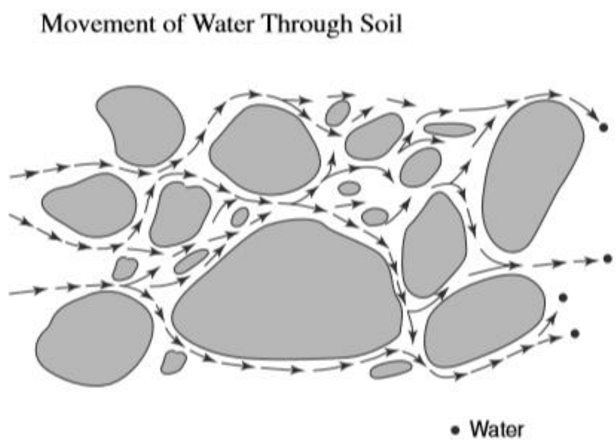
PERMEABILITY

Soil, being a particulate material, has many pore or void spaces existing between the solid grains because of the irregular shape of the individual particles. In a mass of particles that are rounded and roughly equidimensional in shape, such as the gravels, sands, and silts, or are platey or flake like, such as clays, the pore spaces are interconnected. Fluids (and gases) can travel or flow through the pore spaces in the soil. Thus, soil deposits are porous, and the material is considered a permeablematerial. It should be realized that flow is occurring through the void spaces between particles and not actually through the particles themselves. See the figure below.



Schematic diagram indicating manner in which water flows through soil.

The factors that can affect the flow of a fluid through soil are known, but the influence of all factors has not been clearly established. These factors include:

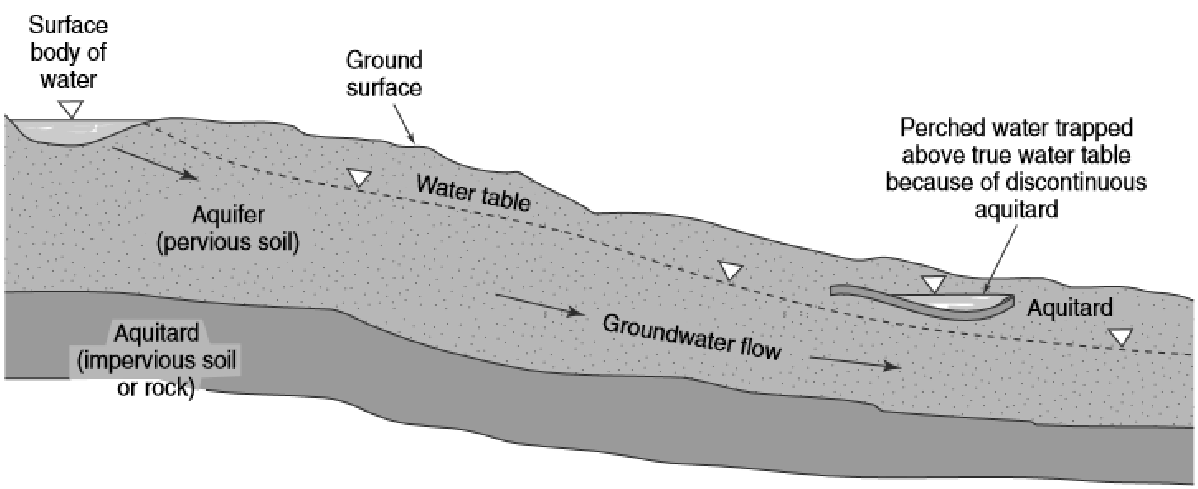
1. The pressure difference existing between the two points where flow is occurring.

2. The density and viscosity of the fluid.

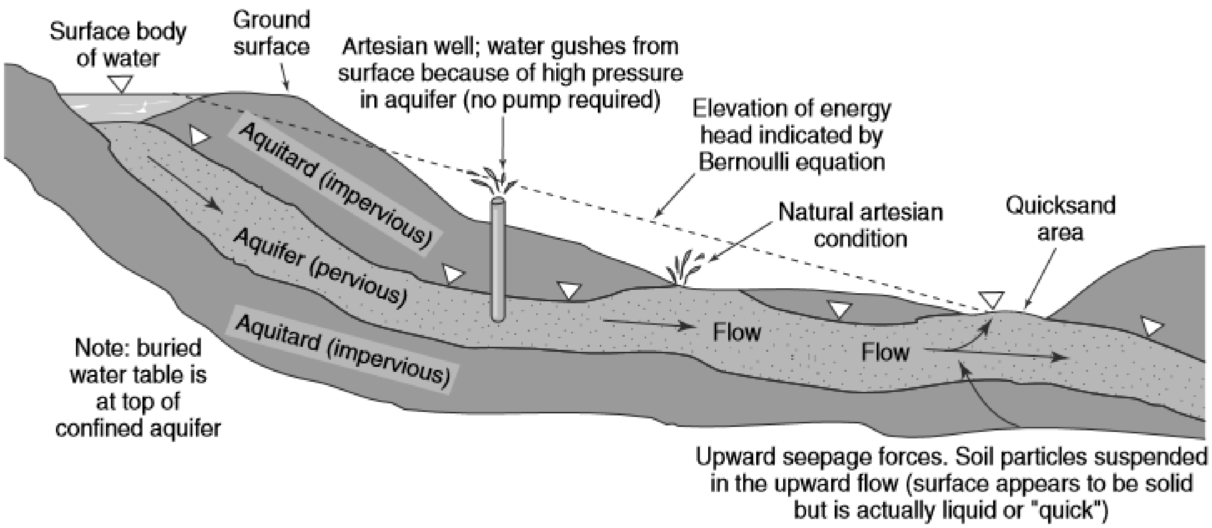
3. The size, shape, and number of pore openings.

4. The mineralogical, electrochemical, or other pertinent properties of the fluid and the soil particles, which affect the attraction between the two materials.

<u>Illustrations of groundwater flow in different types of aquifers:</u>

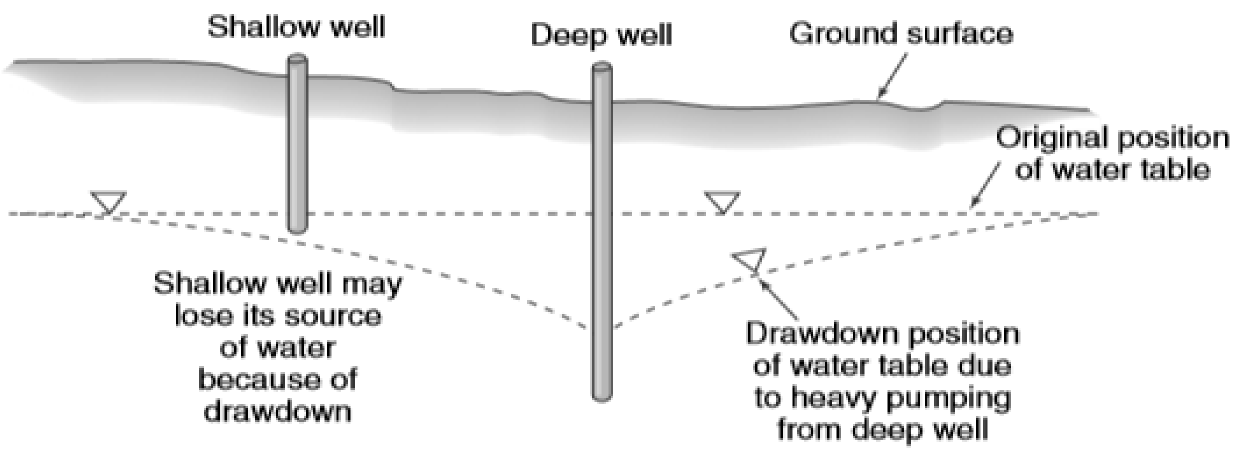


Groundwater flow in unconfined aquifer

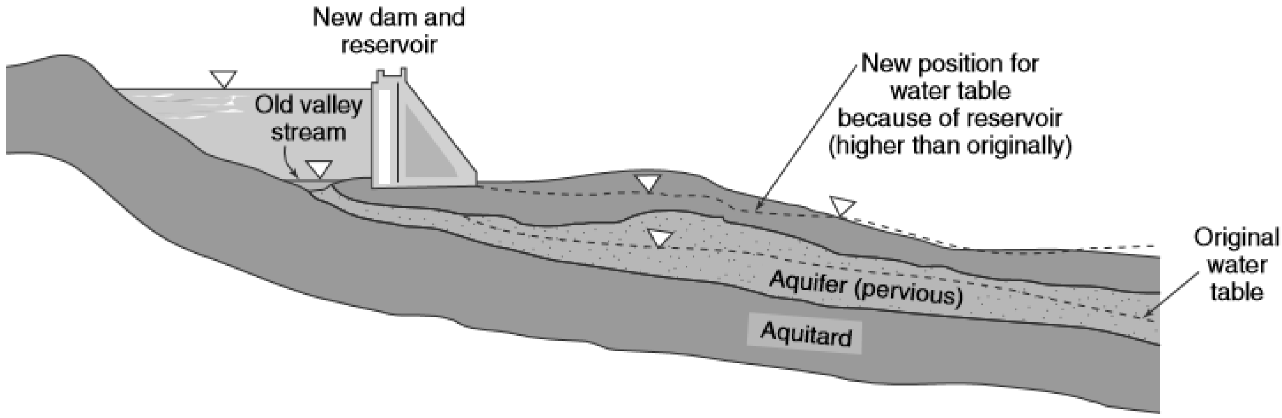


Artesian condition for groundwater flow

<u>Conditions responsible for changed elevation of groundwater table:</u>



Permanent lowering of water table because of heavy well pumping



Conditions responsible for changed elevation of groundwater table.

In many engineering and construction problems, the concern is primarily with the quantityof fluid, usually but not always water, that is flowing through or out of a soil mass. The seepage velocity is frequently sufficiently low that no problems result because of this factor, and it may not even require consideration. An exception is where the velocity is great enough to cause movement of the soil particles, or erosion; this problem is discussed on flow nets. (But for geo-environmental problems where concerns relate to movement of a contaminant fluid including escape from containment, even low velocity and small volumes might be hazardous.)

For the situation where the quantity of flow is to be determined, an average discharge velocity is assumed. This is a fictitious velocity compared to the actual velocity of flow. This discharge velocity is simply the volume of fluid flow per unit of time divided by the total area (soil plus voids) measured normal to the direction of flow. If an average seepage velocity (average actual velocity of flow) is desired, it can be obtained by dividing the average discharge velocity by n, the porosity of the soil.

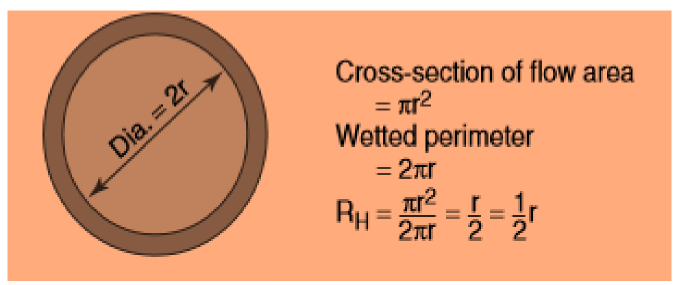
Experimental studies have shown that fluid flow is affected by the shape and dimensions of the channel through which flow is occurring and properties of the fluid such as the viscosity. To relate these effects to flow velocity, the terms hydraulic radius and shape factor have been developed. Hydraulic radius, provides a relation between the cross-sectional area of flow and the channel walls that are in contact with the fluid:

$$R_H = \frac{\text{Area of flow}}{\text{Wetted perimeter}}$$

The coefficient that reflects the shape factor (i.e., the influence of the channel crosssection) is CS. For example, with a circular tube flowing full, the hydraulic radius is one-half the tube radius, and . To indicate how permeable a porous material will be to any flowing fluid (liquid or gas), the term K, absolute or intrinsic permeability, is used. Mathematically:

$$K = C_S R_H^2 n$$

Hydraulic radius for pipe flowing full:



where:

n = porosity of the material.

This term applies only to the material through which the flow could occur. It reflects the effect of the size, shape, and number of flow channels, and is completely independent of any fluid properties. In the dimensional (units) analysis, the shape factor and porosity are dimensionless terms, and therefore K has a unit of L2, or area. The theoretical basis for determining absolute permeability K of a porous material, the Kozeny-Carman equation, and the concepts for flow through soil deposits based on Darcy's law for flow, are presented in the following sections of the chapter. For porous materials such as soil deposits, where the void space channels through which fluids (and gases) flow vary significantly in size and are of irregular cross section, the value for K would typically be determined experimentally. The value of K for soils is expressed in Darcys (one Darcy equals or). This term is little used in practical problems for relating the flow of water in soil deposits but does have application when other fluids are studied or comparisons are made. To indicate the ease or difficulty with which a particular fluid will flow through a permeable material2, the properties of the fluid are incorporated with K, the properties of the permeable material, to provide a coefficient of permeability, k (the lowercase letter is commonly used for this term) or k_{hyd},

where:

$$k = k_{\text{hyd}} = K\frac{\gamma}{\eta_{\text{ad}}} = K\frac{\gamma}{\rho\eta_k}$$

Where:

ρ = density of the fluid

η_k = kinematic viscosity

η_{ad} = absolute or dynamic viscosity of the fluid

γ = unit weight of the fluid (e.g., in kN/m^3, pcf)

NOTE:

The letter "k" historically has been used as the symbol to represent coefficient of permeability (hydraulic conductivity) and continually appears in engineering literature and references for that property. Somewhat unfortunately, k is also used to represent other terms or properties associated with soil deposits. To help prevent misinterpretation of symbols or the application of equations, the modification khyd is used in this text to indicate soil coefficient of permeability and hydraulic conductivity (the "hyd" subscript adapted as an abbreviation for and reference to hydraulic).

Units for absolute or dynamic viscosity are FT/L^2; units for kinematic viscosity are L^2/T. In the SI system, absolute-dynamic viscosity is expressed in Pascal-sec; in traditional metric units, the absolute-dynamic viscosity is expressed in poises or centipoise (cp) (where 1 sec or 0.1 Pa sec; and in U.S. Customary units, the absolute-dynamic viscosity is expressed in lb sec/ft^2. For kinematic viscosity, the SI units are cm2/sec, and the U.S. Customary units are ft^2/sec. For water at 20°C (68°F), absolute viscosity is 1cp, or 0.001 Pa sec, or lb sec/ft^2; the kinematic viscosity is 0.0112 cm^2/sec, or ft^2/sec.

(The SI unit of cm2/sec for kinematic viscosity is also called a Stoke; that is, 1 .)

When the values of unit weight, viscosity, and density for a fluid are not known, the information can often be found listed in reference manuals that tabulate physical properties; it is important to recognize that values for unit weight and viscosity usually vary with temperature. Historically, the phrase coefficient of permeability has been an engineering term. For this same property, geologists, environmentalists, hydrologists, and groundwater specialists use the term hydraulic conductivity. This latter term is descriptive of a physical property associated with the transmission of matter or energy, in the family of terms such as electrical conductivity and thermal conductivity. Geotechnical personnel have become familiar with this dual usage of terms; both are commonly found (used) in engineering literature. To avoid confusion between the terms permeability and coefficient of permeability, the hydraulic conductivity phrase will eventually be adopted by everyone.

Darcy's Law for Flow

In the mid-eighteenth century, H. Darcy performed experiments to study the flow of water through sands. With an arrangement represented by Figure 8, it was found that the quantity of water flowing through the soil in a given period was proportional to the soil area normal to the direction of flow and the difference in water levels indicated in the piezometers (open standpipes), and inversely proportional to the length of soil between piezometers through which flow took place.

Mathematically:

$$\frac{Q}{t} \propto \frac{(\Delta h)A}{L} = (\text{a constant})\frac{(\Delta h)A}{L}$$