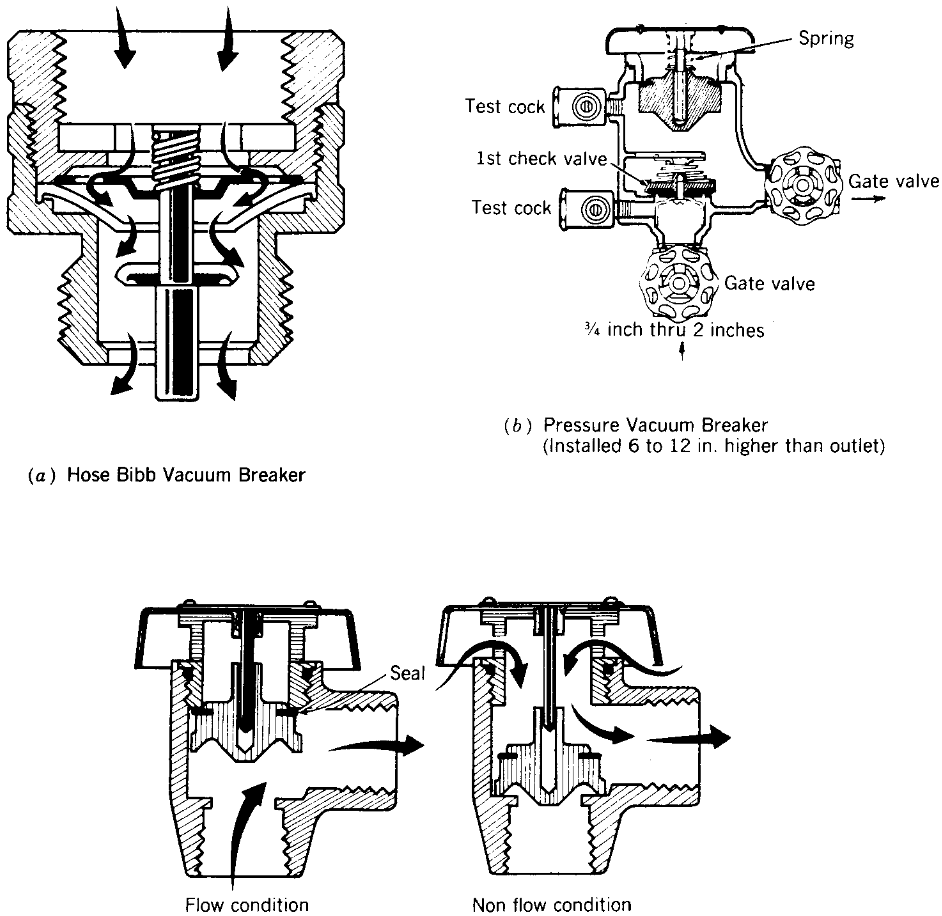


Figure 10-13 Vacuum, nonpressure-type siphon-breakers: (*a*), (*b*), (*c*) Moving parts; (*d*) Nonmoving part. Installed *after* fixture valve. [*Source:* R. B. Hunter, G. E. Golden, and H. N. Eaton, "Cross-Connections in Plumbing Systems," Research Paper RP 1086, *J. Res. Natl. Bur. Stand.*, **20** (April 1938).]

be installed where backpressure may occur. Figure 10-14 also shows a hose bib vacuum breaker and an atmospheric vacuum breaker.

In some instances, an air gap cannot be installed and it is necessary to connect a potable water supply to a line, fixture, tank, vat pump, or other equipment to permit backflow of nonpotable water due to backpressure or backsiphonage. Under such circumstances, an approved reduced-pressure-principle backflow preventer *may* be permitted by the regulatory authority. It is essentially a modified double check valve with an atmospheric vent capability placed between the two checks. See Figure 3-27.

Cross-connection control and the use of backflow preventers are also discussed in Chapter 3.



(*a*) Hose Bibb Vacuum Breaker

(*b*) Pressure Vacuum Breaker (Installed 6 to 12 in. higher than outlet)

(*c*) Atmospheric Vacuum Breaker

Figure 10-14 Vacuum breakers. (*a*) Generally attached to sill cocks and, in turn, are connected to hose supplied outlets such as garden hoses, slop sink hoses, and spray outlets. (*b*) A spring on top of the disc and float assembly, two added gate valves, test cocks, and an additional first check make possible its utilization under constant pressure. (*c*) Must be installed vertically, must not have shutoffs downstream, and must be installed at least 6 in. higher than the final outlet. (*Source: Cross-Connection Control Manual*, EPA 570/9-89-007, U.S. Environmental Protection Agency, Office of Water, Washington, DC, June 1989, pp. 17–18.)

Indirect Waste Piping

Waste pipes from fixtures or units in which food or drink is stored, prepared, served, or processed must not connect directly to a sewer or drain. Stoppage in the receiving sewer or drain would permit polluted water to back up into the fixture or unit. Waste piping from refrigerators, iceboxes, food rinse sinks, cooling or refrigerating coils, laundry washers, extractors, steam tables, egg boilers, steam kettles, coffee urns, dishwashing machines, sterilizers, stills, and similar units should discharge to an open water-supplied sink or receptacle so that the end of the waste pipe terminates at least 2 in. above the rim of the sink or receptacle, which is directly connected to the drainage system.

A commercial dishwashing machine waste pipe may be connected to the sewer side of a floor drain trap when the floor drain is located next to the dishwashing machine, if permitted by the regulatory agency.

An alternate to the installation of a water-supplied sink waste receptor is the provision of an air gap in the fixture waste line, at least twice the effective diameter of the drain served, located between the fixture and the trap.

The water-supplied sink or air-gap waste receptor should be in an accessible and ventilated space and not in a toilet room.

Plumbing Details

A few typical details and principles are illustrated for convenient reference and as guides to good practice. Many variations are to be found, depending on local conditions and regulations. See Figure 10-15.

Other

See Tables 4-6, 4-7, and 10-7 for fixture unit ratings for sewage flow computations, trap sizes, drain sizes, special fixture values, and fixture unit load to building drains and sewers. Figure 3-26 gives curves for estimating probable water demand of a sum of water supply fixture units. Table 3-24 lists demand weights of fixtures, and Table 3-25 gives the size of fixture supply pipe, rate of flow, and required pressure during flow for different fixtures.

INDOOR AIR QUALITY

Causes and Sources of Indoor Air Pollution

Improved building construction and insulation, including weather stripping, caulking, and storm and thermopane windows, reduce infiltration and air exchange, which results in less air dilution and an increase in the concentration of indoor air pollution. Inadequate ventilation and the recirculation of contaminated used air to save on energy costs for heating and cooling further aggravate the problem. Good practice would dictate that at least one-third of the recirculated air should be clean fresh air, even though this would increase energy costs, unless an air-to-air heat exchanger is used.

Household appliances, aerosol applications, cleaning products, pesticides, photocopying machines (ozone), interior furnishings and building materials

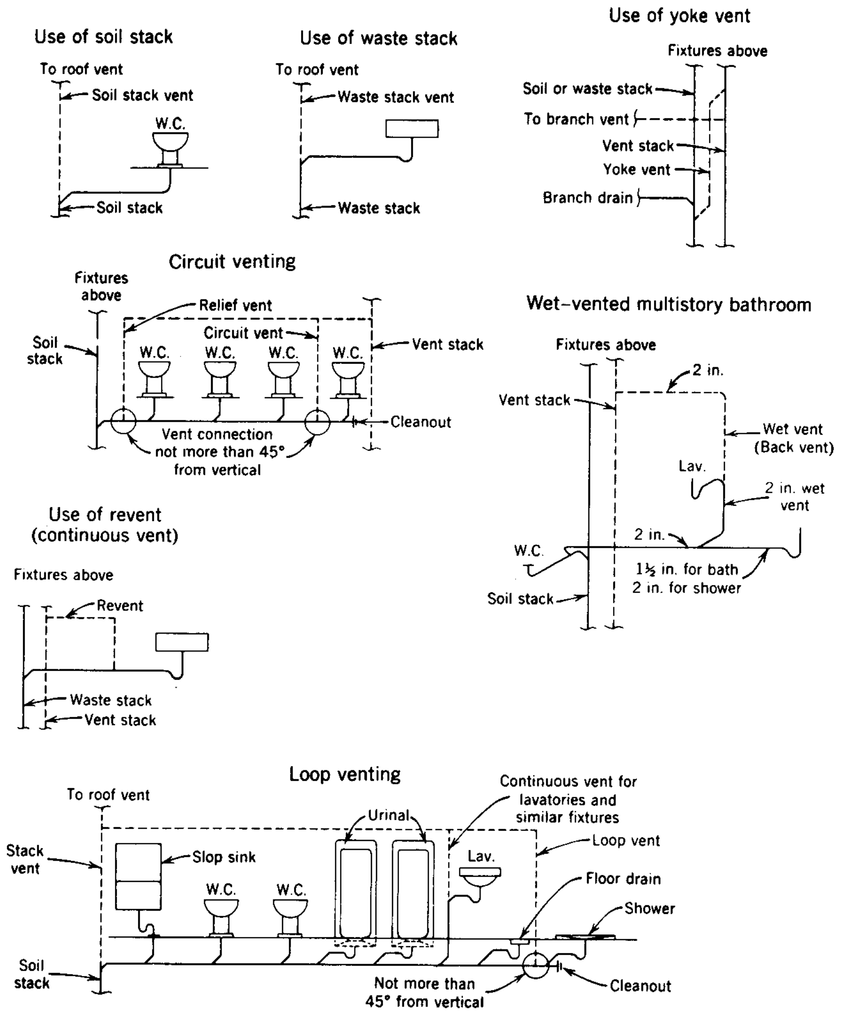


Figure 10-15 Some fixture plumbing details. (*Source: New York State Uniform Fire Prevention and Building Code*, Division of Housing and Community Renewal, New York, January 1, 1984.)

(formaldehyde and volatile organic compounds), tobacco smoke, dry cleaned clothing, and radon may also contribute to the indoor air pollution problem. Noise might also be included. Table 10-10 lists major pollutant/sources, specific contaminants, and acceptable levels. Additional air contaminants and effects are given in Table 1-18. The contaminants may be found in the new or rehabilitated home, office, or other workplace; in the automobile, airplane, or bus; or in the school, auditorium, indoor ice skating rink, restaurant, enclosed shopping center, commercial and public building, hospital, and nursing home.

TABLE 10-10 Sources and Exposure Guidelines of Indoor Air Contaminants

Pollutant/Sources[a]	Guidelines
Asbestos and other fibrous aerosols: friable asbestos—fireproofing, thermal and acoustic insulation, decoration; hard asbestos—vinyl floor and cement products, automatic brake linings (O)	0.2 fibers/ml for fibers longer than 5 μm (based on ASHRAE[b] guidelines of 1/10 of U.S. 8-hr occupational standard)
Biological aerosols: human and animal metabolic activity products, infectious agents, allergens, fungi, bacteria in humidifiers, bacteria in cooling devices	None available
Carbon monoxide: kerosene heaters, gas stoves, gas space heaters, wood stoves, fireplaces, smoking, and automobiles (O)	9 ppm for 8 hr (NAAQS[c]); 35 ppm for 1 hr (NAAQS)
Formaldehyde: particleboard, paneling, plywood, ceiling tile, urea-formaldehyde foam insulation, other construction materials	0.1 ppm (based on Dutch and West German guidelines as reported in ASHRAE Guidelines, 1981, and National Research Council report, 1981)
Inhalable particulates: smoking, vacuuming, combustion sources (O), industrial sources, fugitive dust (O), and other organic particulate constitutents	55–110 $\mu g/m^3$ annual[d] 150–350 $\mu g/m^3$ for 24 hr[d]
Metals and other inorganic particulate contaminants:	
Lead—old paint, automobile exhaust (O)	1.5 $\mu g/m^3$ for 3 months (NAAQS)
Mercury—old paint, fossil fuel combustion (O)	2 $\mu g/m^3$ for 24 hr (ASHRAE)
Cadmium—smoking, use of fungicides (O)	2 $\mu g/m^3$ for 24 hr (ASHRAE)
Arsenic—smoking, pesticides, rodent poisons	None available
Nitrates—outdoor air	None available
Sulfates—outdoor air	4 $\mu g/m^3$ annual, 12 $\mu g/m^3$ for 24 hr (ASHRAE)
Nitrogen dioxide: Gas stoves, gas space heaters, kerosene space heaters, combustion sources (O), automobile exhaust (O)	0.05 ppm annual (NAAQS)
Ozone: photocopying machines, electrostatic air cleaners, outdoor air	Not exceeding 0.12 ppm once a year (NAAQS)

Pesticides and other semivolatile organics: Sprays and strips, drift from area applications (O)	5 $\mu g/m^3$ for chlordane (NRC)[e]
Polyaromatic hydrocarbons and other particulate constituents: woodburning, smoking, cooking, coal combustion, and coke ovens (O)	None available
Radon and radon progeny: diffusion through floors and basement walls from soil in contact with a residence, construction materials containing radium, untreated groundwater containing dissolved radon, combustion of natural gas used in cooking and unvented heating, radon from local soil emanation (O)	0.01 working level (ASHRAE guidelines)
Sulfur dioxide: kerosene space heaters, coal and oil fuel combustion sources (O)	80 $\mu g/m^3$ annual; 315 $\mu g/m^3$ for 24 hr (NAAQS)
Volatile organics: Cooking, smoking, room deodorizers, cleaning sprays, paints, varnishes, solvents and other organic products used in homes and offices, furnishings such as carpets and draperies, clothing, furniture, emissions from waste dumps (O)	None available

Source: N. L. Nagada, H. E. Rector, and L. A. Wallace, *Project Summary Guidelines for Monitoring Indoor Air Quality,* EPA-600/S4-83-046, U.S. Environmental Protection Agency, Office of Minitoring Systems and Quality Assurance, Washington, DC, January 1984.

[a] (O) refers to outdoor sources.

[b] American Society of Heating, Refrigerating and Air Conditioning Engineers.

[c] U.S. National Ambient Air Quality Standards.

[d] These numbers indicate the probable range for the new NAAQS for particulates of 10 μm or less in size. Based on ‘‘Recommendations for the National Ambient Air Quality Standards for Particulates—Revised Draft Paper,’’ Strategies and Air Standard Division, Office of Air Programs, U.S. Environmental Protection Agency, Washington, DC, October 1981.

[e] National Research Council, 1982, ‘‘An Assessment of Health Risk of Seven Pesticides Used for Termite Control,’’ National Academy Press, Washington, D.C.

Most urban dwellers spend 16 hr a day and as much as 80 to 90 percent of their time indoors. The primary types of indoor air quality problems are inadequate ventilation (52 percent), contamination from inside the building (17 percent), contamination from outside the building (11 percent), microbiological contamination (5 percent), contamination from building fabrics (3 percent), and unknown (12 percent).[26]

Biological Contaminants and Health Effects

Bacteria, viruses, fungi, pollens, house dust, and mite droppings are found in indoor air. Fungi, including spores and molds, multiply in the presence of increased humidity level (greater than 70 percent, some say 45 to 60 percent[27]). Pollens, fungi, and other allergens are also brought indoors by ventilation systems, clothing, tracking, and open doors and windows. Substantial reduction in ventilation rates will tend to increase concentrations of contaminants and the probability of infection and allergy to the extent contaminants remain viable and airborne.

Sources of biological contaminants include air-conditioning systems; humidifiers; air ducts; cooling towers; grass, tree, and weed pollens; occupants; and household pets. Keep air-conditioning systems clean and empty, clean humidifiers and sanitize frequently, and minimize household dust.[28] Some unit air cleaners are effective in removing particulates but may also incubate fungi and microorganisms. Air cleaners, such as electrostatic precipitators, ionizers, or filters, are not designed to remove radon or other gases. Humidifiers and filters require scheduled cleaning or filter replacement. Prevent the accumulation of water in equipment; ensure proper drainage. Recirculating or independent steam humidification is said to be preferable to the filter-type humidifier for room humidification. Ensure that the water used is not contaminated with toxic volatile compounds.

The spread of respiratory diseases is facilitated by infectious agents and particulates in contaminated air. Overcrowding and the recirculation of contaminated air, if not adequately diluted, cleaned, or disinfected, permit continual seeding and accumulation of pathogenic microorganisms at a rate exceeding the natural die-off rate. A study at U.S. Army training centers showed a 45 percent increase in respiratory infection in energy-efficient buildings providing 1.8 ft^3 per minute per person outside air. This was compared to older barracks providing 14.4 ft^3 per minute per person outside air where the infection rate was lower.[29]

Legionnaires' disease, meningococcal meningitis, the common cold, influenza, and other respiratory diseases, such as listed in Table 1-6, may be transmitted by airborne aerosols. Comprehensive studies on the health effects of long- and short-term exposure to indoor (and outdoor) contaminants are limited. Young children, the elderly, and people suffering from respiratory diseases will be the first to show signs of discomfort from indoor air contamination. Some common complaints are headache; fatigue; eye, nose, and throat irritation; fever; and dizziness. See also Respiratory Illness Control below.

Other Contaminants

Major air contaminants are listed in Tables 1-18 and 11-10. These substances are associated with noninfectious and communicable disease and are environmentally related. They may also aggravate respiratory and heart diseases and cause nausea, headache, eye, nose, and throat irritation, discomfort, and allergies. Death from chronic or acute exposure may also result. More information on the health effects of specific indoor contaminants is needed, but this does not preclude taking preventive action, particularly where information is available, such as for carbon monoxide, formaldehyde, asbestos, radon, and biological aerosols.

Carbon monoxide, lead poisoning, and asbestos hazards and controls are discussed in Chapter 1. Other contaminants and sources are reviewed below.

Radon Radon is an odorless, colorless, and tasteless chemically inert radioactive gas released in the decay of radium from uranium in most soils and rocks. It is found naturally in soil gas, underground water, and outdoor air. It is 60 times more soluble [at 50°F (10°C)] than oxygen in water. Radon has a half-life of 3.8 days. Thorium, one of the uranium decay products, also releases radon. Radon and primarily its alpha-emitting decay products (especially polonium) contribute a major portion of the biologically significant dose associated with natural background radiation. The beta and gamma emissions are not significant. The alpha particles, however, adhere to dust particles that, when inhaled, can become attached to the lungs and remain to irradiate the surrounding tissue, contributing to the cause of cancer.

It has been estimated that exposure to "one working-level month" over a lifetime (assumed to be 70 years) would result in about 350 additional lung cancer deaths per million people exposed. Exposure to a radon level of 4 pCi/l* for 12 hr per day would result in an annual exposure of 0.5 working-level months.[30]† Working level is explained below. It has also been estimated that radon causes 13,000 cancer deaths per year.‡ Smokers are at much greater risk. In view of this, a screening program to identify problem areas and recommend mitigation alternatives to home owners is indicated. Also indicated is radon measurement before the purchase of a new or existing home.

*Picocuries per liter: 4 pCi/l = 150 Bq/m^3 (bequerel per cubic meter).

†*Source: Health Risks of Radon and Other Internally Deposited Alpha-Emitters: Bier IV*, National Academy Press, Washington, DC.

‡National Research Council estimate, 1988 (see ref. 31). Lung cancer may be causing 5000–10,000 lung cancer deaths per year in the United States based on an average annual dose of 2.4 rem.

The hazard associated with radon is related to the concentration and time of exposure. Radon should not exceed 2 to 5 pCi/l indoors. The U.S. Environmental Protection Agency (EPA) has set a guideline limit of 4 pCi/l per 24 hr for homes (this is believed to be conservative) and a standard of 20 pCi/l in underground uranium mines. Special problems exist at uranium tailings and phosphate slag sites. The EPA estimates 20 million homes exceed the 4-pCi/l limit.* The action level for existing dwellings in the United Kingdom is 10 pCi/l and 20 in Canada, with 2.5 in new dwellings in the United Kingdom.[32]

Major potential entry sources of indoor radon from the soil are cracks in dwelling concrete floor slabs and basement walls; pores and cracks in concrete blocks, mortar joints, and floor-wall joints; spaces behind brick veneer walls that rest on uncapped hollow-block foundations; floor drains; footing drains; and exposed soil in the bottom of drainage sumps. Radon-contaminated water, when agitated, aerated, or splashed as in dishwashing, clothes washing, showering, toilet flushing, and opened faucets or when water is heated, permits the release of radon. In addition to rock and soil underlying dwellings, construction materials (some stone masonry, concrete blocks, bricks, concrete), and some well and seepage waters and gas supplies may be the source of radium and radon. In the average dwelling, 10,000 pCi/l of radon in the water can be assumed to release 1 pCi/l to the air, but the actual indoor concentration will be dependent primarily on the amount of radon entering from the soil and on the extent to which the indoor air is diluted by outside air.[33]

The EPA is proposing a level of 200 to 500 pCi/l for drinking water, which might be increased to perhaps 1000. A level of 20,000 pCi/l in water is considered a significant concentration. If the water is high in radon, it can be removed by filtering through a granular activated-carbon (GAC) filter, by storage until the radon has decayed, or by aeration before it enters the dwelling water system. But the carbon becomes radioactive and in decay releases gamma radiation, which can be a health hazard. Aeration appears to be the most cost-effective procedure for public water systems and a GAC filter for a private dwelling having its own well-water supply, if needed. Activated carbon concentrates the radon and decay products and, hence, poses a disposal problem. Consult with the equipment dealer, the state or local health department, and radiation protection office for the proper way to dispose of the used carbon.

Radon contamination in an existing dwelling, if it is a problem, can be reduced by preventing its entry or by removing the radon. It can be reduced by closing and caulking all cracks, joints, and openings of the structure in the basement or in contact with the ground, or in the flooring above the crawl space, and by tightly covering open drains and sumps as previously noted.

*See W. W. Nazaroff and K. Teichman, "Indoor Radon," *Environ. Sci. Technol.*, June 1990, p. 777.

Good insulation of water pipes and underflooring beneath living areas would be required in the crawl space in areas subjected to subfreezing temperatures[34] and to reduce heating or cooling costs. If this is not sufficient to reduce the indoor radon level, natural or mechanical forced-air ventilation into basement and crawl spaces can be provided, with openings to allow radon-laden air to exit. Exhaust ventilation would be needed for tightly covered sumps and footing drains. In Florida, a vent area of 1 ft^2 for each 150 ft^2 of floor area for wooden flooring or at least 1.5 ft^2 of opening for each 15 ft of linear perimeter wall for nonwooden flooring is required by the housing code. To reduce radon levels in basements and enclosed crawl spaces, bring in outside air to dilute and displace the inside air. Forced-air ventilation may be necessary; exhaust fans in living areas and combustion air for warm-air furnaces and fireplaces would depressurize the dwelling and draw in radon from the basement and should not be used. Provide outside air vent for furnace and hot-water gas heater and outside air duct for wood stove and fireplace.

In a new building, the gravel under the basement floor or floor slab could have perforated pipe embedded in it to intercept and vent radon gas above the roof using a mechanical exhaust fan. Wind turbines and natural convection are not effective. A polyethylene sheet would be placed under the basement concrete floor slab above the gravel before it is poured. The ventilation method used must not reduce the air pressure within the dwelling. Sealing major potential sources of radon entry as stated above and ventilation should greatly reduce radon concentrations to ‘‘safe’’ levels in most cases. The need for radon protection, such as built-in ventilation under the basement floor or floor slab, is best provided in new construction and required in building codes where needed. Local geological information and in-home radon measurements will give an indication of need.

Measurement for radon exposure is in working-level units, which include radon’s first four daughter products, that will result in MeV of potential alpha energy per liter of air. A working level of 1.0 is assumed to be equivalent to a 1-month total of 200 pCi/l of radon in most indoor environments (at 50 percent equilibrium).[35] A working-level month (WLM) is equivalent to an average of 173 hr spent in a mine by a uranium worker. Exposure must not exceed 4 WLMs in any calendar year. The occupational limit for workers is 4.8 WLMs according to the 1985 recommendation of the International Commission on Radiological Protection (ICRP Publication 31). The National Council on Radiation, Protection, and Measurement says radon level should not exceed 2 WLMs per year, or 8 pCi/l (NCRP Report 77, December 1984). The U.S. Mine Safety and Health Administration has set a maximum exposure level of 8 pCi/l for miners.

State and local health departments or state radiation protection offices can usually provide a list of companies supplying radon testing services. Federal and state publications are available to assist the homeowner to understand the problem and take corrective action if indicated.[36] Seek professional advice if a significant problem exists.

Formaldehyde Formaldehyde, a colorless gas, may cause extreme discomfort and contact dermatitis indoors. The odor can be detected at less than 1 ppm. Exposure to 1.0 to 5.0 ppm or less can cause burning of the eyes, tearing, and general irritation of the upper respiratory passages. Levels of 0.3 to 2.7 ppm have been found to disturb sleep and to be irritating to some persons. Exposure to 10 to 20 ppm may produce coughing, tightening in the chest, a sense of pressure in the head, and palpitations. Exposures of 50 to 100 ppm and above can cause serious injury, including pulmonary edema and pneumonitis, and possibly death when above 100 ppm. Exposure to formaldehyde solutions, or urea–formaldehyde-containing resins, is a well-recognized problem.[37] However, a four-year study at the National Cancer Institute concluded that there is ‘‘little evidence that mortality from cancer is associated with formaldehyde exposure at levels experienced by workers in this study.’’[38]

Sources of formaldehyde are resins and glues to bond particle board and plywood, urea–formaldehyde foam insulation, permanent press fabric, embalming fluid, drugs, disinfectants, and cosmetics as well as chemicals used in pathology and anatomy laboratories and in the manufacture of automobiles, furniture, paper, and electrical equipment.[39] Formaldehyde problems are also related to materials in mobile homes and prefabricated housing. Users of formaldehyde should wear protective clothing, use protective equipment, and apply engineering controls such as hoods and separate exhaust systems. The workplace should provide a minimum ventilation of five air changes per hour. Some ameliorative measures suggested, where urea–formaldehyde is a problem, are to remove the product; seal with a specially formulated coating, vinyl covering, latex paint, or varnish after two years; and increase ventilation. Sealing will prevent the penetration of moisture, contact with urea–formaldehyde, and release of formaldehyde gas. The gas release from materials tends to decline in time. Improper formulation of urea–formaldehyde foam insulation is believed to exacerbate the problem. It is no longer used in the United States. Phenol–formaldehyde resins are generally used in outdoor materials and do not release significant quantities of formaldehyde; however, they cost more than urea–formaldehyde products.

The Occupational Safety and Health Administration (OSHA) 8-hr time-weighted average occupational exposure has been reduced from 3.0 to 1.0 ppm with a maximum short-term exposure level of 2.0 ppm for any 15-min period.[40]* The National Research Council has established a limit of 0.1 ppm for space flights. The Department of Housing and Urban Development (HUD) has set a limit of 0.4 ppm for indoor air.

Polychlorinated Biphenyls (PCBs) PCBs are considered ‘‘probable’’ human carcinogens based on animal studies. Although manufacture was banned in 1979, many products containing PCBs remain in use. Possible major exposure

*Average level is proposed to be reduced to 0.75 ppm.

routes to PCBs are inhalation when electrical transformers and other equipment containing PCBs are ruptured or burned, breathing PCB-contaminated air or skin contact in the work environment, the ingestion of food (fish) or drinking water containing PCBs, and spills or illegal dumping of fluids containing PCBs. Fluorescent light ballasts and vinyl-coated paper are also a common source of PCBs. It is best to use caution and seek advice immediately from your health or environmental protection department should there be an actual or potential exposure to PCBs.

The Occupational Safety and Health Administration has established an airborne exposure limit of from 0.5 mg/m^3 (54 percent chlorine content) to 1 mg/m^3 (42 percent chlorine content) as an 8-hr time-weighted average (skin).* The National Institute of Occupational Safety and Health (NIOSH) recommends that the airborne exposure to PCBs in the workplace be 1 $\mu g/m^3$ or less.† The EPA has proposed a limit of 100 $\mu g/m^2$ in areas where frequent and regular skin contact with surfaces is possible.

Tobacco Smoke Environmental tobacco smoke consists of a suspension of 0.01- to 1-μm particles leaving the burning tobacco condensate. Also produced are numerous hazardous gases including carbon monoxide. The involuntary chronic exposure to cigarette smoke, also referred to as passive smoking, is associated with an increased risk of lung cancer according to a 1986 report of the National Academy of Science (NAS).[41] In addition, children of smoking parents have increased respiratory illnesses compared with children whose parents do not smoke; however, data on other diseases such as other cancers and cardiovascular diseases are insufficient. According to the NAS report, passive smoking causes irritation of the eyes, nose, and throat of many nonsmokers. Ventilation rates of up to five times higher in smoking areas are suggested to achieve acceptable indoor air quality. Office spaces should provide at least 20 ft^3/min per occupant of clean outside air where smoking is permitted and at least 5 ft^3/min per occupant in nonsmoking areas.[42] Effort should be directed to the prohibition of smoking in enclosed spaces and the discouragement of smoking.

Volatile Organic Compounds (VOCs) VOCs are a broad range of chemical compounds with boiling points in the range of approximately 120 to 480°F (50–260°C) and vapor pressures greater than about 4×10^{-5} to 4×10^{-6} in. Hg.[43] Several hundred VOCs have been identified in the indoor environment.[44] The Large Buildings Study by the EPA developed a VOC sample target list that includes aliphatic hydrocarbons, halogenated hydrocarbons, and oxygenated hydrocarbons such as aldehydes, alcohols, ketones, esters, ethers, and

*Potential contribution to overall exposure by the cutaneous route, including mucous membranes and eyes.

†See "NIOSH, CDC, Recommendations for Occupational Safety and Health Standards, 1988," DHHS, PHS, NIOSH, CDC, *MMWR,* Supplement, August 26, 1988, pp. 23 and 24.

acids.[45] Sources of VOCs in nonindustrial environments include building materials, furniture, furnishings, ventilation systems, household and consumer products, office equipment, and outdoor-related activities (e.g., traffic, neighborhood industry).

Little is known about the symptoms of overexposure to VOCs, but some are suspected of causing adverse health effects such as sensory irritation, odor, and the more complex set of symptoms of sick-building syndrome. Also researchers have found that neurotoxic effects may follow from low-level exposures to gaseous air pollutants.[46] Reactions include runny eyes and nose, high frequency of airway infections, asthmalike symptoms among nonasthmatics, along with odor or taste complaints. There is also a possible link between the increase in allergies throughout the industrialized areas of the world and exposure to elevated concentrations of VOCs.

Emission source control, gas-phase air filtration using activated-carbon filters or photocatalytic reactors, and ventilation are common ways of controlling indoor VOCs.

Other Emissions Unvented kerosene, fuel oil, and wood stove space heaters, gas cooking and heating appliances, power equipment including automobiles, and gas clothes dryers lead to the emission of particulates, in addition to hazardous gases. Portable heaters also present risks of burns, injuries, fires, and explosions. Their use should be prohibited. Unvented kerosene space heaters can emit organic compounds, in addition to nitrogen dioxide, carbon dioxide, carbon monoxide, and sulfur dioxide. The concentrations can exceed the EPA ambient air standards, particularly in small spaces and where ventilation is inadequate. Poor-quality kerosene exacerbates the problem. Gas cooking appliances are also sources of carbon dioxide, nitrogen dioxide, formaldehyde, and other organic compounds, in addition to carbon monoxide. Carbon monoxide, nitrogen oxides, and particulates from automobile exhaust in garages can produce increased and hazardous concentrations in office buildings above the garage and in public areas. Gasoline-powered ice resurfacing machinery can cause the same effect in indoor ice-skating rinks and forklifts in enclosed spaces.

The smoke from cooking and heating with open fires in houses in some underdeveloped countries is the cause of serious respiratory illness in infants. Pregnant women exposed to the smoke produce lower birthweight children.[47]

Thermal and Moisture Requirements

Good ventilation requires that the air contain a suitable amount of moisture and that it be in gentle motion, cool, and free from offensive body and other odors, poisonous and offensive fumes, and large amounts of dust. Comfort zones for certain conditions of temperature, humidity, and air movement are given by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).[48] Air movement, radiant heat, the individual, and the tasks being performed must also be taken into consideration.

There is no one temperature and humidity at which everyone is comfortable. People's sensations, health, sex, activity, and age all enter into the comfort standard. McNall[49] recommends a temperature range between 73 and 77°F (23 and 25°C) and humidity between 20 and 60 percent for lightly clothed adults engaging in sedentary activities in residences. Lubart[50] suggests a comfort level within the range of 68°F (20°C) at inside relative humidity of 50 percent to 76°F (24°C) with 10 percent relative humidity. The EPA recommends a relative humidity of 30 to 50 percent for homes.[51] Indoor relative humidity of 60 percent or higher would cause excessive condensation and greater mildew, corrosion, and decay. Excessive moisture can cause condensation and increasing deterioration of building materials. Humidities above 70 percent promote germination and growth of fungal spores. Ordinarily, however, only temperature and ventilation control is used in the home, with no attempt made to measure or control the relative humidity. Humidity control becomes more important with reduced ventilation since the products of respiratory and metabolic processes and certain indoor operations and activities contribute moisture vapor. In a confined space, this can lead to the accumulation of contaminants and moisture and discomfort or illness.

Ventilation

Indoor air should be free of objectionable odors, unhealthy levels of microorganisms, allergens, and chemical contaminants. The design of a ventilation system should avoid uncomfortable drafts and large temperature variations. National, state,[52] and local building and energy conservation codes specify ventilation requirements for various space uses and should be consulted. It has been proposed that the generally accepted minimum supply of fresh air per occupant be 15 or 20 ft^3/min.[53] Much higher fresh air supply is needed in rooms where smoking is permitted or where other polluting activities are permitted. The OSHA requirements must be met in the workplace. In true air conditioning, air is treated to simultaneously control its temperature, humidity, cleanliness, and distribution to meet requirements of the conditioned space. Room air inlets and returns should be arranged to ensure proper air mixing and ventilation of the space and to avoid drafts.

The tendency to reduce air infiltration and fresh air makeup in ventilation has increased the buildup of air contamination, with resultant occupant complaints. To alleviate the problem, minimum ventilation standards, including fresh air intakes, have been established or proposed in building codes and other publications.[53] In addition, the use of certain indoor products such as urea–formaldehyde insulation and unvented kerosene space heaters has been banned in some jurisdictions. However, owner- or occupant-provided equipment, materials, and furnishings not under regulatory control and ambient air quality may nevertheless contribute to indoor air pollution. Ventilation may be provided by natural or mechanical means. Investigation of an indoor air pollution problem could well start with carbon dioxide tests and interrogation of management, employees, and custodial and union people. If carbon dioxide concentrations are below 600 ppm, with comfortable temperature and humidity levels, complaints about air quality should be minimal. The ideal indoor concentration is 250 to 350 ppm (ref. 26, pp. 13, 16).

Natural Ventilation A minimum of one or two air changes per hour can often be secured by normal traffic and leakage through walls, floors, and ceilings and through or around doors and windows, but previously mentioned energy conservation measures may reduce air infiltration and air change by 50 percent or more. Under ordinary circumstances, adequate ventilation can be obtained in residences by natural means with properly designed windows. Openable windows, louvers, or doors are needed to ventilate and keep attics, basement rooms, pipe spaces, and cellars relatively dry. The tops of windows should extend as close to the ceiling as possible, with consideration to roof overhang, to permit a greater portion of the room to be exposed to controlled sunlight. The minimum total window or skylight area, measured between stops, for a habitable room should be at least 8 percent of the floor area and the openable area at least 45 percent of the window or skylight area.[54] The ventilation of modern buildings is usually dependent on mechanical air conditioning and air recirculation, including controlled fresh air intake. Some examples and design criteria are discussed below.

Schools Separate venting of each classroom to the outside is preferred. Good standards specify that the mechanical ventilating system provide a minimum air change of 15 to 20 ft^3/min per student to remove carbon monoxide and odors, without drafts. The air movement should not exceed 25 ft/min, and the vertical temperature gradient should not vary more than 5°F (3°C) in the space within 5 ft of the floor and 2 ft or more from exterior walls. Temperature should be automatically controlled.

Public Areas In recreation halls, theaters, churches, meeting rooms, and other places of temporary assembly, a system of mechanical or induced ventilation is usually needed to meet the requirement of at least 15 ft^3 of clean air per minute per person. Any system of ventilation used should prevent short circuiting, uncomfortable drafts, and the buildup of unhealthy levels of air contaminants. Approximately one-third of the recirculated air should be clean outside air.

Correctional Institutions Where dependence is on natural ventilation, window or other openings should provide an area of at least 12.5 percent of the floor space of the sleeping, living, educational, and work areas and be located to provide cross-ventilation. Gyms and swimming pools require special temperature, humidity, and ventilation controls. If dependence is on mechanical ventilation, 15 to 20 ft^3/min per person is recommended. Where air is recirculated, approximately one-third should be fresh, clean outside air.[55]

Toilets and Bathrooms Bathroom and toilet room ventilation is usually accomplished by means of windows or ventilating ducts. The common specification for natural ventilation is that the window or skylight area be at least 8 or 10 percent of the floor area and not less than 3 ft^3, of which 45 percent is openable. For gravity exhaust ventilation, vents or ducts at least 72 $in.^2$ in area per water closet or urinal and a minimum of 2 ft^3/min of fresh air per square foot of floor area should be provided. A system of mechanical exhaust ventilation providing at least five air changes per hour of the air volume of the bathroom or toilet room during hours of probable use is usually specified for ventilation where windows, ducts, or vents are not relied on or are not available for ventilation. ASHRAE[53] recommends 50 ft^3/min per water closet and per urinal for a public restroom. Exhaust fans activated by the opening and closing of doors or by a light switch do not provide satisfactory ventilation. The recirculation of air supplied to toilets, lavatories, toilet rooms, bathrooms, and restrooms (also kitchens, laboratories, and garages) is generally not permitted.[56]

Air Change Measurement Air in an enclosed space normally diffuses out and outdoor air filters in at a rate dependent on the tightness of the space or building and wind direction and velocity. The air change can be determined by dividing the volume of air entering an enclosed space or room by the volume of the space or room. For example, if 100 ft^3/min enters a room having a volume of 1000 ft^3 occupied by five people, there would be six air changes per hour ($100 \times 60 \div 1000$) and 20 ft^3/min per occupant.

The air change may be measured by use of tracers. Desirable qualities of a tracer gas are detectability, nonreactivity, nontoxicity, neutral buoyancy, relatively low concentration in ambient air, and low cost.[57] The commonly used tracers include nitrous oxide (N_2O), carbon dioxide (CO_2), helium (He), and sulfur hexafluoride (SF_6). Several tracer gas measurement procedures exist, including an American Society for Testing and Materials (ASTM) standard.[58] In the measurement, the tracer is released into the building in a specific manner, and the concentration of the tracer within the building is monitored and related to the building's air change rate. Standardization of devices is necessary.

Monitoring The monitoring and measurement of the quality of indoor air can be accomplished by modification, as needed, of equipment used to sample ambient air and occupational exposure and by adapting laboratory equipment and procedures. Passive measuring devices for carbon monoxide, radon, formaldehyde, and asbestos, although not accurate, are acceptable. The Anderson impactor sampler may be used to collect indoor airborne fungi supplemented by plate incubation for colony count and identification. Psychrometers for measuring temperature and humidity and smoke tubes for determining air movement are also generally used. Samplers for volatile organic compounds and continuous samplers are also available. Standardized methods for the determination of air pollutants in indoor air are listed in Table 10-11.

Respiratory Illness Control

The NIOSH suggestions to minimize respiratory illness include the following:

1. Promptly and permanently repair all external and internal leaks in the heating, ventilation, and air-conditioning system (HVAC).
2. Maintain relative humidity below 70 percent in occupied spaces and in low-air-velocity plenums. (At a higher level of humidity, the germination and proliferation of fungal spores are enhanced.)
3. Prevent the accumulation of stagnant water in cooling-deck coils of air-handling units through proper inclination and continuous drainage of drain pans.
4. Use steam rather than recirculated water as a water source for humidifiers in HVAC systems; however, such steam sources should not be contaminated with volatile amines.
5. Replace filters in air-handling units at regular intervals. (These should have at least a moderate efficiency rating—50 percent or more—as measured by the atmospheric-dust spot test and should be of the extended-surface type; prefilters, e.g., roll type, should be used before passage over the higher efficiency filters.)
6. Discard, rather than disinfect carpets, upholstery, ceiling tiles, and other porous furnishings that are grossly contaminated.
7. Provide outdoor air into ventilation systems at minimum rates per occupant of at least 20 ft^3/min in areas where occupants are smoking and at least 5 ft^3/min in nonsmoking areas. (ASHRAE Recommended Standard 62 specifies a minimum of 15 or 20 ft^3/min per person.[53])

These activities should be considered in ongoing preventive maintenance programs.[59]

The usual method of air purification by washing and filtration is relatively inefficient in removing bacteria or viruses from used air, although it can be effective in removing dust and other airborne particles. Electrostatic air precipitator units and special air filters effectively reduce indoor particulates. See also *Biological Contaminants and Health Effects,* this chapter. Central vacuum cleaning systems are very effective for the removal of dust and other particulates without resuspending the finer particles indoors.

Venting of Heating Units

Proper venting is the removal of all the products of combustion through a designated channel or flue to the outside air with maximum efficiency and

TABLE 10-11 Method for Determination of Air Pollutants in Indoor Air

Method Number	Description	Types of Compounds Determined
IP-1A	Stainless steel canister	Volatile organic compounds (VOCs) (e.g., aromatic hydrocarbons, chlorinated hydrocarbons) having boiling points in the range of 176–392°F (80–200°C)
IP-1B	Solid adsorbent tubes	—
IP-2A	XAD-4 (styrene-divinylbenzene) sorbent tube	Nicotine (gaseous and particulate)
IP-2B	Treated filter cassette	—
IP-3A	Nondispersive infrared (NDIR)	Carbon monoxide and/or carbon dioxide
IP-3B	Gas filter correlation (GFC)	—
IP-3C	Electrochemical oxidation	—
IP-4A	Perfluorocarbon tracer (PTF)	Air exchange rate
IP-4B	Tracer gas	—
IP-5A	Continuous luminox monitor	Nitrogen oxides
IP-5B	Palmes diffusion tube	—
IP-5C	Passive sampling device	—
IP-6A	Solid adsorbent cartridge	Formaldehyde (CH_2O) and other aldehydes/ketones
IP-6B	Continuous colorimetric analyzer	—
IP-6C	Passive sampling device	—
IP-7	Medium-volume polyurethane foam (PUF)/XAD-2 sampler	Polynuclear aromatic hydrocarbons
IP-8	Low-volume PUF sampler followed by gas chromatography/electron capture detection	Pesticides (e.g., organochlorine, organophosphorus, urea, pyrethrin, carbamate, and triazine)
IP-9	Annular denuder system	Acid gases/aerosols/particles (e.g., nitrates, sulfates, and ammonia)
IP-10A	Size-specific impaction	Particulate matter
IP-10B	Continuous particulate monitor	—

Source: W. T. Winberry et al., "EPA Project Summary Compendium of Methods for the Determination of Air Pollutants in Indoor Air," EPA/600/S4–90/010, U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, May 1990.

safety. Gravity-type venting relies largely on having the vent gases inside the vent hotter (thus lighter) than the surrounding air. The hotter the vent gases, the lighter they are and the greater their movement up through the vent. Thus, in order to keep the vent gases hot so that they may work at maximum efficiency, proper installation and insulation are necessary.

Factors that prevent proper venting are abrupt turns; downhill runs; common vents to small, uninsulated vent pipes; conditions that cause backdrafts; obstructions in the flue or chimney to which a furnace, heater, or stove is connected such as birds nests, soot and debris, broken mortar and chimney lining, and old rags; and unlined masonry chimneys. Stained and loose paper or falling plaster around a chimney is due to poor construction. A masonry chimney will absorb a great deal of the heat given off by the vent gases, thus causing the temperature in the chimney to fall below the dew point. The high moisture in vent gases condenses inside the chimney, forming sulfuric acid. This acid attacks the lime in the mortar, leaching it out and creating leaks and eventual destruction of the chimney. Therefore, it is necessary to line a masonry chimney with an insulating pipe, preferably terracotta flue lining.

Figure 10-16 shows chimney conditions apt to result in backdrafts. The flue or vent should extend high enough above the building or other neighboring obstructions so that the wind from any direction will not strike the flue or vent from an angle above the horizontal. Unless the obstruction is within 30 ft or unusually large, a flue or vent extended at least 3 ft above flat roofs or 2 ft above the highest part of wall parapets and peaked roof ridges will be reasonably free from downdrafts.

To ensure proper venting as well as proper combustion, sufficient amounts of fresh air are required, as shown in Figure 10-16. An opening of 100 to 200 in.^{2} will usually provide sufficient fresh air under ordinary household conditions; this opening is needed to float the flue gases upward and ensure proper combustion in the fire box. Proper venting and an adequate supply of fresh air are also necessary for the prevention of carbon monoxide poisoning or asphyxiation.

The connection (breeching) between the furnace or stove and chimney should be tight fitting and slope up to the chimney at least $\frac{1}{4}$ in./ft. Chimneys are usually constructed of masonry with a clay tile flue liner or of prefabricated metal with concentric walls with air space or insulation in between and should be Underwriter's Laboratories approved. All furnaces and stoves should be equipped with a draft hood, either in the breeching or built into the furnace or stove, as required, for proper draft. See Figure 10-16.

Before making any vent installations or installing any gas- or oil-fired appliances, consult the building code and the local gas or utility company. Standards for chimneys, fireplaces, and venting systems, including heating appliances and incinerators, are given by the National Fire Protection Association,[60] building codes, and other publications.

Portable kerosene heaters are a fire hazard and, since they are not vented, emit dangerous gases into a room. Their sale and use should be prohibited. The concentrations of carbon dioxide, nitrogen dioxide, and sulfur dioxide emitted into a room usually greatly exceed ambient air standards.

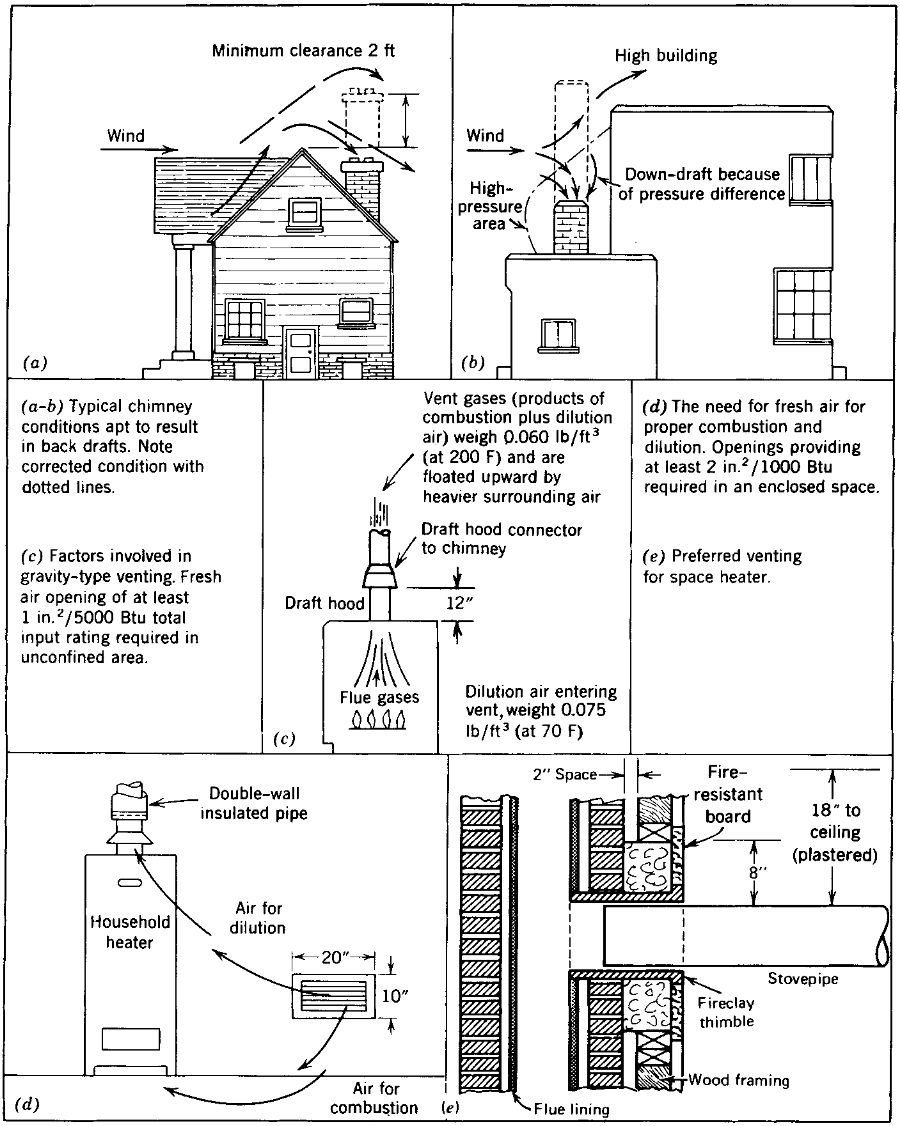


Figure 10-16 Some venting details. (Drawings are typical and not necessarily in full accordance with any code.) *See state and local building and fire prevention codes.* [(*e*) *Source:* J. P. Lassoie and L. D. Baker, "Heating with Wood," Cooperative Extension, Cornell University, Ithaca, NY, October 1979.]

Wood stoves require special fire protection and venting. See Cooperative Extension Service recommendations and local building code requirements.

Chimneys, vents, and ducts can become blocked by bird nests, squirrel nests, soot, grease, leaves, and other debris. Such conditions can develop during the nonheating season and prevent proper venting of the heating unit. Dangerous levels of carbon monoxide can accumulate if chimneys, vents, and ducts are not kept clear.

MOBILE HOME PARKS

Mobile homes are defined as ''transportable, single-family dwelling units suitable for year-round occupancy and containing the same water supply, waste disposal, and electrical conveniences as immobile housing'' (ref. 61, p. 3). A mobile home is also defined as a ''manufactured relocatable living unit.''[62] Mobile homes produced since 1954 are 10, 12, and 14 ft wide and up to 60 or 70 ft long. Wider units are assembled at the home site by combining sections to form double- and triple-wide units.

The Bureau of the Census identified 5.267 million mobile home units in the United States in 1987 as year-round housing occupied by over 13 million residents. There were 3.9 million homes in 1980 and 2.1 million in 1970. In 1987, 99 percent had complete plumbing, 46 percent were connected to a public sewer, 68 percent used public water, 81 percent had central heating, and 34 percent had central air conditioning. Annual sales dropped to 212,000 units in 1975 and increased to 300,000 units in 1977. Between 1980 and 1984, 1,129,000 units were added. Sales peaked in 1973 with 625,000 units. The typical mobile home is 14 ft wide and 65 ft long. Many are double units; some are triple. In 1974, about one-third of the buyers were married couples under 35 years of age and one-third were retired and over 65. In 1987, about 86 percent of the mobile homes were owner occupied. Modern mobile home parks may have all utilities, swimming pool and other recreational facilities, laundry, community buildings, paved streets with curbs or gutters, trees and landscaping, and patio slab and look like an established housing development. Lots are typically 5000 ft^2. Lots larger than 5000 ft^2 permit more flexibility in exposure and siting the mobile home. *It must be kept in mind that, unless the plot is owned by the mobile home owner, continued occupancy is dependent on the desire and future plans of the park owner*; hence, a mobile home park cannot be considered a permanent realty subdivision. Because of the risk of property sale and resultant hardships, consideration has been given to protective laws, cooperative ownership, and contractual arrangements.

The parks established have all of the potential environmental sanitation and safety problems of a small community. Because of this, standards have been prepared to guide mobile home manufacturers, operators, owners, and regulatory agencies to help promote safe and sound manufacture, site preparation, and sanitary practices. Compliance with these standards is facilitated by reference to the pertinent chapters in this text; to the guides cited in the footnotes, which include recommended ordinances; and to the guides published by HUD.[63–65]* (See Chapter 9 for site design and related details.) Other precautions include stable stands, tiedowns to minimize overturning during windstorms, smoke detectors and fire extinguishers in homes, with two exits from each unit, a minimum spacing of 10 ft, minimum site size, protection of water connections against freezing, sufficient electric power for all electrical equipment including approved-type inside wiring, and interior materials that do not cause the release of hazardous pollutants.

INSTITUTION SANITATION

Definition

An institution is a complete property with building, facilities, and services having a social, education, or religious purpose. This includes schools, colleges and universities, hospitals, nursing homes, homes for the aged, day-care centers, jails and prisons, reformatories, and the various types of federal, state, city, and county welfare, mental, and detention homes or facilities.

Institutions as Small Communities

Most institutions are communities unto themselves. They have certain basic characteristics in common that require careful planning, design, construction, operation, and maintenance. These include site selection, planning, and development for the proposed use, including subsoil investigation, accessibility, and proximity to sources of noise and air pollution; a safe, adequate, and suitable water supply for fire protection as well as for institutional use; sewers and a wastewater disposal system; roads and a stormwater drainage system; facilities for the storage, collection, and disposal of all solid wastes generated by the institution; boilers and incinerators with equipment and devices to control air pollution; food preparation and service facilities; fire-resistant housing and facilities for the resident population; laundry facilities; and insect, rodent, and noxious weed control. In addition, depending on the particular institution, they might have recreational facilities, such as a swimming pool or bathing beach. A hospital or educational institution often has its own laundry. A state training school or institution might have a dairy farm or produce farm, pasteurization plant, industrial operation, and food-processing plant. The environmental, health, engineering, and sanitation concerns at all these places are in many instances quite extensive and complex.

*The American National Standards Institute, National Fire Protection Association, and Building Officials & Code Administrators International also have suggested standards for adoption by local governments.

The possibilities for the transmission of illnesses associated with air, water, food, and contact are increased at institutions. Scrupulous cleanliness, hygiene (handwashing), and sanitation are essential at all times. Certain institution advisory committees can be helpful. These might include radiation safety, infection and biohazard control, emergency preparedness, occupational and environmental health and safety, laboratory safety, animal care and research, diving safety, and accident prevention. Institutions provide an ideal environment for the spread of communicable diseases. They require careful surveillance and preventive measures adapted to the particular use and population. The reader is referred to the appropriate subject matter throughout this text for details.

The material that follows will highlight environmental, health, engineering, and sanitation factors at various types of institutions. The institutions have many environmental factors in common.

Hospitals and Nursing Homes

Hospital-acquired, or nosocomial, infections result in additional morbidity, mortality, and costs pointing to the need for greater infection surveillance and control.[66] The majority of nosocomial infections are endemic. They may affect not only the patient who develops the infection but also other patients, the hospital staff, and the community as well. Data accumulated over past years indicate that under certain conditions as much as half of all nosocomial infections may be preventable.[67] Most infections are probably medically or nursing related.

The hospital is expected to provide an environment that will expedite the recovery and speedy release of the patient. Carelessness can introduce contaminants and infections that delay recovery and may overburden the weakened patient, thereby endangering the patient's survival. It has been estimated that 1.5 million patients, out of some 300 million, or about 5 percent, incur infections in hospitals annually.[68]

The hospital-acquired infection rate in 1983 was highest in large teaching hospitals and lowest in nonteaching hospitals, 41.2 and 24.4 per 1000 cases discharged, respectively. Another study found a nosocomial infection rate between 5 and 6 percent. The infection rate was highest on the surgical service, followed generally by medicine, gynecology, and obstetrics. The urinary tract was the most frequent site of infection, followed by surgical wounds and lower respiratory tract, accounting for 70 percent of all infections. *Escherichia coli, Staphylococcus aureus* (coagulase negative), enterococci, and *Pseudomonas aeruginosa* were the most frequently reported pathogens, also *Klebsiella* spp., *Enterobacter* spp., *Proteus* spp., and *Candida* spp.[69] The experience was very similar in 1984.[70]

It is unlikely that the air (or surfaces) in an operating room will be sterile in the strict sense of the word, but it must be maintained at an extremely low bacterial level. Ultraviolet radiation has great potential for reducing the microbial flora of the air, where the patient may be especially vulnerable, but to be effective, particles carrying organisms must make direct contact with the radiation. Chemicals used include aerosols of triethylene glycol, lactic acid, resorcinol, and hypochlorous acid.

Numerous reasons have been offered for hospital-acquired infections: an increase in the number of older patients with chronic diseases; an increase in high-risk patients and surgical procedures such as open-heart surgery and organ transplants; innovations in diagnostic and therapeutic procedures, including widespread use of antibiotics, indwelling catheters, and artificial kidneys; inadequate disinfection or sterilization of respiratory therapy and other equipment; prevalence of *S. aureus* and group A streptococci; and the increasing identification of gram-negative organisms such as *P. aeruginosa,* proteus, *E. Klebsiella,* and *A. aerogenes*; as well as the gram-positive, toxin-producing *Clostridium dificile*.[71–73]

Basic to the prevention of nosocomial infections are hygienic medical, nursing, and staff practices, including frequent handwashing; equipment sterilization; food, water, plumbing, air, laundering, linen handling, and housekeeping sanitation, including floor cleaning to suppress dust; the prevention of overcrowding, minimization of movement of patients and hospital personnel from point to point; and avoidance of antibiotics use when possible. A major control mechanism is the establishment of a representative infection control committee, which should include appointment of a full-time environmental control officer with comprehensive responsibility and authority to coordinate and ensure that medical, nursing, housekeeping, maintenance, and ancillary staffs are following good practices and procedures, including nosocomial infection surveillance and control, proper waste handling, food sanitation, safety including radiation, and occupational health protection. This officer would also have the responsibility of being the liaison between the institution and federal, state, and local regulatory agencies, including fire, health, building, and environmental protection.

The duties of the environmental control officer would include assurance of ‘‘satisfactory’’ responses to all of the items listed in Figure 10-17. Since the survey form is merely suggestive of the broad scope of each subject and far from complete, it is apparent that the environmental control officer must be broadly trained through education and experience to recognize and appreciate the full impact of conditions observed and their possible risk to patients, staff, visitors, and community and the promptness with which unsatisfactory conditions must be corrected. Suggested preparation would include a graduate degree from a recognized institution in environmental health science or a related degree with an internship or training in institutional health management, administrative techniques, and environmental control.

A major concern in hospitals, nursing homes, and other institutions is fire safety. Basic elements include construction, detection and alarm, containment, extinguishment, evacuation, and staff training. The Department of Health and Human Services has a survey report form[74] that is used in Medicare–Medicaid

Name ____________ **Address** ____________ **T.V.C.** ________
Operator ____________ **Persons interviewed** ____________
Inst. No. ________ **No. Cert. Beds** ______ **Inspected by** ____________ **Date** ________

Item	S	U
Structure and grounds		
1. Location		
2. Buildings and grounds		
3. Accessible by emergency vehicles		
4. Service entrances		
5. Elevators		
Water supply		
6. Supply and pressure, hospital and fire		
7. Treatment, physical, biological, chemicals		
8. Quality—hospital, protect, and surveillance; incl. water carafes		
9. Quality—special, medical, and lab.		
10. Hot water		
Liquid and solid wastes		
11. Sewage piping and disposal		
12. Biological wastes collection, storage, disposal		
13. Solid wastes collection, storage, disposal; hazardous per RCRA		
Plumbing		
14. Toilets, lavatories, tubs, showers, sinks		
15. Cross-connection and backflow control		
16. Drinking fountains		
Emergency power and light		
17. Power to vital services		
18. Lighting to vital areas		
Ventilation, heat, and air conditioning		
19. Air flows, rates, pressure, differential		
20. Air filtration		
21. Air temperature		
22. Air humidity		
23. Intake and exhaust locations		
Laundry		
24. Soiled linen handling and transportation		
25. Laundering		
26. Clean linen handling and transportation		
Food protection and quality		
27. Food sources		
28. Refrigerated food storage		
29. Dry food storage		
30. Food preparation		
31. Food serving, hot and cold		
32. HACCP plan		
33. Food equipment and utensils		
34. Ice making and handling		
35. Vending machines		

Item	S	U
Insect and rodent control		
36. Physical controls		
37. Chemical controls		
Infant formula and nursery		
38. Equipment, supplies, technicians, records, practices, isolation		
39. Approved source and handling		
Space provisions		
40. Patient rooms		
41. Isolation rooms		
42. Bath and toilet rooms		
43. Nursing service areas		
44. Other services—rooms, spaces		
45. Central and general storage		
Fire safety		
46. Fire-resistive construction		
47. Interior finishes		
48. Smoke and fire doors, open		
49. Fire-resistant enclosures—chutes, shafts, stairs, kitchen, boiler, and incinerator rooms		
50. Exit doors, access, stair, hall, signs		
51. Flame-retardant fabrics, drapes		
52. Flammable liquids		
53. Flammable anesthetics		
54. Oxygen and nitrous oxides		
55. Fire hydrants, hoses, standpipes		
56. Fire extinguishers, portable		
57. Automatic sprinklers in chutes, soiled linen, trash, and storage rooms		
58. Kitchen hoods and grease removal		
59. Fire-detection systems in boiler, kitchen, labs, laundry, pantry, garage		
60. Fire-alarm system, internal		
61. Alarms connected to fire department or station		
62. Electrical hazards controlled		
63. Anesthesia areas—electrical safeguards		
64. No smoking—signs, supervision		
65. Fire plans—posting, drills, training		
Accident safety		
66. Handrails and grab bars—corridors, stairs, ramps, toilets, bath		
67. No obstacles—corridors, ramps, stairs		
68. Floors—nonslip and nontrip		

Figure 10-17 Hospital environmental health survey form. Use federal or state form where available.

Item	S	U	Item	S	U
69. Burn protection—heaters, hot water			*Supporting services*		
70. Patient furnishings and equipment			81. Housekeeping		
71. Electrical safety hazards			82. Plant maintenance		
72. Accident reporting, records			*Refrigeration (nondietary)*		
73. Lighting levels			83. Pharmaceutical and blood storage		
Infection Control			84. Morgue		
74. Infection control committee			*Pools (therapy or swimming)*		
75. Sterilization facilities			85. Recirculation and filtration		
76. Sterilization—procedure, surveillance, records			86. Disinfection		
			Radiations and hazardous wastes		
77. Sterilization of medical apparatus			87. Diagnostic X-ray units		
78. Disinfection of patient-used articles			88. Therapeutic X-ray units		
79. Cleanliness of operating, delivery, isolation rooms, and nursery			89. Teletherapy units		
			90. Radioact. materials—storage, use		
80. Disinfection of inhalation therapy apparatus			91. Microwave ovens		

NOTE:
S means satisfactory equipment, construction, operation, maintenance.
U means unsatisfactory.
Contract Services ______ Housekeeping ______ Laundry ______ Dietary ______ Other ______. Give name.

Figure 10-17 (*Continued*)

and state programs. The survey report is comprehensive and applicable to a hospital, skilled nursing facility, intermediate-care facility, and facilities with 15 beds or less.

Construction is required to comply with state and local building codes, which usually include extensive fire protection regulations. Requirements relate to such factors as construction materials, exits and exit access, corridors, protection and enclosure of vertical openings, protection of hazardous areas, smoke detection, automatic sprinkler systems, and much more.

Special precautions must be taken with kidney dialysis machines. Water for kidney dialysis machines must be very soft, low in minerals and dissolved solids, and of good physical and microbiological quality. Distillation, deionization or reverse-osmosis treatment, and granular activated-carbon treatment are usually required, as ordinary potable water may be toxic for the dialysis patient. Chloramines in water are harmful to the patient. Chloramines pass through semipermeable membranes.[75] Synthetic resins in softening ion exchange units are damaged by dioxide, chlorites, chlorates, and chlorine and, hence, are unsuitable for this purpose. Granular activated-carbon and reverse-osmosis treatment remove chlorite and free chlorine, but the removal of chlorine dioxide and chlorate is unknown.[76] Peracetic acid at 700 ppm for the cleaning and disinfection of reverse-osmosis equipment and system is reported as a promising, nontoxic substitute for certain water treatment systems.[77] The physician involved should determine the water quality standards for water used in kidney dialysis. European Pharmacopeia specifies that the water must be free of pyrogens and made exclusively by distillation for hospital use.

Wash-water temperatures in the hospital laundry have been studied by numerous investigators. A minimum temperature of 160 to 167°F (71–75°C) for 25 min is generally specified. It appears that the temperature can be reduced to 140°F (60°C) for lightly soiled hospital linens from nonisolation areas, but more investigation is needed to ensure that this temperature is adequate for the laundering of *all* linens, including isolation linens. It appears that dilution, the use of bleach, and the drying cycle are more important than water temperature in the laundering of hospital linens. Cycles at 170°F (77°C) and 72°F (22°C) were compared.[78] In any case, proper handling of laundered linen to prevent cross-contamination and contamination in handling is essential.[79]

Extensive infection surveillance and control program guidelines have been published by the Joint Commission on Accreditation of Hospitals and others.[80–82] Guidelines for protecting health care workers have also been prepared.[83]

Health care is provided in hospitals and nursing homes. A hospital usually provides acute care, including diagnosis and treatment. A nursing home provides long-term care, with limited rehabilitation. An adult home or old-age home provides room and board but not health care. The nursing home levels of care vary from ‘‘heavy care’’ to ‘‘light care’’ and may bridge the gap between the hospital and adult home.

A great deal of special emphasis has been placed on hospital and nursing home construction, equipment, and inspection or survey of operations and services. Federal and state standards are required to be met with respect to fitness and adequacy of the premises, equipment, personnel, rules and bylaws, standards of medical care, and hospital services. Plans for new structures and for additions or modifications of existing facilities are also reviewed for compliance with federal and state requirements to help ensure the best possible facilities for medical care.

The survey or inspection of hospitals and nursing homes takes into consideration the administration, fire prevention, medical, nursing, environmental sanitation, nutrition, accident prevention and safety, operational, and related matters. A proper initial survey of these diverse matters calls for a professionally trained team consisting of a physician, sanitarian, engineer, nurse, nutritionist, and hospital administrator. Figures 10-17 and 10-18 show suggested hospital and nursing home environmental survey items. Of course, they can be greatly amplified.[74] The proper interpretation of the environmental health survey form items requires a well-rounded educational background and specialized training, as previously noted, including thorough knowledge of applicable federal and state laws, with support from consultants when indicated. It is good procedure to coordinate the inspection program with the work of other agencies and develop continuing liaison with the health department, county medical society, accreditation groups, local nursing home association, local hospitals, fire department, building department, social welfare services, and others involved. This can strengthen compliance and avoid embarrassment resulting from conflicting recommendations.

Name ________________ **Address** ________________ **T.V.C.** ________
Operator ____________________ **Person interviewed** ________________
Capacity ____ **Bed patients** ____ **Amb. patients** ____ **Personnel: RN** ____ **Pract. nurses** ____ **Other** ____

Item	Yes	No	CM	Item	Yes	No	CM
Housing and fire safety							
1. Building, floors, stairs structurally sound				29. Slop sink—each floor, and 1 for 24 beds			
2. Rooms, kitchen, cellar, attic, yard clean				30. Bedpan sterilizer—1 for 24 bed patients			
3. Rooms, including kitchen, well lighted				31. Toilet room on each floor			
4. Rooms, including kitchen, well ventilated				32. Separate toilet and shower for help convenient, washbasin with sanitary towels			
5. Rooms, basement, closets free of debris				*Food protection and quality*			
6. Beds 4-ft apart and 1 ft from walls				33. Equipment and facilities sanitary and adequate for food storage, preparation, and serving			
7. Windows, doors, openings screened							
8. Free of rat and vermin infestation				34. Dishes, trays, utensils clean and disinfected			
9. Bedding clean, storage satisfactory				35. Foodhandlers clean, have lockers			
10. Heating suitable and adequate				36. Refrigeration adequate			
				37. Food service, hot and cold. HACCP plan			
11. Fire-resistive construction							
12. Smoke and fire doors provided				38. Pasteurized milk served in indiv. carton			
13. Boiler rm. and incin. fire-resistant				39. Refuse storage and disposal satisfactory			
14. Exit door signs posted				40. No poisons stored in kitchen			
15. Flame-retard. drapes, fabrics				41. Menu planned week in advance			
16. Fire alarm system connec. to fire dept.				42. Meals nutritionally balanced			
17. Fire plans posted; drills				43. Food service attractive			
18. Flammables secured				44. Leftovers used promptly			
19. Elec. hazards controlled							
Water supply				*Medical and nursing service*			
20. Water supply approved; fire hydrant within 500 ft				45. Mental and TB cases prohibited			
21. Adequate supply hot and cold				46. Patient accidents and CD reported			
22. Sanitary drinking fountain or paper cups				47. RN always in attendance			
				48. Adequate competent help available			
23. Cross-connection and interconnection prohibited				49. Employees free of CD			
24. Backflow preventers on WC, flushers—bedpan				50. Helpless patients get special attention			
Sewage and toilet facilities				51. Records kept giving: (*a*) Name of MD for patient (*b*) Name and address of patient, sex, color, age, marital status, occupation, place of birth, admission, diagnosis, discharge, relative			
25. Sewage disposal satisfactory							
26. Waterclosets—1 for 8 beds							
27. Washbasins—1 for 8 beds							
28. Shower or tub—1 for 12 beds							

Figure 10-18 Nursing home inspection form. Use federal or state form where available.

	Yes	No	CM		Yes	No	CM
(c) Clinical history and treatment, medications, signed MD's orders				53. Drugs properly labelled in cabinet			
(d) Qualification of nurses and attendants				54. Adequate dressings and supplies			
(e) Narcotics on hand, dispensed				55. Recreation facilities for patients			
52. Narcotics stored in locked cabinet				56. Occupational therapy 57. Infectious wastes segregated			

Explain "No" items, use back NOTE: CM indicates correction made.

REMARKS ______________________________

____

Date inspected ______________ By ______________

Figure 10-18 (*Continued*)

Special attention should be given to non-fire-resistive hospitals and nursing homes, if permitted. Until such places can be replaced with fire-resistive structures, they should be protected against possible fire. This would include automatic sprinklers and alarms; horizontal and vertical fire stopping of partitions; enclosure and protection of the boiler room; outside fire escapes; fire doors in passageways, vertical openings, and stairways; fire detectors, smoke detectors, and fire extinguishers; a fire evacuation plan and drills; 24-hr surveillance; and the housing of nonambulatory patients on the ground floor. These comments are also generally applicable to other health care facilities. Building and fire protection codes must be followed.

Surveillance by official agencies, voluntary organizations, and individuals should ensure that fire protection, safety, and medical care are not compromised in spite of increased costs or lack of funds.

Hospital and Related Wastes Hospital wastes may include pathological, infectious, hazardous chemical, and radioactive wastes as well as cultures and stocks, blood and blood products, animal carcasses, pharmaceutical wastes, pressurized containers, batteries, plastics, low-level radioactive wastes, disposable needles, syringes, scalpels, and other sharp items. These are in addition to food service, laboratory, bandage, cleaning, and miscellaneous wastes. Proper handling, segregation, packaging, marking, storage, transport, treatment, and disposal of all hospital wastes are necessary to minimize the potential risks to the health of the patient, health care worker, visitor, refuse handler, and community.[84,85] Only about 15 percent of all hospital wastes are infectious. Although of public health and aesthetic concerns, they do not pose a health risk for the general public.

Infectious and pathological wastes, including packaging, disposable needles, syringes, and scalpels, are best disposed of by incineration providing proper temperature, oxygen, and residence time and by autoclaving followed by compaction or shredding. Chemotherapy and pathological wastes are incinerated. Autoclaved wastes are disposed of in a landfill or incinerator. Older hospital incinerator emissions can be expected to be high in particulates, chlorinated toxins, hydrochloric acid, and chlorine (in view of the burning of large quantities of plastic wastes), if the waste is not well mixed and if proper design and operation, including air pollution control devices, are not provided. Most, if not all, old hospital incinerators require upgrading.

Recommendations to equal or exceed air quality standards include temperature of 2000°F (1093°C) with 2 sec residence time and secondary chamber exit temperature of 1800°F (982°C); 97 percent acid gas removal or 30 ppm; particulates 0.010 gram/ft^3; CO emissions 100 ppm hourly average; and opacity less than 10 percent.[86] A controlled starved air incinerator with flue gas scrubbers has been found satisfactory to control emissions.[87]

General hospital and kitchen wastes can usually be disposed of through the community waste collection system. Centralized regional incinerators and autoclaving with compaction or shredding for hospital wastes are usually recommended over individual plants. Other alternatives include chemical disinfection of macerated wastes with discharge to the sewer system (if permitted by the regulatory agency) and microwave disinfection of shredded wastes. Liquid infectious wastes may be carefully poured to a drain connected to a sanitary sewer.[88]

The usual method for the disposal of *low-level* radioactive solid waste is by storage until decayed, followed by disposal with the general waste. Low-level liquid waste, including body wastes, can be diluted and disposed of to the sanitary sewer. Gaseous radioactive wastes are dispersed directly to the outside air, away from any indoor air intakes or occupied areas. The entire process requires responsible regulatory and institutional surveillance.

The EPA regulates the handling of hazardous wastes and OSHA has jurisdiction over chemical carcinogens and other hazardous chemicals in work areas. Hospital wastes are also controlled by the Nuclear Regulatory Commission, the Toxic Substances Control Act, and the Resource Conservation and Recovery Act. State and local regulations must also be followed. It is incumbent upon hospitals and other generators, including clinics, medical laboratories, nursing homes, doctors, dentists, and veterinarians, to identify infectious and hazardous materials. They must protect workers, patients, and visitors from any hazard within the institution, clinic, or office and the community from any discharges or releases to the air, water, and land.[89] See also Infectious and Pathological Wastes, Chapter 5, for definitions, handling of infectious waste, and disposal.

Schools, Colleges, and Universities

Schools, colleges, and universities may incorporate a full spectrum of facilities and services not unlike a community. Involved—in addition to basic facilities such as water supply, sewage and other wastewater disposal, plumbing, solid waste management, and air quality—are control of food preparation and service, on-site and off-site housing, hospital or dispensary, swimming pool, radiation installations and radioisotopes, insect and rodent infestations, and safety and occupational health in structures, laboratories, and work areas, including fire safety, electrical hazards, noise, and hazardous materials. In view of their complexity and their effect on life and health, all institutions should have a professionally trained environmental health and safety officer and staff responsible for the enforcement of standards, such as in a sanitary code, encompassing the areas of concern noted above. Such personnel can work closely with federal, state, and local health and safety regulatory officials and thus provide maximum protection for the student population and teaching, research, and custodial staffs.[90–93] Figures 10-19 and 10-20 suggest the broad areas to be considered when making an inspection. Guidance as to what is considered satisfactory compliance can be found in this text under the appropriate headings and also in federal, state, and local publications.

Correctional Institutions

Correctional institutions include short-term jails, long-term prisons, and various types of detention facilities. The health care services may include primary health care services, secondary care services, health care services for women offenders, mental health care, dental care, environmental concerns, nutrition and food services, pharmacy services, health records, evaluation services, and staffing. Environmental health concerns are discussed below.

Incarceration may result in or intensify the need for health care services. The provision of a safe and healthy environment, services, and facilities would minimize the need. Food poisoning, poor and insufficient food, vermin infestations, inadequate work and recreational programs, and overcrowding are known causes of prison unrest and illness. Overcrowding and poor food quality and food service are major problems at many jails and prisons. Walker[94] summarizes the problem very clearly in pointing out that

> overcrowded conditions often overtax the ventilation system and sanitary facilities, minimize privacy and personal space. Without privacy and personal space, the basic psychological and physiological needs of the residents are not met; tension and hostility grow; security requirements increase; and a negative cycle is put into play.

The elimination of overcrowding and improvement in the wholesomeness, quantity, and sanitation of food service can eliminate major causes of discontent.

The environmental aspects of correctional institutions are in many respects similar to those of other institutions and are concerned with many of the same basic environmental engineering and sanitation facets of a community.

Name ________ **Location** ________ **T.V.C.** ________
Principal ________ **Supt. of Schools** ________ **Date** ________
Grades ____ **No. classrooms** ____ **No. boys** ____ **No. girls** ____ **Public** ____
Private ____ **Parochial** ____ **Boarding** ____

Item	Yes	No	CM
1. Water system approved by health department			
2. One sanitary drinking fountain for every 75 children, or			
3. One sanitary paper-cup dispenser for every 75 children, where needed			
4. One washbasin with warm and cold water for every 30 students			
5. Soap, paper towels, and mirrors provided			
6. One toilet including tissue and partition for every 35–45 girls, and one toilet including tissue and one urinal for every 30–40 boys; separate.			
7. Toilet and lavatory rooms convenient, clean, free of odors, ventilated; floors impervious and drained			
8. Shower and locker room clean, drained; adeq. warm water			
9. Sewage and excreta disposal satisfactory			
10. Buildings of fire-resistive construction			
11. Corridors, stairs, exits, doors marked and provide safe and ready escape from building in case of fire			
12. Flammables stored in metal cans			
13. Fire extinguishers, sprinkler heads, fire hydrants, fire hose, fire alarm, fire escapes, panic bolts operable and tested every 6 months.			
14. Fire drills conducted, each floor emptied in 2 min.			
15. Poisons, etc., labeled and secured			
16. Seats in classrooms face away from window or light sources; no glare			
17. Natural and artificial light provided			
(*a*) 50-ft-c in classrooms, libraries, offices, shops, laboratories, gymnasium, pool			
(*b*) 75-ft-c in sewing, drafting, and arts and crafts rooms			
(*c*) 50-ft-c in sightsavings classrooms			
(*d*) 10-ft-c in auditorium, assembly rooms, cafeterias			
(*e*) 10-ft-c in locker rooms, corridors, stairs, toilet rooms			
(*f*) 70-ft-c in kitchen			
18. Thermometer at seat level, provided, which reads in winter at			
(*a*) 68–72°F in classrooms, auditoriums, offices, cafeterias			
(*b*) 66–70°F in corridors, stairways, shops, laboratories, kitchen			
(*c*) 60–70°F in gymnasium			
(*d*) 76–80°F in locker and shower room			
(*e*) 80–86°F in swimming pool			
19. In nonheating season, when outdoor temperature reads 80°, 90°, 95°F, inside temperature reads 75°, 78°, 80°F, respectively.			
20. Ventilation and heating satisfactory (10–30 ft^3 per min per person); drafts and excessive heat prevented			
21. Place provided to store clothes, lunch boxes, rubbers			
22. A separate adjustable and movable seat and desk available for each child			
23. Class room provides 25–30 ft^2; per pupil			

Figure 10-19 School sanitation inspection form.

	Yes	No	CM		Yes	No	CM
24. Buildings, windows, rooms, chalk boards, lights, fixtures, corridors, walls, ceilings, etc., clean; grounds free of litter, insects, rodents, weeds, pools of water				28. Solid wastes properly stored and disposal satisfactory			
25. Swimming pool operated and maintained in conformance with sanitary code requirements*				29. Air pollution prevented			
26. Dining room or cafeteria operated and maintained in conformance with sanitary code requirements*				30. A competent person assigned responsibility to see that all environmental hygiene precautions are observed by teachers and students. (Incorporate in curricula.)			
27. Safety precautions taken in shops, laboratories, play area				31. Floors, walls, ceilings in good repair			
				32. No hazardous asbestos			

NOTE: CM indicates correction made.

*Use separate inspection form. Explain "No" items.

REMARKS ______________________________

____

Date inspected ______________ By ______________

Figure 10-19 (*Continued*)

Designs for new construction and major alterations should be reviewed and approved by the regulatory agencies having jurisdiction and, in any case, comply with nationally recognized standards. Regulatory agencies should make annual inspections and reports of the facilities and services in the same manner as is done for other state, municipal, and public facilities and establishments.

Environment Inspection and Report Outline A comprehensive inspection and report would involve investigation of the following items:

1. *Grounds and Structures*
   a. Location, accessibility, service entrances, cleanliness, noise.
   b. Protection from flooding; drainage.
   c. Construction materials and maintenance; dampness, drafts, leaks; sound and in good repair.
   d. Fire protection, municipal and on-site; adequacy; water supply; alarms.
   e. Safety, accident prevention, road signs, lighting.
2. *Utilities*

Name ______ Address ______ T.V.C. ______
Operator ______ Persons interviewed ______
Capacity ______ Men ______ Women ______ Inspected by ______ Date ______

Item	S	U
Water supply		
1. Quality meets drinking water standards		
2. Quantity—yield storage, pressure adequate—hot and cold		
3. Operation, maintenance, and reports satisfactory, no backflow		
4. Qualified operator		
5. On routine sampling schedule		
Sewage and toilet facilities		
6. Flush toilets adequate		
7. Wash basins adequate		
8. Showers adequate		
9. Service sinks adequate		
10. Treatment meets stream standards		
11. Operation, maintenance, and reports satisfactory		
12. Qualified operator		
Air pollution control		
13. Incinerator emissions meet standards		
14. Boiler emissions meet standards		
15. Process emissions meet standards		
16. Fuel composition and use acceptable		
Solid wastes		
17. Garbage storage and collection satisfactory		
18. Refuse storage and collection satisfactory		
19. Disposal satisfactory		
Swimming pool and bathing beach		
20. Life-saving equipment and lifeguards adequate		
21. Adequate clarity		
22. Adequate treatment and reports		

Item	S	U
Dietary		
23. Food sources approved		
24. Refrigerator storage temperature, space, clean		
25. Dry storage clean, dry, space		
26. Food preparation, handling, cooling proper		
27. Food service temperature and protection satisfactory		
28. Utensils and equipment type, condition, satisfactory		
29. Dishwashing—dishes, utensils		
30. Handwashing facil. adequate, convenient		
Structure and grounds		
31. Location suitable		
32. Buildings and grounds well drained		
33. Accessible by emergency vehicles		
34. Service entrances convenient		
35. Elevators serve all floors		
Radiation		
36. Diagnostic X-ray units satisfactory		
37. Therapeutic X-ray units satisfactory		
38. Teletherapy units satisfactory		
39. Radioactive materials properly stored, used		
40. Microwave units satisfactory		
Housing and safety		
41. Rooms clean, lighted, ventilated		
42. Fire escape from rooms		
43. Adequate space for occupancy		
44. Insect and rodent control effective		
45. Clean bedding		
46. Heating safe and adequate for intended use		
47. Fire protection adequate		
48. Fire-resistive construction		
49. OSHA standards met		

S means substantially satisfactory equipment, construction, operation, maintenance.
U means unsatisfactory. Use available codes, rules, and regulations for compliance. Mark items NA if not applicable.
Supplied services ______ Water Supply ______ Sewerage ______ Refuse Collection ______ Dietary ______ Other ______. Give name of contractor or supplier.

Figure 10-20 Abbreviated institution environmental health inspection form. (For comprehensive interpretations, see pertinent sections of this text.)

a. Water supply: source, treatment, storage and distribution, quality, quantity, pressure; quality surveillance and compliance with federal and state standards; operation control.
b. Wastewater collection and disposal: sewage and all other liquid waste collection, treatment, and disposal; compliance with federal and state standards; operation control.
c. Solid wastes: storage, collection and disposal; storage areas or rooms, cans, bins; on-site processing and disposal; hazardous waste handling, storage, and disposal; compliance with federal and state standards.
d. Heating, electricity and air conditioning; adequacy; safety.
e. Air quality: power plant, incinerator, institution operations; compliance with federal and state standards.
f. Emergency power and disaster planning; power to vital services and lighting to vital areas.

3. *Shelter*
   a. Temperature control: heat, ventilation, humidity control, cooling.
   b. Lighting: walkways, assembly areas, cells, kitchens, work areas, special uses, and facilities.
   c. Space requirements: cells, assembly areas, recreational areas, dining rooms, visiting areas.
   d. Fire safety: fire-resistive construction; compartmentation; interior finishes; enclosures, doors, stairs; extinguishers and extinguisher systems, sprinklers, detection and alarm systems; fire water supply; fire plans and drills.
   e. Accident prevention: physical design, working conditions, fire and electrical hazards; occupational exposures and recreational facilities; also, occupational health standards (OSHA) as applied to jails and prisons. Drugs, pesticides, flammables, and other hazardous materials stored in a secure place.
   f. Housekeeping: general cleanliness and maintenance; facility interior surfaces (walls, floors, ceilings, facilities, equipment); equipment and facilities maintenance; grounds and spaces; roster and cleaning schedule.
   g. Noise: interior, exterior; mechanical equipment, work areas comply with OSHA standards.
4. *Services and Facilities*
   a. Food and protection: wholesomeness, refrigeration, storage, preparation, transportation, service; processing; equipment; foodhandler inspection; ice; vending machines.
   b. Radiation protection: diagnostic, therapeutic, teletherapy, X-ray units; radioactive materials storage and use; microwave ovens; industrial uses.

c. Vermin control: rodents, insects, and other arthropods; physical and chemical controls; pesticide storage secure and used as directed on label.
d. Laundry facilities: soiled linen and clean linen separate storage, handling, and transportation; laundering process.
e. Plumbing: water, soil, and waste lines, drains, toilets, washbasins; adequacy of hot and cold water for all purposes; service sinks; cross-connection and backflow control.
f. Recreational facilities: bathing beach, swimming pool; other; life-saving equipment and life guards; water clarity and quality; accident control; maintenance, operation and sanitation facilities; safety.
g. Institutional operations: canning, slaughtering, dairy, pasteurization; other farm operations; manufacturing; vocational training; hospital; laundry; bakery.
h. Facilities available for public and staff: toilets; dressing rooms; visiting areas.
i. Medical care facility area: storage of drugs; disinfection and sterilization; refrigeration of blood and drugs; morgue.

5. *Personal Hygiene*
   a. Personal hygiene: infestation and disinfestation; showers, towels, clothes, toiletries, etc.
   b. Bedding: mattresses, pillows, sheets, blankets, beds.
   c. Toilet and bathing facilities: number and type of water closets, squatting plates, washbasins, showers; removable pail privies.
   d. Barber and beauty shops: room designated, equipped, staffed.
6. *Personnel and Supervision*
   a. In-service training: staff and inmates having environmental sanitation responsibilities.
   b. Self-inspection: qualified person designated, responsible to administrator.
   c. Regulatory agencies: inspection and approval of facilities and services annually.

Because of the diverse facilities and services involved, it is essential that the regulatory person assigned to make inspections be broadly trained and have the experience and maturity to know when to call upon a specialist to investigate in greater detail and resolve complex problems. Many resources, including specially trained consultants, laboratory facilities, regulations, and inspection services, are available from various departments and agencies of the government (including federal) as well as national organizations. These should be utilized to identify and help resolve potential and actual deficiencies.

The basic principle involved, the public health rationale, and the basis for satisfactory compliance for each item listed above are given in *Standards for Health Services in Correctional Institutions*.[55]

Day-Care Centers

Day-care centers provide an environment for children of an age conducive to the spread of respiratory, contact, and water- and foodborne diseases discussed in Chapter 1 and in this section. They can also lead to other disease complications. Diapering and food preparation and service are critical activities requiring scrupulous cleanliness and frequent handwashing. Enteric and respiratory disease transmission via the fecal–oral route and by intimate contact is more common among children in a day-care center. Multiple pathogen infection is not uncommon. *Cryptosporidium* spp., *Giardia lamblia, Salmonella, Shigella sonnei, E. coli* (toxic strain), and enteroviruses are some of the more commonly found enteric pathogens in reported outbreaks. The increased interest and private, federal, and state support of day-care centers and their consequent expansion make their regulation an important public health function. Here is an opportunity to apply known preventive measures, including frequent handwashing, hygiene, food sanitation, separation of ill children, and education of staff and management, in disease transmission and prevention.[95]

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11 Environmental Emergencies and Emergency Preparedness

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INTRODUCTION

Currently, and for the foreseeable future, the focus of emergency preparedness will likely be in two areas: protecting environmental media as well as public health and safety from the potential effects of releases of hazardous substances and protecting vital services from possible terrorist attacks.

Before the toxic release catastrophe of Bhopal, India, in 1984, emergency planning was the exception rather than the rule for institutions other than the nuclear industry because there was no regulatory impetus for them to do otherwise. In the wake of the Bhopal tragedy and other accidental chemical releases, public concern escalated dramatically. This became even more acute with the advent of environmental regulations that sought to identify the magnitude of the release of hazardous substances to the environment. Whether "chemophobia" results from actual or perceived dangers is unclear, but in the public mind, perception is reality, and thus emergency preparedness is now commonplace.

The Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard, or Worker Right-to-Know, became fully effective in May 1986 and amended as of February 13, 1996.[1] Its purpose is to ensure that employees are aware of hazards in the workplace. The public continued to demand protection, and the Emergency Planning and Community Right-

This chapter is based in part on "Emergency Preparedness" by C. C. Burns and P. M. Armenante, in *Risk Assessment and Risk Management for the Chemical Process Industry,* H. R. Greenberg and J. J. Cramer (Eds.), John Wiley & Sons, New York, 1991, pp. 263–304.

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0-471-41813-7

to-Know Act (EPCRA), Title III of the Superfund Amendments and Reauthorization Act (SARA) of October 1986, was the result.[2] The onus of Title III is on states and local communities to develop plans for responding to hazardous materials emergencies. Additional federal regulation, that is, OSHA 1910.120—Hazardous Waste Operations and Emergency Response often referred to as HAZWOPER, became effective in March 1990.[3] It mandates emergency response and preparedness programs for industry that include required interface activities with off-site agencies and prompt notification to them of an emergency situation. Companies must have a written emergency action plan in place to comply with 29 CFR 1910.38,[4] and an employee alarm plan per 29 CFR 1910.165.[5] Some states have even more prescriptive regulations. New Jersey's and Delaware's Toxic Catastrophe Prevention Acts (TCPA)[6] are examples. In addition to the sudden release of a substance, environmental emergencies can take on other forms. The discovery of a leaking underground tank or a number of buried drums requires a response that seeks to protect human health or the environment, particularly when the release threatens a water supply or a fragile ecosystem. The response to these situations involves equally important planning activities among federal, state, and local groups.

The planning process is the key to successful emergency preparedness. Relationships among the plant, local government, and the community are often fragile. The planning promotes interaction among participants. The planners become aware of one another's strengths and weaknesses, which are factored into the response mechanism. Therefore, the planning process should not be circumvented by reworking a document prepared by others because this diminishes the importance of the planning process and the interaction of those responsible for implementing it.

The planning process can take many forms. Normally, emergency response planning is thought of as being undertaken for unpredictable but anticipated sudden events, such as a spill or gas release. However, planning is critical to the response to any environmental event as well. For example, a concern about the indoor air quality at a school or office building requires detailed planning with regard to sample collection, instrumentation, and analytical procedures if the data are to be meaningful and useful to design a remedial approach.

EMERGENCY PLANNING FOR INDUSTRIAL FACILITIES

Initially, the emergency planning process focuses on analysis of the situation. Members of the planning team use analytical skills to approach the problem. They will, for example, analyze the hazards associated with the facility; assess the resources currently available to control a potential emergency event, determine the facility command structure, determine what external resources exist, collect information on applicable codes and regulations, and analyze existing plans and assess their validity.

Once this initial work has been completed and relevant material has been collected, emphasis switches toward the preparation of the actual plan document. This includes allocation of the resources needed to control emergency events, procedures to raise the alarm and assess the severity of the situation, establishment of a chain of command and emergency response structure and definition of response strategies to protect people, the environment, and property while mitigating an event. These activities lead to synthesis of the previously accumulated information into a cohesive emergency response organization and structure.

An effective emergency response plan should include pre-emergency planning and off-site coordination, identification of roles and responsibilities of assigned personnel, training programs, communication structure, emergency recognition and prevention, identification of safe distances, places of refuge and evacuation routes, decontamination procedures, emergency medical treatment and first aid training and locations, emergency alerting and response procedures and identification of personal protective equipment (PPE), and emergency equipment.

Resources

Facility response teams typically comprise specially trained personnel normally operating the plant itself and therefore familiar with it and its hazards. However, as part of the planning process, a resource assessment should be performed. Figure 11-1 presents a sample format for performing a resource assessment. The list is comprehensive; facilities should select only those resources appropriate for their anticipated response activities.

The resource assessment should consider not only facility resources but also those available in local municipalities and at neighboring industrial facilities. The local fire department, however, may be trained to cope only with the most common emergencies, such as structural fires and rescue, or perhaps for hazardous material transportation accidents. Thus, they may only support the primary response actions that plant personnel must implement in a serious emergency. Local resources will, however, become essential if the emergency spreads beyond the plant boundary or is the result of a transportation accident.

Emergency Operations Centers (EOCs)

All but very small plants should establish an EOC from which response activities can be directed and coordinated whenever a major emergency is declared or anticipated. Upon declaration of an emergency, the emergency management staff, including the highest ranking persons in charge of the operation, will activate the EOC. The EOC should be equipped with adequate communication systems such as telephones, radios, and other equipment to allow unhampered communication with the site response teams, external agencies, and other response organizations.

Resources	*Current*	*Required*	*To Be Acquired (Acquisition Date)*
Emergency control/operations center			
Media center			
Site notification system			
Off-site notification system			
Communications equipment			
Personal protective equipment			
Meteorological equipment			
Firefighting equipment			
Spill control equipment			
Monitoring equipment			
First aid capability			
Security and access control equipment			
Auxiliary power			
Trained employees			

Figure 11-1 Resource assessment chart.

The EOC should be located where the risk of exposure to accidental releases is minimal. When possible, it should also be located close to routes easily reached by response personnel. Only a limited and prearranged number of people should be admitted to the EOC. This eliminates unnecessary interference and reduces confusion.

The EOC should be designed to protect its occupants against releases, especially against infiltration of toxic vapors. A small meteorological station (or at least a wind sock) should be located nearby to monitor wind direction and velocity. The EOC should have an uninterruptible power supply or at least backup power for lighting and electric communication system operation. The EOC should always be ready for operation. It need not be a single-purpose room; a conference room can be easily adapted for this purpose.

Media Center

A media center is a designated room located on or near plant property where representatives of the various news media would be admitted during an emergency. This center should be located near the plant entrance and be the only area accessible to news reporters. This limits access to the facility for all nonessential personnel.

The public affairs officer should ensure that the necessary media material is stored at or near the media center. Such material should include a fact sheet on the facility describing the number of employees, annual payroll, taxes paid to the community, a simple description of the plant processes, consumer products that are produced either at the facility or ultimately from its operations, and a facility map.

Communication Equipment and Alarm Systems

Communication equipment and alarm systems are essential to notify plant personnel, to notify external agencies, and to coordinate response operations. Initial notification equipment and procedures are especially important because their effectiveness determines how rapidly the response actions can be initiated. Communication equipment must be available to each function within the response organization to prevent communication breakdowns.

Horns, Sirens, and Public Address Systems Audible alarm systems are commonly used in many industrial facilities. Horns and sirens rely on different types and lengths of tones to convey messages. An alarm should not just warn but also instruct people to perform specific assignments. However, horns and sirens can convey only a very few simple messages. Public address systems are limited in areas of excess external noise. In high-noise areas, it is appropriate to install a visual signal (e.g., a flashing light) as well as an audible alarm system. Systems that use belt-worn vibrators as alarm signals are also in use.

Telephones Telephones are often the preferred means of communication for reporting emergencies and for communicating between different areas of the plant. The EOC should be equipped with enough telephone lines to enable all the members of the response teams to communicate effectively. Some lines should be equipped for outgoing-only capability. Cellular phones are also very useful in emergencies. They can be used to notify response personnel who are away from the plant, by emergency management to direct operations while on the way to the site, and even to coordinate the entire response effort.

Portable Radios Radios are most effective for communicating with emergency response teams operating in the field. In addition, they can be a backup system in case of telephone communication breakdown. Emergency response radios should operate on a frequency dedicated for emergency communications only.

Personal Protective Equipment (PPE)

The main function of PPE is to protect personnel from a hazard while performing rescue or emergency control operations. Protective clothing for protection against heat radiation or those having high resistance to chemical assault (acid suits) are typically used by response personnel. The most important pieces of protective equipment in both fire and toxic release events are the self-contained breathing apparatus (SCBA).

Personnel performing tasks that require prolonged exposure to a toxic environment such as smoke or toxic vapors typically use SCBA. The use of SCBA requires training. It is also important to remember that personnel performing any such containment or control operations must be trained in accordance with the appropriate levels of emergency response mandated by 29 CFR 1910.120 (q).[3] The PPE and SCBA should be stored in strategic locations throughout the plant, for example in control rooms, EOCs, the firehouse, special plant units, and the emergency supply storage area. A compressor is required for refilling the cylinders. The SCBA should be inspected and serviced periodically through a preventive maintenance program.

In addition to protective clothing, there are a variety of instruments available to monitor the conditions surrounding emergency response personnel. Portable gas detectors that are intrinsically safe for service in hazardous environments are available. These devices can be supplied with sensors that can monitor methane, toxic gases, lower explosive limit, chlorine gas, hydrogen sulfide, carbon monoxide, and oxygen deficiency. Also, portable gas chromatographs are available that can provide compound-specific data on the concentrations of gases in the breathing zone as well as preliminary information on contaminated soil or water.

Firefighting Facilities, Equipment, and Supplies

Medium-sized and large plants usually have some type of firefighting capability. Fire pumper trucks are the most important units. National Fire Protection Association (NFPA) standards provide details on the equipment to be carried on pumpers and on ladder trucks. For example, NFPA provides guidelines for the use, maintenance, and service testing of fire department ground ladders.[7] A firewater distribution system is common to many industrial facilities. Arrangements should be made to access water tank trucks to supply additional water if the need arises.

Specialized firefighting equipment is often necessary at industrial sites because of the unusual chemical process. For example, dry chemical units carrying large quantities of dry extinguishing material such as potassium bicarbonate (purple K) may be necessary where water cannot be used as an extinguishing agent.[8] Fire extinguishing foam is probably the most frequently used nonaqueous medium.

Spill and Vapor Release Control Equipment

Few methods are available to control a vapor release after it has occurred. Fixed abatement systems (e.g., water curtains) spraying an absorbent such as water into the dispersed cloud of a soluble vapor such as ammonia and hydrogen chloride or fluoride are sometimes used.[9,10] Sometimes, dispersion of gases in air below their flammability point can be achieved using water streams.

Special tools may be required to perform some response operations such as plugging a leak or shutting off jammed isolation valves. Equipment for stopping and containing a liquid spill is also necessary. Emergency containment systems, such as booms and portable dikes, can be built to limit the leaching of spilled material into the ground and to nearby sensitive areas. Quick-setting foams can be applied to create an impermeable barrier to limit leaching of spills into the ground. These foams can also be used to temporarily plug a leak.[11] Also, emergency spill containment barriers designed for rapid deployment are available. These units are manufactured from chemical-resistant flexible membranes and have self-supporting perimeter chambers. Vacuum trucks are another useful type of spill response equipment. These trucks can quickly collect surface liquids for transport to appropriate disposal facility.

Medical Facilities, Equipment, and Supplies

Most industrial facilities have a medical center. This facility should be equipped to deal with the most likely medical emergencies at the particular site and contain a file of material data safety sheets (MSDSs) on site-specific chemicals. Additionally, the plant response team personnel should be trained in cardiopulmonary resuscitation and should be equipped with the most common types of rescue equipment.

Meteorological Equipment

During toxic release emergencies, meteorological conditions greatly affect migration speed and direction. The most important of these parameters are wind direction and speed. A facility should have one or more meteorological stations where this key information is constantly monitored. The station needs not be complex. Care should be taken to avoid locations where the presence of buildings and other structures may result in faulty readings. In addition to mounting windsocks on the highest point for optimum visibility, windsocks should also be located close to the ground so that people leaving a building in an emergency know in which direction to run to avoid a toxic plume.

Security and Access Control Equipment

In an emergency, it is likely that traffic flow around the plant may have to be redirected, especially if toxic material has contaminated nearby areas. Equipment such as flares, emergency lighting, road barriers, reflective vests, reflective tape and traffic control cones should be available to security personnel.

Environmental Testing

While initially the emphasis of the emergency response will focus on containment and control of the situation, it will quickly shift to evaluation of the potential impacts to the environment. Thus, planning should also include methods to quickly assess the degree of potential environmental impacts. While it is not normal for a facility to own a drill rig or soil-testing apparatus, planning should include mechanisms to acquire these services rapidly, if needed. By quickly assessing the magnitude of potential impacts, an effective remedial response that will control potential threats can be developed. Hydraulic push soil-sampling machines are very useful to collect near surface soil and groundwater samples, and a variety of instruments are available to do field analysis of the samples. Also, arrangements should be made with a nearby environmental testing laboratory to provide rapid turnaround analysis of samples.

EMERGENCY ACTION LEVELS

A practical way to classify the seriousness of an incident and quickly convey this information to other personnel is to use emergency action levels (EALs), which may be designated by code names or numbers associated with situations of different intensities. The higher the number, the more serious the problem. A three-level classification system is adequate, as described below[12]:

Level 1: Alert The lowest emergency level, this EAL may be associated with an unusual event that is either under control or can be easily brought under control by plant personnel.

Level 2: Site Emergency This intermediate emergency level is associated with fires, explosions, or toxic releases that affect more than the immediate area but have not spread beyond the plant boundary. Off-site populations are not expected to be affected by this event.

Level 3: General Emergency This is the most critical emergency level and implies that the emergency event already has spread or has the potential for spreading beyond plant boundaries. If a toxic release has occurred, the outside population may be affected and, depending on the type of release, may be instructed to take shelter or evacuate.

The use of EALs has the advantage of standardizing response to different classes of events in terms of the resources mobilized to cope with the emergency. It also improves communications during critical times.

EMERGENCY RESPONSE ORGANIZATION

The major objective of contingency planning is the creation of a response organization structure capable of being deployed in the shortest time possible during an emergency. For this purpose, the following needs to considered:

- Who will be in command of emergency operations?
- Will the command structure change as more response personnel reach the event site?
- How will the command structure evolve if the emergency worsens?
- Who will decide what company resources to allocate to mitigate the consequences of the event?
- Who maintains communication with whom during an emergency?
- Which emergency functions (e.g., firefighting, engineering, medical) should be deployed?
- Who will be in charge of each specific emergency response function?
- Where should the command post(s) be located?
- Who decides which protective actions to recommend?
- Will environmental testing be required?
- Who decides when the emergency is over?
- Who is responsible for recovery operations?

A response organization, complete with command structure, should be developed. One method of arriving at this is to first develop a responsibility matrix of emergency organization functions versus the departments or positions that will have primary and support responsibilities for performing them. An example of such a matrix is presented in Figure 11-2.

Function / Department/ Individual										

Figure 11-2 Emergency responsibility matrix.

Initial-Response Organization

The timely implementation of appropriate initial response actions may significantly mitigate the consequences of an emergency. One person should be designated to be in charge of the initial response. Usually, responsibility for coordinating these early emergency response actions is assigned to the shift supervisor. The shift supervisor assumes the function of emergency director and assesses the level of severity of the emergency event using the emergency action level classification system; notifies the appropriate personnel, departments and agencies; and directs the response activities.

Other plant personnel are also assigned the task of covering the other key functions in the initial emergency response organization until the predestinated personnel arrive to relieve them. Initially, the production or operations manager, who could also act as the field operations coordinator, takes the post of response operations coordinator. Alternatively, the production supervisor of the unit where the emergency occurs could take the latter position. These two coordinators are in charge of organizing response activities and directing response operations at the actual emergency scene.

Full Emergency Response Organization

The deployment of the full emergency organization is required only in the case of severe emergencies. An example of a full emergency organization chart is given in Figure 11-3. Multiple personnel are assigned to all emergency functions in the event that the principal person is unavailable to cover that position. The personnel assigned to each of the different functions shown in

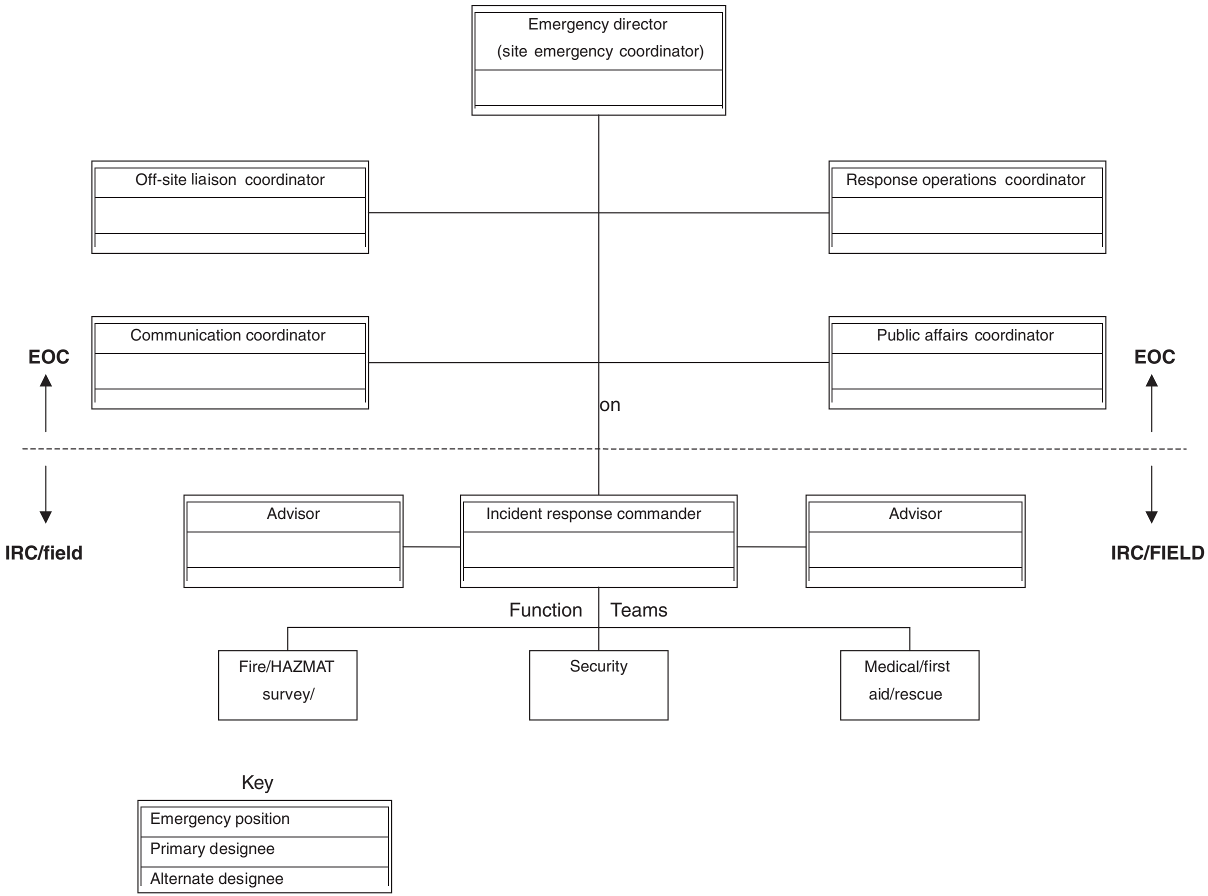

Figure 11-3 Emergency response organization.

Figure 11-3 play key roles in implementing the decisions made by the emergency director. They decide what appropriate response actions to take, such as shutting down the plant, fighting fires, evacuating plant personnel, recommending that the public be evacuated from certain areas, carrying out emergency repair work, arranging for supplies or equipment, and coordinating actions with local off-site agencies.

Emergency Director (Site Emergency Coordinator)

The emergency director responsibility includes those actions necessary to bring the emergency under control and the overall supervision of the protective actions recommended for the public, employees, and the environment. It is recommended to the degree possible that the same hierarchical structure used during normal operation should be maintained during an emergency. Thus, the plant manager should be assigned the emergency director position, if possible.

Response Operations Coordinator

The response operations coordinator operates in the EOC and is responsible for coordinating the activities. The response operations coordinator performs the following functions:[12]

- assists the emergency director in organizing and directing emergency activities,
- formulates strategies on actions to be taken to mitigate consequences of the event,
- maintains direct communication with the on-scene incident commander, and
- requests additional personnel and equipment resources.

The response operations coordinator should be very knowledgeable of the plant and its response plan and organization. In small plants, this position may coincide with the emergency director function. In other cases, the plant manager may assume the emergency director function, mainly because of the responsibilities associated with this role and his or her overall responsibility for the safety of the facility. The response operations coordinator may perform the bulk of the coordination activities.

Incident Response Commander (IRC, Field Operations Coordinator)

The incident response commander or field operations coordinator is the highest ranking officer at the scene of an emergency event. The command post from which that person directs the emergency response should be located as close as possible to the emergency field operations. The main responsibilities associated with this position are

- direction and coordination of all field operations,
- assessment of severity of the incident,
- recommendation of on-site protective actions,
- implementation of response actions at the scene of the event, and
- coordination of these actions with the emergency preparedness coordinator.

The incident response commander must also be very familiar with the facility and have solid technical expertise.

Emergency Functions

Implementation of an emergency response plan relies on a number of functions that deal with different aspects of the emergency. The most important emergency functions are as follows:

- *Communications* Ensures that the flow of communications among the response personnel within the on-site response is effective and uninterrupted.
- *Fire and Rescue Teams* Most facilities have an emergency response team, primarily trained to handle fires and rescue operations and typically composed of personnel from the different plant units or departments. These teams usually have some basic training in the handling of other types of emergencies (such as spills) to control the situation before more specialized teams arrive at the scene. Team members are trained in comprehensive first aid, search-and-rescue procedures, and emergency equipment handling.
- *Special Hazard* (*HAZMAT*) *Team or Spill Control* Personnel specially trained in dealing with any emergency caused by the presence of special hazards such as releases of toxic or hazardous materials. The handling of these emergencies depends on the physical state of the material released, type of hazardous material (e.g., poisonous gas, explosive, flammable liquid), type of facility from which the material is released (e.g., storage tank or reactor), and type of event (e.g., vessel rupture, overfilling, spill, fire, toxic vapor release).
- *Process/Utilities* Controls the process during the emergency and ensures that the necessary facility units are shut down. This function is also responsible for generating the necessary utilities during the emergency and isolating the impacted portions of the manufacturing process.
- *Engineering/Technical Assistance* Provides the technical support for strategies to isolate damaged process equipment, designs emergency

transfer of materials to safe vessels, and is responsible for all other process-related emergency management.

- *Environmental and Field Survey* This person is responsible for reducing the impact of an emergency on the environment. This function develops programs to monitor potential migration of the release and assesses impacts.
- *Medical* This person is responsible for providing first aid to the victims and arranging for their prompt transportation to an appropriate hospital. He or she also provides information on the nature and properties of the chemical and identifies the most appropriate emergency treatment of injured or exposed personnel.
- *Security* This person is responsible for ensuring that plant security is maintained, making sure that unauthorized persons are not admitted to the plant, and controlling the entry and exit of contractor and other appropriate response personnel.
- *Off-Site Liaison* This function coordinates actions between the on-site response organization and the various external response teams, departments, local representatives, agencies, and neighboring industries.
- *Public Affairs/Legal Counsel* The person in this position is responsible for providing news releases and legal counsel during an emergency.
- *Resources/Supplies* This function ensures that the necessary supplies are available to the emergency response teams and organizes and maintains the staging area where emergency material and equipment is temporarily stored.

All these functions report to the emergency director or to the incident response commander. A team is established, the size and composition of which depends on the task to be performed and the size of the facility. These teams operate according to instructions provided by the emergency director's staff and utilize preformatted, written procedures to accomplish their tasks.

EMERGENCY RESPONSE ACTIONS

One important aspect of emergency preparedness is the identification of the actions implemented by the various response functions. While the emergency response plan includes generic descriptions of the functions, specific details are incorporated in the annexes to the plan. For simplicity and user friendliness, these are best formatted as checklists.

Concept of Operations

An outline of the response sequence should be included in the emergency plan. This plan should include a brief description of the following points:

- warning upon discovery of an abnormal event,
- event evaluation and classification,
- emergency declaration and response team activation,
- notification of off-site response teams,
- implementation of on-site response actions,
- identification of protective actions,
- coordination of response actions with external resources, and
- completion of the response and plant reentry.

Emergency Response Implementing Procedures

Emergency response organization implementation is organized according to the type of hazard. Different manufacturing facilities use varying types of chemicals in their processes, which require customizing the response to the situation. For each hazard, a set of procedures is developed, which includes checklists of detail steps to be followed by the response teams for the release situation.

Environmental Considerations

An environmental emergency such as a hazardous substance spill or gas release requires not only notification and mobilization of containment and control response teams but also an understanding of the potential migration pattern of the material in the environment. Basic site information, such as geology, soil types, proximity to water bodies, and general meteorological conditions, needs to be available so that this information can be used to design a sampling program. It is important to quickly obtain data on soil, air, or water impacts in order to assess risk and define the magnitude of the affected area. For example, if a facility has a shallow water table, a surface spill could impact groundwater quality. This situation would require groundwater sampling as well as soil. Conversely, if the water table is deep or separated from the surface by a low permeable layer, then groundwater sampling may not be necessary and the focus of sampling may be toward soil and surface-water impacts.

Another important need for sampling media at the time of the emergency is to establish a database that can be used to protect the responsible party from unjustified damage claims. Environmental damage lawsuits are common in today's world and in many cases are driven by emotional issues. Hard data, acquired at the time of the incident, can be very useful in controlling damage claims and establishing a factual representation of the impacts from the event.

Recovery, Reentry, and Restoration

One area typically neglected in the emergency plan is postemergency activities. Specific procedures for recovering from an emergency and reentering a facility must be determined on a case-by-case basis. However, guidelines for response team activities following termination should be included.

Once the critical phase of the emergency is concluded, an inspection team appointed by the emergency director should enter the damaged area and ensure that it is safe for recovery operations.

The impact of an emergency event may be felt throughout the plant even if only a relatively minor emergency has occurred. If toxic or flammable materials have been involved in the event, the area must be decontaminated and the procedures used should be discussed in the plan. The main objective of the recovery phase is to restore the plant to its initial condition so that normal plant operating conditions can be established as quickly as possible. After the emergency is concluded, the emergency response should be reviewed and the plan adjusted accordingly.

TRAINING, EXERCISES, AND PLAN MAINTENANCE

An emergency plan, no matter how carefully prepared, cannot be effective unless accompanied by a training program. The objectives of training and drills are to

- familiarize personnel with the content of the plan;
- train new personnel or personnel;
- train specific response personnel in certain special skills;
- introduce personnel to new equipment and techniques;
- keep personnel informed of changes;
- test the preparedness of response personnel;
- test the validity, effectiveness, and timing of the plan;
- test emergency equipment preparedness; and
- maintain cooperative capability with other response organizations.

Anyone assigned to a position within the emergency response organization needs initial training. Members of off-site emergency response organizations should participate in training exercises because it strengthens the cooperation among response groups and improves communication procedures. Drills and exercises are vital to emergency preparedness. Both involve enactment of the implementation of the response actions performed during an emergency. There are three types of training: tabletop drills, functional drills, and full-scale exercises. Tabletop drills are useful for orientation purposes, while functional drills are designed to test a limited aspect of the response capability (e.g., a fire drill). Full-scale exercises are more comprehensive and test the entire response organization up to and including communication with off-site response organizations. An important benefit of training exercises is that the response plan is reviewed during these activities, a process referred to as plan maintenance.

EMERGENCY PLANNING AT THE LOCAL LEVEL

Regulatory requirements exist under OSHA and the Environmental Protection Agency (EPA) for interaction with local, state, and, in some cases, federal agencies[2,3] and require the development of hazardous materials emergency response plans for local communities. For communities to develop these plans, they need to be aware of the hazards presented by facilities within their planning district. Those facilities that fall within the planning district must, by law, provide a representative to assist the community with its planning.

Emergency Management

Effective emergency planning at the local level provides assurance to a community as to how citizens and the environment will be protected in a disaster. Emergency response plans on the local level have the following objectives:

- to create an ensured level of preparedness;
- to ensure an orderly and timely decision-making process;
- to ensure the availability of necessary services, equipment, supplies, and personnel; and
- to ensure a consistent, preplanned response.

The optimum emergency management plan delineates actions that may be required for any hazard.[12] Such broadly applicable functions as direction and control, warning, communications, and public protective actions are generic to the management of events.

A multihazard emergency operations or contingency plan consists of a basic plan, generic functional annexes, and hazard-specific appendices.[13] The basic plan provides an overview of the local entities approach to emergency management, while the generic functional annexes address the specific activities required in all emergency response on the local level. Hazard-specific appendices provide response direction for special problems identified during the hazards analysis process. They detail the tasks to be performed by preassigned organizational elements at projected places under specific circumstances, based on plan-defined objectives and a realistic assessment of response capabilities.

Leadership Commitment

Management commitment to emergency preparedness is essential to an effective response at the local level. The motivation for leadership commitment to effective emergency preparedness comes from the concerns of the citizens in the community. Citizen awareness of the potential threats to safety, health, and the environment from hazardous materials is growing. Local government officials have the authority and access to resources necessary to develop the plan that will allay their fears. They also have the credibility to interact effectively with industry leaders and other government jurisdictions.

Management of a crisis and authority to direct the response must be vested in an individual who is responsible and accountable. Alternates should be named for each defined position in the local emergency organization. Alternates must have the same responsibility and accountability. The question of direction and control must be confronted directly before an emergency occurs because it is impossible to establish a line of command and control while a crisis is in progress. The chain of command needs to be clearly laid down and accepted within an organization long before an incident occurs.

The chief executive of a community is charged with coordinating the functions of the local fire and police departments and any other agencies involved in aspects of local emergency response. These groups may have differing views about their roles in managing an incident. It is up to the community leader to resolve these differences before an emergency situation arises. It is important to note that the responsibility for assuring proper local incident response is assigned to the appropriate office and not the individual.

Planning Team

Successful planning requires community involvement and support throughout the process. When a community participates in the planning process, then it will accept the plan. Cooperative interaction among responders and the community begins with the planning process. Most important in the development a community emergency preparedness plan is a leader that has the respect of the organizations involved in the local emergency response. Management and communication skills are essential for gaining the cooperation of all concerned parties.

The team should be staffed with individuals with expertise in many areas. Representatives of industrial facilities in the community that could be potential sources of hazardous substance releases should be included, as well as knowledgeable officials from transportation, community resources, and utilities. The group should represent all elements of the community and be able to work cooperatively.

Planning Process

As discussed in previous sections, the planning process is the key to success. Agreeing to use a document prepared by others substantially reduces the value of the planning process and diminishes the commitment of those who must prepare the plan. The relationships of the industry, government, and the local community are often fragile. The process itself provides an opportunity to interact with the participants so they become aware of their strengths and weaknesses.

Planning Team Tasks

The key components of the planning team's responsibilities are now discussed.

Hazards Analysis Hazards identification, vulnerability analysis, and risk analysis together comprise the hazards analysis task. Help with this process is available. The EPA has developed a publication jointly with the Federal Emergency Management Agency (FEMA) and U.S. Department of Transportation (DOT) to assess the hazards related to potential airborne releases of extremely hazardous substances [''Technical Guidance for Hazards Analysis'' (''Green Book'')]. Information on this and other relevant publications is available elsewhere.[14]

Hazards Identification Identification of the hazards determines whether a plan is really needed. High-priority hazards should be addressed first. For facilities or transportation routes where the identified hazard is toxic or flammable material, the identity, location, and quantity must be precisely determined. The facility that manufactures, processes, stores, or uses such material is the logical source of this information.

Vulnerability Analysis The vulnerability analysis, sometimes called a consequence analysis, involves determination of the areas, populations, and facilities that may be at risk if a release occurs.

Risk Analysis The purpose of the risk analysis task is to determine the potential and severity of a possible incident. Methodologies are available for calculating estimates of the quantity of a release, the rate of dispersion, and possible concentrations that could affect human health. The previously identified EPA document[14] lists a number of publications and computer programs available from federal agencies, such as the *Handbook of Chemical Hazards Analysis Procedure* (''Brown Book''), which provide fairly detailed information useful for estimating the size of zones considered vulnerable to toxic effects from accidental releases. These documents give additional information on suggested levels of concern. When completed, a local risk and vulnerability analysis should provide the following:

- geographic description of the areas deemed vulnerable to the identified hazard,
- size and type of populations expected to be in the defined vulnerable zones,

- property and essential utilities services that may be affected, and
- environmental media that may be affected.

Examples of emergency planning information that result from this process include needs for facilities and equipment; identification of safe zones for conducting response coordination and the type of equipment needed for event mitigation, emergency worker protection, and spill cleanup. Also, criteria for determining the extent of emergency response required can be established.

Additional information that should be included in the risk analysis is identification of important community resources. Sources of water are particularly vulnerable to environmental emergencies. Groundwater supply wells or surface-water reservoirs should be located on maps. Water supply distribution systems, important transportation routes, electrical supply substations, and wastewater treatment plants are examples of community resources that should be factored into risk analysis. Recently, geographic information systems (GISs)—computer systems capable of assembling, storing, manipulating, and displaying geographically referenced information—have become widely used to electronically map community resources, thus enabling risk planners who must respond to emergency situations to have access to relevant data identified according to their geographic locations, such as population densities, wetlands, groundwater resources, or critical conservation areas.[15]

Emergency action levels (EALs) or an incident classification system should be included in the planning process because they are preestablished conditions that can be used to trigger a desired response. The definition of EALs during the planning removes the ambiguity of uncertainty attitude when a problem emerges.

Resources

Resources, in terms of people as well as facilities and equipment, are necessary for the contingency plan to work. Questionnaires should be developed in order to identify available resources. The questionnaires should be provided to the sources of identified hazards (facilities, transporters) and to local response and government agencies. The National Response Team's *Hazardous Materials Planning Guide* (NRT-1, 2001 update) contains a list of questions.[16]

Personnel he people available to implement the contingency plan must be identified. The specific community points of contact should be identified by position and title, along with their areas of responsibility. A list of the individuals who hold these positions and their alternates should be developed separately. Since positions stay constant, the plan should identify position titles only, with names of responsible individuals and 24-hr phone numbers in a separate, easily updated document. Once the personnel resources and areas of responsibility are identified, a matrix of groups versus functions is readily constructed.

Facilities In most cases, local governments already have facilities in place to handle the types of emergency situations they are likely to face. To the degree possible, the facilities should be integrated into the plan and augmented as necessary for industrial emergency response. In order to develop mutual understanding, letters of agreement or memoranda of understanding must be executed between government leaders and the organizations responsible for buildings that may be needed during an emergency. Normally a section of the town hall or police or fire department headquarters is established to store the equipment necessary to set up of a center from which to direct emergency response.

The public receives most of its information about emergency situations through the media. For this reason, a media center should be available, staffed by spokespersons from industry as well as from local government and response agencies. Other facilities that may be needed in local response to an emergency depend on what has been identified during the hazards analysis phase. A government inventory survey (GIS) can be very useful in quickly identifying available resources. For example, if emergency response personnel may be exposed to toxic or radioactive materials, a decontamination center may be required. Portable, inflatable tents have been designed for this purpose. Whatever means are employed, procedures should be in place for their use. Additional consideration should also be given to the possible need for vehicle decontamination. For example, some commercial car washes recycle their wastewater, and agreements could be made with them.

The planning team should make arrangements assuring that emergency medical treatment will be available. The plan should consider the placement of a triage area near the scene of an event. Agreements should be established with local ambulance companies who will be directed to this area to transport the severely injured to area hospitals or treatment centers. The planning team should ensure that medical personnel at the designated centers are aware of the potential health hazards.

Sheltering in place is the most desirable mode of public protection in fast-moving industrial emergency events. However, evacuation of areas near the scene may be necessary. The planning team should develop an evacuation plan that describes optimal routes and identifies relocation centers. Public schools are often designated as relocation centers because they have cafeterias, adequate sanitary facilities, and large open gymnasiums.

Equipment The equipment needed for emergency operations at the local level is to some degree generic, yet also hazard specific. Emergency operations centers are equipped to handle any kind of major emergency. Communications equipment will be essentially the same in all cases, as will public warning systems and notification methods, traffic and access control, public works, law enforcement, and health and medical services. Computers connected to the Internet and copy and fax equipment should be available for electronic/hard-copy transmission and reception of data and messages.

Large-scale maps of the planning area should be prominently displayed in the local EOC. Major transportation and evacuation routes as well as identified hazard locations with their vulnerable zones are provided on the base map. Airborne dispersion plume projection overlays or templates are useful additions, especially for transportation accidents involving toxic releases or spills, with known wind speed and direction and populations at risk identified promptly for protective action. Specialized equipment for response to industrial plant emergencies depends on the nature of the identified hazards. Much of this necessary planning information comes from the hazards analysis process. Here, again, a GIS is useful because it allows a large amount of information to be stored electronically and then integrated with other relevant information to evaluate relationships.

Content of the Plan and Procedures

The best local-level contingency plan attempts to consider all potential hazards and is adaptable enough to accommodate those identified in the future. However, it is overly optimistic to consider that all hazards can be planned for; thus, a better term for the plan is a multihazard emergency operations plan (EOP). Such a plan comprises a basic plan providing an overview of the general approach to emergency management, functional annexes in support of the basic plan to address specific activities critical to emergency response and recovery, and hazard-specific appendices to the plan that address specified emergency situations. Dealing with the aspects common to all hazards first and then examining hazard-specific characteristics unique to the planning district is both efficient and economical.

Basic Plan The basic EOP is an umbrella plan that contains a substantial amount of the generally applicable organizational and operational detail. The basic plan cites the legal authority for the plan, summarizes the situations addressed, explains the concept of operations, and describes the organization and responsibilities for emergency planning and operations. The basic plan should also include maps, organization charts, and the emergency responsibility matrix. The plan should also identify critical environmental resources and environmentally vulnerable areas within the planning area.

Functional Annexes The generic functional annexes define and describe the policies, procedures, roles, and responsibilities that are inherent in the functions before, during, and after an emergency. These should include standard operating procedures, which are user friendly, checklist-type instructions for the various segments of the emergency response organization to execute the functions defined in the annexes. A telephone roster listing the names and phone numbers of key members of the emergency response organization (and their alternates) should be provided. Additional information that should be contained in the annexes is local environmental data. This would include critical habitat areas, water supply information, groundwater resources, and potentially sensitive receptors such as hospitals and schools.

One area too often overlooked in the local planning process is the step taken to return to normal conditions following an emergency. It is suggested that the planning team visit a community where an emergency event has previously occurred to learn from them what recovery problems they faced and how they resolved them.

Hazard-Specific Appendices The unique characteristics of hazards identified specific to the local planning district are included as appendices to the functional plan. A single appendix should address all response function requirements related to a particular hazard.

Plan Integration Coordination of contingency planning between industry and community is necessary to develop mutually acceptable solutions to anticipated events. Should an actual emergency response be necessary, cooperation and commitment supply the means for orderly, timely decision making. It takes time to lay the groundwork among the members to establish an approach to cooperative problem solving. Industry should provide personnel to local planning teams and community planners should be invited to industry planning meetings.

PUBLIC INFORMATION

Public information has two roles in contingency planning: education about the plan itself and notification of an emergency condition. The first is a public relations function and the second a necessary part of the plan itself.

Public Education

Residents and businesses in industrial areas are increasingly aware of potential threats to their well-being from industrial and transportation emergencies. The more information citizens have about environmental conditions and potential threats in their communities, the better equipped they are to participate in measures for their own protection. The hazards in a community and what both industry and the jurisdiction are doing to minimize the risks must be made known clearly and explicitly to the public. Perception and truth can be the same in the public eye. People react differently to the same risk, depending on their backgrounds and their level of risk acceptance. Voluntary risks such as smoking and not wearing a seat belt are usually accepted, whereas the involuntary risks of exposure to asbestos, contaminated drinking water, or a toxic plume are not. Health risks, especially long term, are of primary concern to those who resent risks not of their own choosing. While risk comparisons may be valid, it is better to focus discussion on preventive measures, emergency preparedness, and containment and remediation procedures. The public gets most of its information through the media, which can sometimes oversimplify complex situations. The key is to present essential factual information in readily understandable terms.

When the first round of planning is complete and the plan is initially approved by the panning committee, a familiarization program should be undertaken so that citizens will understand their expected actions. Presentations to community groups are good, but they may not reach all that could be affected. Experience has shown that readily accessible emergency information presented positively and in an attractive format is remembered and used. For example, one possible method is the creation of an attractive calendar distributed annually to households and commercial establishments that contains simple instructions for citizens to follow. Another option is to provide the information on one- or two-page inserts in local telephone directories. Public confidence is enhanced when citizens have the factual information needed to make intelligent decisions.

Emergency Public Information

When an emergency does occur, the local emergency response team must be promptly notified, and a public warning issued to all who may be affected. A standardized notification message form should be available to both sender and receiver of the initial information. How the media are treated while an emergency is in progress determines, to a large extent, public perception and reaction. Establishment of a media-briefing center or public information center is important. Here the local designated spokesperson can coordinate the timely provision of accurate, detailed, and meaningful information to media representatives.

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12 Soil and Groundwater Remediation

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San Mateo, California

INTRODUCTION

Although the current activity regarding the cleanup of contaminated soil and groundwater is primarily driven by the passage of laws beginning with the Resource Recovery and Conservation Act (RCRA) of 1976 and the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), site remediation predates these laws by several decades. Industry, when faced with obvious contamination of either their own property or adjacent property, has, on occasion, conducted cleanups not significantly different than those conducted today. Indeed, as early as 1947, groundwater contaminated by gasoline in the town of Arlington, Virginia, was remediated by pumping the contaminated wells to remove the accumulated gasoline.[1] In fact, pumping followed by periods of intermittent pumping as smaller amounts of gasoline was recovered is a remediation technique commonly seen today in remediation of contaminated groundwater. Groundwater contamination from the disposal of chromium wastes in Nassau County, New York, was remediated by elimination of the source of the chromium wastes through treatment.[2] This approach, commonly referred to today as source control, was practiced in the early 1950s. In 1954, Powell[3] described a method for remediating groundwater that included excavation of the heavily contaminated soil followed by 18 months of groundwater pumping and replenishment of the aquifer with good-quality water. In 1952, a paper discussed the use of a well point system for cleaning up an oil-contaminated aquifer.[4]

There are two separate but interrelated elements with respect to soil and groundwater remediation: the technical elements to which this chapter is de-

Environmental Engineering, fifth edition, Edited by Joseph A. Salvato, Nelson L. Nemerow, and Franklin J. Agardy
ISBN 0–471-41813-7

voted and site operations in the context of issues such as by the Occupational Safety and Health Administration (OSHA). That subject has been addressed in the 1994 Supplement to *Environmental Engineering and Sanitation.*[5] It is recommended that the reader obtain a copy of that supplement to become familiar with these additional health and safety issues.

CONTAMINATION HISTORY

The history of groundwater pollution is extensive and has been discussed by many authors and an excellent summary is found in Chapter 3. Perhaps the most recent and easily read history can be found in *A Practical Environmental Forensics*.[6] A few examples of the early history of soil and groundwater pollution should provide the reader with an appreciation of just how much was known and understood prior to the more recent federal legislation. In fact, these examples should suffice to let the reader know that much of what we do today with regard to remediation is nothing more that a rediscovery and a refinement of what had gone before. Indeed, there is not that much new today, only variations on a theme. Although groundwater contamination references go back as far as 1841 and characterization of and associated damages from such contamination were routinely reported by the turn of the twentieth century, recent references are generally more detailed and more specific as to both the nature of the contamination and the sources and effects. Sources such as the *Journal of the American Water Works Association* (1947,[7] 1959[8]), *Wastes Engineering* (1953[9]), *Sewage and Industrial Wastes* (1955[10]), *Geological Society of America Bulletin* (1961[11]), *Journal of the Water Pollution Federation* (1964[12]), and *Public Works* (1964[13]), all addressed the issue of groundwater pollution, and this list alone illustrates the broad and comprehensive coverage given to this subject.

In similar fashion, most states included consideration of groundwater when passing laws designed to protect waters of the state, with many of the laws going back to the early 1960s and some as far back as the 1920s. A number of authors also proposed additions to state laws in the late 1940s to early 1950s addressing this specific pollution issue.[14–16]

Finally, as early as 1962, Geraghty[17] described in great detail just how contaminants, both organic and inorganic, found their way into groundwater and how they traveled once in groundwater. In his 1965 paper, LeGrand amplified Geraghty's work regarding contaminant travel in groundwater. Even earlier studies documented the travel of inorganics (metals) and detergents in groundwater.

Thus, long before the U.S. Environmental Protection Agency (EPA) addressed the issue beginning in the 1970s, engineers, scientists, and lawyers had already visited the issue, spelled out the problem, suggested and described necessary legislation, and implemented remedial activities.

REGULATORY OVERVIEW

As stated above, current remedial actions are driven almost exclusively by federal mandate following the passage of RCRA and CERCLA; therefore, these laws deserve a more detailed discussion as to how they influence remediation.

RCRA as originally intended was meant to address ongoing handling, storage, and disposal of hazardous materials. In that vein, organizations either manufacturing, handling, treating, or storing materials defined (again by federal rule) as hazardous had to comply by filing a Part A RCRA application by no later than November 1980. Several texts contain excellent descriptions of materials listed as hazardous and, indeed, are eminently more readable than the *Federal Register*.[19,20] Also, Chapters 2, 3, and 4 address RCRA and CERCLA.

If, as it turned out, an organization planned to continue storing or treating hazardous materials, then that organization had to file a Part B RCRA application. Under this program, an organization was required to confine and contain hazardous materials, monitor the underlying groundwater to determine if any contamination had occurred, close the hazardous facility (when the organization decided that it was appropriate to do so), and conduct postclosure activities to ensure that contamination did not result. This program required that site investigations be conducted so as to address the issues posed by the RCRA permit. Thus, a more detailed and nationwide site investigation process was born (as illustrated earlier, site investigations predated the EPA by decades) and, in no small measure, its elements were spelled out by EPA regulations. No longer did the organization control its own fate but rather had to be responsive to a higher power—the U.S. government.

With the passage of CERCLA in 1980, the government addressed the issue of abandoned waste sites and added the element of cost recovery through legal action against former site owner/operators. With the passage of both pieces of legislation, the groundwork was complete for a comprehensive and massive nationwide focus on all aspects of past and present pollution of soil and groundwater. Thus, the era of extensive investigation and remediation had been put into place and begun. An excellent discussion of legal history of both RCRA and CERCLA can be found in the literature.[6]

SOURCES OF CONTAMINATION

Almost any man-made activity coincidently produces waste products, which have been traditionally discharged to the air, underlying soil, or surrounding and underlying bodies of water. Unfortunately, the poor housekeeping typical at many industrial sites has resulted in the deposition of not only wastes but also spills and leaks of basic chemicals. In the broad sense, the sources of contamination are often related to leaks from underground storage tanks and associated piping. However, industries often discarded wastes on their property in areas often referred to as the "back forty." Thus, the accumulation of both liquid and solid wastes on land or into natural depressions coupled with the discarding of drums, often filled with wastes and buried on site, has left a legacy of contamination across the country. Industry also made use of ponds and lagoons for the storage and treatment of wastes. These structures, which were almost always earthen, leaked and contributed wastes to the underlying soil and groundwater. While it has often been argued that this was common industrial practice, all too often industry ignored available state-of-art technology as being too costly and thus simply postponed more appropriate actions to a later, more costly time period.

In the eyes of the general public, the most common type of leakage was from underground tanks storing gasoline (i.e., the neighborhood gas station). Most of these tanks were steel, single walled, and noncoated, which corroded over time, thereby releasing their contents to the underlying soil and groundwater. When the loss of product appears minimal or is imprecisely measured, such leaks can go on for years before being discovered. With the increased use of chlorinated solvents following World War II, even greater numbers of above- and below-ground storage tanks came into use; as a result, a greater number of soil and groundwater events associated with the chlorinated hydrocarbons were observed. Not to be left out were the chemicals used by the dry cleaning industry. Discharges of perchloroethylene, a chemical widely used in dry cleaning, have been found in soil and groundwater throughout the United States. The manufactured gas industry, which has a history going back to the beginning of the nineteenth century, has also contributed its share of contaminants, tars primarily, to the environment. A final addition to this list of sources is the deposition of many inorganics associated with the smelting and mining industries.

Another source of groundwater contamination results from leachate generated by landfills. Although sanitary landfills were considered to be a major improvement over dumps, the fact remains that, along with domestic garbage, most landfills also accepted many types of commercial and light industrial wastes. Additionally, as more household products containing solvents and other chemicals came to market, these materials also ended up in sanitary landfills. In spite of admonishments by engineers, many landfills were located in areas where contact with groundwater was inevitable; thus, without proper underdrains or engineered impervious layers, the generated leachate carried these contaminants down into the underlying groundwater.

The list of sources as well as the nature, specificity, and amount of contaminants is almost endless. It is hoped that the above discussion is sufficient to paint a picture of the sources and nature of the contamination with which we are dealing with today.

SITE INVESTIGATIONS

The remediation process begins with a site investigation. The purpose of the investigation is to define, as completely as possible, the nature of the hazardous materials on site, their location(s), the degree of contamination (if any), and the extent of the contamination (in both soil and water, recognizing that contamination can, and indeed does, manifest itself in surface waters and sediments as well as in groundwaters). Once the scope of any contamination is identified, the steps required to eliminate or isolate the contaminant source(s), remove the contamination, and prevent further spread of the contamination are specified and required by law. Having said that, the actual process is a bit more complicated. As is often said, the devil is in the details—namely the government definition—spelled out in great detail at every step in the process. To further complicate matters, the government oversite role in reviewing the work may require further investigation and definition.

As a rule, the initial site investigation can be considered exploratory and, unfortunately, often less than required to adequately define the problems. Such an investigation usually includes the development of several monitoring wells and collection of soil samples in areas of the site that might, due to prior site activity, contain contaminants. Assuming that contamination is found and chemicals of concern identified, the next step becomes a more formal process generally referred to as a remedial investigation (RI). This phase attempts to fully define the nature and scope of the contamination, that is, to determine the presence of contaminants in as great a detail as possible, and thus develop a comprehensive baseline of what is on the site. This phase is followed by the feasability study (FS) wherein the remedial alternatives are spelled out and examined for their appropriateness in cleaning up the contamination.

As an example, current regulatory requirements (CERCLA)[21] stipulate that remedial actions taken under the Superfund program meet both federal and state standards and criteria under an umbrella of applicable or relevant and appropriate requirements (ARARs). Applicable requirements include local, state, and federal standards, requirements, criteria, or limitations that directly address a contaminant, location, or action that is site specific. Relevant and appropriate requirements apply to situations that bear some degree of situational similarity to warrant consideration. Under the federal ARARs, one must address such environmental statutes as the Clean Air Act (CAA), the Clean Water Act (CWA), or the Solid Waste Disposal Act (SWDA). Similar requirements appear state by state and must also be addressed.

The items included in a typical action plan are shown in Table 12-1, whereas the content of a typical final report is shown in Table 12-2.

Table 12-3 lists the items often necessary to define the site and waste characteristics.

TABLE 12-1 Typical Action Plan Outline

Introduction
Site background
Site history
Identification of regulatory requirements
Preliminary risk evaluation
Focused Feasibility study (for each contaminated area)
Schedule
Summary
List of figures
List of tables

REMEDIATION OBJECTIVES

Simply stated, the elements of remediation can be summarized as follows:

1. Eliminate the source of the contamination.
2. Prevent any future contamination from the source.
3. Contain or remove contaminants from area soil.
4. Contain or remove contaminants from area groundwater.
5. Prevent contamination from leaving the site of origin.
6. Remove contamination that has migrated off-site.

TABLE 12-2 Typical Final Report Outline

Executive summary
Introduction
Background
Site setting
Site history
Site geology and hydrogeology
Previous investigations
Remedial actions
Prior remedial activities
Recent remedial actions
Current site conditions
Groundwater monitoring results
Chemicals of consequence
Contaminant transport modeling
Potential receptors
Public involvement
Summary and conclusions
References
List of figures
List of tables

TABLE 12-3 Site and Waste Characteristics

Site Characteristics	
Site volume	Depth to bedrock
Site area	Depth to agricludes
Site configuration	Degree of contamination
Disposal methods	Directon and rate of groundwater flow
Climate	Receptors
Precipitation	Distance to
Temperature	Drinking water wells
Evaporation	Surface water
Soil texture and permeability	Ecological areas
Soil moisture	Existing land use
Slope	Existing land use
Drainage	Depth to groundwater or to plume
Vegetation	
Waste Characteristics	
Quantity	Infectiousness
Chemical composition	Solubility
Carcinogenicity	Volatility
Toxicity	Density
Chronic	Partition coefficient
Acute	Safe Levels in the environment
Biodegradability	Compatibility with others
Radioactivity	Chemicals
Ignitability	
Reactivity/corrosiveness	
Treatability	

Having listed these simple steps, one would assume that the objectives are apparent. However, there are many variables that can affect the final solution. In some situations, such as when groundwater is unsuitable for use, as may be the case with brackish waters, the cleanup of contaminants may not be considered necessary. In similar fashion, when contaminants in soil are considered static or not subject to movement, they may be left in place, with the only remedy being a cap to prevent human contact and/or infiltration of surface water, which could result in the movement of the contaminants.* Under circumstances where portions of an aquifer are contaminated, pumping water from several wells, including water from uncontaminated wells, and employing mixing to dilute the contaminant level(s) below required limits

*A perfect illustration is the method by which Italy dealt with a major dioxin-contamination. Rather than dig up the dioxin-contaminated soil and incinerate it (as was done at Times Beach, Missouri), it was decided to cover the area with several feet of soil and convert the area to a park.

could be a solution. In somewhat similar fashion, treatment of contaminated groundwater, at the point of use, has been employed in lieu of a massive groundwater cleanup. Finally, the concept of nonattainment zones has gained acceptance. Under this approach, contamination is left in place so long as the contaminated water is not intended for use (brackish water fits this scenario), there is no nearby body of surface water that might be adversely impacted, and there are other sites in the area that have the same problem. In cases such as these, it is common to employ deed restrictions to limit and define the future land use of a contaminated site. Another variation of the leave-it-in-place approach is to rely on natural attenuation. This approach can be employed, but since no engineered system is directly constructed, careful studies of site hydrogeology, geochemistry, and microbiology need to be conducted. Also, the approach does require monitoring so as to appropriately access the movement and degradation of the contaminant plume. Renner[22] describes such an approach for the reduction of trichloroethylene (TCE) at a source approximately one-half mile from Lake Michigan. Initial TCE concentrations in excess of 200,000 μg/l were reduced to 200 μg/l or less at the shoreline, and, after entering the lake, concentrations dropped as a result of dilution below EPA allowable levels. Now, just to add perspective to this solution, it took about 20 years for the plume to reach the lake, which provided ample time for bioremediation to take place.

Although all of the above alternatives have been proposed and in many instances accepted as solutions, cleanups continue to be the norm and remedial methods continue to be used both nationwide and worldwide.

REMEDIAL METHODS

Remedial methods for remediation of soil and/or groundwater fall into a short list of technological approaches:

A. Soils
  - Excavation
  - Vapor extraction
  - In situ treatment: chemical, biological, thermal
  - Capping (in place)

B. Groundwaters
  - Containment: barriers—slurry walls, sheet piling
  - Extraction (pumping)
  - In situ treatment: chemical, biological

Physical Methods

The most simple but not necessarily the least costly remedial methods include excavation and containment. However, capping, while leaving contaminants in place, is often a very cost-effective alternative.

Excavation does not require much explanation; the waste materials are removed to a prescribed physical level (such as to the groundwater if groundwater is relatively close to the ground surface) or to a prescribed chemical concentration level (such would be the case where the *contaminant of concern* was allowed to remain in the soil as long as it did not exceed a specified concentration). Thus, the soil is excavated, layer by layer, until clean soil, so to speak, is encountered. At this point, the excavation is considered complete. The major drawback to excavation has to do with the hazardous constituents contained therein, which dictate to which class of landfill the material can be sent. Thus, the cost of hauling as well as the cost of landfilling may prove to be very expensive, indeed prohibitively so. In some cases, such as the dioxin contamination in Times Beach, Missouri, the excavated soil has to be incinerated—a very costly operation.

The excavation of contaminated sediments from lakes, streams, and estuaries can be considered a subset of excavation. Not only is sediment excavation expensive, but there is the very real possibility of resuspension and further solubilization of the contained contaminant material. According to Hartig,[23] over the past 13 years, more than \$580 million has been spent on 38 sediment remediation projects in 19 areas of concern. Of the 19 sites studied, only 1 employed in situ capping. Excavated volumes ranged from a low of 200 m^3 (at a cost of \$350,000 Canadian) to a high of 624,600 m^3 (costing \$44 million U.S.).

Slurry walls, usually constructed of compacted clay but also of sheet piling (many other names come to mind such as grout curtains and trench walls), simply prevent the further flow of contaminated water. This technology also has its limitations and is unsuitable in areas where soils are permeable (water always seems to be able to find its way through these barriers given enough time). Thus, slurry walls, even under the best of circumstances, require continuous monitoring to make sure that the contamination has not made it way through the barrier.

Well systems, employed to hydraulically control contaminated groundwater plumes, are used to modify or manipulate (by injection or withdrawal of water) the hydraulic gradient of groundwater. Well point systems, consisting of closely spaced shallow wells, are most common. These wells are interconnected to a suction lift pump. In one situation, a well point system acted as a barrier to the escape of groundwater containing phosphates from beneath a phosphate waste pile. The pumped water was returned to the top of the phosphate pile where it was allowed to evaporate. This took place in a southeastern state where the evaporation rates greatly exceeded precipitation rates. Well systems are best suited for application in shallow aquifers as pumping costs can be considerable, but because of their ease of construction and deployment coupled with their pumping rate flexibility, these are ideal systems when rapid response to a contaminant situation is required.

Capping is perhaps the simplest and least costly of the physical methods. Many wastes remain stationary so long as there is no driving force, such as rainfall and subsequent percolation of water, to move the soluble fraction of the contaminants (physically) downward or, for that matter, to move the water insoluble chemicals downward. The major disadvantage of capping is that the waste remains in place and may cause a problem at a later date if the site undergoes further development.

However, one must never overlook the no-action alternative. In one sense, *no action* can be classified as a process or remedial approach. This alternative is almost always expected to be addressed when developing a list of remedial approaches. No action may be the selected method under the circumstance of being able to develop a scenario wherein the site is effectively in a nonattainment zone. The elements of obtaining a nonattainment exemption was discussed in detail in a prior section.

HAZARDOUS WASTE TREATMENT TECHNOLOGIES

Hazardous waste treatment can take place both in situ and after the waste has been removed from the environment. Necessarily, the nature and location of the contaminants as well as ease of extraction all play a part in the selection of treatment processes. Consideration must also be given to the complexity of the contaminants, particularly if the contaminant mix includes both organics and inorganics. An excellent example of this complexity issue concerns the treatability of groundwater contaminated by MTBE (methyl tertiary butyl ether), a contaminant that has been found to be very difficult to remove using the more conventional treatment methods; however, the use of ozone and hydrogen peroxide has been reported to degrade MTBE into simpler, biodegradable products.[24] Even radiation has been reportedly employed, in combination with alumina, to break down toxic waste in soil.[25] Reactive treatment walls have been tried, most recently to remove strontium from groundwater[26] This process uses a buried barrier containing zeolites through which the strontium-contaminated water passes. The zeolite traps the strontium, thereby removing it from the groundwater. The city of Albuquerque, New Mexico, has experimented with several technologies to remove arsenic from groundwater including ion exchange, microfiltration, and activated alumina.[27]

Soil Vapor Extraction

In many cases, the initial step in remediation is source removal. In those situations where excavation is not practical (such as when contamination is under a building) or when excavation and hauling costs are prohibitive, soil vapor extraction is often the technology of choice. Soil vapor extraction, or soil venting, is a technique whereby contaminant vapors in the unsaturated zone are removed. The most common method uses a system of extraction wells where vacuum is applied to remove the trapped vapors. The process can be accelerated by the introduction of air through injection wells, thus driving the vapors to the extraction wells. A variant of this technique is soil flushing, where water or water–surfactant solutions are injected so as to dissolve contaminants or mobilize the contaminants into the water table, where they can be removed by extraction wells.

In situ Treatment Processes

In situ processes usually consist of injecting a chemical, which will oxidize constituents in place, or introducing bacteria to break down contaminants into simpler and less hazardous end products.

Bioremediation

The introduction of bacteria into the soil and/or the groundwater environment, with the proper support of nutrients, has been demonstrated to be effective in accelerating the breakdown of contaminants. Simpler contaminants such as gasoline appear to be more amenable to this method of remediation. Organics, such as molasses, have been added along with bacteria. The molasses acts as a substrate, accelerating bacterial growth. Research and field studies appear to support the fact that such methods work best under aerobic conditions rather than anaerobic conditions. Thus, along with the introduction of bacteria, there is the need to aerate the below-ground environment.

Chemical Treatment

Recognizing that most contaminants can be oxidized and thereby broken down to simpler compounds, the introduction of oxidants has also been demonstrated to have a positive effect. Again, as with any in situ application, the contaminants in question will most often dictate the approach. By illustration, heavy metals can be immobilized by the introduction of sulfides, while cyanide can be destroyed by oxidizing agents. Potassium permanganate has also been used to oxidize hydrocarbons in groundwater. A recent pilot study[28] at an industrial site used potassium permanganate as a chemical oxidant to transform carbon compounds (TCE) into carbon dioxide and water and less hazardous breakdown by-products. A permanganate concentration of approximately 2.5 percent was introduced at six injection points. The TCE concentrations in the alluvium zone ranged from 460 to 18,000 μg/l prior to treatment. Monitoring results showed near-complete volatile organic compound (VOC) destruction within the treatment zone for a period of at least 65 days and even with some rebound, the concentrations remained low through the six-month monitoring period.

External Treatment Processes

After having removed contaminants from either the soil or groundwater, external treatment is usually required, depending on the concentrations contained in the removal stream, before final discharge of either treated vapors or water. The first step is to remove the contaminants from the contaminated environment. Soil vapor extraction and soil washing have already been discussed. Beyond that, the most common method of extraction is pump and treat. The pump portion is the extraction step and consists of drilling extraction wells into the affected aquifer(s), usually within the contaminated plume area and extracting the contaminated liquid. Pumping rates usually vary from well to well and are greatly influenced by the porosity of the soil/groundwater environment. Once the liquid and/or vapor is extracted, treatment begins. Again, as always, there are physical, chemical, and biological treatment methods available, including dilution. Typical treatment technologies along with targeted contaminants include the following:

Technology	Contaminants Treated
Biological: aerobic, anaerobic	Wide range of organics
Physical	
Clarification/coagulation, flocculation/ sedimentation, granular filtration, membranes (ultrafiltration)	Wide range of organics
Air stripping	Volatile organics
Thermal: incineration	
Liquids	Organics; sludges;
Vapors	contaminated soils; Fumes
Chemical: neutralization, oxidation, stabilization and solidification, precipitation	Metals, sulfides

Although the list is extensive, practical experience based on hundreds to thousands of actual treatment systems installed tend to revolve around physical and chemical processes. Biological systems are somewhat limited by the very toxic nature of the contaminants treated. Thermal systems also have their limitations, primarily cost. The most commonly employed systems include physical/chemical systems such as coagulation/flocculation to separate the components (and significantly reduce the volume of material requiring further treatment), which then can be further treated chemically or incinerated. Chemical systems are generally employed to fix or oxidize the contaminants. The removal of metals such as arsenic, cyanide, mercury, and hexavalent chromium lends itself to this type of treatment. Hydrocarbons, particularly those of the halogenated variety, are most often treated by granular (activated) carbon. The adsorbed constituents can then be removed by incineration (carbon regeneration) coupled with halogen scrubbing. Volatile organics, such as are found in an air stream, are also often treated by activated carbon.* Membrane systems (e.g., reverse osmosis) have also been employed where the initial concentrations of the organic contaminants are in low concentration (micrograms per liter) but still above the allowable discharge level (typically set at 5 μg/l for many halogenated and nonhalogenated organics).

REMEDIATION COSTS

Remedial costs can vary widely depending upon such factors as source control, type and volume of flow to be extracted and treated, contaminants to be removed and the remedial goal (level of removal required), extent of contamination (horizontal and vertical), number of aquifers contaminated, the presence or absence of dense nonaqueous phase liquids (DNAPLs), local hydrogeologic factors, the particular treatment technologies employed, the area of the nation where the remediation takes place (e.g., labor costs), the soil contaminant classification, the location of approved disposal sites (concurrently, the haul distance), and the anticipated time interval over which remediation is expected to be completed. With so many variables, not to mention the frequency of monitoring and the variability of laboratory costs, costs can and do vary greatly.

The EPA published a report in 1999 summarizing experience at 28 operating sites.[29] In attempting to gain an insight into operations and efficiency, EPA-summarized remedial costs and unit costs are shown in Table 12-4.

TABLE 12-4 Typical Remedial Costs

Cost Category	Range	Median	Average
Years of operation	1.0–9.6	4.1	4.9
Average volume of groundwater treated per year (1000 gal)	230–550,000	12,000	57,000
Total capital cost ($)	250,000–15,000,000	1,600,000	3,200,000
Average operating cost per year ($)	26,000–4,400,000	180,000	610,000
Capital cost per volume of groundwater treated per year ($/1000 gal)	2.9–1600	140	310
Average annual operating cost per volume of groundwater treated ($/1000 gal)	0.21–170	21	36

*It is not uncommon, depending on the contaminant concentration and the amount released daily, to simply discharge the stripped contaminants to the atmosphere without further treatment under local air discharge permits.

Although the EPA was not able to develop a definitive relationship between contaminant removal, volume removed, and cost, sufficient information was available such that on an average basis the following relationships could be estimated:

Contaminant Mass Removed	Average Volume Treated	Average Cost Cap + Op	Cost per Unit Removed
43,000 lb	57×10^6 gal	$6,189,000	$143.93/lb

The same relationship can be developed using the median values:

2000 lb	12×10^6 gal	$2,338,000	$1169/lb

It is apparent from this EPA report alone that costs of remediation (excluding investigative costs) can and do show wide ranges and simple answers as to cost are not easily forthcoming. Thus, each site should be considered unique and evaluated in context.

Thermal Destruction of Fumes

In order to destroy organic materials, knowledge of their flammability (upper and lower explosive limits) is very important to selection of the appropriate thermal technology. Choices vary between flares, thermal oxidizers, and catalytic oxidizers. As with all thermal destruction applications, the thermal properties of the fumes must be carefully considered and evaluated so as to prevent explosions and destruction of the treatment device through the formation of aggressive end products, such as hydrochloric and hydrofluoric acids. For properly designed systems, destruction efficiencies between 95 and 99+ percent are routinely achieved. Typical cost ranges are as follows:[30]

Type	Size (scfm)	Installed Cost
Thermal oxidizers	2,800	$120,000
	8,000	325,000
Regenerative systems	10,000	425,000
	20,000	575,000
Catalytic systems	5,000	225,000

Recovery Wells

Typical costs are shown in Table 12-5.

Typical monitoring elements are shown in Table 12-6.

TABLE 12-5 Installation and Drilling Costs per Well

Cost Element	Cost Range
Drilling costs	
Drill and install	\$120–130/ft
Well development	\$20–30/ft
Material	
Screen	\$40–40/ft
Casing	\$8–10/ft
Sand	\$20/bag
Bentonite	\$10/bag
Inspection costs	
Labor	\$40–60/ft
Travel	Site location related
Direct	\$500/well
Miscellaneous Costs	
Mobilization fee (one time)	\$500
Contingency (drilling ad material)	10%
Administrative costs	15%
Legal/license/permit fees	10% of capital costs

Sheet Piles

Considerations with respect to the use of sheet piles include overall dimension, depth of piles, geologic formation, method of driving, geographic location, and local cost of materials. Commonly used steel sheet piles range in price from \$640 to \$770 per ton; shipping charges might run \$1.50/mile and typical installation might run \$120 to \$317 per ton.[31]

Slurry Walls

As mentioned earlier, slurry walls are commonly employed to block plume movement. As with sheet piles, factors to be considered include overall site

TABLE 12-6 Monitoring Elements (Monitoring Recovery Wells): Annual

Hydrology monitoring
Water quality sampling
Laboratory analyses
Data tabulation
Data review and reporting, 300–400 hr/year
Data management
Quarterly report
Half-year report
Annual report
Project management

dimensions, excavation (nature of material), depth of wall, backfill material, and installation method. Costs range from $\$2/ft^2$ to $\$20/ft^2$.

Grout Curtains

A simple cement grout curtain can cost as little as $0.95/gal and as high as $6.65/gal. Converting this to a placement cost results in a range of between $4 and $10 per cubic foot.

Capping

There are a wide range of issues that must be considered when designing a cap, with possibly the most important being the ultimate use of the capped surface. By way of example, if the cap is meant to simply prevent the infiltration of rain water, the solution might be a simple membrane, clay, or asphalt cap (subject to settling conditions of the area being capped). However, if the capped site might subsequently have to handle heavy loads, such as would be the case with a construction yard or bus depot, then the cap takes on a significantly different role and a much more substantial cap, such as a concrete cap, is required.

Typical costs can be summarized as follows:

Synthetic cap	$\$1.96/ft^2$
Clay cap	$\$2.96/ft^2$
Concrete cap	$\$0.46–0.67/ft^2$

(See ref. 32.)

REMEDIATION EXPERIENCES

Groundwater contamination at Aerojet's Rancho Cordova, California, site has received close scrutiny for over 20 years, and recently several new technologies and approaches have been used to deal with this contamination. According to the *Sacramento Bee,*[33] $2 million will be spent on an ultraviolet beam technology to break down rocket fuel residues, $5 million for microbe use, and a $7 million network of replacement wells serving the Rancho Cordova community. The upshot of all this is the possibility that the results will allow development of a major portion of Aerojet property, thereby providing an excellent example of rehabilitation of a damaged resource.

The EPA report referenced earlier[29] developed, in great detail, the operating results from 28 sites. The majority of the sites (26 of the 28) employed pump and treat technology (either singly or in combination with in situ technology) for groundwaters in multiple aquifers and at depths typically no deeper than 50 ft below ground surface (ft bgs). Average pumping rates ranged from a minimum of 3.1 gpm to a maximum of 1041 gpm. As of the date of the EPA report, only two sites had completed their remediation, based on the criteria of having reduced the contaminant(s) in the groundwater to the targeted remedial level.

EXAMPLES

Hot Spot Excavation at a Former Commercial Manufacturing Site After the completion of a site investigation, it was determined that three hot spots were present on the site and removal of these *hot spots* was required in order to clear the title so that the site could be sold. The estimate cost of this removal is shown in Table 12-7.

Groundwater Containment at a Former Mining and Acid-Processing Site After many months of site investigation, the local regulatory agency approved containment as the best alternative at the site. Containment had to address groundwater plume movement as well as the possible plume interface with a drainage ditch that discharged into the nearby bay.

Comparison of Containment Alternatives

Alternative 1: The first alternative assumes the construction of a 22-ft deep slurry wall around the perimeter of the site to prevent movement of groundwater onto or off of site and the capping of the site's surface:

TABLE 12-7 Hot Spot Cleanup Cost

Cost Item	Quantity	Unit Cost	Item Cost ($)
Demolish pavement	10 cy	$12.47/cy	125
Excavate contaminated soil hot spots[a]	Four 10 × 10 × 7 pits (104 cy)	$2.89/cy	300
Haul contaminated soil to Class II landfill	168 tons	$8/ton	1,344
Dispose contaminated soil at landfill	168 tons	$12/ton	2,016
Backfill pits with compacted clay	104 cy	$10.34/cy	1,075
6 in. asphalt paving	500 ft^2	$3.00/$ft^2$	1,500
Sampling/reporting	—	$5000	5,000
Mob/demobilization	—	$2500	$2,500
Contingency	—	10%	1,386
Total			15,246

Source: R. S. Means, *Environmental Restoration Unit Cost Book,* 1997; also quotes from local vendors.

[a]Based on four discrete soil "hot spots" having diesel levels in excess of 5 ppm.

TABLE 12-8 Groundwater Remediation Cost—Summary

Component	Cost Asumptions	Total Cost (2002 dollars)
Using air stripper/GAC system		
Air stripper/GAC installation and 30-day start-up	Assume water treatment system capacity of 1000 gpm; treat extracted water using filtration, air stripping with liquid GAC, treat vapor (stripper vapor) using GAC, perform system start-up	402,404
Total capital costs		**402,404**
Operations and Maintenance (O&M)		
Maintain air stripper and GAC system and conduct performance monitoring	Maintain equipment, replenish chemicals, monitor system performance	71,302
Monthly reporting	Monthly reports to regulatory agency	25,759
Total annual O&M costs		**97,061**
Total Costs		**499,465**

Slurry wall, 1850 ft × 22 ft × $5/ft^2	$203,000
Clay cap, 6 acres × $30,000/acre	180,000
Design/construction management	45,000
Total	428,000

Alternative 2: This assumption assumes the construction of three parallel trenches (4 ft wide, 25 ft deep) containing a mixture of soil, 25 percent limestone, and 10 percent ferric chloride that will passively treat any contaminated groundwater before it leaves the site.

Trench construction, 620 ft × 25 ft × $35/ft^2	$542,500
Limestone, 860 tons × $30/ton	25,800
Ferric chloride, 340 tons × $335/ton	113,900
Design/management	50,000
Total	$732,200

Additional step slurry wall along drainage ditch: The assumption here is that placement of a 22-ft-deep slurry wall around the northeast boundary of the site immediately adjacent to the drainage ditch will prevent movement of groundwater into that ditch.

TABLE 12-9

Element	Rate ($)	Quantity	Units	Cost ($)
Project manager	103.80	9	hr	830.40
Project scientist	63.03	40	hr	2,521.00
Sample tech with PPE and equipment	440.00	5	days	2,200.00
Unburdened total				5,551,40
Total with 0.98 localization factor applied				5,440.37
Labor subtotal				5,440.37
Equalization tank	16,490.00	1	Lump sum	16,490.00
Filtration unit	20,332.00	1	Lump sum	20,332.00
Stripper tower	91,567.00	1	Lump sum	91,567.00
Water pump	4,436.00	1	Lump sum	4,436.00
Packing and internals	9,225,00	1	Lump sum	9,225.00
Stripper installation	8,235.00	1	Lump sum	8,235.00
Chemical feed unit	1,017.00	1	Lump sum	1,017.00
Controls	6,255.00	1	Lump sum	6,255.00
Blower	33,217.00	1	Lump sum	33,217.00
Dual carbon unit (liquid)	14,026.00	1	Lump sum	14,026.00
Carbon charge to liquid unit	1.23	3520	lb	4,329.60
Vapor recovery system (300 SCFM)	5,927.00	1	One time	5,927.00
Carbon charge to vapor unit	1.23	1600	lb	1,968.00
Miscellaneous piping	5,000.00	1	Lump sum	5,000.00
Disposable equipment	7.91	16	Per sample	126.56
VOC sample analysis (air)	405.00	4	Samples	1,620.00
VOc sample analysis (water)	183.33	12	Samples	2,199.96
Unburdened total				**225,971.12**
Total with 0.98 localization factor applied				**221,451.70**
State tax 6%				**13,287.10**
Contingency 20%				**44,290.34**
Overhead and profit 45%				**99,653.26**
Materials subtotal				**378,682.40**
Subtotal				
Year 2000				384,122.77
Year 2002				402,403.71

Note: Cost component: Air stripper/GAC system installation and start-up.

TABLE 12-10

Element	Rate ($)	Quantity	Units	Cost ($)
Project scientist	63.03	24	hr	1,512.60
Sample tech with PPE and equipment	440.00	12	days	5,280.00
Unburdened Total				6,792.60
Total with 0.98 Localization Factor Applied				6,656.75
Labor Subtotal				6,656.75
Carbon regeneration	1.23	20,480	lb/year	25,190.40
Disposable equipment	7.91	16	Per sample	126.56
VOC sample analysis (air)	405.00	8	Samples	3,240.00
VOC sample analysis (water)	183.33	8	Samples	1,466.64
Stripper repack	3,632.00	1	Annually	3,632.00
Pump and blower motor repairs	614.67	2	Annually	1,229.34
Antifoulat chemicals	500.00	1	Annually	500.00
Carbon unit removal and reinstallation	314.48	4	Annually	1,257.92
Unburdened total				36,642.86
Total with 0.98 localization factor applied				35,910.00
State tax 6%				2,154.60
Contingency 20%				7,182.00
Overhead and profit 45%				16,159.50
Materials subtotal				61,406.10
Subtotal				
Year 2000				68,062.85
Year 2002				71,302.06

Note: Cost component: Air stripper/GAC system O&M.

TABLE 12-11

Element	Rate ($)	Quantity	Units	Cost ($)
Project manager	103.80	8	hr	830.40
Project scientist	63.03	20	hr	1,260.50
Unburdened total				2,090.90
Total with 0.98 localization factor applied				2,049.08
Year 2000 annual charge for monthly reports				24,588.98
Year 2002 annual charge for monthly reports				25,759.20

Note: Cost component: monthly treatment monitoring reports.

Slurry wall cost:

$$475 \text{ ft} \times 22 \text{ ft} \times \$5/\text{ft}^2 = \$\ 52{,}250$$

Note: A depth of 22 ft was chosen to ensure that the slurry wall was tied into underlying clayey deposits.

Interceptor Trench System at an Industrial Site located Adjacent to a River At an industrial site located adjacent to a river, an interceptor trench system was installed, with tile underdrains so as to capture the contaminated groundwater. An air stripping/granular activated-carbon system was employed to remove the contaminants. Table 12-8 summarizes the treatment and operations and management (O&M) costs. Table 12-9 lists all of the elements making up the treatment system cost, and Table 12-10 gives the elements of the O&M costs. Finally, Table 12-11 details the system monitoring costs.

SUMMARY

A great deal has been written on the subject of hazardous waste remediation and thousands of sites have been investigated and remediated either at the expense of industry or under the federal CERCLA program. Alternative methods of treatment have been attempted and the results published. With the introduction of each new contaminant there appears a new method of treatment. In the final analysis, most engineers fall back on the most proven technology, based on past operating experience and reports. As yet, no magic bullet has been found that addresses all types and locations of contamination; indeed, there probably never will be such magic forthcoming. However, if source control is fully implemented and protective engineering employed at new facilities, future hazardous waste problems will have been essentially controlled. In the most simple terms, if there is no discharge of contaminants, there will be no resulting groundwater contamination. Excellent examples through which waste minimization and industrial collaboration have greatly reduced the production of waste materials have been reported by Nemerow.[34] Perhaps some would look upon this as wishful thinking, but it does represent the best solution available today and for the future. As many of us were taught as children, an ounce of prevention is worth a pound of cure.

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APPENDIX I
Abbreviations and Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
AFDO	Association of Food and Drug Officials
AIRS	Aerometric Information Retrieval System
ANSI	American National Standards Institute
APHA	American Public Health Organization
ASCE	American Society of Civil Engineers
ASDWA	Association of State Drinking Water Administrators
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
AWWA	American Water Works Association
BAT	Best available technology
BMI	body mass index
BOD	biochemical oxygen demand
CAA	Clean Air Act
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act (Superfund)
CFR	*Code of Federal Regulations*
CFU	colony-forming unit
CIAQ	Council on Indoor Air Quality
COD	chemical oxygen demand
CPSC	Consumer Product Safety Commission
CWA	Clean Water Act
DHEW	Department of Health, Education, and Welfare (now DHHS)
DHHS	Department of Health and Human Services
DOE	Department of Energy
EAL	emergency action level
EIS	environmental impact statement
EOC	emergency operations center
EOP	emergency operations plan
EPA	Environmental Protection Agency

EPCRA	Emergency Planning and Community Right-to-Know Act
FAA	Federal Aviation Administration
FAO	Food and Agriculture Organization (of the UN)
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FHA	Farmers Home Administration
FRC	Federal Radiation Council
FSIS	Food Safety and Service
FTU	formazin turbidity unit
GAC	granular activated carbon
HAZMAT	hazardous materials
HAZWOPER	Hazardous Waste Operations and Emergency Response
HUD	Department of Housing and Urban Development
ICRP	International Commission on Radiation Protection
IRC	incident response commander
JTU	Jackson turbidity unit
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
MPN	most probable number
MSDS	material safety data sheet
NAS	National Academy of Science
NCRP	National Council on Radiation Protection
NEMA	National Electrical Manufacturers Assocation
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NHANES	National Health and Nutrition Examination Survey
NIH	National Institutes of Health
NIOSH	National Institute of Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council; Nuclear Regulatory Commission
NSF	National Sanitation Foundation
NTU	nephelometric turbidity unit
OSHA	Occupational Safety and Health Administration
OTA	Office of Technology Assessment
PAHO	Pan American Health Organization
PEL	Permissible exposure limit (OSHA)
PFU	plaque-forming unit
PHS	Public Health Service
PPE	personal protective equipment
PSI	Pollutant standard index
RCRA	Resource Conservation and Recovery Act
REL	Recommended exposure limit (NIOSH) (8- or 10-hr TWA and/or ceiling)

SARA	Superfund Amendments and Reauthorization Act, also known as Emergency Planning and Community Right-to-Know Act, Title III
SCBA	self-contained breathing apparatus
SDWA	Safe Drinking Water Act
SPL	sound pressure level
TCPA	Toxic Catastrophe Prevention Acts
TCU	true color unit
TDS	total dissolved solids
TLV	Threshold limit value
TOC	total organic carbon
TSCA	Toxic Substances Control Act
TSP	total suspended particulate
TSS	total suspended solids
TWA	(Eight-hour) time-weighted average (OSHA)
UC	uniformity coefficient
UL	Underwriters Laboratories
USDA	U.S. Department of Agriculture
USGS	United States Geological Survey
VOC	Volatile organic compound
WHO	World Health Organization
WPCF	Water Pollution Control Federation, renamed Water Environment Federation
WQI	Water quality index

APPENDIX II
General Engineering Data

MISCELLANEOUS DATA*

°C = $\frac{5}{9}$ (°F − 32); °F = $\frac{9}{5}$ °C + 32

Circumference of circle	= $2\pi r = \pi D$; $\pi = 3.1416$; r = radius; D = diameter
Area of circle	= $\frac{1}{4}\pi D^2 = 0.7854D^2$
Area of sphere	= πD^2
Volume of sphere	= $\frac{1}{6}\pi D^3 = 0.5236D^3$
Volume of cone	= area of base × $\frac{1}{3}$ altitude
Volume of pyramid	= area of base × $\frac{1}{3}$ altitude
Area of triangle	= $\frac{1}{2}$ altitude × base
Area of trapezoid	= $\frac{1}{2}$ (sum of parallel sides) × altitude
1 acre	= 43,560 ft^2
1 square mile (mi^2)	= 640 acres
1 inch (in.)	= 2.54 centimeters (cm)
1 ppm (in water)	= 1 mg per liter = 8.34 lb per million gal
1 cubic foot (ft^3)	= 7.48 gal = 62.4 lb
1 U.S. gallon (gal)	= 8.345 lb = 3.785 liters = 231 $in.^3$ = 0.833 British Imperial gallons
1 pound (lb)	= 7000 grains = 0.4536 kg = 16 oz
1 grain per gallon	= 17.12 parts per million (ppm)
1 pound per square inch (psi)	= 2.31 ft vertical head of water = 2.04 in. of mercury = 6.9 kilonewtons per square meter (kN/m^2)

* See Appendix III for customary-to-metric conversion factors.

Atmospheric pressure	= 33.9 ft of water at sea level
	= 31.6 ft of water at 2000 ft
	= 28.3 ft of water at 5000 ft
	= 23.4 ft of water at 10,000 ft
1 gallon per minute (gpm)	= 1440 gal per day
	= 0.133 cubic feet per minute (cfm)
	= 0.0038 cubic meters per minute (m^3/min)
1 cubic foot per second (cfs)	= 0.646 million gallons per day
1 million gallons per day (mgd)	= 1.547 cfs
1 horsepower hour (hp-hr)	= 0.746 kW-hr = 2546 Btu
	= (33,000 × 60) ft-lb
	= 0.065 gal of diesel oil (approximate)
	= 0.110 gal of gasoline (approximate)
	= 10-20 ft^3 of gas
1 British thermal unit (Btu)	= quantity of heat required to raise the temperature of 1 lb of water 1°F
1 Btu per minute	= 17.57 watts
1 Btu	= 778 ft-lb
	= 0.000393 hp-hr
1 ton of refrigeration	= 288,000 Btu per 24 hr
	= 2000 lb of ice × 144 Btu; 1 lb of ice absorbs 144.3 Btu of heat in melting
1 pound of water evaporated from 212°F	= 0.284 kW-hr = 970.3 Btu
1 kilowatt-hour (kW-hr)	= 3413 Btu per hour
1 boiler horsepower	= 33,479 Btu per hour
Water surface heat loss	= ± 14.3 Btu per hour per ft^2 per degree temperature difference between water and air
1 therm of natural gas	= 100,000 Btu

Pump Efficiencies

Deep-well displacement pumps have an efficiency of 35 to 40 percent. Small centrifugal pumps (10–40 gpm) have an efficiency of 20 to 50 percent. Larger centrifugal pumps (50–500 gpm) have an efficiency of 50 to 80 percent. Check with manufacturer.

Small duplex, triplex, and reciprocating pumps in general have efficiencies of 30 to 60 percent, but large pumps have efficiencies of 60 to 80 percent. Check with manufacturer.

Horsepower to Pump Water

$$\text{Horsepower to pump water} = \frac{\text{gal of water pumped per min} \times \text{total head pumped against in ft} \times \text{weight of 1 gal of water in lb}}{\text{33,000 ft-lb/min} \times \text{pump efficiency (as a decimal)}}$$

$$\text{Horsepower of motor drive} = \frac{\text{gal/min} \times \text{total head in ft}}{3960 \times \text{pump efficiency} \times \text{motor efficiency}}$$

$$= \frac{3600 \times \text{number meter disk revolutions} \times \text{disk constant}}{\text{number of seconds}}$$

$$\text{Power input to a motor in watt hours} = \text{voltage} \times \text{amperage} \times \text{power factor} \times 3600 \times \begin{cases} 1 \text{ for single phase} \\ 1.41 \text{ for two phase} \\ 1.73 \text{ for three phase} \end{cases}$$

Note: One rotation of meter disk equals watts marked on disk.

HYDRAULIC FORMULAS

Waterfall

Power of waterfall = 0.114 × cfs × head in ft × efficiency (efficiency = ±88%).

Channel Flow (or Pipe Not Flowing Full)

$$V = \frac{1.486R^{2/3}S^{1/2}}{n} \quad \text{(Manning formula)}$$

where $R = \dfrac{\text{cross-sectional area of water (ft}^2\text{)}}{\text{perimeter wet (ft)}} \times$ hydraulic radius
S = slope of water surface (ft/ft)
n = 0.015 ± (see hydraulic texts)(Manning discharge coefficient)

and

$$Q = VA$$

where Q = quantity of water (cfs)
V = average velocity of flow (fps)
A = area of pipe or conduit (ft^2)

TABLE A Motor Wiring for Various Horsepowers, Motor Types, and Currents

	Three-Phase Squirrel-Cage Induction Motors						Single-Phase Induction Motors						Direct-Current Motors					
	220 V			440 V			115 V			230 V			115 V			230 V		
Horsepower	Approximate Full-Load Amperes	Wire Size, min AWG	Branch Circuit Fuse, A	Approximate Full-Load Amperes	Wire Size, min AWG	Branch Circuit Fuse, A	Approximate Full-Load Amperes	Wire Size, min AWG	Branch Circuit Fuse, A	Approximate Full-Load Amperes	Wire Size, min AWG	Branch Circuit Fuse, A	Approximate Full-Load Amperes	Wire Size, min AWG	Branch Circuit Fuse, A	Approximate Full-Load Amperes	Wire Size, min AWG	Branch Circuit Fuse, A
$\frac{1}{2}$							7.4	14	25	3.7	14	15						
$\frac{3}{4}$							10.2	14	35	5.1	14	15						
1	3.5	14	15	1.8	14	15	13	12	40	6.5	14	20	8.6	14	15	4.3	14	15
$1\frac{1}{2}$	5	14	15	2.5	14	15	18.4	10	60	9.2	14	30	12.6	12	20	6.3	14	15
2	6.5	14	20	3.3	14	15	24	10	80	12	14	40	16.4	10	25	8.2	14	15
3	9	14	30	4.5	14	15	34	6[a]	110	17	10	60	24	10	40	12	14	20
5	15	12	45	7.5	14	25				28	8[a]	90	40	6	60	20	10	30
$7\frac{1}{2}$	22	10	70	11	14	35							58	3[a]	90	29	8	45
10	27	8[a]	80	14	12	45							76	2[a]	125	38	6	60
15	40	6	125	20	10	60							112	00[a]	175	56	4	90
20	52	4[a]	175	26	8[a]	80							148	4/0[a]	225	74	2[a]	125
25	64	3[a]	200	32	8	100												
30	78	1[a]	250	39	6	125												
40	104	00[a]	350	52	4[a]	175												
50	125	000[a]	400	63	3[a]	200												
60	150	4/0[a]	450	75	2[a]	250												

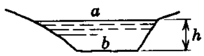
Source: Adapted from General Electric Co., 1955 Diary. See *National Electrical Code* for additional details.

Note: Values given are for not more than three conductors in a cable. Single-phase and direct-current motors use two conductors.

[a] Next smaller size may be used with RH-type insulation.

For a stream having a trapezoidal section,

$$A = \tfrac{1}{2}\,(a + b)h$$

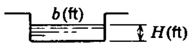


and $V_{(\text{average})} = 0.85 \times$ surface velocity. Surface velocity is time for a floating object to travel a known distance in a fairly straight section of stream.

Weir Discharge

Discharge over 90° weir $= Q = 2.53H^{5/2}$.

Discharge over rectangular weir $= Q = 3.33\ (b - 0.2H)\ H^{3/2}$ (with end contractions).



With no end contractions $Q = 3.33bH^{3/2}$; $b =$ at least $3H$.

Note: Place hook gage at least 3 ft back of weir. No or low velocity of approach.

Water Pressure

$$h\,\frac{P}{w}$$

where $p = \text{lb/ft}^2$

$w = \text{lb/ft}^3 = 62.4$ for water

$h =$ head of water (ft) $= \dfrac{p \times 144}{62.4} = 2.3p$, where p is in psi

$$h = \frac{V^2}{2g}$$

where $g = 32.2$ ft/sec/sec and $V =$ velocity in fps.

Flow of Water in Pipe and Head Loss

$$h = \frac{flV^2}{d2g} \text{ (Darcy-Weisbach formula)}$$

where h = ft head loss
l = ft length
d = ft diameter
f = friction factor = 0.02 for cast iron (see hydraulic text)
v = velocity in fps

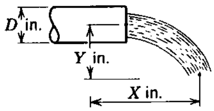
Bernoulli's equation (between any two points):

$$\frac{p_1}{w} + Z_1 + \frac{V_1^2}{2g} = \frac{p_2}{w} + Z_2 + \frac{V_2^2}{2g} + \text{loss head (ft)}$$

where Z_1 and Z_2 = ft available potential energy; elevation of the center line of the pipe, at each point.

$$\text{Flow from full-flowing horizontal pipe} = \frac{2.83D^2X}{\sqrt{Y}} \quad \text{(in gpm)}$$

Use a carpenter's square to measure X and Y.



To determine flow primarily in a pressure conduit or a conduit flowing full, i.e., sewers, water lines, and small channels:

$$V = 1.318\, CR^{0.63}\, S^{0.54} \quad \text{(Hazen–Williams formula)}$$

where V = average velocity of flow in fps
R = hydraulic radius; (cross-sectional area in ft^2)/(wetted perimeter in ft)
S = slope of hydraulic grade line; loss of head in ft divided by its corresponding horizontal length
C = Hazen–Williams friction coefficient

and C equals 140 for cement asbestos; 40–120 for old unlined cast iron; 130–150 for cement lined cast iron, brass, copper; 140–150 for bitumastic enamel-lined, plastic, and new unlined steel; 135 for centrifugally spun concrete and rubber-lined fire hose; 145–150 for coal-tar enamel lined; 100–140 for vitrified pipe; 110 for wood-stave; 140 for glass; and 120 for galvanized iron (see hydraulic texts).

Substituting in $Q = VA$ and converting Q into gpm and pipe diameter into in.,

$$Q = 0.285\ Cd^{2.63}\ S^{0.54}\ \text{(use Hazen–Williams nomogram).}$$

Electromotive Series of Principal Metals

Potassium	Chromium	Arsenic
Sodium	Cadmium	Copper
Barium	Iron	Antimony
Strontium	Cobalt	Bismuth
Calcium	Nickel	Mercury
Magnesium	Tin	Silver
Aluminum	Lead	Platinum
Manganese	Hydrogen	Gold
Zinc		

CLASSIFIED LIST OF UNITS

Units of Weight

1 kilogram (kg)	=	1000 grams (g)
1 milligram (mg)	=	10^{-3} g
1 microgram (μg)	=	10^{-6} g
1 nanogram (ng)	=	10^{-9} g
1 picogram (pg)	=	10^{-12} g

Units of Concentration—for Solids

1 part per million (ppm)	=	1 mg/kg	=	1 μg/g
1 part per billion (ppb)	=	μg/kg	=	1 ng/g
1 part per trillion (ppt)	=	1 ng/kg	=	1 pg/g

Units of Concentration—for Water (on a weight-to-weight basis)

1 milligram per liter = 1 mg/l = approx. 1 ppm, or = 1 ppm × specific gravity
1 microgram per liter = 1 μg/l = approx. 1 ppb
1 nanogram per liter = 1 ng/l = approx. 0.001 ppb

Units of Concentration—for Air (on a weight-to-volume basis corrected for temperature and pressure)

TEMPERATURE CONVERSION TABLE, °F to °C: °C = (°F − 32)/1.8

°F	°C	°F	°C	°F	°C
-40.	-40.0000	32.	0.0	122.	50.000
-38.	-38.8889	34.	1.111	124.	51.111
-36.	-37.7778	36.	2.222	126.	52.222
-34.	-36.6667	38.	3.333	128.	53.333
-32.	-35.5556	40.	4.444	130.	54.444
-30.	-34.4445	42.	5.556	132.	55.556
-28.	-33.3333	44.	6.667	134.	56.667
-26.	-32.2222	46.	7.778	136.	57.778
-24.	-31.1111	48.	8.889	138.	58.889
-22.	-30.0000	50.	10.000	140.	60.000
-20.	-28.8889	52.	11.111	142.	61.111
-18.	-27.7778	54.	12.222	144.	62.222
-16.	-26.6667	56.	13.333	146.	63.333
-14.	-25.5556	58.	14.444	148.	64.444
-12.	-24.4444	60.	15.556	150.	65.556
-10.	-23.3333	62.	16.667	152.	66.667
-8.	-22.2222	64.	17.778	154.	67.778
-6.	-21.1111	66.	18.889	156.	68.889
-4.	-20.0000	68.	20.000	158.	70.000
-2.	-18.8889	70.	21.111	160.	71.111
0.	-17.7778	72.	22.222	162.	72.222
2.	-16.6667	74.	23.333	164.	73.333
4.	-15.5556	76.	24.444	166.	74.444
6.	-14.4445	78.	25.556	168.	75.556
8.	-13.3333	80.	26.667	170.	76.667
10.	-12.2222	82.	27.778	172.	77.778
12.	-11.1111	84.	28.889	174.	78.889
14.	-10.0000	86.	30.000	176.	80.000
16.	-8.8889	88.	31.111	178.	81.111
18.	-7.7778	90.	32.222	180.	82.222
20.	-6.6667	92.	33.333	182.	83.333
22.	-5.5556	94.	34.444	184.	84.444
24.	-4.4444	96.	35.556	186.	85.556
26.	-3.3333	98.	36.667	188.	86.667
28.	-2.2222	100.	37.778	190.	87.778
30.	-1.1111	102.	38.889	192.	88.889
32.	0.0	104.	40.000	194.	90.000
		106.	41.111	196.	91.111
		108.	42.222	198.	92.222
		110.	43.333	200.	93.333
		112.	44.444	202.	94.444
		114.	45.556	204.	95.556
		116.	46.667	206.	96.667
		118.	47.778	208.	97.778
		120.	48.889	210.	98.889
				212.	100.000

Source: Milk Pasteurization Controls and Tests, U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration, Rockville, MD, 1986, pp. 342–343.

TEMPERATURE CONVERSION TABLE, °C to °F: °F = 1.8°C + 32

°C	°F	°C	°F
0.	32.0	50.	122.0
1.	33.8	51.	123.8
2.	35.6	52.	125.6
3.	37.4	53.	127.4
4.	39.2	54.	129.2
5.	41.0	55.	131.0
6.	42.8	56.	132.8
7.	44.6	57.	134.6
8.	46.4	58.	136.4
9.	48.2	59.	138.2
10.	50.0	60.	140.0
11.	51.8	61.	141.8
12.	53.6	62.	143.6
13.	55.4	63.	145.4
14.	57.2	64.	147.2
15.	59.0	65.	149.0
16.	60.8	66.	150.8
17.	62.6	67.	152.6
18.	64.4	68.	154.4
19.	66.2	69.	156.2
20.	68.0	70.	158.0
21.	69.8	71.	159.8
22.	71.6	72.	161.6
23.	73.4	73.	163.4
24.	75.2	74.	165.2
25.	77.0	75.	167.0
26.	78.8	76.	168.8
27.	80.6	77.	170.6
28.	82.4	78.	172.4
29.	84.2	79.	174.2
30.	86.0	80.	176.0
31.	87.8	81.	177.8
32.	89.6	82.	179.6
33.	91.4	83.	181.4
34.	93.2	84.	183.2
35.	95.0	85.	185.0
36.	96.8	86.	186.8
37.	98.4	87.	188.6
38.	100.4	88.	190.4
39.	102.2	89.	192.2
40.	104.0	90.	194.0
41.	105.8	91.	195.8
42.	107.6	92.	197.6
43.	109.4	93.	199.4
44.	111.2	94.	201.2
45.	113.0	95.	203.0
46.	114.8	96.	204.8
47.	116.6	97.	206.6
48.	118.4	98.	208.4
49.	120.2	99.	210.2
		100.	212.0

1 milligram per cubic meter	=	1 mg/m^3
1 microgram per cubic meter	=	1 $\mu g/m^3$
1 nanogram per cubic meter	=	1 ng/m^3

Power of Ten

One quintillion	= 1,000,000,000,000,000,000	= 10^{18}, exa (E)*
One quadrillion	= 1,000,000,000,000,000	= 10^{15}, peta (P)
One trillion	= 1,000,000,000,000	= 10^{12}, tera (T)
One billion	= 1,000,000,000	= 10^{9}, giga (G)
One million	= 1,000,000	= 10^{6}, mega (M)
One thousand	= 1,000	= 10^{3}, kilo (k)
One hundred	= 100	= 10^{2}, hecto (h)
Ten	= 10	= 10^{1}, deka (da)
Ten to zero power	= 1	= 10^{0}
One-tenth	= 0.1	= 10^{-1}, deci (d)
One-hundredth	= 0.01	= 10^{-2}, centi (c)
One-thousandth	= 0.001	= 10^{-3}, milli (m)
One-millionth	= 0.000,001	= 10^{-6}, micro (μ)
One-billionth	= 0.000,000,001	= 10^{-9}, nano (n)
One-trillionth	= 0.000,000,000,001	= 10^{-12}, pico (p)
One-quadrillionth	= 0.000,000,000,000,001	= 10^{-15}, femto (f)
One-quintillionth	= 0.000,000,000,000,000,001	= 10^{-18}, atto (a)

Orders of Magnitude (greater than 1)

One	=	1×10	=	10^1
Two	=	1×100	=	10^2
Three	=	1×1000	=	10^3
Four	=	$1 \times 10,000$	=	10^4
Five	=	$1 \times 100,000$	=	10^5, etc.

Logarithm

Log_{10} 1	=	0 Log_{10} 0.1	=	-1
Log_{10} 10	=	1 Log_{10} 0.01	=	-2
Log_{10} 100	=	2 Log_{10} 0.001	=	-3
Log_{10} 1000	=	3, etc. Log_{10} 0.0001	=	-4, etc.

Log Reduction in Percent

One log reduction	=	90 percent reduction
Two log reduction	=	99 percent reduction

*Prefixes and symbols.

Three log reduction	=	99.9 percent reduction
Four log reduction	=	99.99 percent reduction
Five log reduction	=	99.999 percent reduction
Six log reduction	=	99.9999 percent reduction, etc.

Units of Size

One kilometer	=	1000 meters (m)
One meter	=	100 centimeters (cm)
One centimeter	=	10 millimeters (mm)
One millimeter	=	0.001 meter (m)
One millimeter	=	1000 micrometers (μm)
One micrometer	=	1 micron (μm)
One micron	=	0.0000394 inches (in.)

FINANCE OR COST COMPARISONS

Compound Interest

$$A = P(1 + i)^n$$

where A = amount or sum of principal and interest
P = principal or amount borrowed
i = rate of annual interest, or value of money
n = number of years money draws interest

Present Worth

$$P_w = \frac{A}{(1 + i)^n}$$

where P_w = present worth of a sum of money A due in n years at compound interest rate i.

Sinking Fund (annuity)

$$S = \left[\frac{(1 + i)^n}{i}\right] d$$

where S = sinking fund or an amount that will accumulate in n years by making equal annual installments d, at interest rate i or

$$d = \frac{Si}{(1 + i)^n - 1}$$

Bond Issue

$$d = B\left[\frac{i}{(1 - i)^n - 1} + i\right]$$

where B = bond issue or present sum of money to be paid off in equal annual installments d in n years at interest rate i. The bond issue includes principal, legal and engineering fees, and interest.

Capitalized Cost—Economic Comparison

$$S_c = C + \frac{O}{i} + \frac{C - \text{salvage}}{(1 + i)^n - 1} + \frac{R}{(1 + i)^x - 1}$$

where S_c = capitalized cost of a project having a useful life of n years. It includes renewal or first cost C, annual cost of maintenance operation O/i, and depreciation $(C - \text{salvage})/[(1 + i)^n - 1]$ at interest rate i, and major repairs $R/[(1 + i)^x - 1]$ every x years. Where the salvage value of project or major repairs are nil, omit.

Total Annual Cost—Economic Comparison

$$S_c i = Ci + O + \frac{i(C - \text{salvage})}{(1 + i)^n - 1} + \frac{Ri}{(1 + i)^x - 1}$$

where $S_c i$ = total annual cost and $Ci/[(1 + i)^n - 1]$ represents the annual rate of depreciation or money set aside each year at compound interest i to equal the first cost C at the end of n years.

Capital Recovery

$$R = P\left[\frac{i(1 + i)^n}{(1 + i)^n - 1}\right]$$

where R = annual rate of capital recovery
P = principal or first cost of installation
n = capital recovery period or useful life
i = interest rate

APPENDIX III
English–Metric Conversion Factors for Common Units

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
Acre	ac	4.047×10^{3}	m^{2a}
		0.4047	ha (hectare)
Acre-foot	ac-ft	1233	m^{3a}
Ampere-hour	A-hr	3600	C^{a} (coulomb)
Ampere-second	A-sec	1.000	C^{a}
Angstrom[b]	Å	1.0×10^{-10}	m^{a}
		1.0×10^{-1}	nm
Atmosphere	atm	101.3	kPa^{a} (pascal)
Bar[b]	bar	100.0	kPa^{a}
Barrel (oil)	bbl	0.1590	m^{3a}
		159.0	L (liter)
Barrel (water)	bbl	0.119 2	m^{3a}
		119.2	L
British thermal unit	Btu	1.055	kJ (kilojoule)
British thermal units per cubic foot	Btu/ft^{3}	37.26	kJ/m^{3a}
British thermal units per gallon	Btu/gal	278.7	kJ/m^{3a}
		0.278 7	kJ/L
British thermal units per hour	Btu/hr	0.2931	W^{a} (watt)
British thermal units per hour per square foot	$Btu/hr/ft^{2}$	3.155	$J/m^{2}{\cdot}s^{a}$
British thermal units per pound	Btu/lb	2.326	kJ/kg^{a}
British thermal units per ton	Btu/ton[c]	1.163	J/kg^{a}
bushel (U.S. dry)	bu	3.524×10^{-2}	m^{3a}
Calorie international[b]	cal	4.187	J^{a} (joule)

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
15°C		4.186	J[a]
20°C		4.182	J[a]
Calories per second	cal/sec	4.187	W[a]
Candelas per steradian	cd/sr	1.000	lm (lumen)
Candelas per square foot	cd/ft^2	10.76	cd/m^2[a]
Candle	candle	1.019	cd[a] (candela)
Centipoise[b]	cP	1.000×10^{-3}	Pa·s[a]
Cubic feet per gallon	ft^3/gal	7.482	m^3/m^3[a]
		7.482×10^{-3}	m^3/L
Cubic feet per hour	cfh or ft^3/hr	7.867×10^{-6}	m^3/s[a]
		7.867×10^{-3}	L/s
Cubic feet per hour per square foot	cfh/ft^2	8.467×10^{-5}	$m^3/m^2{\cdot}s$[a]
		304.8	L/m^2 h
Cubic feet per million gallons	ft^3/mil. gal	7.482	mL/m^3
Cubic feet per minute	cfm or ft^3/min	$4\,719 \times 10^{-4}$	m^3/s[a]
		0.4719	L/s
Cubic feet per minute per foot	cfm/ft	1.549	L/m·s
Cubic feet per minute per thousand cubic feet	cfm/1000 ft^3	1.667×10^{-2}	$L/m^3{\cdot}s$
Cubic feet per minute per thousand gallons	cfm/1000 gal	0.124 7	$L/m^3{\cdot}s$
Cubic feet per pound	ft^3/lb	6.243×10^{-2}	m^3/kg[a]
Cubic feet per second (or second-feet)	cfs	2.832×10^{-2}	m^3/s[a]
		28.32	L/s
Cubic feet per second per acre	cfs/ac	6.997×10^{-6}	$m^3/m^2{\cdot}s$[a]
		69.97	L/ha·s
Cubic feet per second per square mile	$cfs/mile^2$	1.093×10^{-8}	$m^3/m^2{\cdot}s$[a]
		0.109 3	L/ha·s
Cubic foot	ft^3	2.832×10^{-2}	m^3[a]
		28.32	L
Cubic inch	$in.^3$	16.39×10^{-6}	m^3[a]
		16.39	mL
Cubic yard	yd^3	0.764 6	m^3[a]
Curie[b]	Ci	3.700×10^{10}	s^{-1}[a]
Cycles per second	cps	1.000	Hz (hertz)
Degrees Fahrenheit	°F	0.5556 (°F − 32)	°C
Rankine	°R	0.5556	K (kelvin)

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
Degrees per second	degrees/sec	1.745×10^{-2}	rad/s[a]
Degrees per second squared	degrees/sec^2	1.745×10^{-2}	rad/s^2[a]
dyne[b]	dyn	1.000×10^{-5}	N[a] (newton)
Electronvolt	eV	1.602×10^{-19}	J[a] (joule)
Erg[b]	erg	1.000×10^{-7}	J[a]
Fathom	fathom	1.829	m[a]
Feet of head	ft	0.3048	m[a]
Feet per hour	ft/hr	8.467×10^{-5}	m/s[a]
Feet per minute	ft/min or fpm	5.080	mm/s[a]
Feet per second	ft/sec or fps	0.3048	m/s[a]
Feet per second squared	ft/sec^2	0.3048	m/s^2[a]
Feet per year	ft/yr	0.3048	m/a (meters per annum)
Foot	ft	0.3048	m[a]
Foot-candle	ft-c	10.76	lx[a] (lux)
Foot-head	ft-head	2989	Pa[a]
Foot-lambert	ftL	3.426	cd/m^2[a] (candelas per square meter)
Foot-pound	ft-lb	1.356	N·m[a]
Foot-pounds per degree	ft-lb/°	77.69	N·m/rad[a]
Foot-pounds per inch	ft-lb/in.	1.659	J/m[a]
Foot-pounds per minute	ft-lb/min	2.259×10^{-2}	W[a]
Foot-pounds per second	ft-lb/sec	1.355	W[a]
Gallon	gal[c]	3.785×10^{-3}	M^3[a]
		3.785	L
Gallons per day	gpd	4.381×10^{-5}	L/s
		3.785×10^{-3}	m^3/d
Gallons per day per acre	gpd/ac	1.083×10^{-11}	m^3/m^2·s[a]
		1.083×10^{-8}	L/m^2·s
		9.353	L/ha·d
Gallons per day per capita	gpd/cap	3.785	L/cap·d
Gallons per day per linear foot	gpd/ft	1.437×10^{-7}	m^3/m·s[a]
		1.437×10^{-4}	L/m·s
		1.242×10^{-2}	m^3/m·d
Gallons per day per foot of manhole diameter per foot-head	gpd/ft/ft-head	4.074×10^4 (mL/m·d)/m	
Gallons per day per inch of diameter per mile	gpd/in. dia./mile	92.60	(mL/m·d)/m
Gallons per day per mile	gpd/mile	2.720×10^{-11}	m^3/m·s[a]
		2.352	mL/m·d

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
Gallons per day per square foot	gpd/ft^2	4.715×10^{-7}	m^3/m^2·s^a or m/s^a
		4.074×10^{-2}	m^3/m^2·d or m/d
		40.74	L/m^2 d
Gallons per day per thousand square feet	gpd/1000 ft^2	4.074×10^{-2}	L/m^2·d
Gallons per hour	gph	1.051	mL/s
Gallons per hour per foot of diameter per foot-head	gph/ft dia./ ft-head	11.32	(mL/m·s)/m
Gallons per hour per inch diameter per thousand feet	gph/in. dia./ 1000 ft	488.9	(mL/M·h)/m
Gallons per mile	gal/mile	2.352	mL/m
Gallons per million gallons	gal/mil. gal	1.000	mL/m^3
Gallons per minute	gpm	6.308×10^{-5}	m^3/s^a
		6.308×10^{-2}	L/s
		5.451	m^3/d
Gallons per minute per acre	gpm/ac	0.155 8	L/ha·s
Gallons per minute per cubic foot	gpm/ft^3	2.228	L/m^3·s
Gallons per minute per foot	gpm/ft	2.070×10^{-4}	m^3/m·s^a
		2.07	L/m·s
Gallons per minute per square foot	gpm/ft^2	6.791×10^{-4}	m/m·s^a
		0.6791	L/m^2·s
		58.67	m^3/m^2·d
Gallons per pound	gal/lb	8344	mL/kg
Gallons per ton	gal/ton	4.173	mL/kg
Gallons per ton per mile	gal/ton/mile	2.593×10^{-3}	mL/kg·m
Gauss^b	G	1.000×10^{-4}	T^a (tesla)
Grain	gr	64.80	mg
Grains per gallon	gr/gal	17.12	g/m^3
		17.12	mg/L
Hectare	ha	1.000×10^4	m^{2a}
Horsepower	hp	745.7	W^a
Horsepower-hour	hp-hr	2.685	MJ
Horsepower-hours per pound	hp-hr/lb	5.919	MJ/kg
Horsepower-hours per thousand cubic feet	hp-hr/1000 ft^3	26.34	W/m^3
Horsepower-hours per thousand gallons	hp-hr/1000 gal	0.7103	kJ/L

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
Horsepower-hours per thousand pounds	hp-hr/1000 lb	5.919	kJ/kg[a]
Horsepower per gallon per minute	hp/gpm	11.82	MJ/m^3[a]
		11.82	kJ/L
Horsepower per million gallons	hp/mil. gal	0.1970	W/m^3[a]
		1.970×10^{-4}	W/L
Horsepower per thousand gallons	hp/1000 gal	197.3	kW/m^3
Inch	in.	2.540×10^{-2}	m[a]
		25.40	mm
Inches of water	in. H_2O	0.2488	kPa
Inches of mercury	in. Hg	3.377	kPa
Inches per foot	in./ft	8.333	%
Inches per hour	in./hr	2.540	cm/h
		25.40	mm/h
Inches per year	in./yr	25.40	mm/a (millimeters per annum)
Inches to the fourth	$in.^4$	4.162×10^5	mm^4
Kilowatt-hour	kWh	3.600	MJ
Kilowatt-hours per day	kWh/d	41.67	W[a]
Kilowatt-hours per gallon	kWh/gal	951.1	MJ/m^3
		0.9511	MJ/L
Kilowatt-hours per million gallons	kWh/mil. gal	951.1	J/m^3[a]
		0.9511	J/L
Kilowatt-hours per pound	kWh/lb	7.936×10^{-3}	MJ/kg
Kilowatt-hours per thousand pounds	kWh/1000 lb	7.936	kJ/kg
Kilowatt-hours per ton	kWh/ton	3.969	kJ/kg
Kip	kip	4.448	kN (kilonewton)
Kip-feet	kip-ft	1.356	kN·m
Kip-feet per second	kip-ft/sec	1.356	kN·m/s
Kips per foot	kip/ft	14.59	kN/m
Kips per square foot	kip/ft^2	47.88	kPa
Knot	kn	1.852	km/h
Maxwell[b]	Mx	1.000×10^{-8}	Wb[a] (weber)
Micron[b]	μ	1.000	μm
Micromhos per centimeter[b]	μmho/cm	0.1000	mS/m (millisiemens per meter)
Mil	mil	25.40	μm
Mile	mile	1.609	km
Miles per hour	mph	0.4469	m/s[a]
		1.069	km/h

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
Million gallons	mil. gal	3.785×10^3	m^3[a]
		3.785	ML
Million gallons per day	mgd	4.383×10^{-2}	m^3/s[a]
		43.83	L/s
		3.785×10^3	m^3/d
		3.785	ML/d
Million gallons per day per acre	mgd/ac	1.083×10^{-5}	$m^3/m^2 \cdot s$[a]
		9.353×10^3	$m^3/ha \cdot d$
		9.353	ML/ha·d
Most probable number per hundred milliliters	MPN/100 mL	10.00	MPN/L
Nautical mile	na. mile	1.852	km
Ounce (mass)	oz	28.35	g
Ounce (fluid)	oz	29.57	mL
Ounces per gallon	oz/gal	28.35	g/L
Parts per billion	ppb	1.00 (approx.)	μg/L
		1.000	μg/kg
Parts per million	ppm	1.00 (approx.)	mg/L
		1.000	mg/kg
Persons per acre	cap/ac	0.4047	cap/ha
Persons per square mile	$cap/mile^2$	2.590	cap/km^2
Pint (dry) (liquid)	pt	0.5506	L
		0.4731	L
Poise[b]	P	0.1000	Pa·s[a]
Pound (force)	lbf	4.448	N[a]
Pound (mass)	lb	0.4536	kg[a]
Poundal	pdl	0.1383	N[a]
Pound-foot	lb-ft	1.356	N·m[a]
Pound-feet per second	lb-ft/sec	1.356	N·m/s[a]
Pound per acre per day	lb/ac/d	1.297×10^{-9}	$kg/m^2 \cdot s$[a]
		0.1121	$g/m^2 \cdot d$
		1.121	kg/h·d
Pounds per acre-foot per day	lb/ac-ft/d	0.3677	$g/m^3 \cdot d$
Pounds per capita per day	lb/cap/d	0.4536	kg/cap·d
Pounds per cubic foot	lb/ft^3	16.02	kg/m^3[a]
Pounds per cubic foot per hour	$lb/ft^3/hr$	4.449×10^{-3}	$kg/m^3 \cdot s$[a]
		16.02	$kg/m^3 \cdot h$
Pounds per thousand cubic feet	$lb/1000\ ft^3$	16.02	g/m^3[a]
Pounds per cubic yard	lb/yd^3	0.5933	kg/m^3[a]

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
Pounds per day	lb/d	5.250	mg/s[a]
		0.4536	kg/d
Pounds per day per acre	lb/d/ac	0.1121	g/m²·d
Pounds per day per acre-foot	lb/d/ac-ft	0.3677	g/m³·d
Pounds per day per cubic foot	lb/d/ft³	16.02	kg/m³·d
Pounds per day per pound	lb/d/lb	11.57	mg/kg·s[a]
Pounds per day per square foot	lb/d/ft²	56.51	mg/m²·s[a]
		4.882	kg/m²·d
Pounds per day per thousand cubic feet	lb/d/1000 ft³	1.602×10^{-2}	kg/m³·d
Pounds per day per thousand square feet	lb/d/1000 ft²	4.882	g/m²·d
Pounds per foot	lb/ft	1.488	kg/m[a]
Pounds per foot per foot of diameter	lb/ft/ft dia	47.88	(N/m)/m[a]
Pounds per gallon	lb/gal	0.1198	kg/L
Pounds per hour	lb/hr	0.1260	kg/s
		0.4536	kg/h
Pounds per hour per square foot	lb/hr/ft²	4.883	kg/m²·h
Pounds per hour per cubic feet	lb/hr/ft³	57.67	kg/L·s
Pounds per million gallons	lb/mil. gal	0.1198	g/m³
		0.1198	mg/L
Pounds per pound	lb/lb	1000	g/kg
Pounds per square foot (mass dose)	lb/ft²	4.883	kg/m²[a]
Pounds per square foot (force)	lb/ft²	47.88	Pa[a]
Pounds per square foot per hour	lb/ft²/hr	1.356	g/m²·s
		4.882	kg/m²·h
Pounds per square inch (force)	psi	6895	Pa[a]
		6.895×10^{-2}	bar[b]
		7.031×10^{-2}	kgf/cm²[b]
Pounds per thousand cubic feet	lb/1000 ft³	16.02	g/m³
Pounds per thousand gallons	lb/1000 gal	0.1198	g/m³

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
Pounds per ton	lb/ton	0.500	g/kg
Pounds per year per acre	lb/yr/ac	1.121	kg/ha·a
Pounds per year per cubic foot	$lb/yr/ft^3$	16.02	$kg/m^3 \cdot a$
Pounds per year per square foot	$lb/yr/ft^2$	4.882	$kg/m^2 \cdot a$
Pound-seconds per square foot	$lb\text{-}sec/ft^2$	47.88	Pa·s[a]
Pound-square feet per second	$lb\text{-}ft^2/sec$	4.883	$kg \cdot m^2/s$[a]
Quart	qt	0.9463	L
Rad[b]	rad	1.000×10^{-2}	Gy[a] (gray)
Revolutions per minute	rpm	1.000	r/min
Revolutions per second	rps	1.000	r/s[a]
Röentgen[b]	R	2.579×10^{-4}	Ci/kg[a] (curies per kilogram)
Slug	slug	14.59	kg[a]
Square foot	ft^2	9.290×10^{-2}	m^2[a]
Square feet per capita	ft^2/cap	9.290×10^{-2}	m^2/cap[a]
Square feet per cubic foot	ft^2/ft^3	32.83	m^2/m^3[a]
Square feet per foot	ft^2/ft	0.3048	m^2/m[a]
Square feet per second	ft^2/sec	9.290×10^{-2}	m^2/s[a]
Square inch	$in.^2$	6.452×10^{-4}	m^2[a]
		645.2	mm^2
Square mile	mi^2	2.590	km^2
Square yard	yd^2	0.8361	m^2[a]
Stoke[b]	st	1.0×10^{-4}	m^2/s[a]
Ton (long)	ton	1.016	Mg
Ton (short)		0.9072	Mg
Ton (short)		907.2	kg[a]
Tons per acre	ton/ac	0.2242	kg/m^2[a]
		2.242	Mg/ha
Tons per cubic yard	ton/yd^3	1.187	Mg/m^3
Watt-hour	W-hr	3.600	J[a]
Watts per square foot	W/ft^2	9.290×10^{-2}	W/m^2[a]
Yard	yd	0.9144	m[a]

Source: "Units of Expression for Wastewater Management," in *Water Pollution Control Federation MOP6*, 1982. Reprinted with permission.

[a] Basic or coherent unit.

[b] Obsolete metric units that should not be used with SI.

[c] gal = U.S. gallon; ton = short ton (2000 lb).

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