Isotropic & homogeneous
Anisotropic & heterogeneity
Energy and Hydraulic Head

(G306-Second semester 2021-2022)

Lecture -2

Dr.Inass Abdal Razaq Al-Mallah

Porosity and Permeability

Porosity is the amount of pore space in a rock (the spaces between the grains).
Porosity is *independent of grain size.*

Porosity depends on:

•Sorting of the grains (or uniformity of grain size)
Are the grains all the same size (well sorted),
or are a variety of grain sizes present, with finer grains filling the spaces between the larger grains (poorly sorted)

•Shape of the grains

•Packing and arrangement of grains.

n= Vv / Vt

n porosity, Vv volume of voids, Vt total volume of soil or rock

Porosity is important in ground water hydrology because it tell us the maximum amount of water that a rock contain when it saturated , however , it is equally important to know that only a part of this water is available to supply a well or spring.

Interstices

Those portions of a rock or soil can be occupied by ground water. These spaces are known as water voids, interstices, pores, or pore space. They are characterized by their (size, irregularity, distribution, and their shape).

Type of interstices:

1- Primary openings\ were the voids formed at the same time as the rocks like sand, gravel, lava tubes, and other openings in basalt.

2- Secondary openings\ were the voids formed after the rock was formed like: fractures in granite, and consolidated sedimentary rocks.

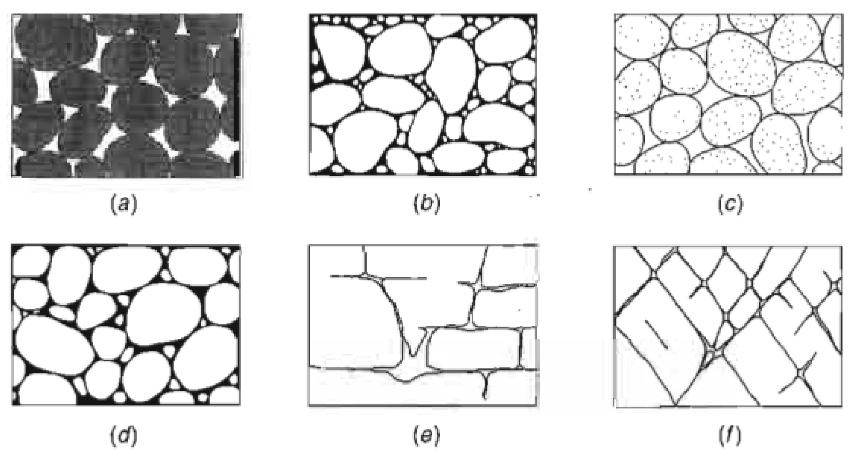


Figure 2.2.1. Examples of rock interstices and the relation of rock texture to porosity. (*a*) Well-sorted sedimentary deposit having high porosity. (*b*) Poorly sorted sedimentary deposit having low porosity. (*c*) Well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity. (*d*) Well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices. (*e*) Rock rendered porous by solution. (*f*) Rock rendered porous by fracturing.[42]

Permeability is the ease with which fluids flow through a rock or sediment.

Permeability depends on:

- Grain size
  Coarser-grained sediments are more permeable than fine-grained sediments because the pores between the grains are larger.
- Sorting
- Grain shape
- Packing (controls pore size)

Isotropic & homogeneous : this means that the hydraulic conductivity(Permeability) is the same throughout the geologic formation and the same in all direction.

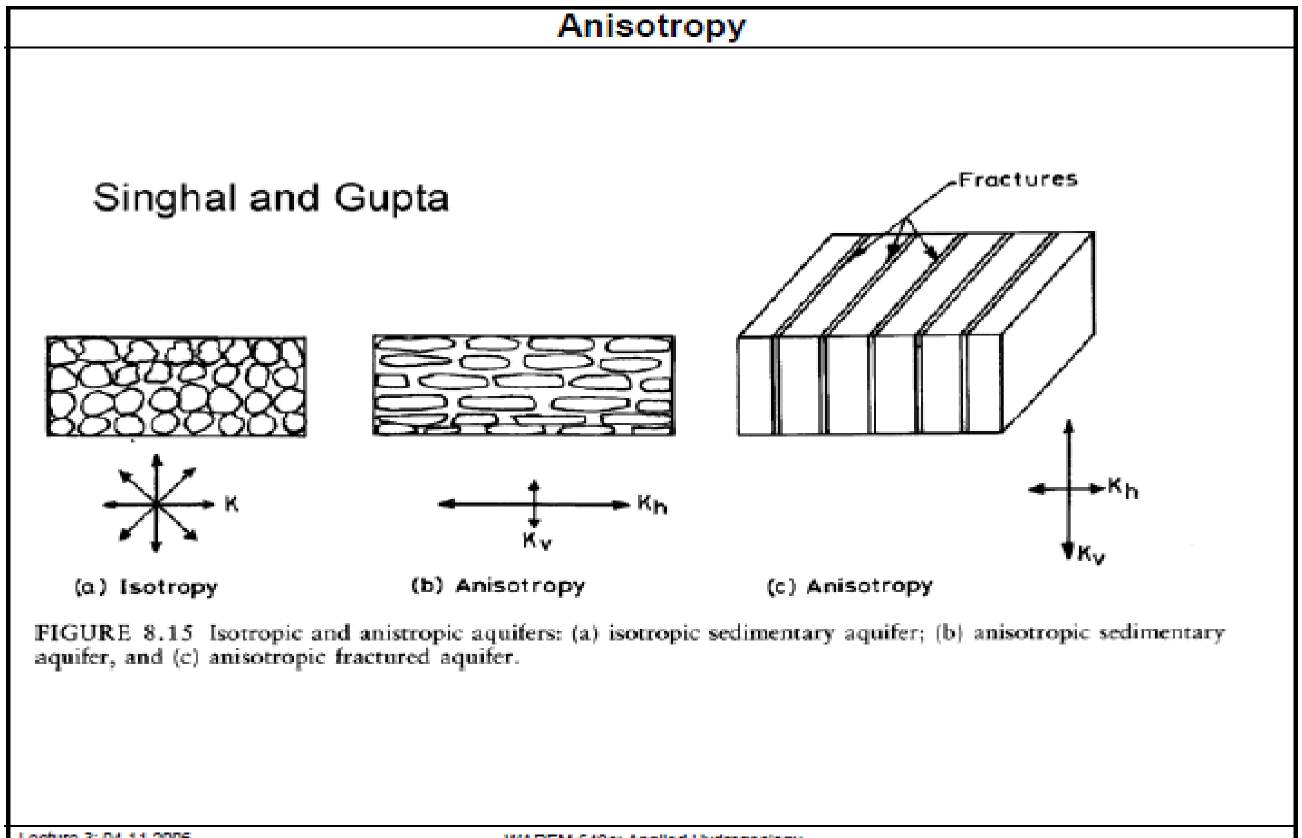
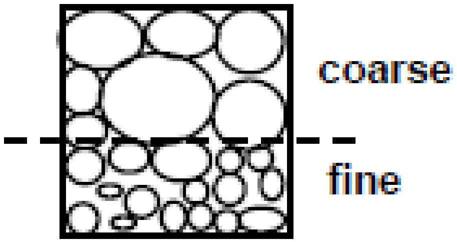


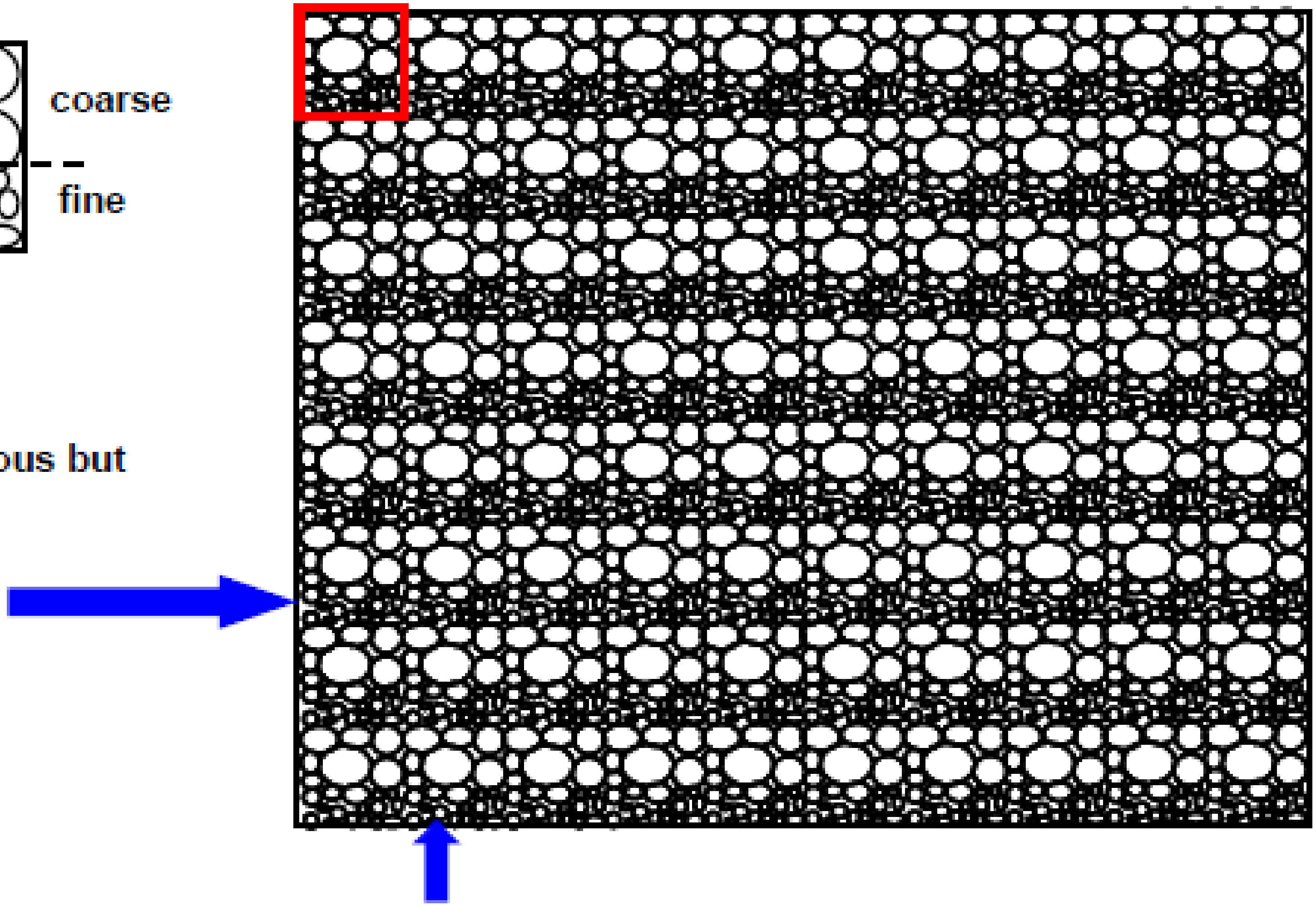
FIGURE 8.15 Isotropic and anistropic aquifers: (a) isotropic sedimentary aquifer; (b) anisotropic sedimentary aquifer, and (c) anisotropic fractured aquifer.

Anisotropy and Heterogeneity: Scale-Dependence

The question whether an aquifer or a porous medium in general can be regarded as **homogeneous** is often a question of scale.



Homogeneous but anisotropic



Important difinitions

Hydraulic conductivity (k): is the volume of water that 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. Measured in m/day (length/time)

Hydraulic conductivity is less in unconsolidated rocks(like clay 10^{-1}-10^{-8})

Hydraulic conductivity in fractured rocks depending on density of fractured and width of their apertures.

Transmisivity (T): is the rate of flow under a unit of hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer.

T=kb

Where b the saturated thickness of the aquifer

T measured in m^2/day or m^2/sec

Specific storage (Ss): the specific storage of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head.

Storativity (S): the storativity of a saturated confined aquifer of thickness D is the volume of water released from storage per unit surface area of the aquifer per unit decline in the component of hydraulic head normal to that surface.

S=Ss.D

Groundwater Flow

* Groundwater head/ The groundwater head for an elemental volume in an aquifer is the height to which water will rise in a piezometer (or observation well) relative to a consistent datum. Figure 2.1a shows that the groundwater head

$$h = \frac{p}{\rho g} + z \qquad (2.1)$$

where p is the pressure head, rise the density of the fluid and z is the height above a datum. All pressures are relative to atmospheric pressure.
In Figure 2.1a a piezometer pipe enters the side of an elemental volume of aquifer. However, an observation well usually consists of a vertical drilled hole with a solid casing in the upper portion of the hole and an open hole or a screened section with slotted casing at the bottom of the solid casing. So that the groundwater head can be identified at a specific location in an aquifer, the open section of the piezometer should extend for no more than one metre.

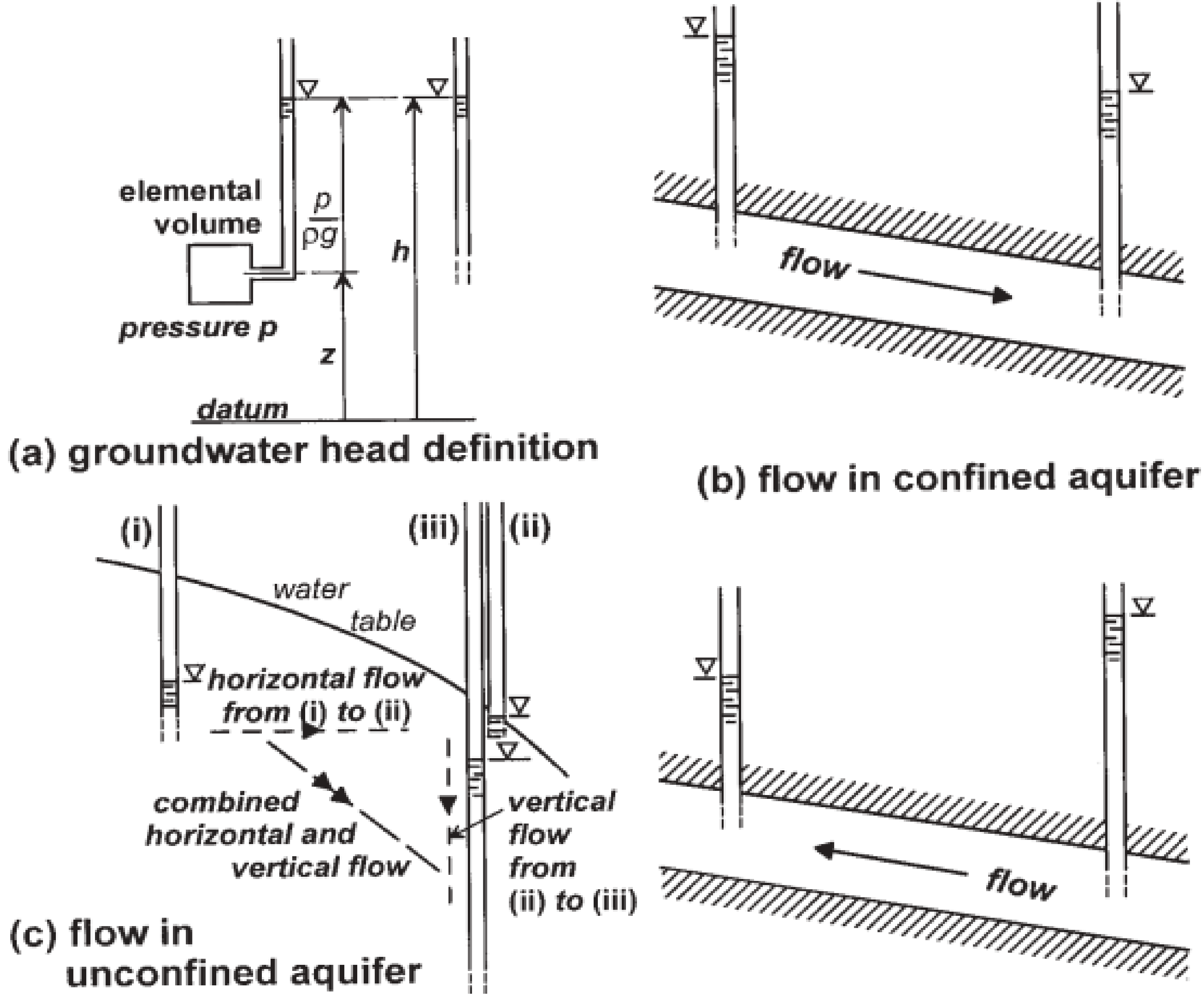


Figure 2.1 Groundwater head definition and determination of flow directions from groundwater head gradients

Direction of flow of groundwater

Groundwater flows from a higher to a lower head (or potential). Typical examples of the use of the ground-water head to identify the direction of groundwater flow are shown in Figure 2.1b.

In this confined aquifer there are two piezometers which can be used to identify the direction of flow. In the upper diagram the flow is from left to right because the lower groundwater head is in the piezometer to the right; this is in the direction of the dip of the strata. For the lower diagram, the groundwater flow is to the left since the

water level in the left hand piezometer is lower. Consequently the direction of the flow is up-dip in the aquifer. This flow could be caused by the presence of a pumped well or a spring to the left of the section.

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Energy and Hydraulic Head

Water flows from one place to another in response to uneven distributions of mechanical energy within the water. Water always flows from regions with higher mechanical energy towards regions with lower mechanical energy. The mechanical energy in water can take on three forms:

1. elastic potential energy,
2. gravitational potential energy, and
3. kinetic energy.

Elastic potential energy is gained by compressing water, gravitational potential energy is achieved by lifting water to higher elevation, and kinetic energy stems from the velocity of water.

These forms of mechanical energy were first quantified by Daniel Bernoulli in 1738. The Bernoulli Equation, a fundamental equation of fluid mechanics, can be written as

$$E = PV + mgz + \frac{1}{2}mv^2$$

This equation describes the mechanical energy E of water with mass m, pressure P, elevation z, volume V, and velocity v

For analysis of water flow, a more convenient parameter is energy per weight of water. Taking Eq. 2.11 and dividing each term by the weight of water m g gives a new quantity called the hydraulic head h

$$h = \frac{E}{mg} = \frac{P}{\rho_w g} + z + \frac{v^2}{2g}$$

hydraulic head has the simple unit of length. The three terms on the right side of Equation above are called the pressure head, elevation head, and velocity head, respectively. The hydraulic head h is also called head.

Water always flows towards regions of lower hydraulic head

Groundwater flows with very low velocity, usually less than a few meters per day, so that in most cases the velocity head contributes an insignificant amount to the hydraulic head. The velocity head is generally negligible, so Equation above may be reduced to the following for groundwater flow, it is important that all measurements of z are made relative to one elevation datum, a horizontal surface from which elevations are measured.

$$h = \frac{P}{\rho_w g} + z$$

Piezometric Head

- **Confined aquifer**

$$h = \frac{p}{\gamma} + z$$

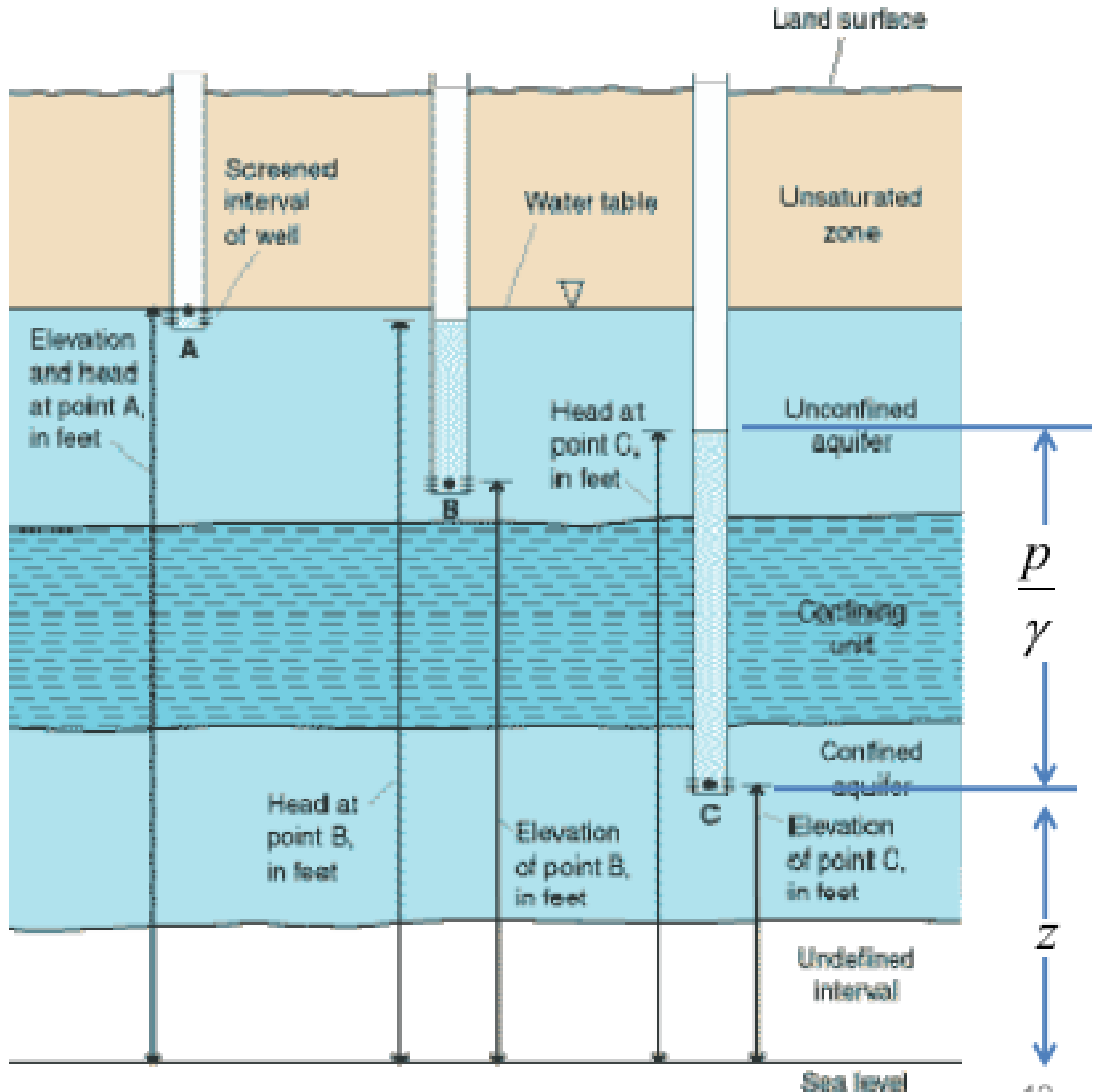
- **Unconfined aquifer**

$$h = \frac{p}{\gamma} + z$$

$$p = 0$$

Pressure head = 0

$$h = z$$



Aquifer Storage

- Storativity (*S*) - ability of an aquifer to store water
- Change in volume of stored water due to change in piezometric head.
- Volume of water released (taken up) from aquifer per unit decline (rise) in piezometric head.