Chapter 4

WATER SUPPLY

4.1 Introduction

Supply of water (mostly freshwater) is critical issues for the survival of human being and all other living organism. Freshwater (that generally contain less than 500 ppm of dissolved salts whereas Seawater or Brine has more than 50 parts per thousand.) is naturally occurring water on the Earth's surface in rivers, streams, lakes, ponds and groundwater, cave water, springs, floodplains, and wetlands (bogs, marshes, and swamps). The ultimate source of fresh water is rain and snow (Beaglehole and Bonita 2008). Freshwater provides water for drinking, sanitation, industrial process, agriculture, transport, electricity generation and recreation. It also creates habitats for a diverse range of animals and plants. Freshwater lakes, most notably Lake Baikal in Russia and the Great Lakes in North America, contain seven-eighths of this fresh surface water. Swamps have most of the balance with only a small amount in rivers, most notably the Amazon River. The atmosphere contains 0.04% water (Wilkinson, Smith et al. 2007). In areas with no freshwater on the ground surface, freshwater derived from precipitation may, because of its lower density, overlie saline ground water in lenses or layers.

In this chapter, the following points related to water supply are discussed in terms of:

- sources of water
- the hydrologic cycle and water availability,
- groundwater supplies,
- surface water supplies, and
- water transmission.

The direction of the discussion is that sufficient water supplies exist for the world, and for the nation as a whole, but many areas are water poor while others are water rich. Adequate water supply requires engineering the supply and its transmission from one area to another, keeping in mind the environmental effects of water transmission systems. In many cases, moving the population to the water may be less environmentally damaging than moving the water. This chapter concentrates on measurement of water supply, and the chapter 6 discusses treatment methods available to clean up the water once it reaches areas of demand.

4.2 Sources of Water

97% of the water on the Earth is salt water, and only 3% is fresh water of which slightly over two thirds is frozen in glaciers and polar ice caps (Figure 4.1). The remaining unfrozen freshwater is mainly found as groundwater, with only a small fraction present above ground or in the air. Fresh water is a renewable resource, yet the world's supply of clean, fresh water is steadily decreasing. Water demand already exceeds supply in many parts of the world and as the world population continues to rise (Humphreys, Solarsh et al. 2008), so too does the water demand. Awareness of the global importance of preserving water for ecosystem services has only recently emerged as, during the 20th century, more than half the world's wetlands have been lost along with their valuable environmental services. Biodiversity-rich freshwater ecosystems are currently declining faster than marine or land ecosystems.

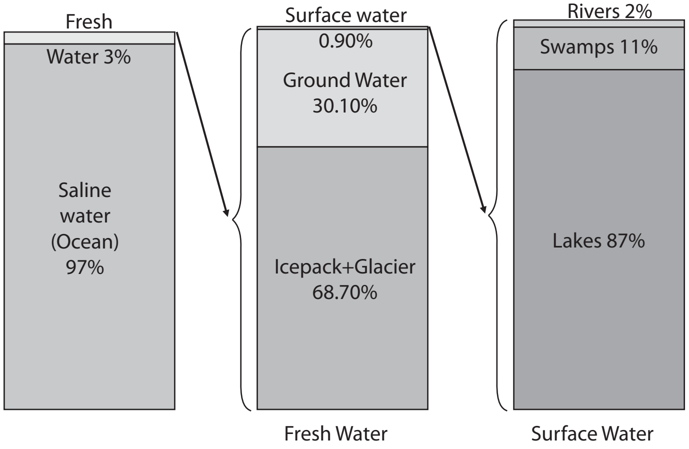

Figure 4.1: **Distribution of Earth's water**

4.3 The Hydrologic Cycle and Water Availability

The source of almost all freshwater is precipitation from the atmosphere, in the form of mist, rain and snow. Hence the hydrologic cycle is a useful starting point for the study of water supply that ensures sustainability of fresh water supply. This demonstrates the way of going back the water from different water sources to atmosphere from where it precipitates. The water that goes to the atmosphere by evaporation and transpiration/ evapo-transpiration comes back again in the form of precipitation under favourable climatic condition.

The hydrologic cycle is a useful starting point for the study of water supply. This cycle, illustrated in Figure 4.2, includes precipitation of water from clouds, infiltration into the ground or runoff into surface water, followed by evaporation and transpiration of the water back into the atmosphere. The rates of precipitation and evaporation/transpiration help define the baseline quantity of water available for human consumption. Precipitation is the term applied to all forms of moisture falling to the ground, and a range of instruments and techniques for measuring the amount and intensity of rain, snow, sleet, and hail have been developed. The average depth of precipitation over a given region, on a storm, seasonal, or annual basis, is required in many water availability studies. Any open receptacle with vertical sides is a common rain gauge, but varying wind and splash effects must be considered if amounts collected by different gauges are to be compared.

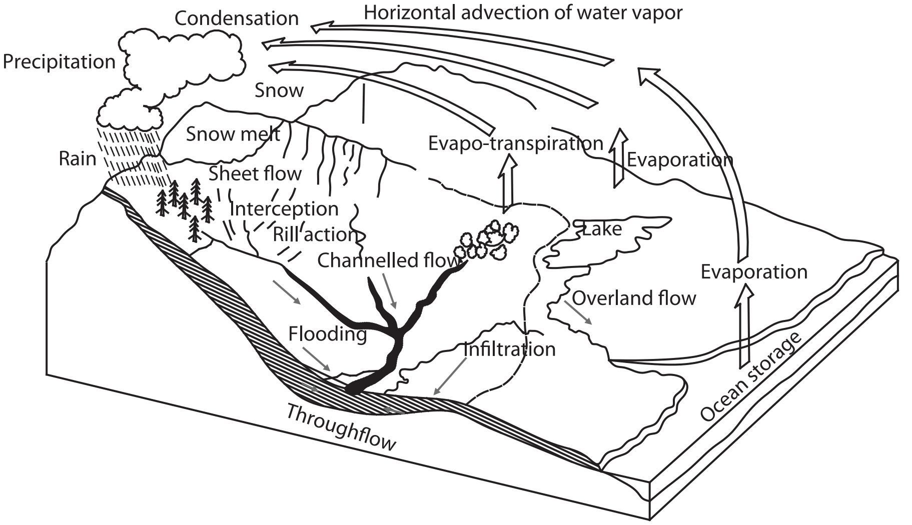

Figure 4.2: Hydrologic cycle

Evaporation and transpiration are the movement of water back to the atmosphere from open water surfaces and from plant respiration. The same meteorological factors that influence evaporation are at work in the transpiration process: solar radiation, ambient air temperature, humidity, and wind speed. The amount of soil moisture available to plants also affects the transpiration rate. Evaporation is measured by measuring water loss from a pan. Transpiration can be measured with phytometer, a large vessel filled with soil and potted with selected plants. The soil surface is hermetically sealed to prevent evaporation; thus moisture can escape only through transpiration. Rate of moisture escape is determined by weighing the entire system at intervals up to the life of the plant. Phytometers cannot simulate natural conditions, so results have limited value. However, they can be used as an index of water demand by a crop under field conditions, and thus relate to calculations that help an engineer determine water supply requirements for that crop. Because it is often not necessary to distinguish between evaporation and transpiration, the two processes are often linked as evapotranspiration, or the total water loss to the atmosphere.

4.4 Surface Water Supplies

Surface water is water in a river, lake or fresh water wetland. Surface water is naturally replenished by precipitation and naturally lost through discharge to the oceans, evaporation, evapotranspiration and sub-surface seepage (Adeel 2004). Although the only natural input to any surface water system is precipitation within its watershed, the total quantity of water in that system at any given time is also dependent on many other factors. These factors include storage capacity in lakes, wetlands and artificial reservoirs, the permeability of the soil beneath these storage bodies, the runoff characteristics of the land in the watershed, the timing of the precipitation and local evaporation rates. All of these factors also affect the proportions of water lost. Human activities can have a large and sometimes devastating impact on these factors. Humans often increase storage capacity by constructing reservoirs and decrease it by draining wetlands. Humans often increase runoff quantities and velocities by paving areas and channelizing stream flow (Ahluwalia, Carter et al. 1979). The total quantity of water available at any given time is an important consideration. Some human water users have an intermittent need for water. For example, many farms require large quantities of water in the spring, and no water at all in the winter. To supply such a farm with water, a surface water system may require a large storage capacity to collect water throughout the year and release it in a short period of time. Other users have a continuous need for water, such as a power plant that requires water for cooling. To supply such a power plant with water, a surface water system only needs enough storage capacity to fill in when average stream flow is below the power plant's need. Nevertheless, over the long term the average rate of precipitation within a watershed is the upper bound for average consumption of natural surface water from that watershed. Natural surface water can be augmented by importing surface water from another watershed through a canal or pipeline. It can also be artificially augmented from any of the other sources listed here, however in practice the quantities are negligible. Humans can also cause surface water to be "lost" (i.e. become unusable) through pollution. Brazil is the country estimated to have the largest supply of fresh water in the world, followed by Russia and Canada (Carr and Norman 2008).

4.5 Groundwater Supplies

Groundwater is both an important direct source of supply that is tapped by wells and a significant indirect source, since surface streams are often supplied by subterranean water. Near the surface of the earth, in the zone of aeration, soil pore spaces contain both air and water. This zone, which may have zero thickness in swamplands and be several hundred feet thick in mountainous regions, contains three types of moisture. After a storm, gravity water is in transit through the larger soil pore spaces. Capillary water is drawn through small pore spaces by capillary action and is available for plant uptake. Hygroscopic moisture is water held in place by molecular forces during all except the driest climatic conditions. Moisture from the zone of aeration cannot be tapped as a water supply source.

In the zone of saturation, located below the zone of aeration, the soil pores are filled with water, and this is what we call groundwater. A stratum that contains a substantial amount of groundwater is called an aquifer. At the surface between the two zones, called the water table or phreatic surface, the hydrostatic pressure in the groundwater is equal to the atmospheric pressure. An aquifer may extend to great depths, but because the weight of overburden material generally closes pore spaces, little water is found at depths greater than 600 m (2000 ft).

The amount of water that can be stored in the aquifer is the volume of the void spaces between the soil grains. The fraction of voids volume to total volume of the soil is termed porosity, so that

$$\text{Porosity} = (\text{Volume of voids}) / (\text{Total volume}). \qquad 4.1$$

However, not all of this water is available because it is so tightly tied to the soil particles. The amount of water that can be extracted is known as specific yield, defined as the percent of total volume of water in the aquifer that will drain freely from the aquifer.

The flow of water out of a soil is illustrated in Figure 4.3 and analyzed using the continuity equation, as

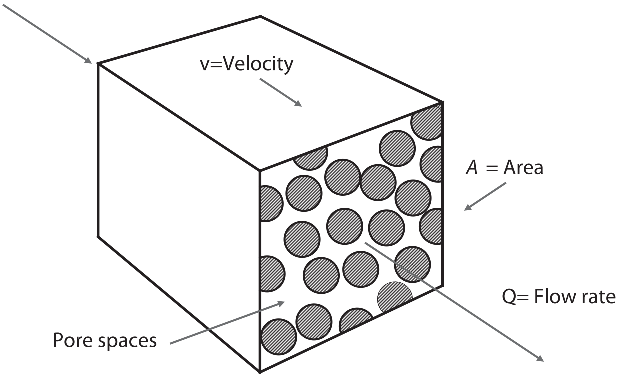

Figure 4.3: **The flow of water through a soil sampler.**

$$Q = Av \qquad 4.2$$

Where

Q = flow rate (m^3/s),
A = area of porous material through which flow occurs (m^2), and
v = superficial velocity (m/s).

The superficial velocity is of course not the actual velocity of the water in the soil, since the volume occupied by the solid particles greatly reduces the available area for flow. If A is the area available for flow, then

$$Q = Av = av',$$

Where v' = the actual velocity in the soil, and a = the area available for flow. Solving for ,

$$v' = (Av)/a \qquad 4.3$$

If a sample of soil is of some length L, then

$$v' = (AV)/a = (AvL)/aL = v/porosity \qquad 4.4$$

Water flowing through the soil at a velocity v' loses energy, just as water flowing through a pipeline or an open channel. The head loss is defined as

$$\frac{\Delta h}{\Delta L} \qquad 4.5$$

Where h is the pressure head. The flow through a porous medium such as soil is related to the head loss using the Darcy equation,

$$Q = KA\frac{\Delta h}{\Delta L} \qquad 4.6$$

Where

K = coefficient of permeability (m^3/day-m^2), and
A = cross-sectional area (m^2).

The coefficient of permeability varies dramatically for different soils ranging from about 0.04 m^3/day-m^2 for clay to over 200 m^3/day-m^2 for gravel. Typical values of porosity specific yield and the coefficient of permeability are shown in Table 4.1. The coefficient of permeability is measured commonly in the laboratory using a parameter, which consists of a soil sample through which a fluid like water is forced. The flow rate is measured for a given driving force, and the permeability calculated.

Table 4.1: **Estimate of average permeability and porosity for selected materials**

Material	% Porosity	% Specific yield	Permeability (gal/day-ft^2)	Permeability K (m^3/day-m^2)
Clay	45	3	1	0.04
Sand	35	25	800	32
Gravel	25	22	5000	200
Sandstone	15	8	700	28
Granite	1	0.5	0.1	0.004

Source: (McGauhey 1968)

Example 4.1: A soil sample is installed in a permeameter as shown in Figure 4.4. The length of the sample is 0.1 m, and it has a cross-sectional area of 0.05 m^2. The water pressure placed on the sample is 2 m, and a flow rate of 2.0 m^3/day is observed. What is the coefficient of permeability?

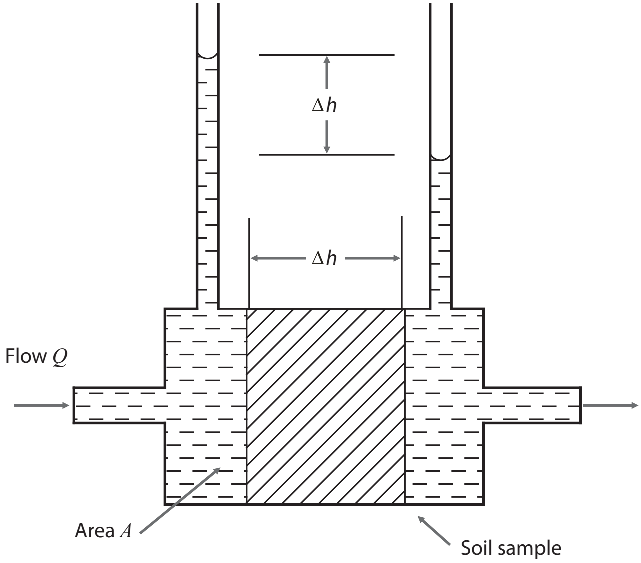

Figure 4.4: Permeameter for example 4.1

Solution:

Using the above equation, and solving for *K*, we have

$$K = \frac{Q}{A(\Delta h/\Delta L)} = \frac{2.0}{.05 \times 2/.1} = 2m^3/m^2 - day$$

4.6 Aquifer and its Types

An aquifer confined between two impermeable surfaces (aquacludes) is called a confined aquifer (Figure 4.5a) and can be thought of as a very large permeameter. The pressure loss due to the flow can be determined by measuring the water level in two wells, the second one being directly downstream of the other.

If a well is sunk into an unconfined aquifer, shown in Figure 4.5b, and water is pumped out, the water in the aquifer will begin to flow toward the well. As the water approaches the well, the area through which it flows gets progressively smaller, and therefore a higher superficial (and actual) velocity is required. The higher velocity of course results in an increasing loss of energy, and the

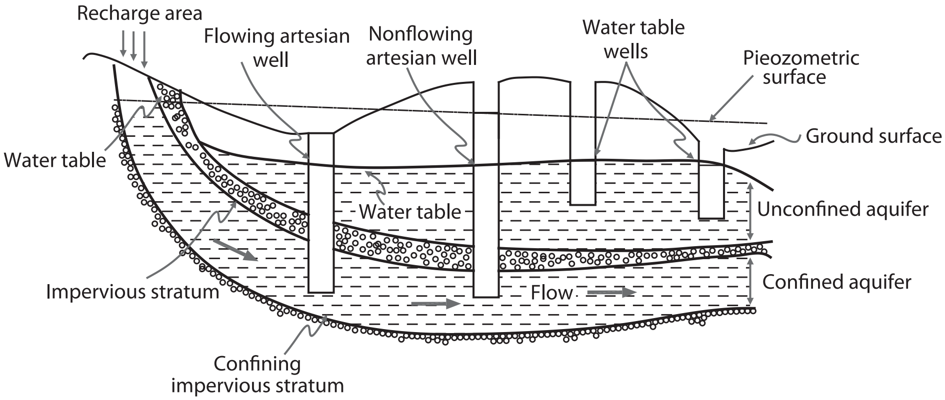

Figure 4.5a: **Confined and unconfined aquifers**

pressure gradient must increase, forming a cone of depression. The reduction in the water table is known in groundwater terms as a drawdown. If the rate of water flowing toward the well is equal to the rate of water being pumped out of the well, the condition is at equilibrium, and the drawdown remains constant. If, however, the rate of water pumping is increased, the radial flow toward the well must compensate, and this results in a deeper cone or drawdown.

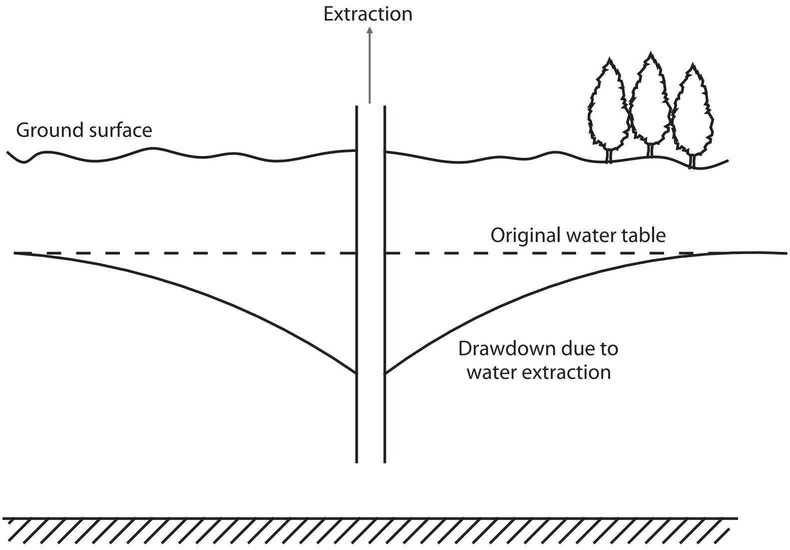

Figure 4.5b: **Drawdown in the groundwater table when water is pumped out of a well**

Example 4.2: A confined aquifer is 6 m deep and the coefficient of permeability in the soil is $2m^3/day\text{-}m^2$. The wells are 100m apart, and the difference in the water elevation in the wells is 3.0 m. find the flow rate and the superficial velocity through the aquifer.

Solution:

The slope of the pressure gradient, $\frac{\Delta h}{\Delta L} = 3/100 = .03$, and the flow rate for a section of aquifer 1 m wide is

$$Q = KA\frac{\Delta h}{\Delta L} = 2 \times 6 \times .03 = .35m^3 / day$$

The superficial velocity is

$$v = \frac{Q}{A} = \frac{.36}{1 \times 6} = .06m/day$$

4.7 Hydraulic Characteristics

The hydraulic characteristics of an aquifer (which are described by the storage coefficient and the aquifer permeability) may be determined by laboratory or field tests. The three most commonly used field methods are the application of tracers, use of field permeameters and aquifer performance tests. A discussion of aquifer performance tests will be given here along with the development of flow equations for wells. Aquifer performance tests may be classified as either equilibrium or nonequilibrium tests. In the former, the *cone of depression* must be stabilized for the flow equation to be derived. In the latter, the derivation includes the condition that steady-state conditions have not been reached. They published the first performance tests based on equilibrium conditions in 1906.

The equilibrium equation for an unconfined aquifer can be derived using the notation of Figure 4.6a. In this case, the flow is assumed as radial, the original water table to be horizontal, the well to fully penetrate the aquifer of infinite areal extent, and steady-state conditions must prevail. Then the flow toward the well at any location *x* from the well must equal the product of the cylindrical element (Figure 4.6b) of area at that section aid the flow velocity towards the centre. As the cylindrical surface area is $2\pi rh$ (Figure 4.6b), using Darcy's law, this becomes for a section of a variable area

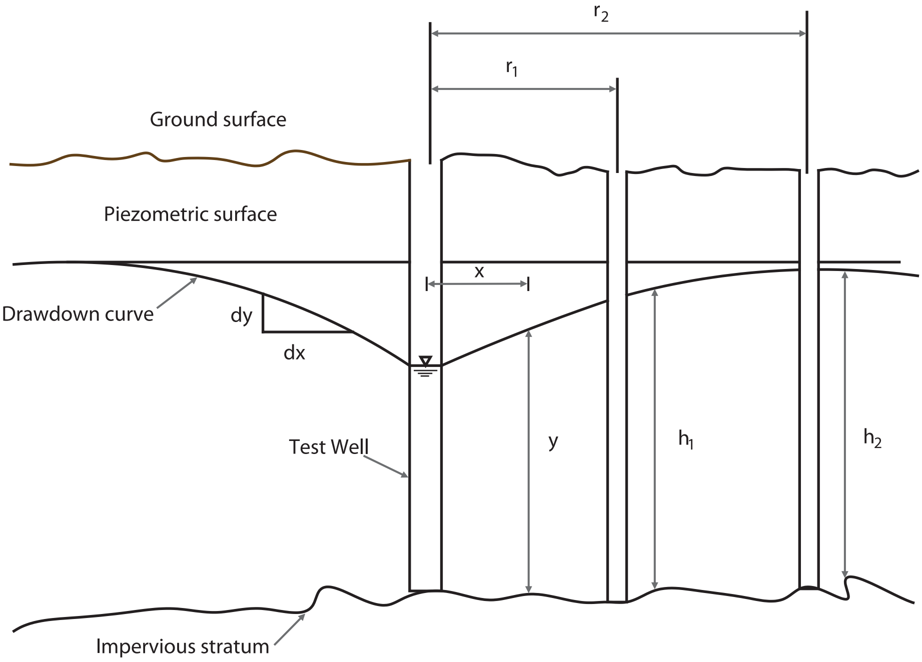

Figure 4.6a: Radial flow to a well in an unconfined aquifer

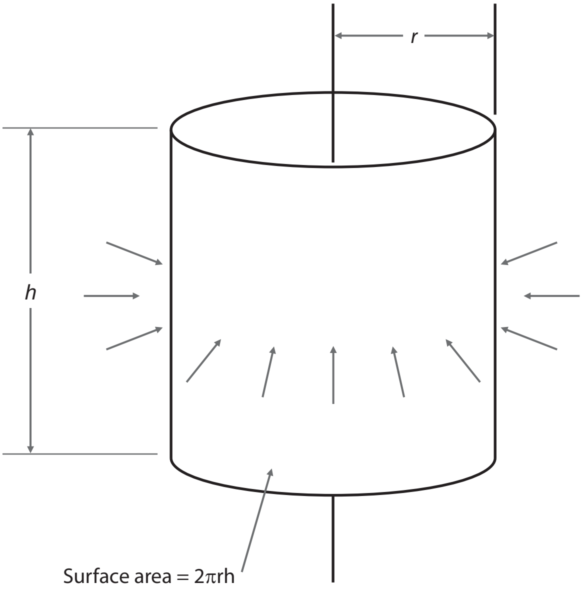

Figure 4.6b: Cylinder with water flowing through its sides towards the centre

$$Q = K_f A \frac{\Delta h}{\Delta L} = 2\pi xyK_f \; dy/dx \tag{4.7}$$

Where $2\pi xy$ = area at section, m^2

$K_f dy/dx$ = flow velocity, m/s

Q = discharge, m^3/s

Integrating over the limits specified below yields

$$\int_{r_1}^{r_2} Q(\frac{dx}{x}) = 2\pi K_f \int_{h_1}^{h_2} yd_y \tag{4.8}$$

$$Q\ln(\frac{r_2}{r_1}) = \frac{2\pi K_f (h_2^2 - h_1^2)}{2} \tag{4.9}$$

And

$$Q = \frac{\pi K_f (h_2^2 - h_1^2)}{\ln(r_2/r_1)} \tag{4.10}$$

These equations can be used to estimate the pumping rate for a given drawdown any distance away from a well, using the water level measurements in two observation wells in an unconfined aquifer (where the water table is free to change), as shown in Fig. 4.6c (used also for the example 4.3). Also, knowing the diameter of a well, it is possible to estimate the drawdown at the well, the critical point in the cone of depression. If the drawdown is expressed all the way to the bottom of the aquifer, the well "goes dry" it cannot pump water at the desired rate.

The equation 4.10 is known as the formula of Dupuit.

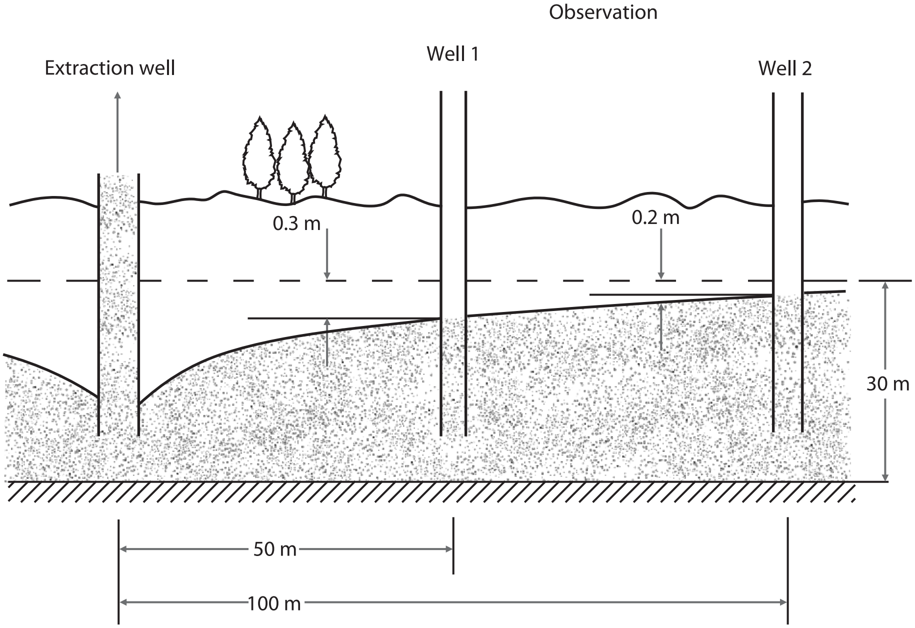

Figure 4.6c: Two monitoring wells showing drawdown during extraction

Although the derivation of the foregoing equations is for an unconfined aquifer, the same situation would occur for a confined aquifer, where the pressure would be measured by observation wells. The basic equilibrium equation for a confined aquifer can be obtained using the notation of Figure 4.7. The same assumptions apply. Mathematically the flow may be determined as following Theim's method.

$$Q = 2\pi x m K_f \frac{dy}{dx} \tag{4.11}$$

Integrating, we obtain

$$Q = 2\pi m\, K_f \frac{h_2 - h_1}{\ln(r_2/r_1)} \tag{4.12}$$

Where m = aquifer thickness.

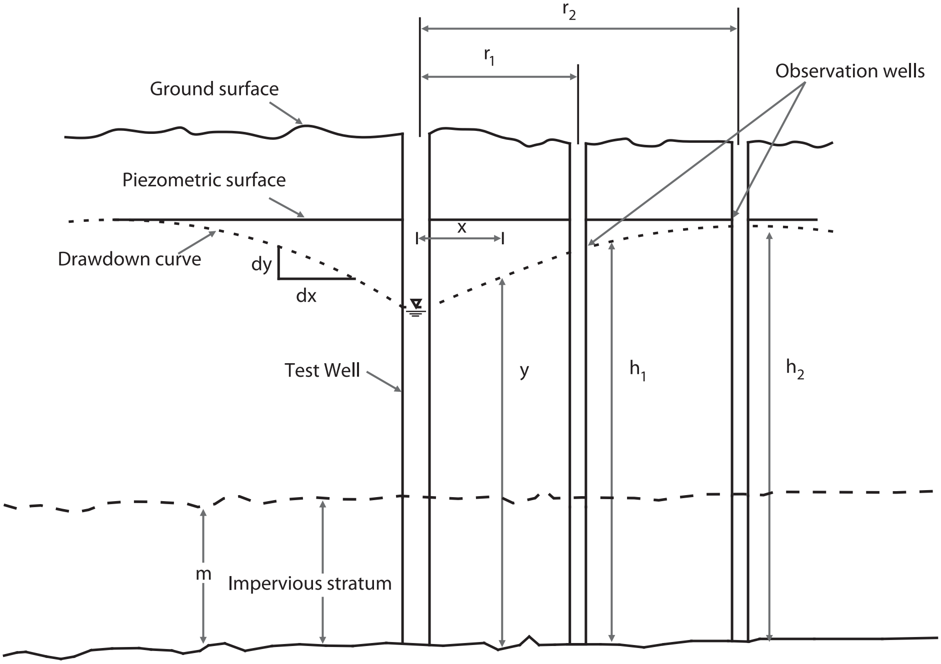

Figure 4.7: **Radial flow to a well in a confined aquifer**

The coefficient of permeability may be determined by rearranging Eq. 4.12 to the form

$$K_f = \frac{2.30\, Q \log_{10} (r_2/r_i)}{2\mu m\, (h_2 - h_1)} \qquad 4.13$$

Example 4.3: A well is 0.2 m in diameter and pumps from an unconfined aquifer 30 m deep at an equilibrium (steady-state) rate of 1000m^3 per day. Two observation wells are located at distances 50 and 100m, and they have been drawn down by 0.2 and 0.3 m, respectively (Figure 4.6c). What is the coefficient of permeability and estimated drawdown at the well?

Solution:

$$K_f = \frac{Q \ln(r_2/r_1)}{\pi\,(h_2^{\,2} - h_1^{\,2})} = \frac{1000 \ln(100/50)}{\pi[(29.8)^2 - (29.7)^2]} = 37.1 m^3 / m^2 - day$$

Now if the radius of the well is assumed to be 0.2/2 = 0.1 m, this can be plugged into the same equation, as

$$Q = \frac{\pi K (h_2^2 - h_1^2)}{\ln(r_2/r_1)} = \frac{\pi \times 1.97 \times [(27^2 - h_1^2)]}{\ln(50/.1)} = 1000$$

And solving for h_1,

h_1=28.8m

Since the aquifer is 30m deep, the drawdown at the well is 30 - 28.8 = 1.2 m.

4.8 Safe Yield

The development engineer must be able to determine of water. He or she must also be able to evaluate the consequences that will result from the imposition of various drafts on the underground supply. Knowledge of the safe yield of an aquifer is therefore exceedingly important. Following are pertinent definitions:

- **Safe yield:** The quantity of water that can be withdrawn annually without the ultimate depletion of the aquifer.
- **Maximum sustained yield:** Maximum rate at which water can be withdrawn on a continuing basis from a given source.
- **Permissive sustained yield:** Maximum rate at which withdrawals can be made legally and economically on a continuing basis for beneficial use without the development of undesired results.
- **Maximum mining yield:** Total storage volume in a given source that can be withdrawn and used.
- **Permissive mining yield:** Maximum volume of water that can be withdrawn legally and economically, to be used for beneficial purposes, without causing an undesired result.

Methods for determining the safe yield of an aquifer have been proposed by Hill, Harding, Simpson, and others.

The Hill method, based on groundwater studies in Southern California and Arizona, will be presented here. In this method, the annual change in groundwater table elevation or piezometric surface elevation is plotted against the annual draft. The points can be fitted by a straight line, provided that the water supply to the basin is fairly uniform. That draft that corresponds to zero change in elevation is considered to be the safe yield. The period of record should be such that the supply during this period approximates the long-time average supply. Even though the draft during the period of record may be an overdraft, the safe yield can be determined by extending the line of best fit to an intersection with the zero change in elevation line. An example of this procedure is given in Figure 4.8.

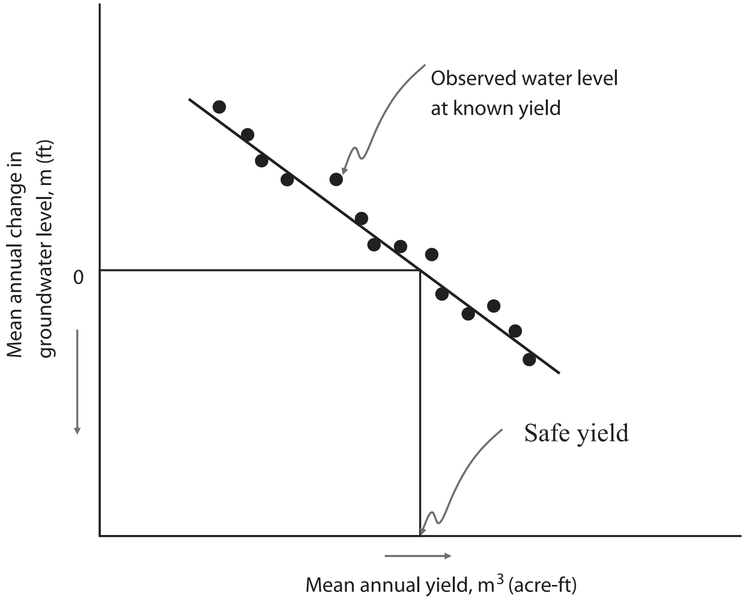

Figure 4.8: **Graphical determination of safe yield by the Hill method**

It should be noted that the safe yield of a groundwater basin may be variable with time. This is because the groundwater basin conditions under which the safe yield was determined are subject to change, and these changes will be reflected in the modified value of the safe yield.

4.9 Source Contamination

All groundwater sources should be located a safe distance from sources of contamination. In cases where sources are severely limited, however, a groundwater aquifer that might become contaminated may be considered for a water supply if treatment is provided (Christen, Navarro et al. 2009). After a decision has been made to locate a water source in an area, it is necessary to determine the distance the source should be placed from the origin or contamination and the direction of water movement. Table 4.2 is offered as a guide in determining these distances.

4.10 Ground Water Development

The type of groundwater development to be undertaken is dependent upon the geological formations and hydrological characteristics of the water bearing formation. The development of groundwater falls into two main categories:

- Development by wells
    - Nonartesian or water table
    - Artesian
- Development from springs
    - Gravity
    - Artesian

Table 4.2: Distance to Source of Contamination

Formation	Minimum acceptable distance from well to source of contamination
Favorable (unconsolidated)	50ft; lesser distances only on health department approval following comprehensive sanitary survey of proposed site and immediate surroundings.
Unknown	50ft only after comprehensive geological survey of the site and its surroundings has established, to the satisfaction of the health agency that favourable formations do exist.
Poor (consolidated)	Safe distances can be established only following both the comprehensive geological and comprehensive sanitary surveys. These surveys also permit determining the direction in which a well may be located with respect to sources of contamination. In no case should the acceptable distance be less than 50ft.

4.10.1 Wells

Nonartesian wells are those that penetrate formations in which groundwater is found under water table conditions. Pumping from the well lowers the water table in the vicinity of the well and water moves toward the well under the pressure differences thus artificially created.

Artesian wells are those that penetrate aquifers in which the groundwater is found under hydrostatic Pressure. Such a condition occurs in an aquifer that is confined beneath an impermeable layer of material at an elevation lower than that of the intake area of the aquifer. The intake areas or recharge areas of confined aquifers are commonly at high-level surface outcrops of the formations. Groundwater flow occurs from high-level outcrop areas to low-level outcrop areas, which are areas of natural discharge. It also flows toward points where water levels are lowered artificially by pumping from wells. When the water level in the well stands above the Lop of the aquifer, the well is described as artesian. A well that yields water by artesian pressure at the ground surface is a flowing artesian well.

4.10.2 Springs

Gravity springs occur where water percolating laterally through permeable material overlying an impermeable stratum comes to the surface. They also occur where the land surface intersects the water table. This type of spring is particularly sensitive to seasonal fluctuations in groundwater storage and frequently dwindles to a seep or disappears during dry periods. Gravity springs are characteristically low-discharge sources, but when properly developed, they make satisfactory individual water supply systems. Artesian springs discharge from artesian aquifers. They may occur where the confining formation over the artesian aquifer is ruptured by a fault or where the aquifer discharges to a lower topographic area. The flow from these springs depends on the difference in recharge and discharge elevations of the aquifer and on the size of the openings transmitting the water. Artesian springs are usually more dependable than gravity springs, but they are particularly sensitive to the pumping of wells developed in the same aquifer. As a consequence, artesian springs may be dried by pumping.

Springs may be further classified by the nature of the passages through which water issues from the source.

Seepage springs are those in which the water seeps out of sand, gravel, or other material that contains many small interstices. The term as used here includes many large springs as well as small ones. Some of the large springs have extensive seepage areas and are usually marked by the presence of abundant vegetation.

The water of small seepage springs may be colored or carry an oily scum because of decomposition of organic matter or the presence of iron. Seepage springs may emerge along the top of an impermeable bed, but they occur more commonly where valleys are cut into the zone of saturation of water-bearing deposits. These springs are generally free from harmful bacteria, but they are susceptible to contamination by surface runoff which collects in valleys or depressions.

Tubular springs issue from relatively large channels, such as the solution channels and caverns of limes tone, and soluble rocks and smaller channels that occur in glacial drift. They are sometimes referred to as, "bold" springs because the water issues freely from one or more large openings. When the water reaches the channels by percolation through sand or other fine-grained material, it is usually free from contamination. When the channels receive surface water directly or receive the indirect effluent of cesspools, privies, or septic tanks, the water must be regarded as unsafe. Fissure springs issue along bedding, joint, cleavage, or fault planes. Their distinguishing feature is a break in the rocks along which the water passes. Some of these springs discharge uncontaminated water of deep source origin. A large number of thermal springs are of this type. Fissure springs, however, may discharge water which is contaminated by surface drainage from strata close to the surface.

4.11 Flow of Groundwater

The rate of movement of water through the ground is of an entirely different magnitude than that through natural or artificial channels or conduits. Typical values range from 5 ft/day (1.5 in/day) to a few feet per year. Methods for determining these transmission rates are primarily based on the principles of fluid flow represented by Darcy's law. Mathematically, this law can be stated as

$$V = ks \tag{4.13}$$

Where, V = velocity flow
k = coefficient having the same units as velocity
s = slope of the hydraulic gradient

Darcy's law is limited in its applicability to flows in the laminar region. The controlling criterion is the Ids number.

$$N_r = \frac{Vd}{\mu} \qquad 4.14$$

Where, N_r = Reynolds number
d = mean grain diameter
μ = kinematic viscosity
V = flow velocity

For Reynolds numbers of less than 1 unit, groundwater flow may be considered laminar. Departure from laminar conditions develops normally in the range of Reynolds numbers from 1 to 10, depending on grain size and shape. Under most conditions, with the exception of regions in close proximity to collecting devices, the flow of groundwater is laminar and Darcy's law applies.

4.12 Safeguards in Groundwater Development

Some of the safeguards for groundwater development are:

- diversion of surface water from intake structures
- drainage of overflow or spill age waters away from intake structures
- water tightness of intake works for at least 10 ft
- below the ground surface and, if necessary, until the aquifer is reached; and
- prevention of backflow into intakes.

4.13 Interference Between Multiple Extraction Wells

Multiple wells in an aquifer can interfere with each other and cause excessive drawdown. Consider the situation in Figure. 4.9 Where first a single well creates a cone of depression. If a second extraction well is installed, the cones will overlap, causing greater drawdown at each well. If many wells are sunk into an aquifer, the combined effect of the wells could deplete the groundwater resources and all wells would "go dry".

The reverse is also true, of course. Suppose one of the wells becomes an injection well, then the injected water flows from this well into the others, building up the groundwater table and reducing the drawdown. The judicious use of extraction and injection wells is one way that the flow of contaminants from hazardous waste or refuse dumps can be controlled.

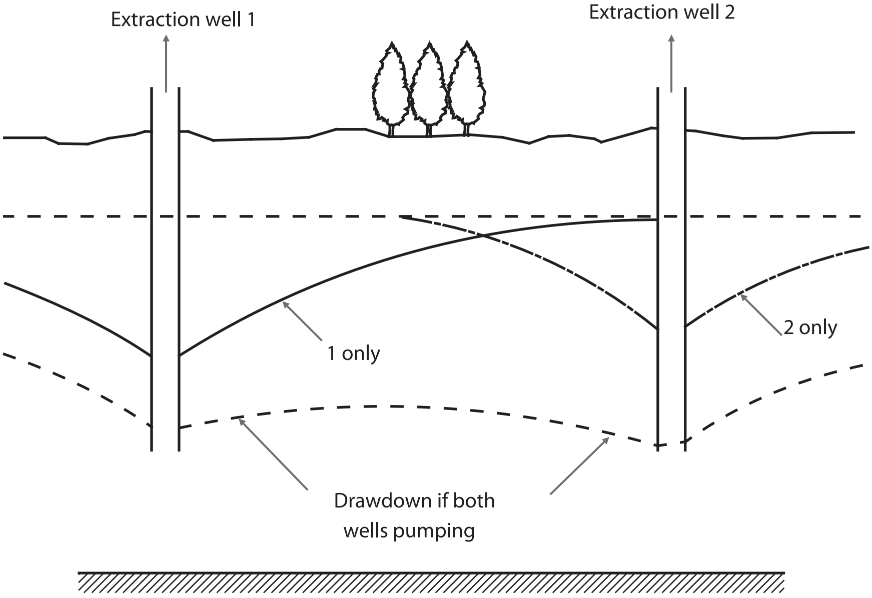

Figure 4.9: Interference between two extraction wells.

Finally, a lot of assumptions are made in the above discussion.

- First, it is assumed that the aquifer is homogeneous and infinite; that is, it sits on a level aquaclude and that the permeability of the soil is the same at all places for an infinite distance in all directions.
- Second, steady-state and uniform radial flow is assumed. The well is assumed to penetrate the entire aquifer, and is open for the entire depth of the aquifer.
- Finally, the pumping rate is assumed to be constant.

Clearly any of these assumptions may be unwarranted and cause the analysis to be faulty. This model of aquifer behaviour is a relatively simple illustration. Modelling the behaviour of groundwater is a complex and sophisticated science.

4.14 Infiltration Gallery

An infiltration gallery is horizontal drain made from open jointed or perforated pipes, or a block drain, which is laid below the water table and collects groundwater (Figure 4.10). Infiltration galleries need soils that are permeable to allow sufficient water to be collected. The gallery should be surrounded with a

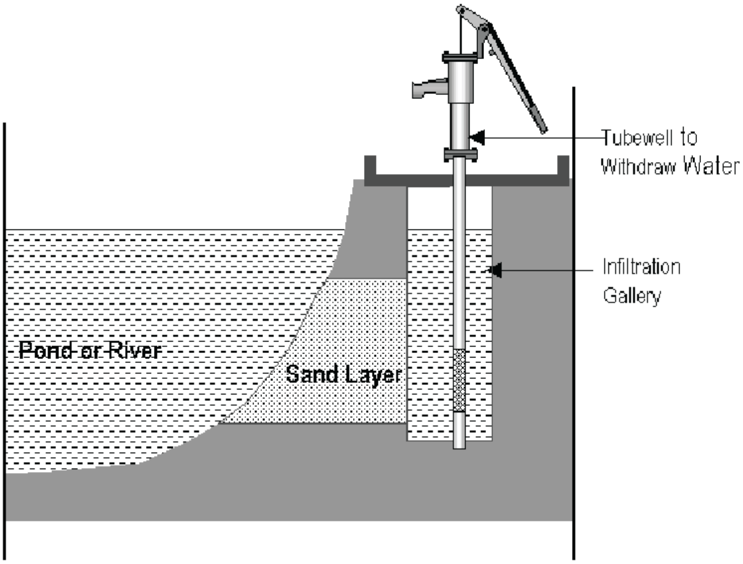

Figure 4.10: Infiltration

gravel and sand pack to improve flow towards it and any large particles that might block the perforations.

Infiltration galleries can be used to collect sub-surface flow from rivers. Water is taken to a collection well, or sump, and then either withdrawn directly or pumped to a storage tank.

Galleries are often used in conjunction with other water supply systems as a means of increasing the quality of water intake in areas of poor water yield. In this instance one or more galleries are built which drain into a central point, such as hand-dug well or spring box. These are called collector wells. When an infiltration gallery is built, it is important to protect it from contamination by locating it uphill and the minimum safe distance from any latrines. The gallery should also be constructed to ensure that unfiltered surface water cannot enter.

Infiltration galleries vary in size, from a few meters feeding into a spring box, to many kilometers forming an integral part of an urban water supply.

4.15 Conclusion

As the hydrologic cycle indicates, water is a renewable resource because of the driving force of energy from the sun. The earth is not running out of water, though enough water or enough clean water may not be available in some areas because of climate and water use. Both groundwater and surface water supplies are available to varying degrees over the entire earth's surface, and can be protected by sound engineering and environmental judgment.

The next chapter addresses the use of pumps and hydraulic mechanism of pumps in transmitting water for distribution and consumption once the supply has been provided.

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