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Lecture (3)

Water Table and Piezometric Surface

Water table

The water table is the surface of the water level in an unconfined aquifer at which the pressure is atmospheric. It is the level at which the water will stand in a well drilled in an unconfined aquifer.

The water table fluctuates by recharge or outflow from the aquifer. In fact, the water table is constantly in motion adjusting its surface to a balance between the recharge and the outflow.

Generally, the water table follows the topographic features and is high below ridges and low below valleys. However, sometimes the topographic ridge and the water table ridge may not coincide and there may be flow from one aquifer to the other aquifer, called watershed leakage. Wherever the water table intersects the ground surface, a seepage surface or a spring is formed.

Perched water table when a small water body is separated from the main groundwater body by a relatively small impermeable stratum. Wells drilled below the perched water table up to the small impervious stratum yield very small quantity of water and soon go dry.



Piezometric surface

The water in a confined aquifer is under pressure. When a well is drilled in a confined aquifer, the water level in it will rise above the top of the aquifer. The piezometric surface is an imaginary surface to which the water level would rise if a piezometer was inserted in the aquifer. Thus, it indicates the pressure of the water in the aquifer. Hence, a piezometric surface is the water table equivalent of the confined aquifer (see Figure -).

For groundwater "potentiometric surface" is a synonym of "piezometric surface" which is an imaginary surface that defines the level to which water in a confined aquifer would rise were it completely pierced with wells.



Figure --: Water Table and Piezometric Surface "potentiometric surface".



Groundwater flows due to differences in "head"



With valve closed, there is no flow



Aquifer Properties

The following properties of the aquifer are required for the study of groundwater hydrology:



1. Porosity

Porosity (n) is defined as the ratio of the volume of voids to the total volume of the porous medium (rock or soil). The larger the pore space or the greater their number, the higher the porosity and the larger the water-holding capacity. It is defined mathematically by the equation:

$$n = \frac{Vv}{V} X \ 100\%$$

Where:

n is the porosity (percentage).

Vv is the volume of void space in a unit volume of earth materials (L³, cm³, or m³).

V is the unit volume of earth material, including both voids and solids (L^3 , cm³, or m³).

In sediments or sedimentary rocks, the porosity depends on *grain size*, the *shape of the grains*, *the degree of sorting*, and *the degree of cementation*. In rocks, the porosity depends upon *the extent*, *spacing*, and *pattern of cracks and fractures*.

* The porosity of well-rounded sediments, which have been sorted so that they are all about the same size, is independent of particle size, depending upon the packing.

* Well-rounded coarse-grained sediments usually have higher porosity than fine-grained sediments, because the grains don't fit together well (see Figure --).



Fig. --: Porosity of Well-Rounded Coarse-Sediments vs. Fine-Grained Sediments

* In igneous and metamorphic rocks porosity is usually low because the minerals tend to be intergrown, leaving little free space. Higher fractured igneous and metamorphic rocks, however, could have high secondary porosity.

* Since cement tends to fill in the pore space, highly cemented sedimentary rocks have lower porosity (see Figure --).



Figure --: Highly Cemented Sedimentary Rock

* Porosity can range from zero to more than 60%. Recently deposited sediments have higher porosity. Dense crystalline rock or highly compacted soft rocks such as shale have lower porosity.

* It is worth distinguishing between Intergranular or matrix or primary porosity as the latter is the porosity provided by small spaces between adjacent grains of the rock, and the secondary porosity of fractured rocks is the porosity provided by discrete rock mass discontinuities (faults, joints, and fractures).

The nature of porosity:

Figure – shows several types of interstices and their relation to porosity:



The significance of the porosity is that it gives the idea of the water storage capacity of the aquifer. Qualitatively, porosity less than 5% is considered to be small, between 5 and 20% as a medium, and the percentage exceeding 20% is considered as large. Table ---: lists representative porosity ranges from various geologic materials.

Formation	n (%)
Unconsolidated deposits	
Gravel	25 - 40
Sand	25 - 50
Silt	35 - 50
Clay	40 - 70
Rocks	
Fractured basalt	5 - 50
Karst limestone	5 - 50
Sandstone	5 - 30
Limestone, dolomite	0 - 20
Shale	0 - 10
Fractured crystalline rock	0 - 10
Dense crystalline rock	0 - 5

Table --: Range of Values of Porosity (after Freeze & Cherry, 1979)

2. Coefficient of Permeability (Hydraulic conductivity) (K)

The hydraulic conductivity is the constant of proportionality in Darcy's law (Equation ---). It is defined as the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. (Kruseman and de Ridder, 1994).

Rock permeability is the ability of rocks to the passage of water between its granules, rock permeability can be expressed in Darcy's equation:

$$Q = K I A \qquad ; \qquad K = \frac{Q}{IA}$$
$$Q = K \frac{dh}{dl} A$$

where:

K: Permeability (Length/Time), it is usually expressed as cm/s, m/s, m/day, etc.

Q: Volume rate of flow (Length³/Time), in another meaning, is (Discharge (m^3/day) .

A: Cross-sectional area normal to flow direction (Length²), i.e. Area of groundwater (m²).

dh/dl = I: Represent hydraulic gradient (dimensionless unit).

The rocks that allow the water to permeate through its pores are called the *Permeable* or *Previous rocks*. And those that do not allow water to permeate through its pores with the *impermeable* or *impervious rocks*.

Therefore, it is noted that every water-permeable rock is a porous, and porous rock is not necessarily a water-permeable.



The figure below shows a laboratory approach to the type of sediments and their ability to pass water or retention.



[Hazen method] Hydraulic Conductivity can be determined and expressed as follows:

The coefficient of permeability (K) depends on the properties of both *porous medium* and *fluid*. It can be expressed as,

$$K = \frac{[Cd_m^2]\rho g}{\mu}$$

where,

C is the shape factor that depends upon the shape, particle size, and packing of the porous media. d_m is the mean particle size (L, m). ρ is the mass density (M/L³, kg/m³). g is the acceleration due to gravity (L/T², m/s²). μ is the viscosity (M/T. L, kg/s.m).

Another coefficient of permeability, called **intrinsic permeability** (\mathbf{k}) , is sometimes used. The intrinsic permeability depends upon the porous medium and is independent of the properties of the fluid. It is usually expressed as,

$$k = Cd_m^2$$

The intrinsic permeability k has the dimensions of $[L^2]$ and is usually expressed in cm² or Darcy, where 1 Darcy = $0.987 * 10^{-8} \text{ cm}^2$.

The intrinsic permeability is rarely used in groundwater hydrology, but this term is very popular in the petroleum, natural gas industries, and in density-dependent flow problems such as saline water intrusion. The intrinsic permeability is also called the absolute permeability.

Typical values of hydraulic conductivity for unconsolidated and hard rocks are given in Table -- which are taken from Marsily [1986].

Medium	K (m/day)
Unconsolidated deposits	214-10.
Clay	$10^{-8} - 10^{-2}$
Fine sand	1 - 5
Medium sand	5 - 20
Coarse sand	$20 - 10^2$
Gravel	$10^2 - 10^3$
Sand and gravel mixes	$5 - 10^2$
Clay, sand, gravel mixes (e.g. till)	$10^{-3} - 10^{-1}$
Hard Rocks	
Chalk (very variable according to fissures if not soft)	30.0
Sandstone	3.1
Limestone	0.94
Dolomite	0.001
Granite, weathered	1.4
Schist	0.2
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Table --: Hydraulic Conductivity for Unconsolidated and Hard Rocks

References:

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