THE HYDROLOGIC CYCLE

Radiation from the sun evaporates water from the oceans into the atmosphere. The water vapour rises, then forms clouds. Under certain conditions, the cloud moisture condenses and falls back to the earth as precipitation.

Precipitation that falls upon land areas, is the source of essentially all our fresh water supply. We depend upon it to replenish the quantity that is taken from lakes, streams and wells for man's numerous uses.

Some of this precipitation, after wetting plant surfaces and ground, runs off over the soil surface to streams. Another part infiltrates the soil. Much of the water that enters the soil is detained in the plant root zone and eventually is drawn back to the surface by plants or by soil capillarity. Some of it, however, soaks below the plant root zone and under the influence of gravitational forces mores downward into the groundwater reservoir.

On entering the body of groundwater, the percolating water mores through the pores of saturated subsurface materials and may reappear at the surface in areas at lower elevations than the level where it entered the groundwater system. Groundwater discharges naturally at each places in the form of springs, and seeps which maintain the flow of streams during dry period. The streams, carrying both surface runoff and natural ground water discharge, eventually lead back to the oceans.

The hydrologic cycle, then, is the system by which nature circulates water from the oceans through the atmosphere and returns it both overland and underground back to the sea through devious paths -- some short and some long, in terms of both time and space. The forces involved in this process include radiation gravity, molecular attractions and capillarity.

A schematic sketch of the hydrologic cycle is given below (Fig. 1.1)

Fig 1.1: Schematic sketch of the layer Hydrologic cycle.

Soil Moisture and Groundwater

Water that infiltrates the soil is called subsurface water, but not all of it becomes groundwater. Three things may happen to that water. First, it may be palled back to the surface by capillary force and be evaporated into the atmosphere, thus skipping much of the journey through the water cycle. Second, it may be absorbed by plant roots growing in the soil and then reenter the atmosphere by a process of transpiration. Third, water that has infiltrated the soil deeply enough may be pulled on downwards by gravity until it reaches the groundwater system.

Infiltration Factors

The processes involved in the hydrologic cycle have shown that groundwater occurrence is chiefly the result of infiltration from the soil and from streams and lakes, all of which receive their supply of water from precipitation.

In some places, groundwater reservoirs are replenished quickly by rain falling directly on the land surface above them. In other places, surface water in streams and lakes feeds the ground water reservoir, when water levels in these bodies of surface water are higher than the water table and where the stream channel or lake bed is permeable.

The rate of replenishment of the groundwater reservoir varies with the pattern of precipitation, surface runoff, and stream flow. It also varies with the hydraulic conductivity of the soil and other earth materials through which the water must percolate to reach the zone of saturation.

The opportunity for infiltration varies greatly with the condition of the soil, the antecedent soil moisture content, and the drainage not within the drainage area. The slope of the land surface is also an important factor – steep slopes favour quick surface runoff; flatter slopes holds the water longer to favours infiltration. In many areas gentle slopes seem to offer more favourable conditions than the completely flat areas.

Moderate rainfall over an extended period of time favours infiltration. Heavy rains saturate the surface quickly and encourages overland flow to streams and rivers rather than groundwater recharge.

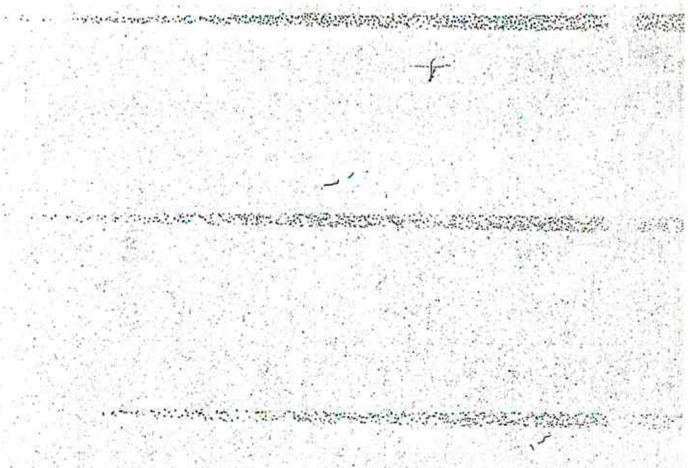

Fig. 1.2: Groundwater is the part of subsurface water within the zone of saturation.

Capillarity holds water in the very small spaces between the soil particles. Only when sufficient water has entered this belt to more than satisfy the water holding capacity f the capillary forces, does water start to percolate downward under the force of gravity.

Water that does pass through the belt of soil water enters the intermediate belt, and continues its movement downward by gravitational action. Like the belt of soil water, the intermediate belt holds suspended water by molecular attraction and capillarity, capillarity being the more important of the two forces. The suspended water in this belt is dead storage, since it cannot be recovered for use. This belt serves only to provide a passage for water from the belt of soil water to the capillary fringe and to the zone of saturation below it. The thickness of the intermediate belt varies greatly, and this has a significant effect on the time it takes water to pass through it to recharge the zone of saturation.

The capillary fringe has immediately below the intermediate belt and above the zone of saturation. It holds water above the zone of saturation by capillary force acting against the force of gravity. The thickness and the amount of water held in the capillary fringe depend on the grain size of the material. The capillary fringe in silt and clay materials is sometimes as much as 2.4m thick. In coarse sand or gravel it may be a few millimeters.

Ground Water

Water in the zone of saturation is the only part of all subsurface water which is properly referred to as **groundwater**. The saturated zone may be viewed as a huge material reservoir whose capacity is the total volume of the pores or openings in the rocks that are filled with water. Ground water may be found in one continuous body or in several strata. The thickness of the zone of saturation varies from a few metres to several metres. The factors that determine its thickness are: the local geology, the availability of pores or openings in the formations, the recharge and the movement of water within the zone from areas of recharge towards points or areas of discharge (See Fig. 1.3).

Fig. 1.3: Subsurface and groundwater phase of the hydrologic cycle.

Formations or strata within the saturated zone from which groundwater can be obtained for beneficial use are called **aquifers**. An **aquifer** is a water saturated geologic unit that will yield water to wells or springs at a sufficient rate so that the wells or springs can serve as practical sources of water supply. To qualify as an aquifer, a geologic formation must contain pores which are filled with water, and these openings must be large enough to permit water to more through them towards wells and springs at a perceptible rate.

Water Table Conditions

Groundwater in some aquifers occurs under water table conditions. This means that the upper limit of the aquifer is defined by the water table itself. At the water table – the top of the saturated portion of the geologic formation – the water in the pores of the aquifer is at atmosphere pressure. Under this condition, the aquifer is referred to as **water-table aquiver**. The term **unconfined aquifer** is also used with reference to this form of groundwater occurrence.

The hydraulic head at any level is equal to the depth from the water table to the point in question and may be expressed in metres of water.

In some cases, a local zone of saturation may occur at some level above the main water table. This situation can occur where an impervious stratum within the zone of aeration interrupts percolation and causes groundwater to accumulate in a limited area above the stratum. The upper surface of the groundwater in such a case is called a **perched water table.**

The water table is not a stationary surface but periodically moves up and down – rising when more water is added to the saturated zone by vertical percolation, and dropping during drought when previously stored water flows out toward springs, streams, wells and other points of groundwater discharge.

The zone of saturation may include both permeable and impermeable layers of earth materials. Where an aquifer is found between impermeable layers above and below it, both the aquifer and the water it contains are said to be confined. Because of the upper confining layer, the water of the aquifer is not open to atmospheric pressure. It thus occurs within the pores of the aquifer at pressures greater than atmospheric.

Artesian Conditions

Groundwater in a confined aquifer is said to be under artesian conditions. The aquifer is also described as a confined aquifer. When a well is drilled through the upper confining layer and into an artesian aquifer, water rises in the well to some level above the top of the aquifer. The water level in the well represents the artesian pressure in the aquifer.

The elevation to which the water level rises in a well that taps an artesian aquifer is referred to as the piezometric level. An imaginary surface representing the artesian pressure or the hydraulic head throughout all or part of the artesian aquifer is called the piezometric surface. The hydrostatics pressure within an artesian aquifer is sometimes great enough to cause the water to rise in a well above the land surface. A flowing artesian well results.

GEOLOGIC FORMATIONS

A geologic formation that will yield significant quantities of water has been defined as an aquifer. Many types of formation serve as aquifers. A key requirement is their ability to store water in the rock pores. Porosity may be derived from intergranular spaces or from fractures. The roles of various geologic formations as aquifers are described below:

Alluvial Deposits

Alluvial deposits are the materials laid down by physical processes in river channels or flood plains. Alluvial materials occur in nearly all regions. Because of the shifting position of river channels and the charging depositional velocities, river deposits have characteristic textural variability that causes much heterogeneity in the distribution of hydraulic properties. Braided rivers generally occur in settings where the sediment available for transport has considerable coarse-grained sand or gravel and where velocities are large because of steep regional topographic slopes. Shifting positions of channels and changing velocity can result in extensive deposits of bedded sand and gravel with minor zones of silty or clayey sediments filling in abandoned channels. Meandering rivers and their associated floodplain environments also have coarse and fine-grained deposits. Wells located in highly permeable strata bordering streams produce large quantities of water, as infiltration from the streams arguments groundwater supplies.

Bedrock Aquifers

These are made up of sandstone, limestone, dolomite and shale.

Sandstone are cemented forms of sand. As such, their porosity and effectiveness have been reduced. However, the tight cementation causes the sandstone to act as a solid body and therefore it is more susceptible to cracking when earth movements or other forces act upon it. In sandstone therefore, the ability of the rock unit to yield water is dependent upon the existence of cracks, crevices and other voids distributed throughout the rock.

Limestone and dolomites can be considered together because of the similarity between the two types of rock. The intergranular permeability of dolomite and limestone is much less than that of sandstone. Both can be thought of as practically impervious to the movement of water between the various crystalline particles of which they are composed. However, there is some evidence to suggest that dolomite in general has a slightly greater-between-the-grains permeability than limestone. In both types of rock, the ability to yield useable quantities of water is a function of the number of fractures, crevices and other openings which have been enlarged by solution.

Shale has the ability to transmit water to wells only after it has been fractured or weathered. Fracturing provides openings through which water can move, and weathering processes tend to split some shales into thin, platy particles which then have void spaces between them. As a general rule, however, the weathering of shale progresses rapidly to a point where the platy structure is destroyed; the shale then becomes clay-like and thus impermeable.

Porosity

The porosity of a water-bearing formation is that part of its volume which consists of openings or pores, that is, the proportion of its volume not occupied by solid materials. Thus can be given by

$$x = \frac{V_v}{V_T} \qquad V_v = \text{Volume of voids} \qquad V_T = \text{Total volume}$$

Specific Yield

When water is drained from a saturated material by gravitational force, only part of the total volume stored in its pores is released. The quantity of water that a unit volume of the material will give up when drained by gravity is called its specific yield.

$$\text{Specific yield} = V_W / V_T \qquad V_W = \text{Volume of water drained by gravity}$$

Specific Retention

The part of the water that is not removed by gravity drainage is held against the force of gravity by molecular attraction and capillarity. The quality that a unit volume retains when subjected to gravity drainage is called the specific retention.

$$\text{or specific retention} = \frac{V_V - V_W}{V_T}$$

Storage Coefficient

A storage coefficient is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit charge in the component of head normal to that surface. For a vertical column of unit area extending through a confined aquifer, the storage coefficient S equals the volume of water released from the aquifer when the piezometric surface decline, a unit distance.

In most confined aquifers, S fall in the range $5 \times 10^{-5} < S < 50 \times 10^{-3}$. Storage coefficients can best be determined from pumping tests of wells.

The fact that S varies directly with aquifer thickness gives the approximation for S as

$$S = 3 \times 10^{-6} D$$

Where D is aquifer thickness.

The storage coefficient for an unconfined aquifer corresponds to its specific yield.

Permeability

Darey's lane:

$$V = \frac{dh}{dl}$$

or

$$V = \frac{dh}{dl}$$

where k is the hydraulic conductivity

K is found to be equal to

$$K = \frac{Kpg}{U}$$

Where P = density of fluid and u the dynamic viscosity, K is the intrinsic permeability. However, the term permeability is used by most people to denote hydraulic conductivity.

Transmissibility, T

The rate at which water will flow through a vertical strip of the aquifer of a unit width and extending through the full saturated thickness under unit hydraulic gradient.

That is,

$$T = kD$$