GROUNDWATER ENGINEERING
CV0612

AQUIFER PROPERTIES

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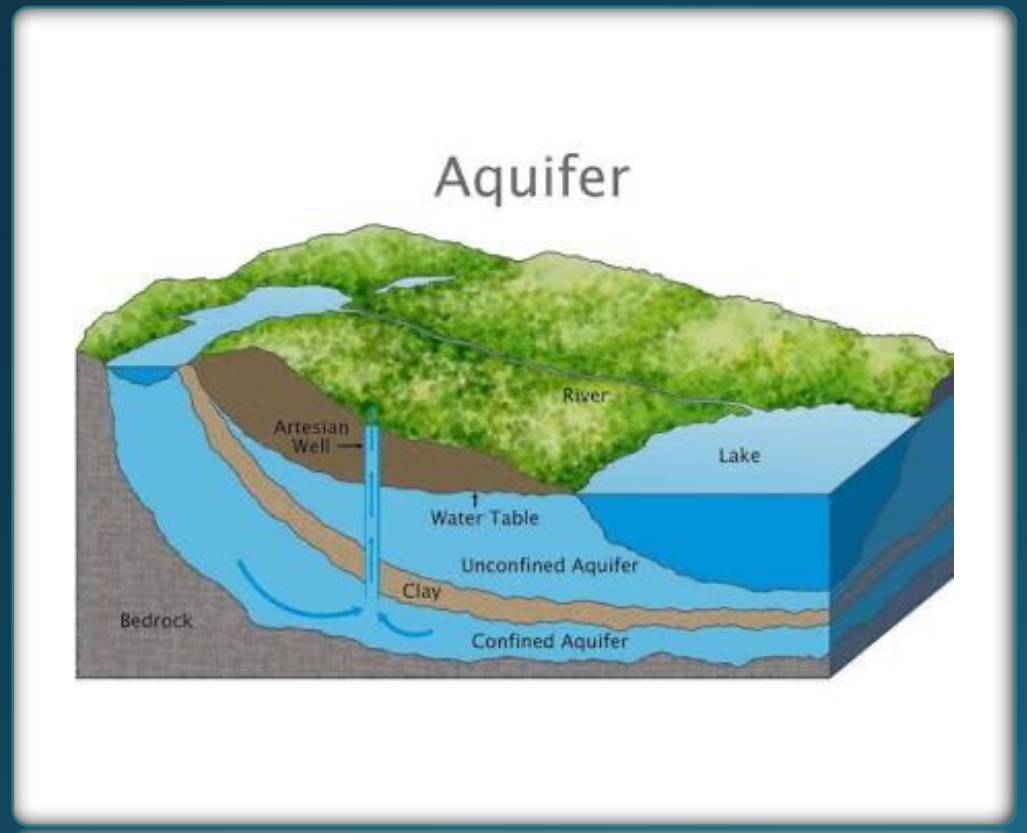
TOPICS

- Aquifer properties
- Movement of groundwater
- Darcy’s Law
- Factors affecting permeability

AQUIFER

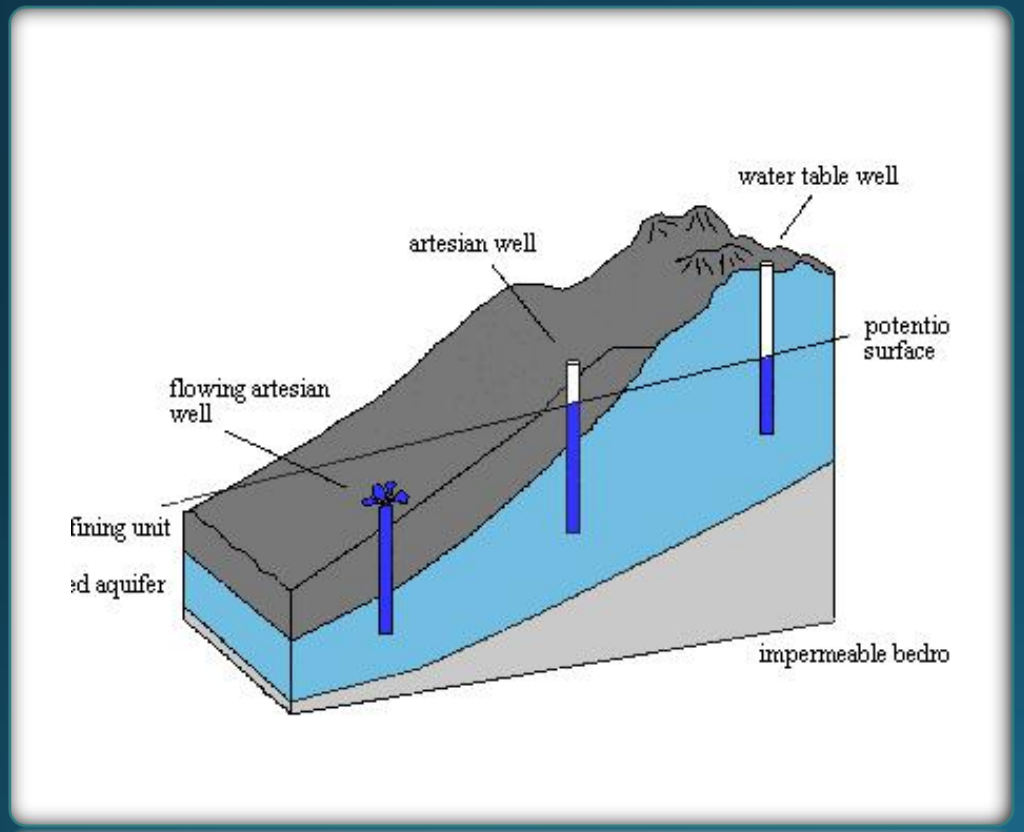


- An aquifer is a permeable geological formation that stores and transmits water.
- An aquifer is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt). Groundwater can be extracted using a water well.

TYPES OF AQUIFERS

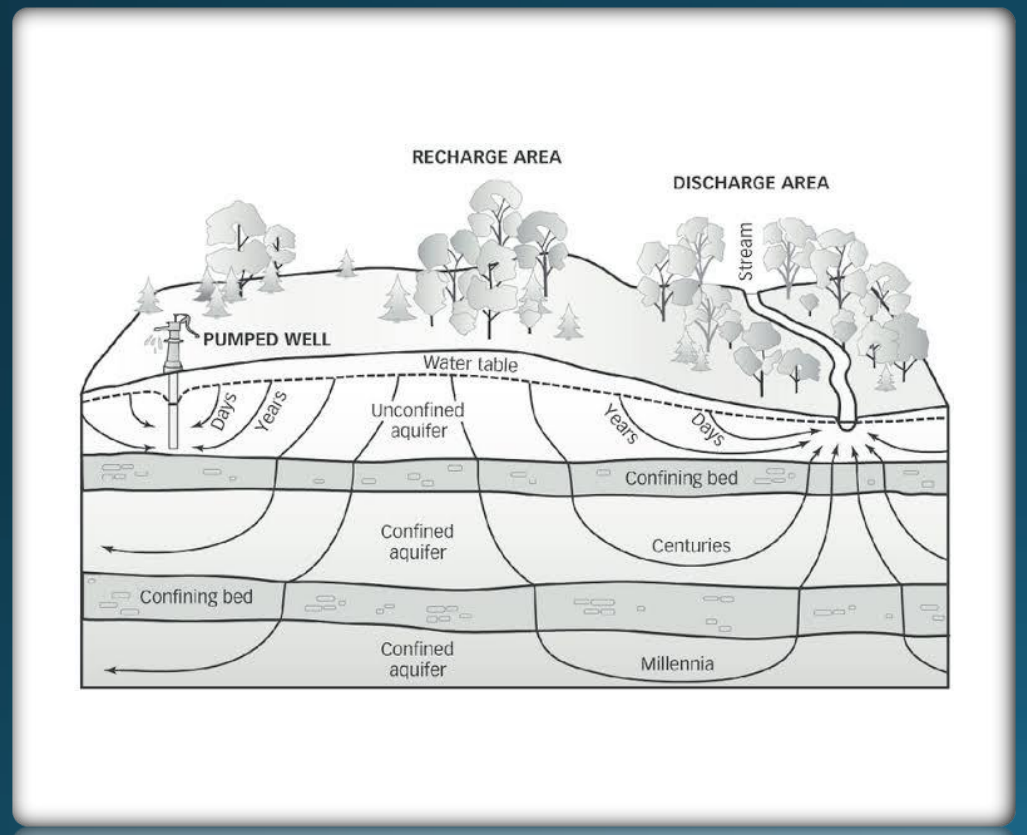
- Confined aquifer
- Unconfined aquifer
- Semi-confined
- Semi-unconfined

CONFINED AQUIFERS



- Confined aquifer is a completely saturated aquifer which is underlain and overlain by impervious layers. The pressure of water is higher than that of the atmosphere.
- It is also known as Artesian Aquifers.
- Confined aquifers exhibit only minor changes in storage and acts as conduits from zones of recharge to those of discharge.

UNCOFINED AQUIFERS



- Unconfined aquifers are those into which water seeps from the ground surface directly above the aquifer.
- It is also known as WATER TABLE AQUIFER.
- Water table undulates in form of depending upon the recharge and discharge , pumpage of wells and permeability and is directly accessible to atmosphere.

SEMI-CONFINED

- An aquifer partially confined by soil layers of low permeability through which recharge and discharge can still occur but at a slow rate is called Semi-aquifer.
- This type of aquifer is also known as Leaky Aquifer.
- By pumping from the aquifer will create a vertical flow of water from semi pervious layer and the horizontal component is neglected as it is very low.

SEMI–UNCONFINED AQUIFER

- A Semi–unconfined aquifer is an aquifer that is partially confined by layers of lower permeability material through which recharge and discharge may occur at low rate.

AQUIFER PROPERTIES

POROSITY

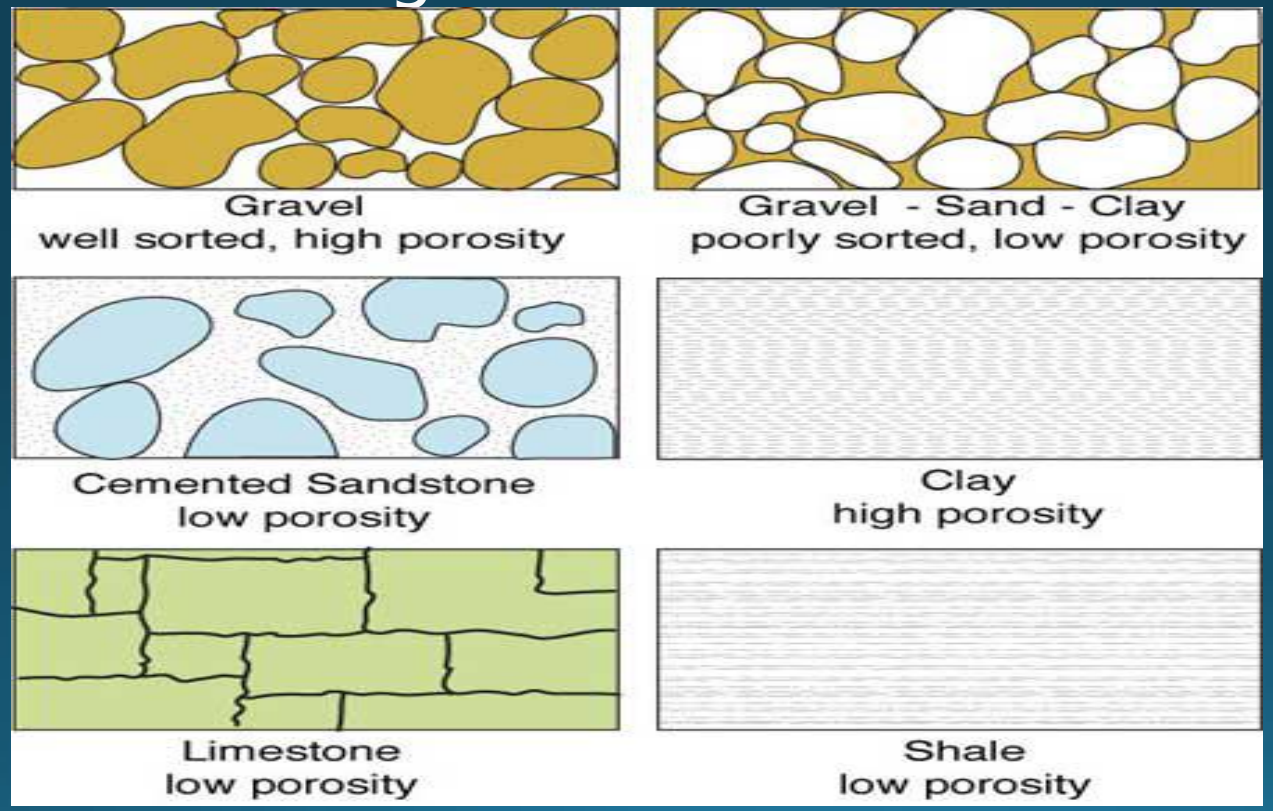
- Porosity(n) is the percentage void spaces present in the rock or soil.
- The larger the pore space , the higher the porosity and larger the water holding capacity of the material.
- FORMULA: $n=(Vv/V)*100\%$

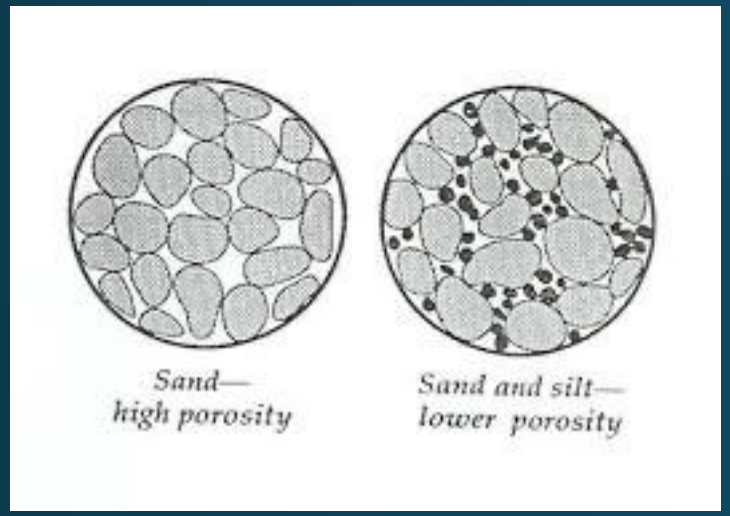
n= porosity(percentage)

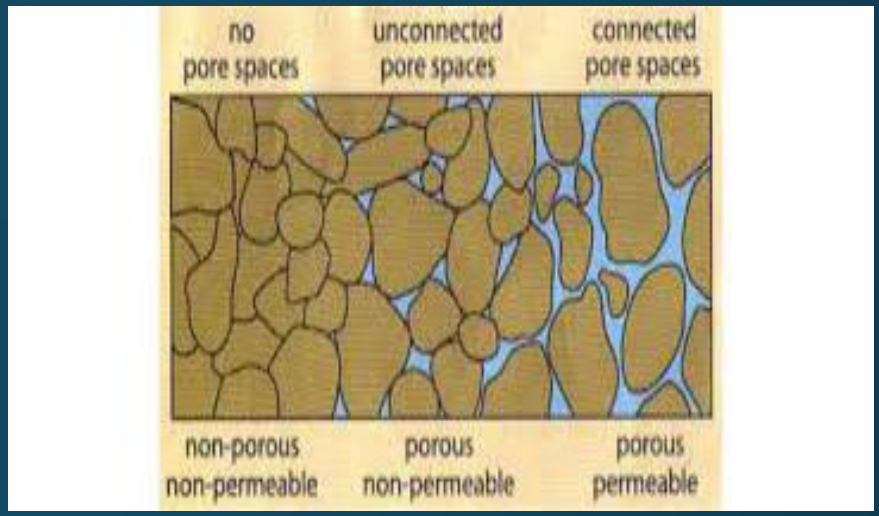
Vv= Volume of void space in a unit volume of material

V= Unit volume of material (both voids and solids)

- In sediments and sedimentary rocks the porosity depends upon various other factors like grain size, shape of grain etc.
- Well–rounded coarse–grained sediments have greater porosity than the fine–grained sediments because the grains don’t fit well together.





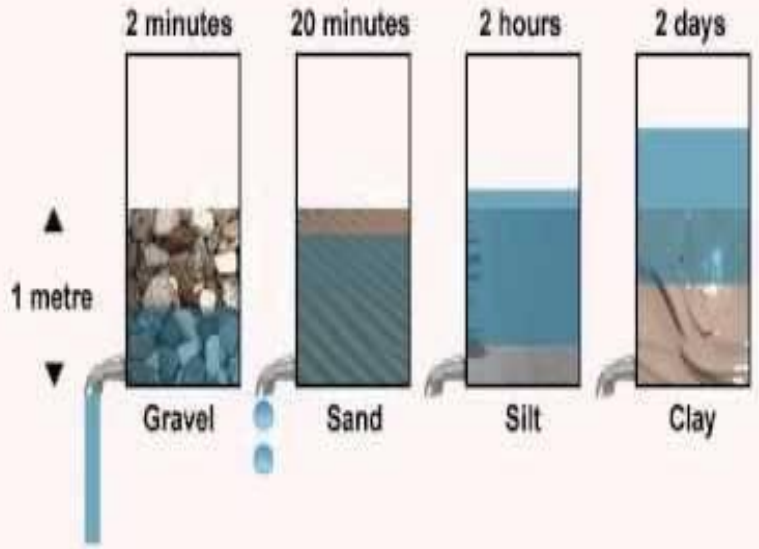


Unconsolidated deposits	Porosity	Rocks	Porosity
Gravel	0.25–0.40	Fractured basalt	0.05–0.50
Sand	0.25–0.50	Karst limestone	0.05–0.50
Silt	0.35–0.50	Sandstone	0.05–0.30
Clay	0.40–0.70	Limestone, dolomite	0.00–0.20
		Shale	0.00–0.10
		Fractured crystalline rock	0.00–0.10
		Dense crystalline rock	0.00–0.05

PERMEABILITY

- The ability of ground water to pass through the pore space in the rock is described as permeability.
- Permeability is mostly affected by the size and arrangement of grain in the soil.
- A soil is highly pervious when water can flow through it easily E.g. gravels.
- In an impervious soil the permeability is very low so the water cannot pass through it easily E.g. clay.

Permeability



Range of Permeability for Various Soils

Soil	*Permeability Coefficient, k (cm/sec)*	*Relative Permeability*
Coarse gravel	Exceeds 10^{-1}	High
Sand, clean	10^{-1} to 10^{-3}	Medium
Sand, dirty	10^{-3} to 10^{-5}	Low
Silt	10^{-5} to 10^{-7}	Very low
Clay	Less than 10^{-7}	Impervious

- Gravels are 1 million times more pervious than clays

SPECIFIC YIELD

- Specific yield is defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of water table.
- It is denoted by Sy.
- FORMULA: $Sy=(Vw/V)*100\%$

  where,

Vw= Volume of water in unit volume of materials

V= unit volume of material including both voids and solids.

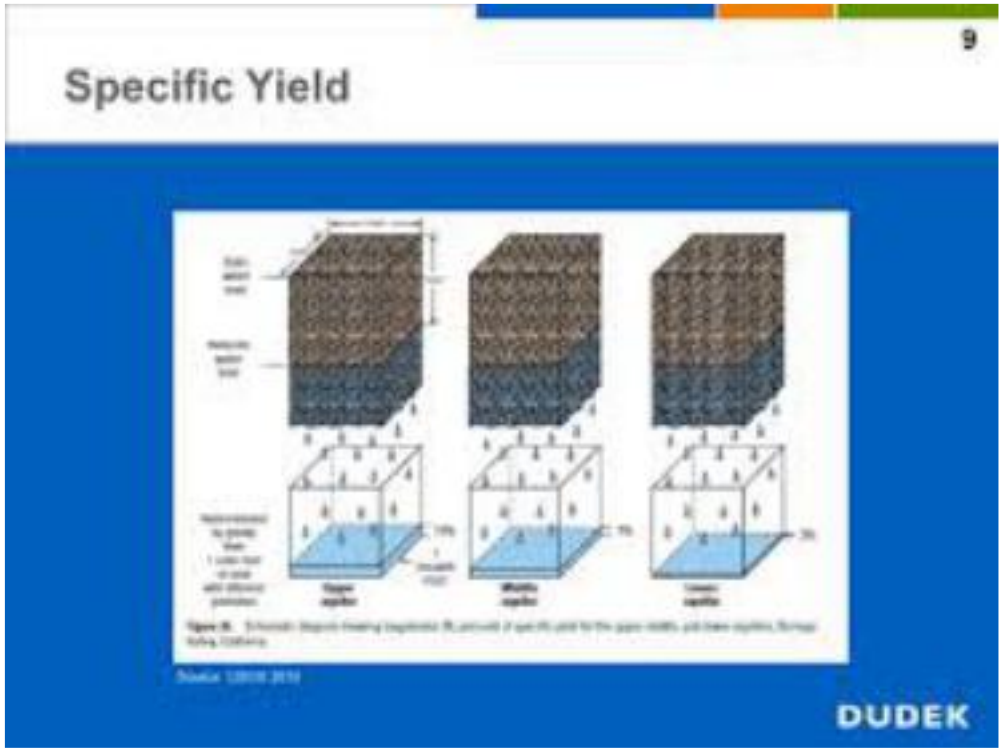


TABLE 5.11

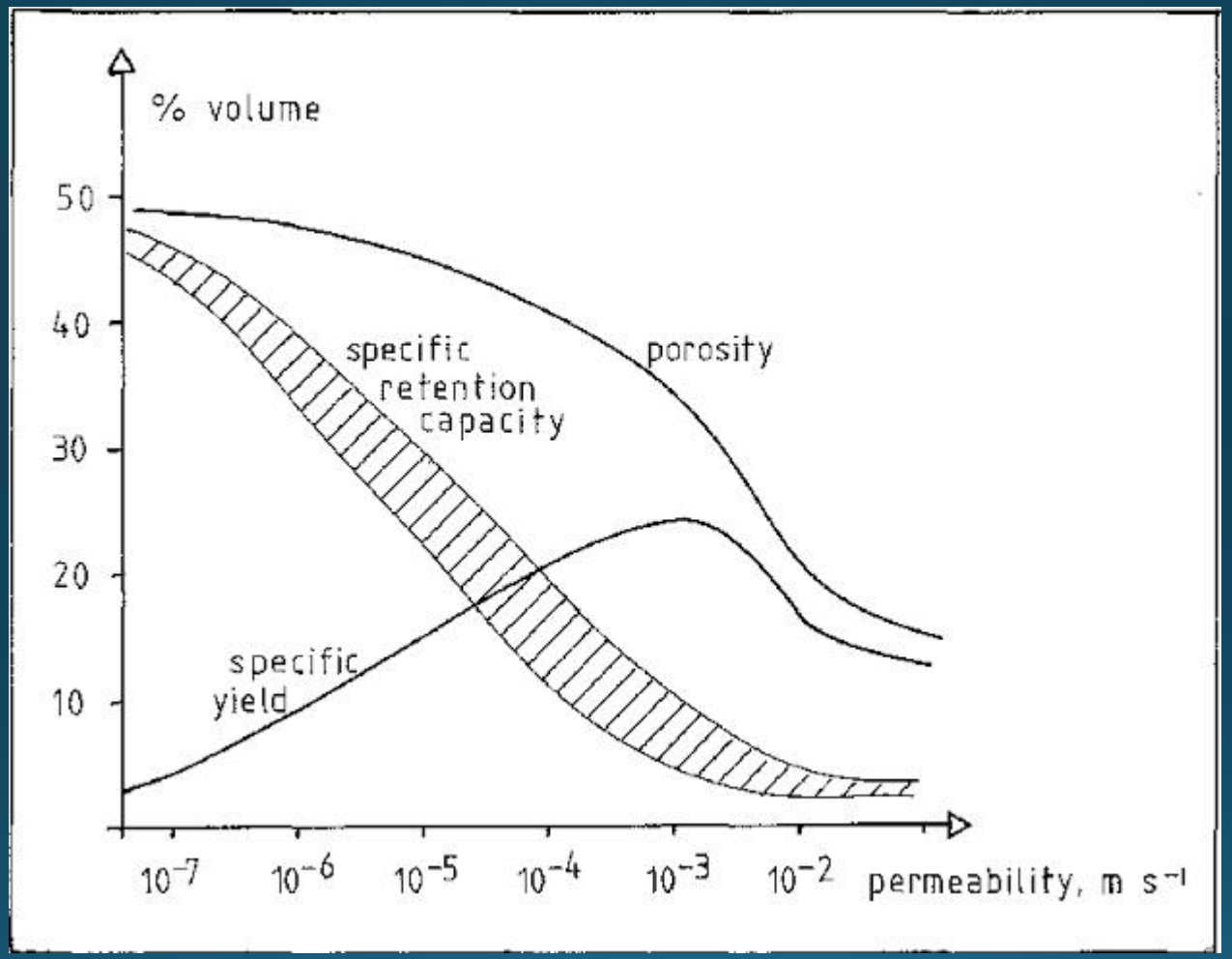
Representative Values of Porosity and Specific Yield

Material	Porosity (%)	Specific Yield (%)
Clay	45	3
Sand	34	25
Gravel	25	22
Gravel and sand	20	16
Sandstone	15	8
Limestone, shale	5	2
Quartzite, granite	1	0.5

Source: Linsley et al., 1992.

SPECIFIC RETENTION

- Specific retention is that volume fraction of water that is held back by adhesion and capillary forces, when an aquifer is drained.
- Since the specific yield represent the volume of the water that a rock will yield by gravity drainage so the specific retention is the remaining product left.
- The specific yield and specific retention depend upon the shape and size of the particles , distribution of the voids and the compaction of formation.
- The specific retention increases with the decrease in grain size.


% volume
50
40
30
20
10
specific
retention
capacity
porosity
specific
yield
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
permeability, m s^{-1}

STORAGE COEFFICIENT

- The volume of water released from storage in a confined aquifer per unit surface area per unit decrease in the hydraulic head.
- The storage coefficient is the product of the specific storage and the aquifers thickness.
- The storage coefficient is also called storativity and is denoted by S.
- It is dimensionless as it is the ratio of the volume of water released from the original unit volume.

- In unconfined aquifers the storage coefficient is the same as the specific yield of the aquifers.
- In the confined aquifers the storage coefficient is the result of the compression of the aquifer and expansion of the confined water when the head pressure is reduced during pumping.

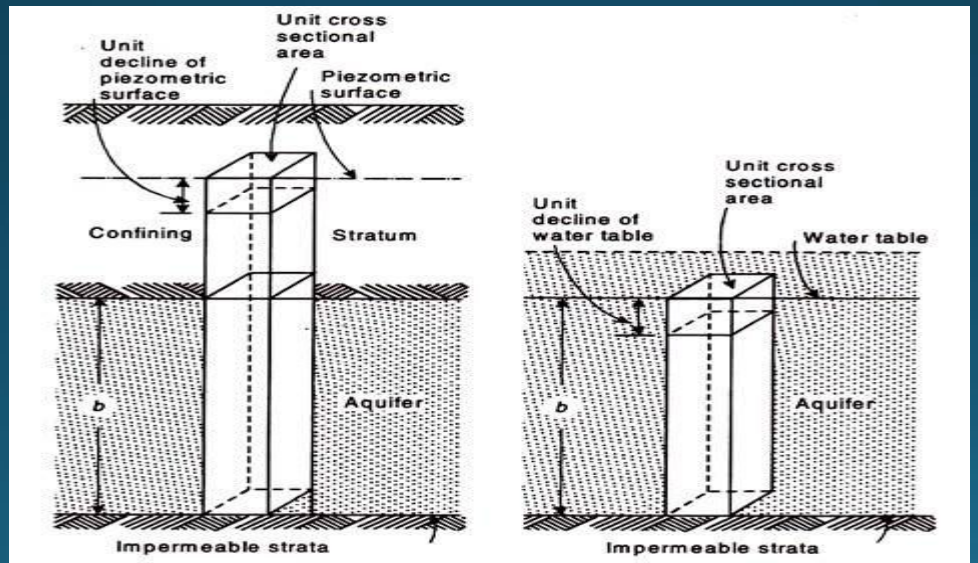


Fig. 4.6 *Storage coefficient of (a) confined aquifer, and (b) unconfined aquifer*

TRANSITIVITY

- It is the discharge rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.
- It is denoted by T.
- FORMULA: $T=Kh$ (unconfined aquifer)

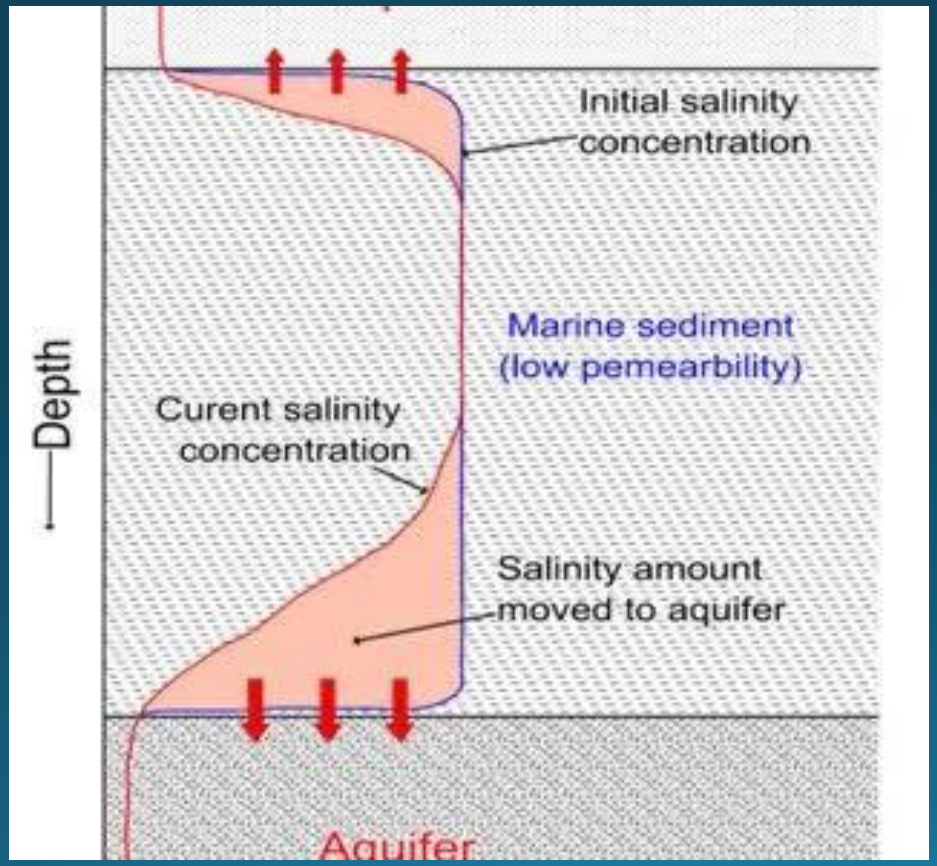
  $T=Kb$ (confined aquifer)

where,

h= saturated thickness of the aquifer.

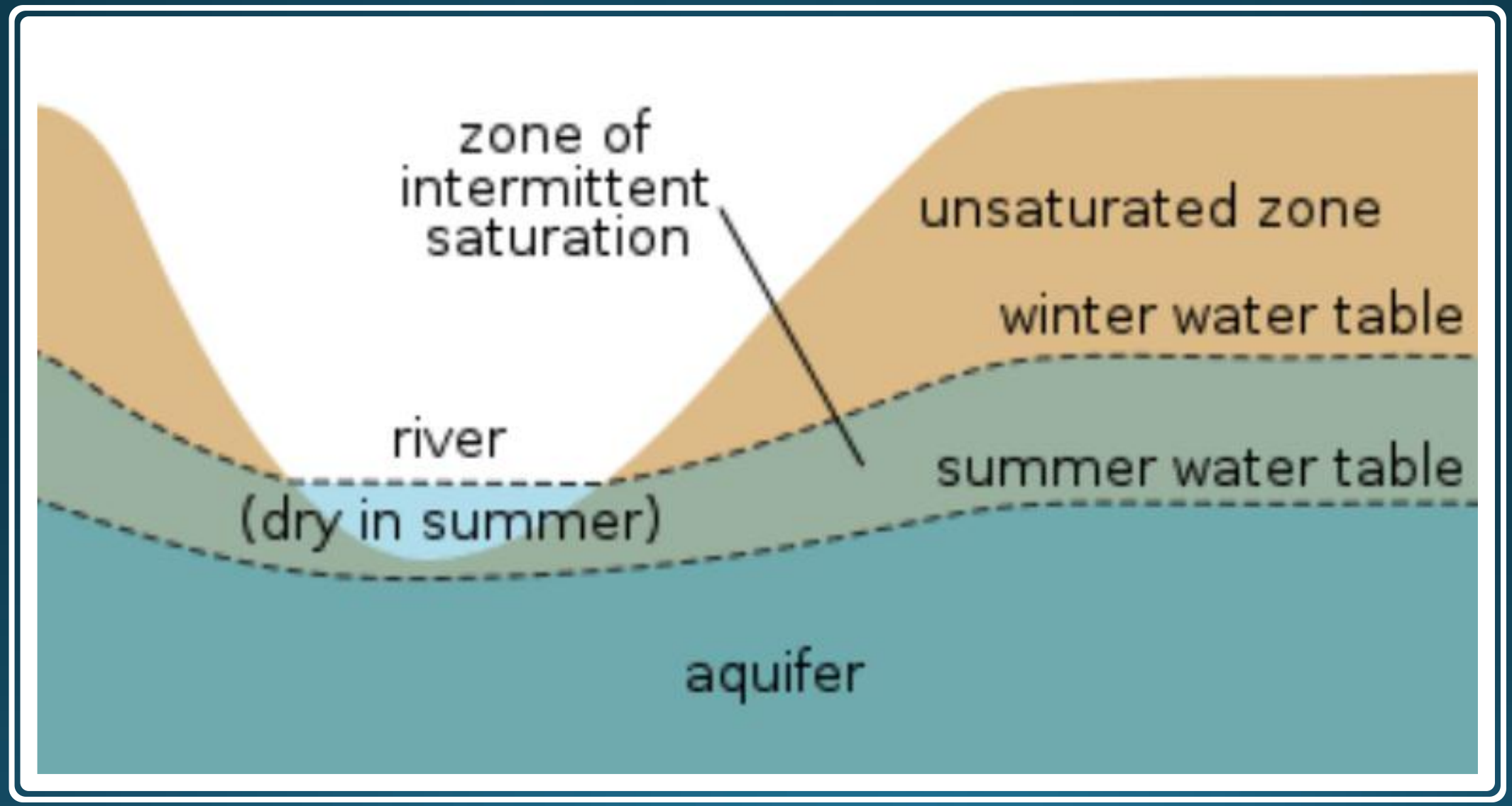
b= depth of the confined aquifer.

- It is equal to the average thickness of the saturated zone of an unconfined aquifer.
- Transmissibility is usually express in m^2/s or $m^3/day/m$.



WATER TABLE

- Water table is the upper level of an underground surface in which soil or rocks are permanently saturated with water.
- Water table is also known as groundwater.
- The water table separates the groundwater zone that lies below it from the capillary fringe or zones of aeration that lies above it.
- The water table fluctuates both with the seasons and from year to year because it is affected by climatic variations and by the amount of the precipitation used by the vegetation.
- It is also affected by excessive withdrawing of water from the wells or by recharging them artificially.

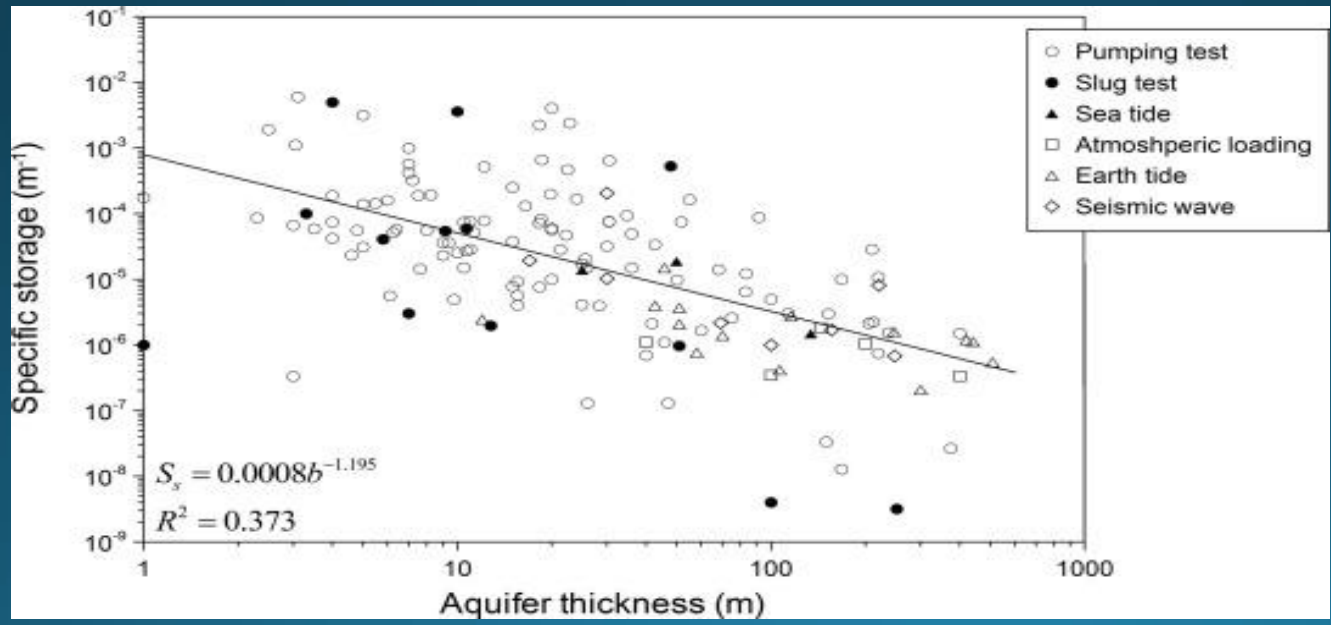

zone of
intermittent
saturation
unsaturated zone
winter water table
river
(dry in summer)
summer water table
aquifer

COEFFICIENT OF PERMEABILITY

- The rate of flow of water under laminar flow conditions through a unit cross-section area of a porous medium under a unit hydraulic gradient and a standard temperature, usually 20 degree Celsius.
- It is denoted as ‘K’ and usually expressed in cm/s or m/s or m/day etc.
- The coefficient of permeability is also called hydraulic conductivity.
- The rate of groundwater flow is mainly controlled by porosity and permeability of the rock.

SPECIFIC STORAGE

- It is the amount of water per unit volume of a saturated formation that is stored or expelled from storage owing to compressibility of the mineral skeleton and the pore water per unit change in head.
- This is also called as elastic storage coefficient.
- This concept can be applied for both aquifers and confining units.



DARCY'S LAW

- " For laminar flow through saturated soil mass, the discharge per unit time is proportional to the hydraulic gradient "

So $q=k.i.A$

$(q/A)=k.i$

Hence,

$v=k.i$ .....Darcy's Law

Where, q= discharge per unit time (rate of flow)

A= total c/s area of soil mass.

i = Hydraulic gradient= h/L

k= Darcy's coefficient of permeability

v= Velocity of flow (discharge velocity)

- This law was given by Henry Philibert Gaspard Darcy who carried out experiments while researching sand filters that lead to Darcy's Law.

ASSUMPTION OF DARCY'S LAW

1. The soil is saturated.
2. The flow through soil is laminar
3. The flow is continuous and steady.
4. The total cross-sectional area of soil mass is consider.
5. The temperature at the time of testing is 27 degree Celsius.

VALIDITY OF DARCY’S LAW

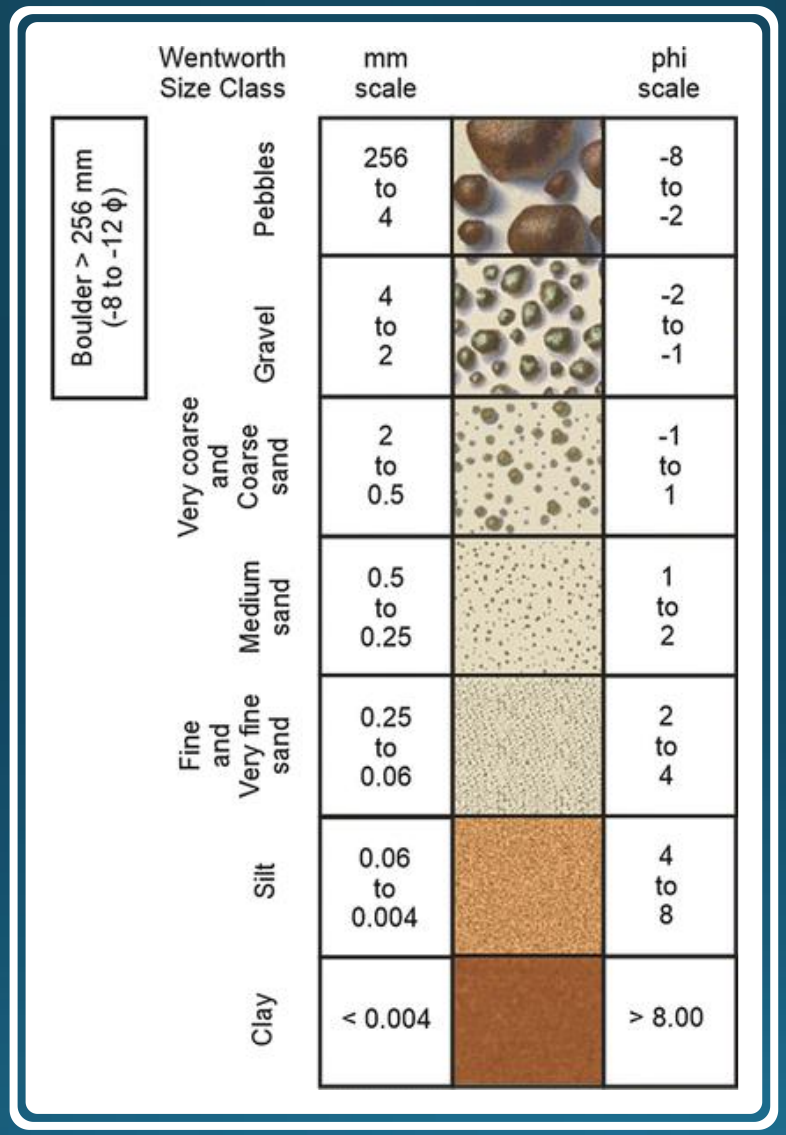
- Darcy’s law is valid if the flow through the soil is laminar.
- It is valid for flow in clays, silts and fine sands. In coarse sand , gravels and boulders, the flow may be turbulent and darcy’s law may not be applicable.
- The relationships between velocity (v) and hydraulic gradient (i) should be linear.
- In extremely fine soil, such as colloidal clay, the interstices are very small. The velocity is therefore very small. In such soil darcy’s law is not valid.

FACTORS AFFECTING PERMEABILITY

- GRAIN SIZE
- PROPERTIES OF PORE WATER PRESSURE
- TEMPERATURE
- VOID RATIO
- SPECIFIC SURFACE AREA OF SOIL PARTICLES
- ORGANIC IMPURITIES
- ADSORBED WATER
- DEGREE OF SATURATION
- SHAPE OF PARTICLES
- STRUCTURE OF SOIL MASS

GRAIN SIZE

- The permeability varies approximately as the square of the grain size.
- It depends on the effective diameter of the grain size.
- The relation between them is K=C $(D10)^2$
- where K is the permeability in cm/s and C is constant and generally lies between 100 to150.
- The permeability increases with the increases in the grain size and decreases with the decrease in grain size.

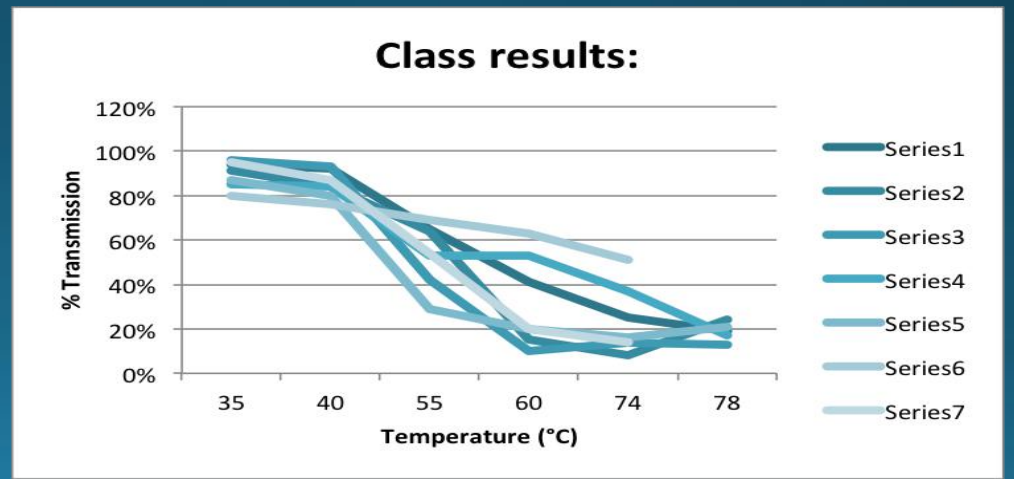

Wentworth Size Class
mm scale
phi scale
Boulder > 256 mm (-8 to -12 ϕ)
Pebbles
256 to 4
-8 to -2
Gravel
4 to 2
-2 to -1
Very coarse and Coarse sand
2 to 0.5
-1 to 1
Medium sand
0.5 to 0.25
1 to 2
Fine and Very fine sand
0.25 to 0.06
2 to 4
Silt
0.06 to 0.004
4 to 8
Clay
< 0.004
> 8.00

PROPERTIES OF PORE WATER PRESSURE

- Pore fluids are the fluids that occupy pore spaces in a soil or a rock.
- Permeability is directly proportional to the unit weight of pore fluid.
- Permeability is inversely proportional to the viscosity of the pore fluid.

TEMPERATURE

- Temperature also affects the permeabilityin soil.
- Permeability is inversely proportional to the viscosity of the fluid.
- Hence, the permeability is directly related to the temperature.
- Greater the temperature , higher will be the permeability.
- Which results into more seepage in summer season than the winter.



VOID RATIO

$$k \alpha \frac{C\, e^3}{1+e}$$

- Permeability increases with the void ratio.
- But is not applicable to all soils. For example clay has high void ratio than any of the soil but it’s permeability is very low.
- This is due to, the flow path through voids in case of clays is extremely small such that water cannot permit through this path easily.
- The relation between coefficient of permeability and void ratio can be expressed.

SPECIFIC SURFACE AREA OF SOIL PARTICLRS

- Specific surface area of soil particles also effects the permeability. Higher the specific surface area lower will be the permeability.

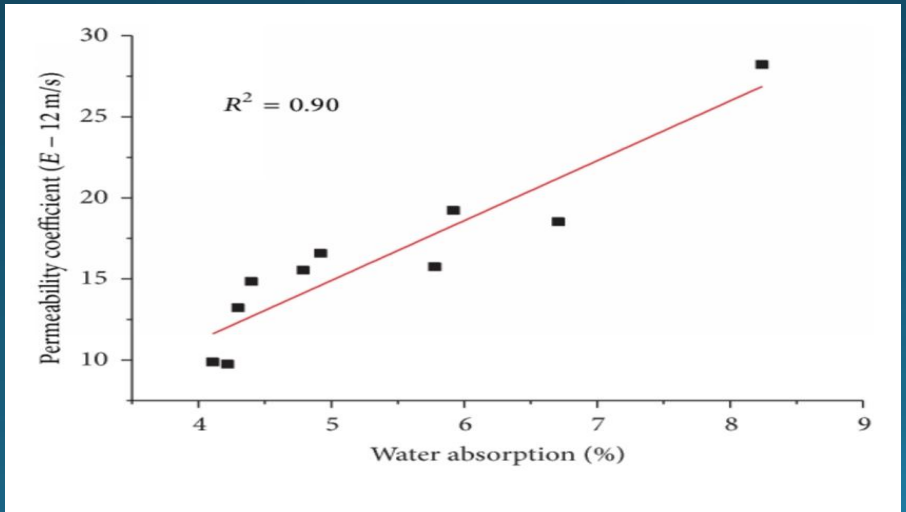
$$k\ \alpha\ \frac{1}{Specific\ Surface\ Area}$$

ORGANIC IMPURITIES

- Presence of organic matter decreases the permeability. This is due to blockage of voids by the organic matter.
- The air entrapped in the soil and organic matter block the passage of water through soil, hence permeability considerably decreases.

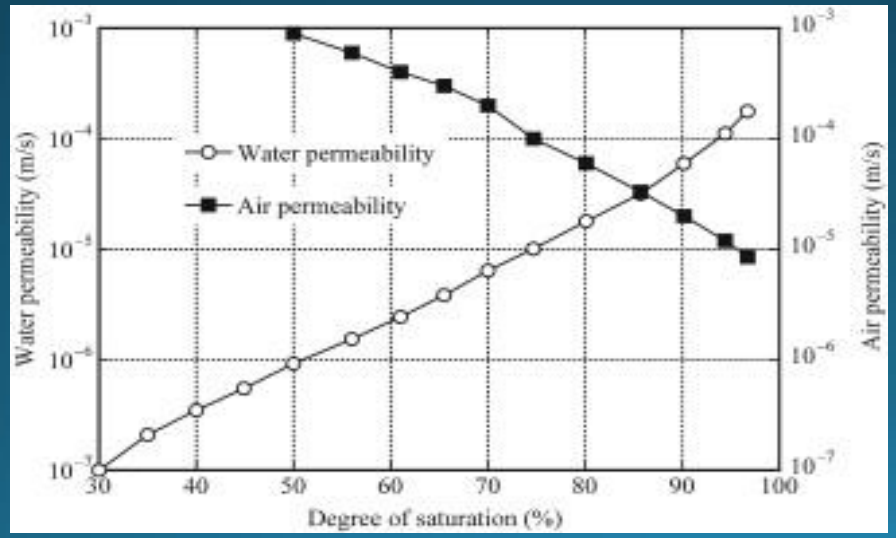
ABSORBED WATER

- Adsorbed water is the water layer formed around the soil particle especially in the case of fine-grained soils.
- This absorbed layer is not free to move under gravity and causes obstruction in the flow of the water.
- This reduces the size of the void space by about 10%. Hence, permeability reduces.



DEGREE OF SATURATION

- Partially saturated soil contain air voids which are formed due to entrapped air or gas released from the percolating fluid or water.
- This air will block the flow path thereby reduces the permeability.
- The permeability of a partially saturated soil is considerably smaller than of fully saturated soil.

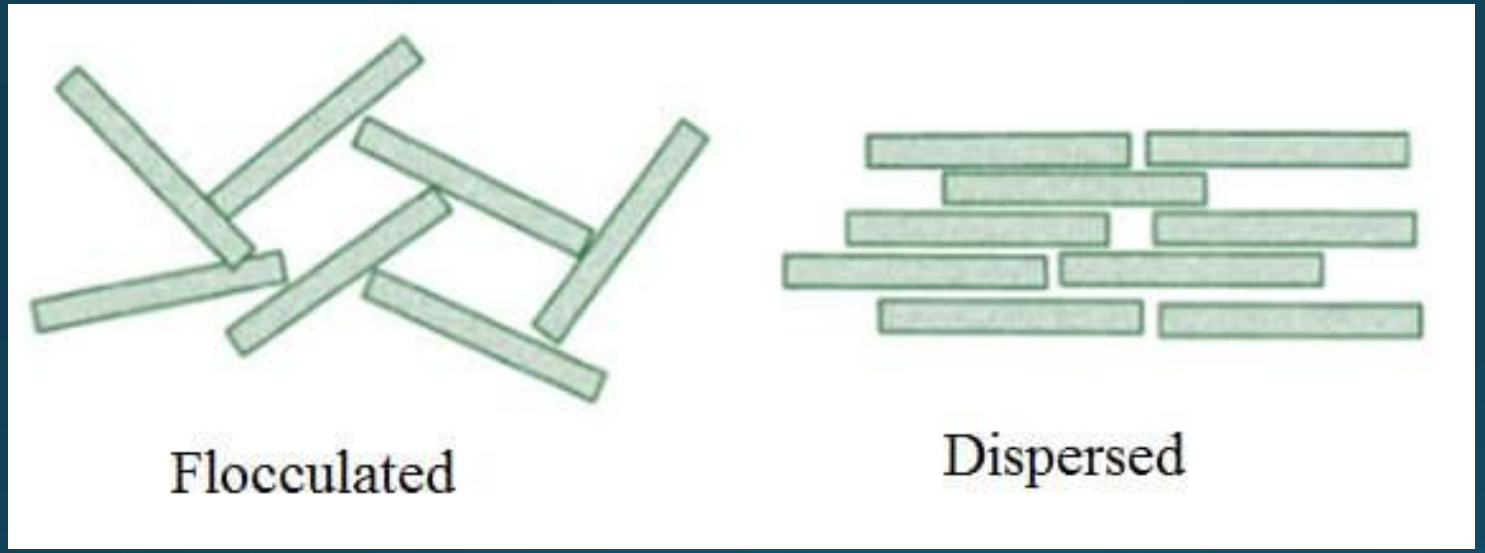


SHAPE OF PARTICLES

- Particle shape is widely considered to be one of the most important factors affecting the behavior of granular soils.
- Rounded Particles will have more permeability than angular shaped.
- It is due to specific surface area of angular particles is more compared to rounded particles.

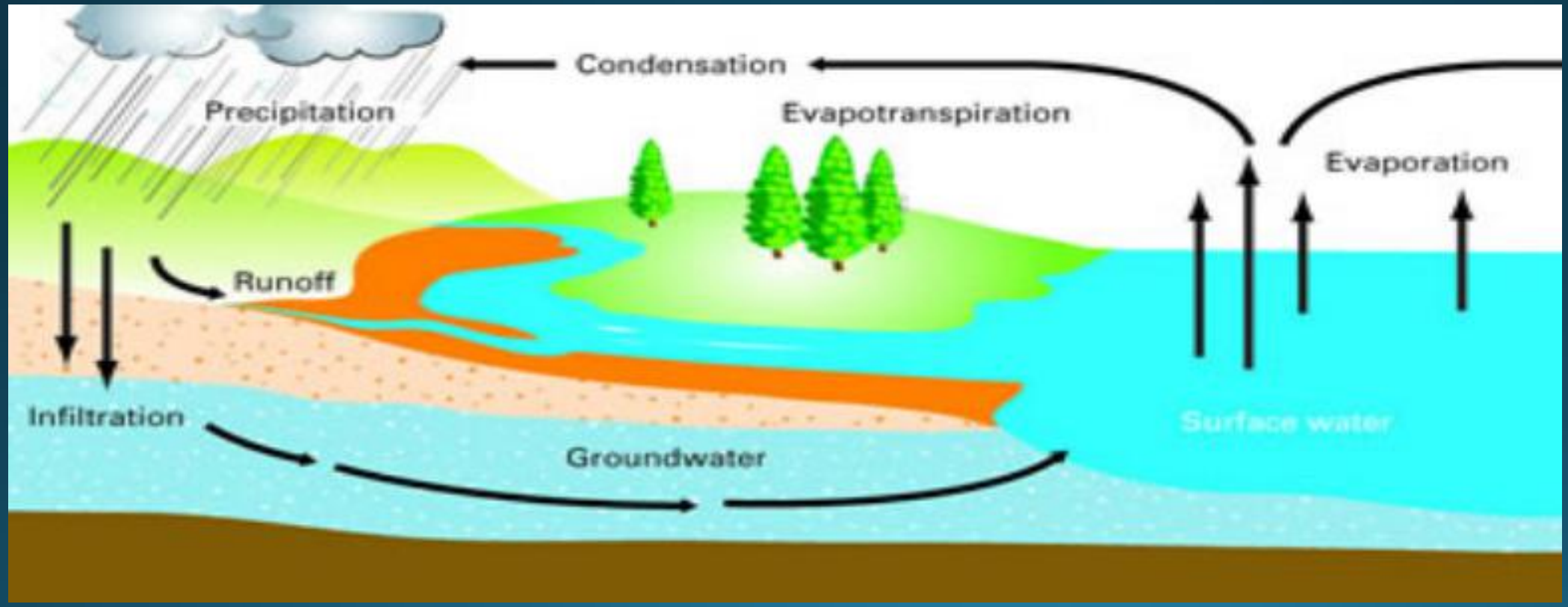
STRUCTURE OF SOIL MASS

- Structure of any two similar soil masses at same void ratio need not be same. It varies according to the level of compaction applied.
- If a soil contains flocculated structure, the particles are in random orientation and permeability is more in this case.
- If the soil contains dispersed structure, the particles are in face to face orientation hence, permeability is very low.
- The permeability of stratified soil deposits also varies according to the flow direction. If the flow is parallel, permeability is more. If it is perpendicular, permeability is less.

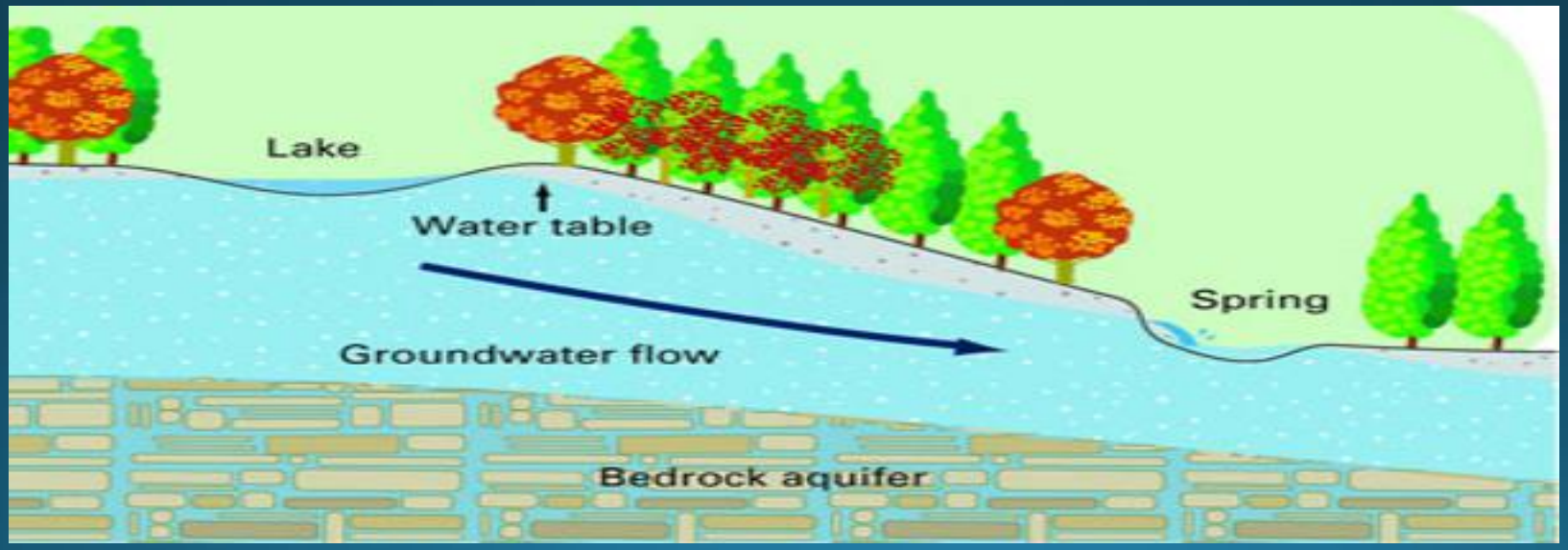

Flocculated
Dispersed

GROUND WATER MOVEMENT

- The water cycle moves water through the environment. As water falls to the ground as rain or snow – it can run off into streams, lakes, rivers or bays.
- Water will evaporate from surface water. Water that evaporates, can later condense (called condensation), forming clouds that can cause rain or snow.

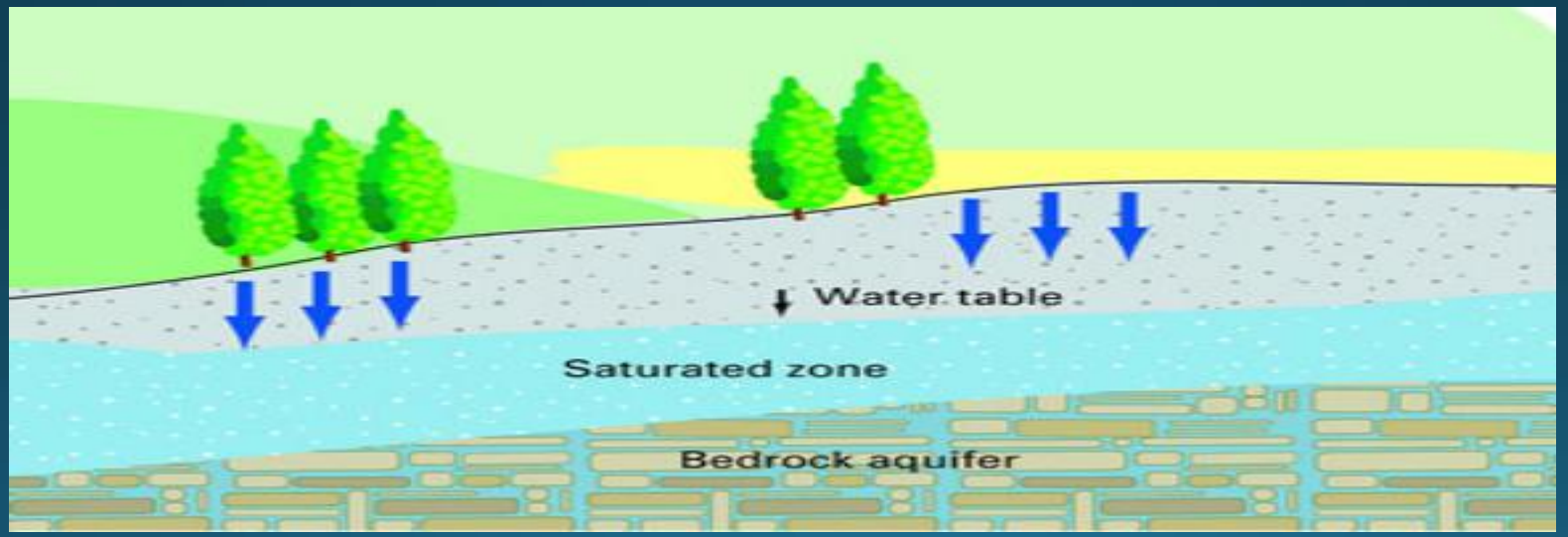


- Groundwater and surface water are interconnected. When the water table rises above the ground, the groundwater discharges to the surface and becomes surface water.
- First the ground water moves downwards but it can also moves upwards because it will flow from higher pressure area to lower pressure area.
- Also, when the water table drops, surface water can recharge the groundwater.



- An aquifer is an area of underground soil or rock that is filled with water. An aquifer can supply water to a drinking water well.
- This water recharge the aquifers and the ground water that reaches the surfaces through streams, lakes, swamps are known as discharge area.

- The water table is the top of the groundwater.
- It is the boundary between the saturated zone below the water table and the unsaturated zone above the water table.
- The water table rises and falls according to the time of year and how much rain or snow we get.



- The ground water is recharged by precipitation and that goes under the ground.
- To obtain this water the wells are dug till it reaches the ground water level .
- In this way the water moves in the ground once it reaches the land and this process goes on continuing.

THANK YOU