5.1 AQUIFERS

Water saturated geological formations underneath the Earth surface, which facilitate reasonable supply of water are known as aquifers.

The rock layer that contains water and releases it in appreciable amounts. The rock contains water-filled pore spaces, and, when the spaces are connected, the water is able to flow through the matrix of the rock. The study of aquifers characteristics and movement of groundwater in aquifers is called as hydrogeology

Geological formations like unconsolidated sedimentary formations with coarse rock granules appear excellent aquifers. Moreover, fractures metamorphic and igneous rocks are also form good aquifers

5.1.1 Classifications of Geohydrological Characteristics

Aquitard

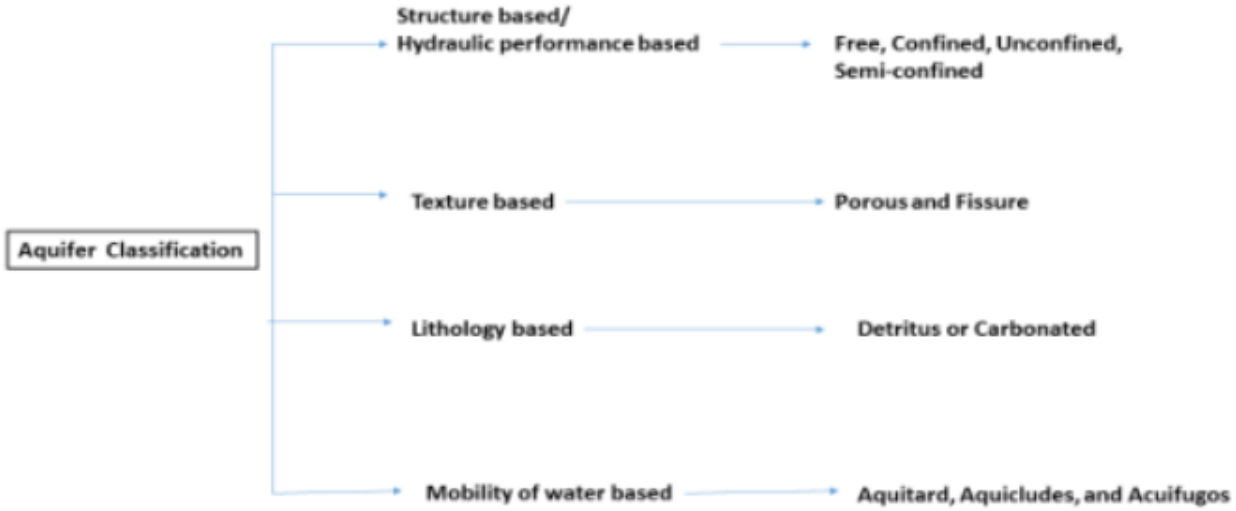
The term aquitard originates from the combination of two latin word i.e. aqua which means "water" and tardo which means "slow down or hinders". Aquitard represent the water saturaed geological structures (like silt, clay, shale) having insufficient permeability and confounding it to behave like resource for water supply. However, aqiutard can permit exchange of groundwater between adjuscent aquifers due to vertical leakage but does not yield water freely to wells or springs. These sufficiently thick geological structures implies to behave like a groundwater storage zone (Todd and Mays, 2005).

Aquiclude

Aquiclude, like other terms, also originated from latin words Aqua means "water" and claudo which means "confines or inaccessible". Aquicludes represent such limiting geological formation like unfractures cryatlline rocks, which are fully or nearly impermeable and favours no interchange of groundwater with other quifers. An aquiclude is solid, impermeable but porous structure underlying an aquifer and can be defined as a "water saturated geological unit that is incapable of transmitting significant quantities of water under ordinary hydraulic gradient"(Freeze and Cherry, 1979).

Aquifuge

Aquifuge represent relatively impermeable structures (like solid granite), which do not have any interconnected openings. Hence, such geological structures can neither store water, nor exchange/ transmit water with other aquifers. Basically, the word aquifuge is coined from combination of two latin word including aqua which means "water" and fuge which means "drive away" (Todd and Mays, 2005).



5.1.2 TYPES AND Properties of aquifers - Governing equations

Types of aquifers

Aquifers are generally classified into four different categories: confined, unconfined, leaky and multiple aquifers. All the different categories of aquifers are discussed in details in below section.

Confined aquifers

Confined aquifers or artesian aquifers or pressure aquifers, are the water saturated geological formation, sandwiched between impervious or semi-pervious unsaturated zone at pressure greater than atmospheric pressure (Fig. 4a). This pressure may sometime results to rise in water level above Earth surface in wells. Generally, the existence of such aquifer systems take place in sedimentary rocks of low permeability in deep beneath the Earth surface where water get entrapped at the time of deposition. These aquifers are characterized with low groundwater circulation intensity, very large storage and inadequate replenishment. The average

replenishment period for a confined aquifer could be extended up to 1000 years which is even less than 0.1% of the aquifer storage period (Margat et al., 2006). These aquifers may be recharged by rain or stream water infiltrating the pervious or semi-pervious rock at some considerable distance away from the aquifer.The water level in borehole or well installed in confined aquifers may sometimes rise above the level of the aquifer, especially in the condition when piezoelectric or potentiometric surface is above the ground surface. There may be possibility of having piezoelectric surface of confined aquifer, above the Earth surface, which resulted to the formation of flowing wells under natural pressure. The term artesian is used to depict the behavior of water rise above Earth surface in such flowing confined aquifers. The water received from these aquifers may be sometime older than thousands of years. Moreover, such aquifer systems are present in deeper layers and hence, less susceptible to natural hazards and human interferences.

The water balance in confined aquifers can be represented through the equation described below, considering negligible replenishment or recharge and loss through evaporation in one day period (Karamouz et al., 2011).

$$W_{sc,i} = W_{sc,i-1} + W_{per} - W_{pc}$$

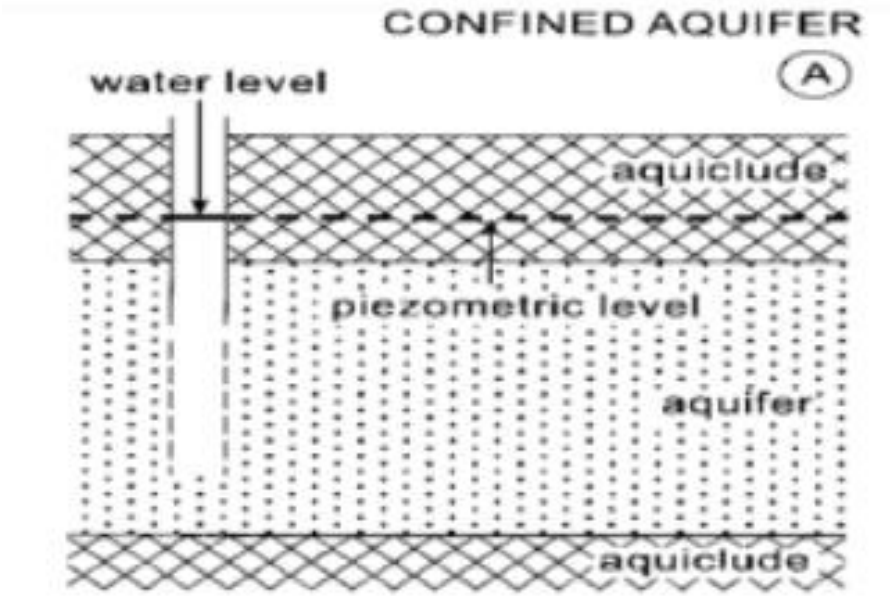
Where

$W_{sc,i}$ =Amount of water stored in the confined aquifer on day i (mm)

$W_{sc,i-1}$ = Amount of water stored in the confined aquifer on day i-1 (mm)

W_{per}= Amount of water percolating from the unconfined aquifer into the confined aquifer on day i (mm)

W_{pc} = Amount of water removed from the confined aquifer by pumping on dayi (mm)



Unconfined aquifers

Unconfined aquifers or phreatic aquifers or water-table aquifers are water saturated geological formations, which is overlain by the free permeable unsaturated zone at the upper boundary of the aquifer. Unlike confined aquifers, saturated zone is open to the atmosphere through open pore spaces of the overlying permeable rock or sediments, which are interconnected vertically and laterally (Fig. 4b). The pressure of water in the unconfined aquifer is equal to the atmospheric pressure and upper groundwater surface is recognized as water-table, which is free to rise and fall. Typically, water does not rise above the water-table in such aquifers.However, depth to the water-table remain variable under various geological factors like topography, geology, season and tidal effects, and the quantities of groundwater being extracted from the saturated zone. Groundwater in such an aquifers is unconfined, threrefore, these aquifers are recognised as unconfined aquifers.Unconfined aquifers are usually replenished with rain or stream water infiltrating directly through the overlying soil. Shallow unconsolidated aquifers are located in unconsolidated glacial or fluvial deposits overlain with permeable unsaturated zone of little thickness, resulting to interface of groundwater with surface water. While, in deep unconfined aquifers exists in consolidated rocks (such as sandstones), overlaid with thick permeable unsaturated zone.

Perched aquifers are some special kind of unconfined aquifers where a small number of aquitard exists between Earth surface and water table. In such water saturated formations, groundwater accumulates above the impervious rocks or sediments like clay layer. In other sense, the occurrence of groundwater is separated from groundwater bodies with relatively impervious strata of aerial extent.

The water balance in unconfined aquifers can be demonstrated with the equation 5, described as under, considering short-term replenishment inputs and interaction of groundwater and surface water (Karamouz et al., 2011).

$$W_{su,i} = W_{su,i-1} + R_r - B_f - W_{sd} - W_{per} - W_{pu}$$

Where

$W_{su,i}$ = Amount of water stored in the unconfined aquifer on day i (mm)

$W_{su,i-1}$= Amount of water stored in the unconfined aquifer on day i-1 (mm)

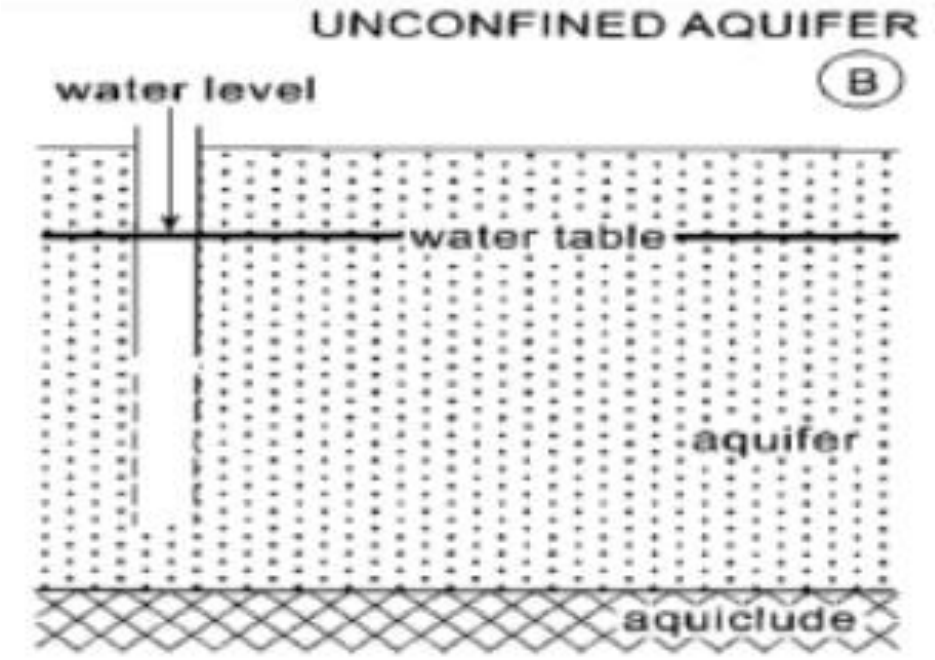
R_r = Amount of recharge entering in the aquifer on day i (mm)

B_f = Base flow to the main channel on day i (mm)

W_{sd} = Amount of water moving into the soil zone in response to water deficiencies on day i (mm)

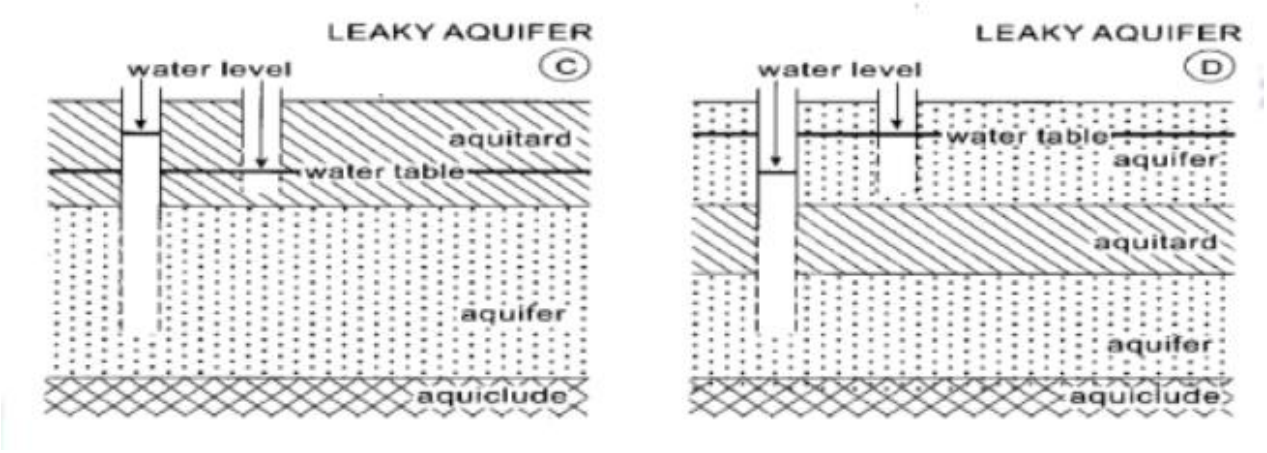
W_{per}= Amount of water percolating from the unconfined aquifer into the confined aquifer on day i (mm)

W_{pu} = Amount of water removed from the unconfined aquifer by pumping on dayi (mm)



Leaky aquifers

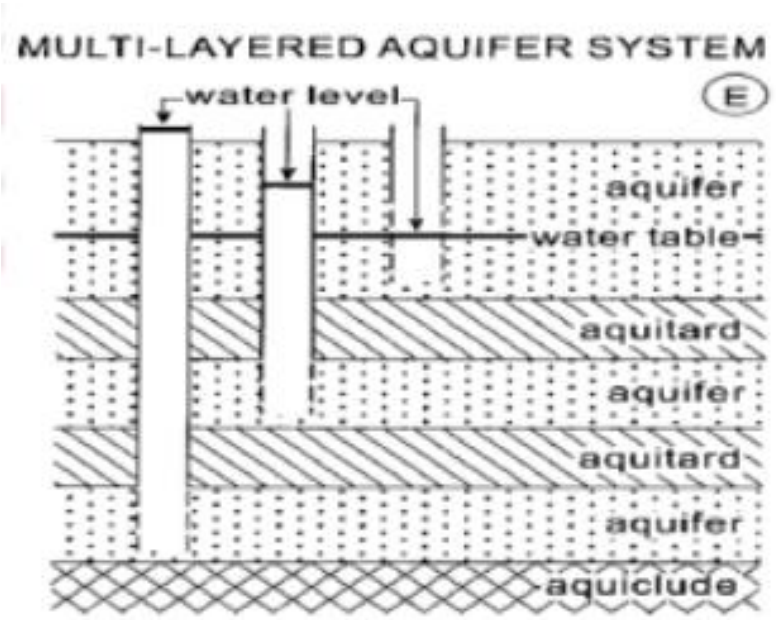
Completely confined or unconfined aquifers are hard to find in nature, however, their existence is more frequently in form of leaky aquifers. These aquifers are overlain or underlain by a semi-confining layer or semi-pervious aquitards, therefore, such aquifers are also recognized as semi-confined aquifers. Generally, aquitards represents the lower permeability beds saturated or partial saturated zone which limit the movement of groundwater between the aquifers.Aquitard will be partially saturated when these extend to the land surface (Fig. 4c).On other hand, aquitard will be available in fully saturated form, when overlain with unconfined aquifers bounded above with the water table (Fig. 4d). These characteristics are reflected especially in alluvial valley plains or former lake basins. Groundwater exploration in wells or bore-wells installed in these aquifers make available water bounded in aquifers as well as in aquitards. Groundwater flows horizontally in aquifers, while movement of groundwater takes place in vertical direction in aquitards during extraction of water.



Multi-layered aquifers

Hydraulically, single aquifer exists infrequently in nature. Generally, aquifer is a part of multiple aquifers, which are arranged in a system. The movement of groundwater in such multi-layered aquifer system is much complex and depends upon the degree of hydraulic communication between the individual aquifers. A multi-layered aquifer system may be one of different types of aquifers available in the system. The aquifer may consists of a system containing two or more aquifers separated with aquicludes (Fig. 4e). The system of such aquifers may consist of confined aquifers or a mixture of unconfined aquifer overlain with a confined aquifer. In such an aquifer system, hydraulic characteristics like transmissivity and storativity of both the individual aquifers are maintained. This system helps to pump out the groundwater from more than one of the aquifer layer at a time, when a well fully penetrate the aquifer system. In another system of multi-layered aquifers, two or more aquifers with their own hydraulic characteristics, are separated by interfaces maintaining unrestricted crossflow of groundwater among the aquifers. The system mimics the similar response to that of a single layered aquifer, where their hydraulic characteristics including transmissivity and storativity behave collectively for the system. This system's response to pumping will be analogous to that of a single-layered aquifer which is equal to the sum of the transmissivity and storativity of the individual layers. In third possibility for a multi-layered aquifer system, two or more aquifers are separated with aquitards, which strengthens the prospective of leaky aquifer system. This kind of aquifer system may have a measurable impact on other aquifer layer, when pumping of water is done from leaky

single-layered aquifer system. However, the impacts may be negligible or measurable, depending upon pumping time.



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