15.3 OBJECTIVES OF WATER SUPPLY

The broad objectives underlying any water supply system are to :

- supply water in adequate quantity;
- supply safe and wholesome water to the consumers;
- make water easily available to consumers.

To supply water in adequate quantity means that the water supplied to the community should meet all the requirements for water and be available when required. Water is safe when it does not cause any harm upon consumption. Wholesome water is unpolluted, significantly free from toxic substances as well as excessive amounts of mineral and organic matters that may impair its quality. The water should comply with the requirements of water quality standards developed on the basis of knowledge of harmful effects of the impurities present in water. The third objective means that the water is accessible and within easy reach of the consumers so as to encourage the use of adequate water for personal and household cleanliness.

15.4 ELEMENTS OF WATER SUPPLY

The essential elements of a water supply are:

- source of supply,
- collection system,
- treatment, and
- distribution system.

The elements of a surface water-based water supply system are shown in Figure 15.1.

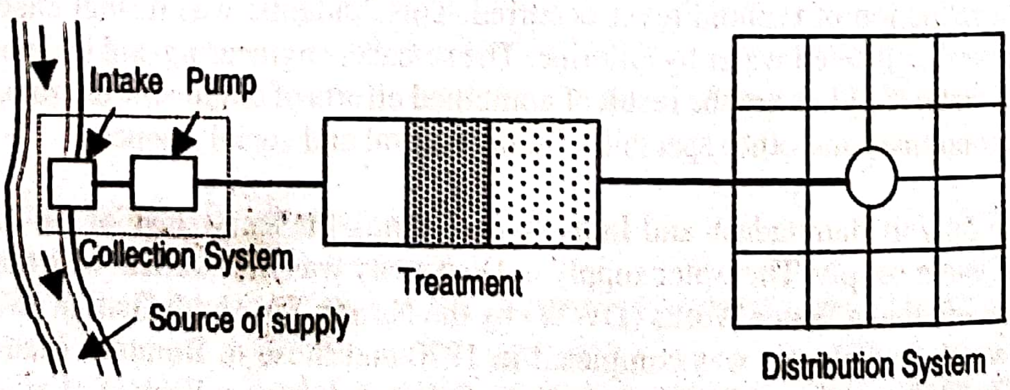

Figure 15.1 Essential elements of a surface water based water supply system

Sources of Supply

All fresh waters on earth come in the form of precipitation evaporated mainly from oceans, seas and other surface water sources. A part of this precipitated water flows as surface water and remains trapped in depressed areas and another part enters in to the earth to form groundwater. Therefore, surface water and groundwater are the main sources of water for water supply. Rainwater, being relatively free from contamination, can be a good source of water supply. The main considerations for the selection of a source of water supply are:

- quantity,
- quality and
- cost.

The quantity of water available at all times of the year should meet all the requirements of the community and the quality of water at the source should be such that the requirement for treatment is minimum. The cost involved in development, operation and maintenance of the water supply system should be reasonably affordable to the consumers.

Collection system

The collection system is dependent on the source of the water supply. An intake with pumping facilities is required if the water is to be collected from a surface water source. Dug wells or tubewells are common collection devices for groundwater, while a permanent roof or an uncontaminated ground surface is needed for collection of rainwater for water supply.

Treatment

Natural waters usually contain impurities which require treatment to make the water suitable for domestic water supplies. The type and degree of treatment required is dependent on the quality of water. In case of most surface waters, the treatment processes may involve removal of turbidity, color, taste and odour, and removal and destruction of pathogenic (disease producing) micro-organisms. Groundwaters are relatively free from disease-producing bacteria but rich in mineral substances and may require removal of iron, hardness, arsenic, fluoride etc. If the dissolved minerals in groundwaters are within acceptable limits, the water may be supplied without any treatment. The most common methods used for treatment include screening, sedimentation, aeration, treatment with chemicals, filtration, demineralization and disinfection.

Distribution system

A distribution system is needed to deliver water to individual consumers. The piped water supplies require distribution networks of pipes with storage reservoirs, pumping devices, standposts, valves, and other appurtenances. In unpiped water supplies, the sources of water are to be distributed to make them easily accessible to the consumers. The rural water supply based on manually operated tubewells does not require a distribution network but the tubewells are required to be distributed over the area in such a way that the distances from the households are reasonable and each tubewell serves an optimum number of households. In the location of community type treatment plants, accessibility and distances from the community are required to be taken into consideration.

Chapter 16

SOURCES OF WATER

Introduction/Hydrological Cycle/Surface water/Groundwater/ Groundwater in Bangladesh/ Rainwater

16.1 INTRODUCTION

Water exists in solid, liquid and gaseous forms. Oceans and seas are the main sources of water on earth, but this water is salty. The fresh liquid water sources on land surfaces and in the ground constitute only about 1% of the total water on earth. These fresh water sources have been formed by condensation of water evaporated mainly from the oceans and seas. The main sources of water in Bangladesh are surface waters in rivers, reservoirs, lakes, canals and ponds, and groundwater in shallow and deep aquifers. The rainwater is an alternative source of water, and has good potential for water supply in Bangladesh.

16.2 HYDROLOGICAL CYCLE

Hydrological cycle refers to the circulation of water in its liquid, vapor or solid states from oceans to air, air to land, over land surfaces or underground, and back to the oceans as shown in Figure 16.1.

Evaporation takes place from the surface of oceans, seas and open water bodies and evapotranspiration from plant surfaces, resulting in the transfer of water vapour to the atmosphere. Under certain conditions this water vapour condenses to form clouds, which subsequently release water as precipitation in the form of rain, hail, sleet or snow. The moisture-laden air or clouds transported by winds towards land may cause precipitation over land surfaces. Precipitation may also occur on oceans and seas,. returning some of the water directly to them. A part of the rain falling to earth evaporates with immediate return of moisture to the atmosphere. The water reaching the ground wets it and runs off into surface streams, finally discharging into the oceans. Another part infiltrates into the ground and percolates to join existing groundwater and ultimately flows to the ocean. The water accumulated as snow and ice on hills and mountains also melts to join surface and groundwaters. Evaporation returns some of the water from wet land surfaces to the atmosphere while plants extract some of the water through their roots and return most of it to the atmosphere through leaves by a process known as *transpiration*.

Most of the water available on earth is saline and found in oceans and seas. The amount of fresh water is less than 3%, about two-thirds of which is stored in ice caps and glaciers. Less than 1% of the world's water stock is found in ground and surface water sources. Most of the liquid fresh water, amounting to 8,000,000 km^3, is in groundwater storage, of which about 6,000,000 km^3 is available within a depth of about 50m below the ground surface. The remainder is available at greater depths. The fresh water contained in surface water sources amounts to 200,000 km^3 and the atmosphere contains only about 13,000 km^3 of fresh water.

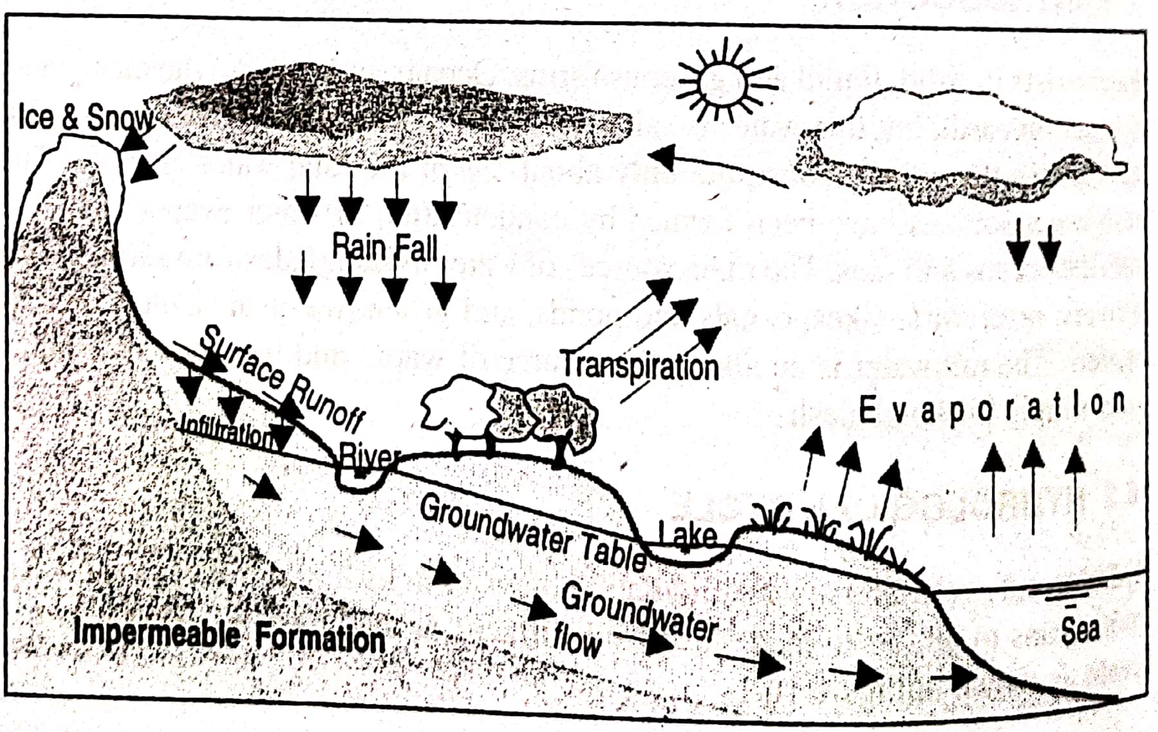

Figure 16.1 Hydrological cycle

16.3 SURFACE WATER

Surface water is abundant in the wet season in Bangladesh. An estimated 795,000 Million cubic meter (Mm^3) of surface water is discharged through the

Ganges-Brahmaputra system, in the downstream of the confluence of the Ganges and the Brahmaputra. This is equivalent to 5.52 m deep water over a land area of 144,000 km^2. There are other rivers in Bangladesh discharging surface water into the Bay of Bengal. An average annual rainfall of 2.30 m within the country partly replenishes surface water sources. Each year about one-third of Bangladesh is submerged in a normal flood, and the area submerged may increase to about two-thirds during severe floods. In the dry season water scarcity persists in many areas. In this period surface water is only available in part of the 22,155 km of major rivers, 1,922 km^2 major standing water bodies and about 1,475 km^2 of ponds in the country. Surface water irrigation systems in the country compete for this available water in the dry season.

In Bangladesh, ground and surface water sources are dependent on each other. Many streams receive a major portion of their flow from groundwater. Elsewhere, water from surface streams is the main source of recharge for groundwater. In general, groundwater flows into the surface water sources in the dry season and surface water enters into ground during the monsoon. The two sources of water are interrelated and the use of one usually affects the water available from the other source. In recent years, large-scale use of groundwater for irrigation purposes has caused a lowering of the groundwater level and drying up of surface water sources.

Surface waters are polluted by agricultural, industrial, domestic and municipal sources. The concentration of silt in turbulent water in the monsoon is high. Similarly algae growth in stagnant water bodies in the dry season is also very high. People's unsanitary practices have greatly contributed to the deterioration of the quality of surface water sources. The faecal coliform concentration in most surface water sources lies in the range of 500 to several thousand per 100 ml. The rivers and surface water sources around densely populated urban areas are four to ten times more polluted than the similar water sources in the countryside. The use of surface water for drinking purposes requires clarification and disinfection by elaborate and extensive treatment processes.

Traditionally, before and during the early stages of tubewells installation, rural water supply was largely based on protected ponds. Sinking of tubewells under community water supply schemes in rural Bangladesh began in 1928. There are about 1,288,222 ponds in Bangladesh (BBS, 1997) having an area of 0.114 ha per pond and 21.5 pond per mauza. About 17% of these ponds are derelict and probably dry up in dry season. The biological quality of water in these ponds is extremely poor due to unhygienic sanitary practices and absence of any sanitary protection. Many of these ponds are chemically and bio-chemically contaminated for fish culture. If one pond per mauza could be protected from contamination, it would provide a source of drinking water with minimal treatment and water for other domestic uses without treatment. The Government of Bangladesh has greatly emphasized the development of protected pond-based water supply systems. The protected ponds should not receive any surface discharge and should only be replenished by rain and groundwater infiltration.

16.4 GROUNDWATER

Groundwater aquifer

The water available in the saturation zone (pores completely filled with water) is known as groundwater. Groundwater, as mentioned above, is available in large quantities in shallow depths and constitutes the most important source of fresh water supply. The soil strata which contain groundwater and will readily yield it to wells are called *aquifers*. The impervious formations or strata containing very little groundwater are termed *aquicludes*. The amount of groundwater which can be obtained from an area depends on the characteristics of the underlying aquifer and the extent and frequency of recharge. An aquifer has interconnected pores filled with water which may be considered as a network of interconnected pipes through which water flows at a very slow rate. These interconnected pores provide both storage and flow, or conduit functions in an aquifer.

Storage function: The storage function of an aquifer is related to two important properties known as *porosity* and *specific yield*. The *porosity* of a formation is the percentage of the total volume of the formation, which consists of openings or pores. It is therefore an index of the amount of groundwater that can be stored in a saturated formation. The yield of a formation is less than that it can store and is represented by *specific yield,* defined as the volume of water released from a unit volume of aquifer materials when allowed to drain freely or by gravity. The remaining volume of water, which cannot be removed by gravity drainage, is held by capillary forces and by other forces of attraction and is called *specific retention*. The porosity ρ, the specific yield ρ_s and specific retention ρ_r can be correlated by the expression:

$$\rho = \rho_s + \rho_r \quad (16.1)$$

An aquifer with a porosity of 0.25 or 25% and specific yield of 0.15 or 15% has a specific retention of 0.10 or 10%. Such an aquifer, having 1,000 m^3 in volume, can store 250 m^3 of water of which only 150 m^3 of water can be yielded by gravity drainage.

Conduit function: The property of water related to the conduit function is known as permeability. Permeability is the measure of the capacity of an aquifer to transmit water. The velocity of flow under laminar or non-turbulent conditions is related to the slope of the hydraulic gradient by the following equation, known as *Darcy's Law*:

$$V = K\, i \quad (16.2)$$

Where V is the velocity of flow, i is the hydraulic gradient, and K is known as the *coefficient of permeability* (often referred to simply as permeability). Thus, *coefficient of permeability* can be referred to as the velocity under unit hydraulic gradient and usually expressed as m/day. It can also be measured by the quantity of water transmitted per unit time through unit area of the aquifer under unit hydraulic gradient.

In an aquifer, the size of the pores and their continuity are very important factors for permeability and capacity of the aquifer for yielding water. The coefficient of permeability depends on the particle size of the aquifer materials and its distribution and can be correlated with effective size of the particles by the expression:

$$K = C D_{10}^2 \qquad (16.3)$$

Where C is a constant and D_{10} is the effective size of the particles of the aquifer. Effective size represents a particle size corresponding to 10% finer in the particle size distribution curve of the aquifer material, i.e., 10% of the aquifer material is finer than that size.

The quantity of flow per unit time Q, through a given cross-sectional area A, may be obtained by multiplying the velocity in equation (16.2) by the area as:

$$Q = AV = K A i \qquad (16.4)$$

The coefficient of permeability may therefore also be defined as the quantity of water that will flow through a unit cross-sectional area of aquifer in unit time under a hydraulic gradient of unity at a specific temperature (usually 60°F). The flow per unit width of the aquifer having a thickness of m can be written from the equation (16.4) as:

$$q = Kmi \qquad (16.5)$$

The product Km in equation (16.5) is termed as *coefficient of transmissibility* or *transmissibility T* of the aquifer. The *coefficient of transmissibility* is, therefore, defined as the rate of flow through a vertical cross-section of an aquifer of unit width and whose height is the total thickness of the aquifer when the hydraulic gradient is unity. The unit of transmissibility is expressed in m^2/day.

Aquifers may be classified as water table and artesian aquifers. A *water table aquifer* is one, which is not confined by an upper impermeable layer. Hence, it is also called an unconfined aquifer. Water in this aquifer is under atmospheric pressure and the upper surface of the zone of saturation is called the water table. The water level in a well constructed in a water table aquifer will be at the same level as the water table. An artesian aquifer is one in which the water is confined under a pressure greater than the atmospheric pressure by an overlying, relatively impermeable layer. The name artesian owes its origin to '*Artois*', the northernmost province of France, where the first deep wells to tap confined aquifers were known to have been drilled. These aquifers are also called confined or pressure aquifers. Unlike water table aquifers, water in artesian wells will rise in the well to a level above the surface of water beneath the confining layer because of the pressure created by the confining layer. The imaginary surface or level to which water will rise to wells located throughout the aquifer is called *piezometric surface* or *level*. Where the piezometric level lies above ground level, water will flow automatically and it is referred to as a flowing artesian well. The types of aquifers are shown in Figure 16.2. Hydraulic gradient is equivalent to the slope of the water table for water table aquifer and slope of the *piezometric surface* for an artesian aquifer.

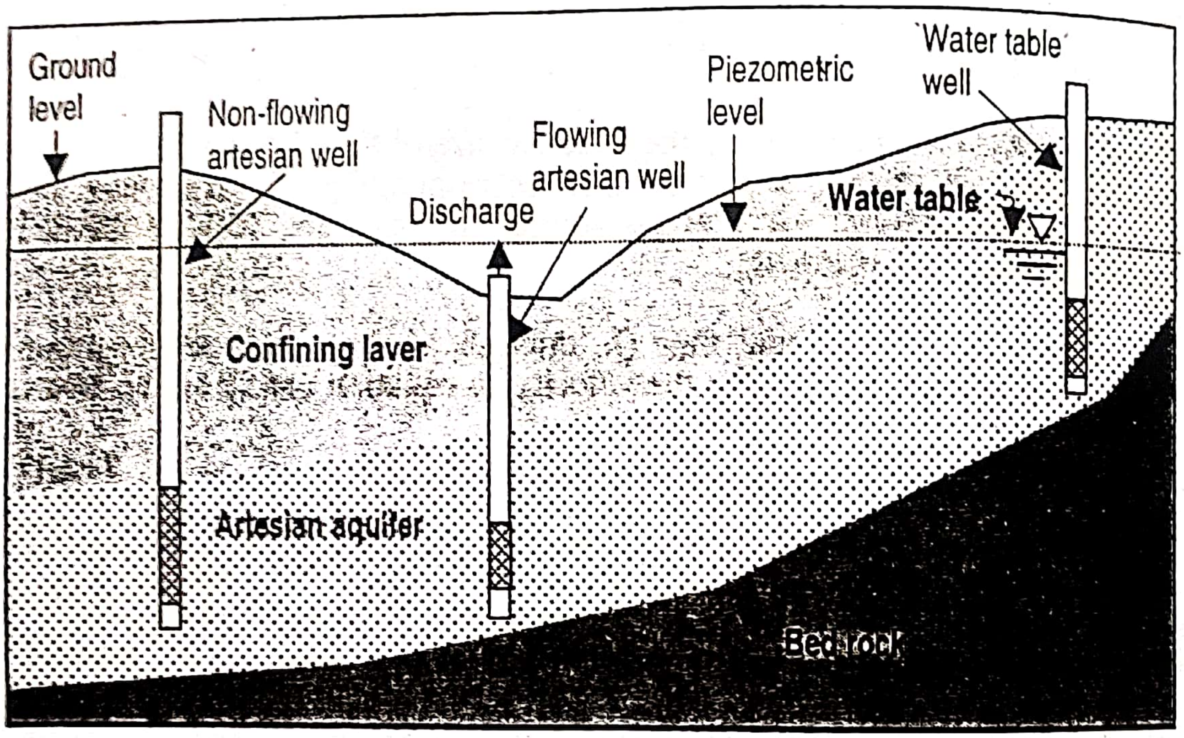

Figure 16.2 Types of aquifers

Flow towards wells

When the well is at rest, the water level in the well is called the *static water level*, which coincides with the water table of a water table aquifer and the piezometric surface of an artesian aquifer. Pumping the well causes lowering of the pressure and induces a flow from all directions into the well due to the difference in pressure. This lower pressure within the well is also accompanied by a lower water level/piezometric level in the aquifer around the well. In a converging flow of water in a tubewell, the velocity close to the tubewell is higher than the velocity at a distance from the tubewell because of the higher area of flow. Again according to Darcy's law, the hydraulic gradient varies directly with the velocity. The increasing velocity towards the well is therefore accompanied by an increasing hydraulic gradient. The water surface or the piezometric surface develops a steeper slope towards the well and takes the form of an inverted cone called the *cone of depression*. The lowest water level in the well is known as the pumping water level. The difference between the static water level and the surface of the cone of depression is called the *drawdown*. Drawdown therefore increases from zero at the outer limits of the cone of depression to a maximum in the pumping well. The radius of influence is the distance from the centre of the well to the outer limit of the cone of depression.

Unconfined steady flow: Dupits's formula for the flow into an ordinary well is based on Darcy's law, presented in equation 16.4. The hydraulics of flow for a well through an unconfined aquifer is presented in Figure 16.3.

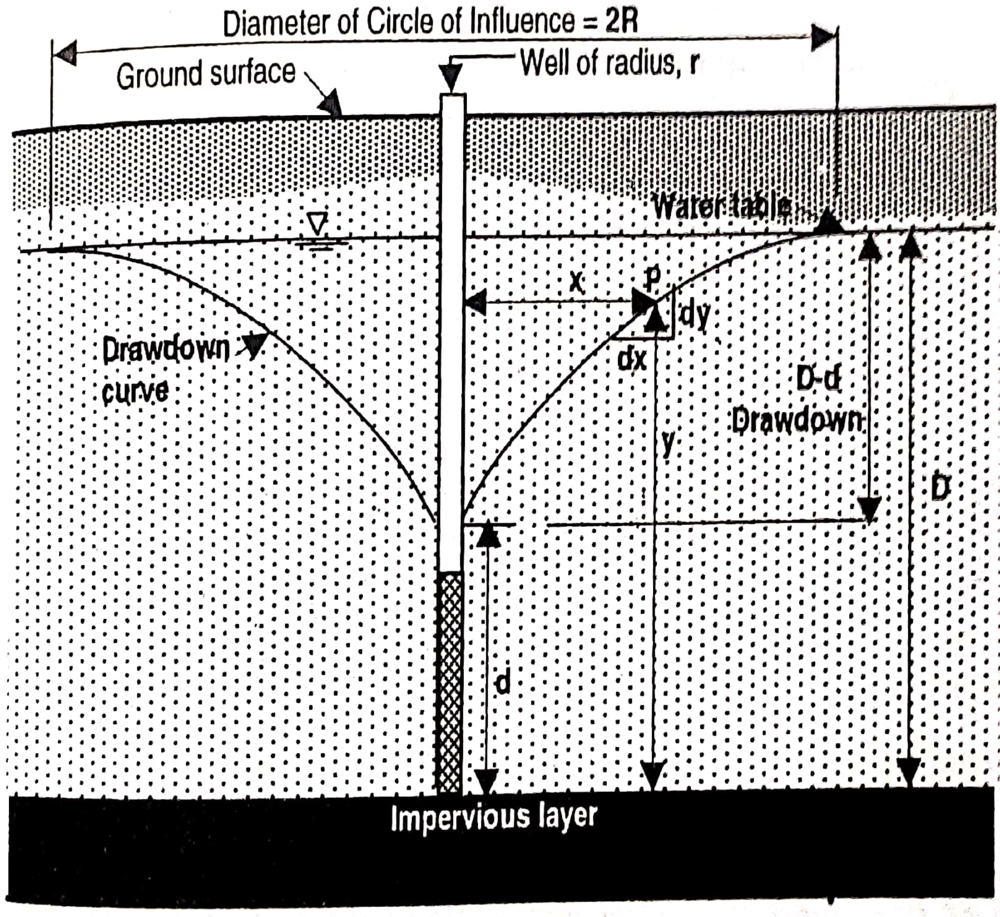

Figure 16.3 Hydraulics of flow in a well through unconfined aquifer

It is assumed that the flow of groundwater is horizontal and radial towards the centre of the well. The slope of the cone of depression and area of flow at a distance x from the centre of the well is respectively given by:

$$i = \frac{dy}{dx} \quad \text{and} \quad A = 2\pi xy$$

Substituting these values in equation (16.4)

$$Q = 2K\pi xy\frac{dy}{dx}$$

or $$Q\frac{dx}{x} = 2\pi Kydy \tag{16.6}$$

by integration $Q \operatorname{Log}_e x = \pi K y^2 + C$ where C is a constant.

For $y = d$ at $x = r$, r being the radius of the well and $y = D$ at $x = R$, R being the radius of the circle of influence or distance of the outer boundary from the centre of the well, the equation (16.6) becomes:

$$Q = \frac{\pi K(D^2 - d^2)}{\log_e(\frac{R}{r})} \tag{16.7}$$

Where
Q = well discharge, m^3/d
K = coefficient of permeability, m/d
D = depth of the aquifer, m
d = static head, m
R = radius of circle of influence, m
r = radius of the well, m

The equation 16.7 shows that if the term (D-d) is small as compared to (D+d), the flow Q varies approximately as (D-d) for a well installed in a particular aquifer. This linear relationship between the rate of flow and drawdown leads to the definition of *specific capacity* of a tubewell installed in an aquifer. *Specific capacity* of a tubewell, therefore, is the rate of flow per unit drawdown, which may be expressed as $m^3/d/m$ of drawdown.

Confined steady flow: The flow condition in an artesian or pressure well has been illustrated in Figure 16.4.

In an artesian tubewell the drawdown occurs in the piezometric surface and the depth of flow remains constant and equal to the thickness of the pressure or artesian aquifer m. In the case of an artesian tubewell:

$$i = \frac{dy}{dx} \quad \text{and} \quad A = 2\pi xm$$

Substituting the value of i and A in equation (16.4)

$$Q = 2K\pi xm(\frac{dy}{dx})$$

or $$Q\frac{dx}{x} = 2\pi Kmdy \tag{16.8}$$

Where m is the thickness of the confined aquifer. Integrating equation (16.8) between the limits $x = r$ for $y = d$ and $x = R$ for $y = D$:

$$Q = \frac{2\pi Km(D-d)}{\text{Log}_e \frac{R}{r}} \qquad (16.9)$$

The rate of flow Q of an artesian well sunk in a confined aquifer is proportional to the drawdown $(D\text{-}d)$.

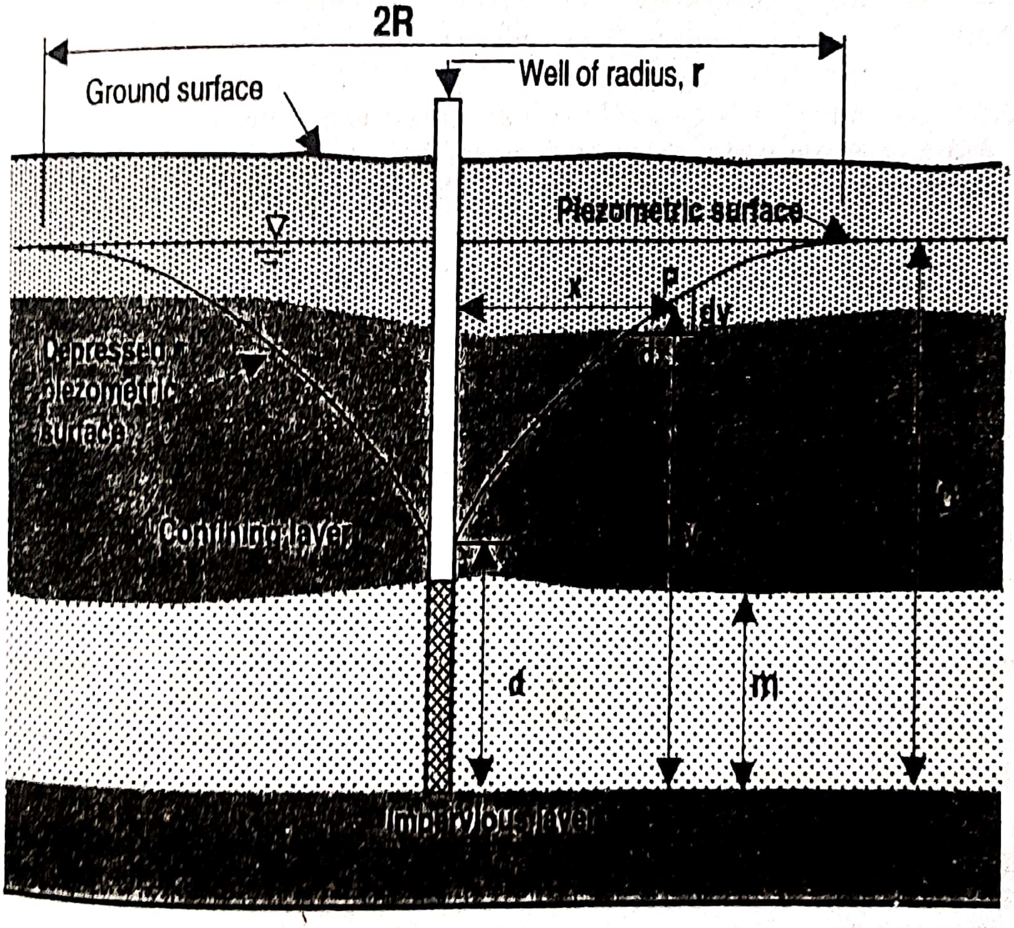

Figure 16.4 Hydraulics of flow in a well through confined (artesian) aquifer

Interference of well: Interference between two or more tubewells occurs when their cones of depression overlap. Interference reduces the discharges of the interfering tubewells. Ideally the tubewells should be spaced enough to avoid interference. Small diameter tubewells installed in fine sand will produce too little drawdown to cause interference.

16.5 GROUNDWATER IN BANGLADESH

Importance

Groundwater is the most important source of water supply in Bangladesh. Except for few hilly regions Bangladesh is entirely underlaid by water-bearing formations at depths varying from zero to 20 m below ground surface. The soil is mostly stratified and formed by alluvial deposits of sand and silt, having occasional lenses of clay. The main constituent of the aquifer materials is the medium-grained sand deposited at the lower reach by the mighty rivers the Ganges, the Brahmaputra and the Megna with their tributaries. Groundwater can be easily abstracted by installation of wells for development of water supply systems. The water abstracted for various purposes is replenished in the monsoon.

Physically groundwater is generally clear, colourless with little or no suspended solids and has a relatively constant temperature. Groundwater is also free from disease-producing micro-organisms which are normally present in large numbers in surface waters. The slow filtering action of fine-grained soil through which the surface water percolates to join the groundwater removes almost all suspended impurities. Moreover, the lack of oxygen and nutrients in groundwater makes it an unfavourable environment for disease-producing micro-organisms to survive, grow or multiply. On the other hand, being a universal solvent, water dissolves many of the minerals present in earth's crust during its slow travel through the ground. Anaerobic conditions in soils in some flood plains, and the presence of organic acids and carbon dioxide increase the solubility of groundwater. As a result, groundwater may contain minerals in varying concentrations depending on soil conditions.

In the context of high prevalence of diarrhoeal diseases in Bangladesh, groundwater received priority as a source of water supply because it is generally free from pathogenic micro-organisms. Almost all rural water supplies and most of urban water supplies are groundwater based. Groundwater collected by tubewells is fit for consumption. Groundwater abstracted from shallow aquifers by hand tubewells has received acceptance in rural areas for drinking purposes, but due to its high iron content, hardness, etc. people do not want to use hand tubewell water for other domestic purposes like cooking, bathing and washing. The high iron in groundwater makes the cooked food blackish in colour and produces stains on utensils. The hard water requires more soap for washing.

Aquifer characteristics

The available geological information and related studies have shown that two types of aquifers exist in Bangladesh. A shallow aquifer which has been termed "main aquifer" lies within 100 m from the surface with an overlying clay/silt blanket which is less than 2 m thick in the northwest and generally increases southward to more than 50 m. Other deep aquifers whose water development potential is not known occur at depths between 300 and 2500 m. In the majority of alluvial basins, the thickness of top clay and silt layers varies between 5 and

15 m. In the extreme northwest this layer does not exist and silty to fine sand occurs at the surface, while in the Madhupur and Barind Tracts as well as in Chittagong District, the thickness of this layer is greater than 35 m.

In the shallow aquifer groundwater flows from north to south with localized outflow into the major rivers. Groundwater gradient varies from 1:1,000 in the northwest to 1:13,000 in central Bangladesh to less than 1:20,000 in the coastal area. Permeabilities of the aquifers are very high and vary from 10 to 200 m/day. Transmissibilities of the main aquifer range from 100 to 10,000 m^2/day with an average value of 2,000 m^2/day. Although the aquifer has high transmissibility the horizontal flow of groundwater is very low because of the low groundwater gradient. The storage capacity of the aquifer in Bangladesh increases with depth because of the increase in the size of aquifer materials. The specific yield varies from 0.02 to 0.25. The two main aquifers with intermediate impermeable layers and three main modes of tubewells for water supply are illustrated in Figure 16.5.

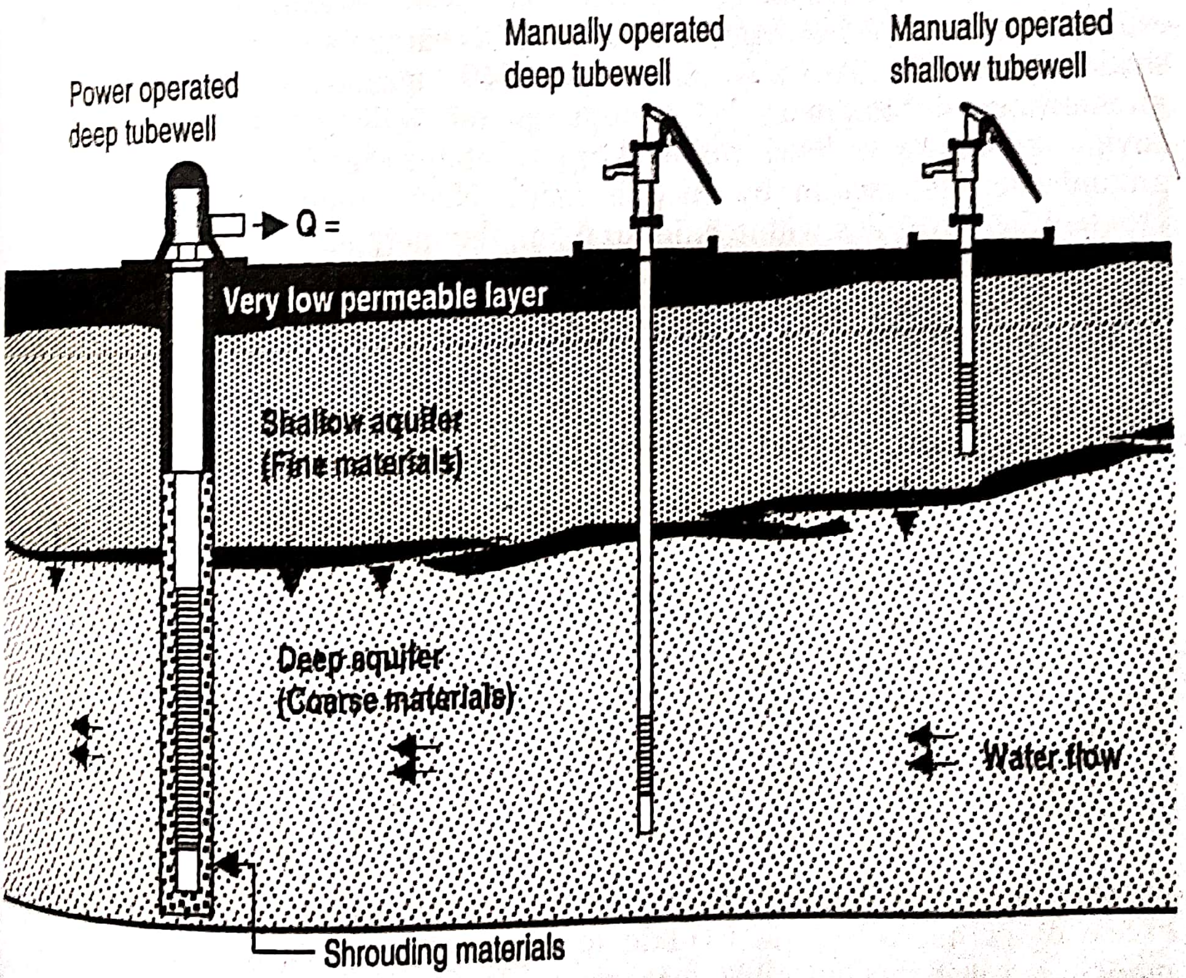

Figure 16.5 The main aquifers and the wells for water supply

Groundwater situation

Groundwater in Bangladesh, except in some places, is available at a shallow depth. Groundwater levels are at or near ground level during the period August-

October and lowest in April-May. Groundwater rises as a result of recharge during May and usually reaches its highest in late July in each year. Between July and October groundwater levels are constant and maintain a balance between surface water levels and the fully recharged aquifers. Groundwater levels fall from October in response to rapid drainage of surface water and changes in base levels. The rate of fall is highest in October-November but equally large changes may take place after January when withdrawal of groundwater for irrigation starts. During the dry season most of the minor rivers are sustained by groundwater outflows.

There are several areas of Bangladesh where groundwater withdrawals are causing a large decline in groundwater levels during dry seasons. Recharge during the wet season enables the groundwater levels except in Dhaka and Comilla areas to recover to their normal level. The groundwater withdrawal and recharge characteristics suggest that the actual recharge can be increased approaching the potential limits by creating additional storage through increased abstraction during the dry season. This process severely restricts the development of suction-mode tubewells, however. According to MPO (1991) estimates, out of 42,543 Mm^3 total useable recharge, 40% is available through shallow tubewells. A study shows that 349 upazilas can adequately allow groundwater development by handpump tubewells of which 197 upazilas having groundwater level within 4.5m of the surface in dry season allows groundwater abstraction by suction mode No.6 pump. In 60 Upazilas, the groundwater level lies within 4.5m to 6.5m, the marginal range for forced mode Tara pump. In 92 Upazilas the water level falls below the limit of suction mode pumps in the later part of dry season, but it is suited for forced type handpumps.

Problems in groundwater development

Groundwater is the main source of water supply in urban and rural areas of Bangladesh. Groundwater in Bangladesh is available abundantly, but the availability of groundwater for drinking purposes has become a problem for the following reasons:

- arsenic in groundwater;
- excessive dissolved iron;
- salinity in the coastal areas;
- lowering of groundwater level;
- rock/stony layers in hilly areas.

Arsenic in groundwater: The concentration of arsenic in drinking water in excess of permissible limit is toxic to human body. According to the WHO guideline value the desirable maximum concentration of arsenic in drinking water should be 0.01 mg/l. In Bangladesh the maximum acceptable concentration in drinking water is considered to be 0.05 mg/l. Symptoms of arsenic toxicity leading to cancer may occur due to excessive intake of arsenic in the human body over a longer period of time. In Bangladesh the presence of arsenic in groundwater was first detected in 1993 at Barogharia union of Chapai

Nawabganj district. Appreciating the gravity of the problem, water sample testing activities started in 1995 by various organizations and agencies. The samples were collected from different parts of the country and examined for arsenic content. It has been observed that about one in every three shallow tubewells is producing water with arsenic in excess of acceptable limits. A map showing arsenic contamination of groundwater in different parts of Bangladesh as on September, 1998 is shown in Figure16.6.

Excessive dissolved iron: In Bangladesh, the permissible limit of iron in groundwater is 1 mg/l but iron content up to 5 mg/l is acceptable for rural water supply. It has been observed that iron content exceeds this limit in many handpump tubewells. People are reluctant to drink this water mainly due to its bad taste. Water with high iron content is not used for cooking, washing and other domestic purposes.

It has been observed from a survey in 1993 that 1,230 unions in Bangladesh have an iron content of more than 5 mg/l. The map showing the iron problem areas of Bangladesh is given in Figure 16.7. It may be observed that dissolved iron in shallow tubewell water in about 67% areas of Bangladesh is in excess of 2 mg/l. However, iron content in deep tubewell water is comparatively lower. In urban areas iron removal plants have been constructed and in rural areas community-type iron removal units attached to handpumps are provided.

Salinity in coastal areas: The concentration of dissolved minerals in groundwater is higher than that in surface water. The distribution of chloride in groundwater in Bangladesh is shown in Figure16.8. The coastal belt of Bangladesh, extended over 86 upazilas, is identified as a problem area where complex hydrogeological conditions and adverse water quality make water supply difficult as compared to other parts of the country. Unlike other areas of Bangladesh, groundwater of acceptable quality at relatively shallow depths, which can be easily withdrawn by conventional handpump tubewells is not available in most parts of the coastal area. In some places low salinity water has been found in deep aquifers. Exploratory drillings with borehole logging have been conducted in many places to locate sweet water aquifers. Based on the availability of fresh groundwater, the Department of Public Health Engineering has divided the coastal regions into three types of areas shown in Figure 16.9. However, there are still many areas in coastal belts where low salinity groundwater is not available within a depth of 1,100 ft. In rural water supply chloride content up to 1,000 ppm is acceptable for coastal belts where the normal acceptable limit is 250 ppm.

Lowering of groundwater level: Although groundwater in Bangladesh is said to be abundant, a considerable areas of the country faces scarcity of groundwater within suction limit in the dry season. Due to the over-exploitation of groundwater for irrigation purposes, the water level declines, rendering thousands of suction mode no.6 tubewells inoperable. These areas are increasing with abstraction of more groundwater for irrigation in the dry season. The study conducted to forecast the decline of groundwater levels in Bangladesh indicated the trend in the change of low water table areas in the country as shown in Table 16.1 (DPHE and UNICEF, 1994):

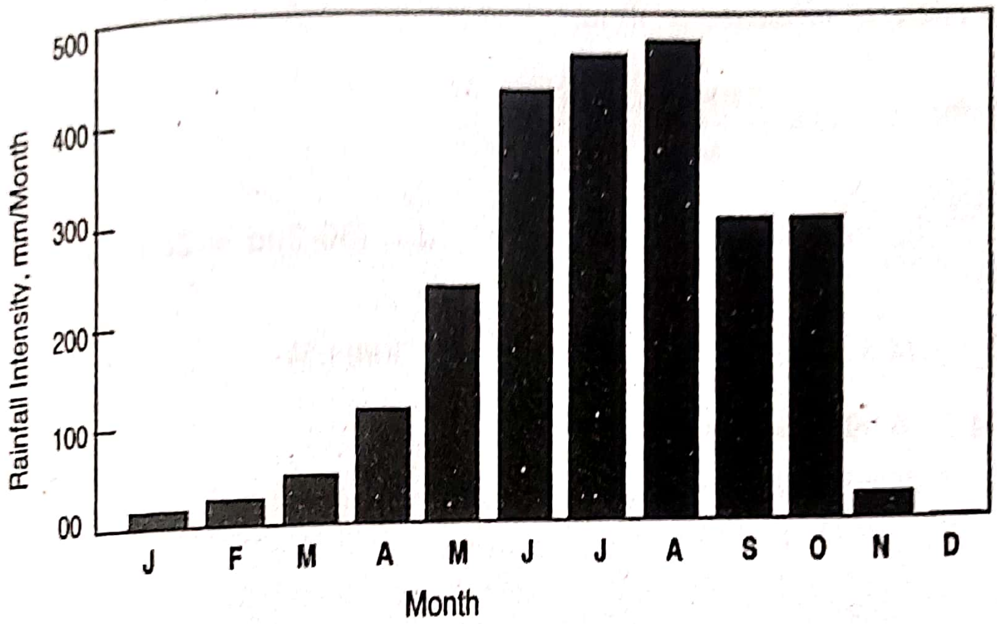

Figure 16.12 Monthly distribution of rainfall in a normal Year in Bangladesh

16.6 WORKED EXAMPLE

Example - 1

A 100 mm diameter tubewell is sunk 35 m below static groundwater level. The depth of water in the tubewell while pumping is 33 m. The radius of drawdown is 30 m and the coefficient of permeability of the aquifer is 0.5 l/s/m². Calculate the probable discharge of the well.

Solution: $$Q = \frac{\pi K(D^2 - d^2)}{Log_e(\frac{R}{r})}$$

$K = 0.5$ lps/m²; $D = 35$m; $d = 33$m; $R = 30$m; $r = 0.05$m

Substituting the values in the above equation:

$Q = 3.14 \times 0.5 \times (35^2 - 33^2) / Log_e (30/0.05)$

$Q = 3.14 \times 0.5 \times 136/6.3969 = 33.4$ lps

Example - 2

A 100 mm diameter tubewell is sunk to withdraw water from a 10 m thick confined aquifer having coefficient of permeability equal to 0.75 lps/m². The depth of water below the piezometric level is 30 m and it falls 2 m in the tubewell while pumping. Calculate the discharge of the tubewell when the radius of the circle of influence is 30 m.

Solution:

$$Q = \frac{2\pi Km(D - d)}{\log_e(\frac{R}{r})}$$

$K = 0.75$ lps/m^2; $m = 10$m; $D = 30$m; $d = (30\text{-}2)$m $= 28$m; $R = 30$m; $r = 0.05$m

$Q = 2 \times 3.14 \times 0.75 \times 10\ (30 - 28) / (\log_e 30/0.05)$

$Q = 94.2 / 6.3969 = 14.73$ lps

Questions:

1. Make a comparative statement of different sources of water for water supply in Bangladesh. Mention the importance of groundwater for water supply in Bangladesh.

2. State the hydraulics of groundwater flow in wells. Deduce mathematical expressions for yield of artesian as well as ordinary wells.

3. Describe the aquifer characteristics and groundwater situation in Bangladesh.

4. Explain the problems in groundwater development in Bangladesh.

5. A 150 mm diameter tubewell produces 100 lps with a drawdown of 3 m and a circle of influence of 120 m in diameter. The static depth of water in the well is 40 m. Calculate the coefficient of permeability of the aquifer in which the tubewell is sunk.