



HYDROGEOLOGY



What is Groundwater?

Groundwater is water that exists underground in the cracks and spaces in soil, sand, and rock.



Importance of Groundwater

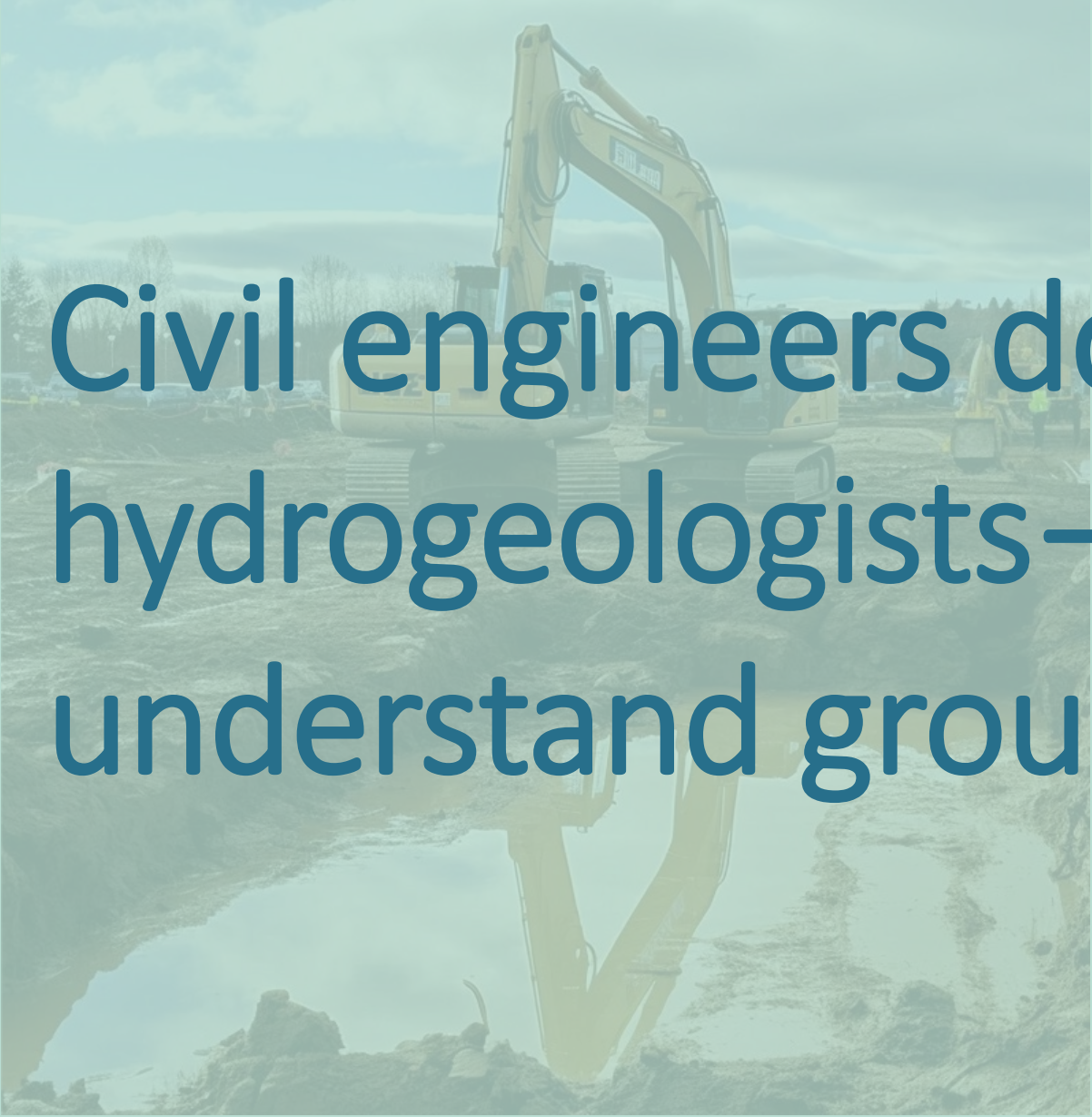
Groundwater is an important source of freshwater for many communities and industries.

It also helps maintain the health of aquatic ecosystems.



Importance of Groundwater

Hydrogeology plays a vital role in several aspects of civil engineering, as it provides essential knowledge for designing, constructing, and maintaining infrastructure projects.



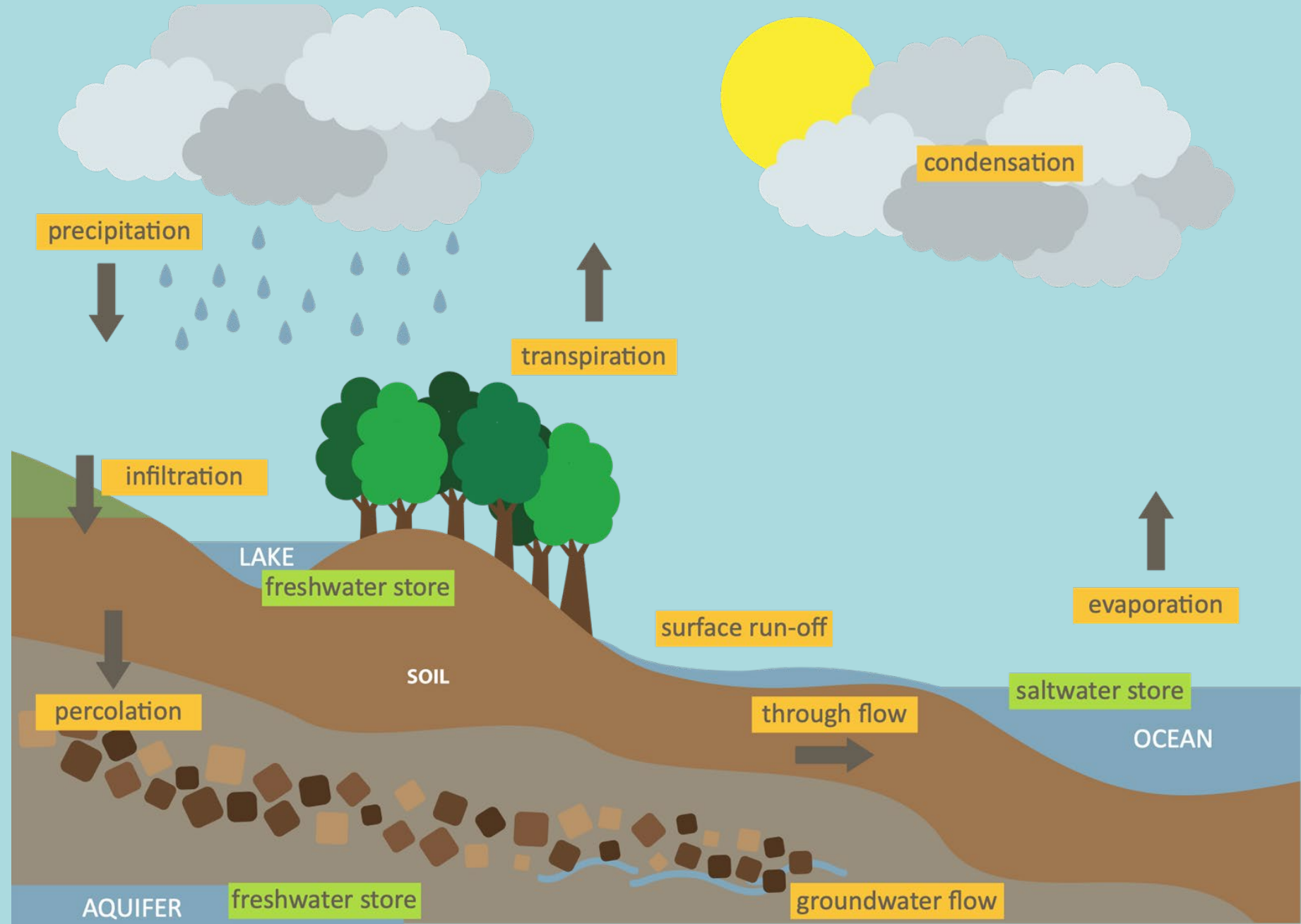
Civil engineers don't need to be hydrogeologists—but they must understand groundwater

Importance of Groundwater

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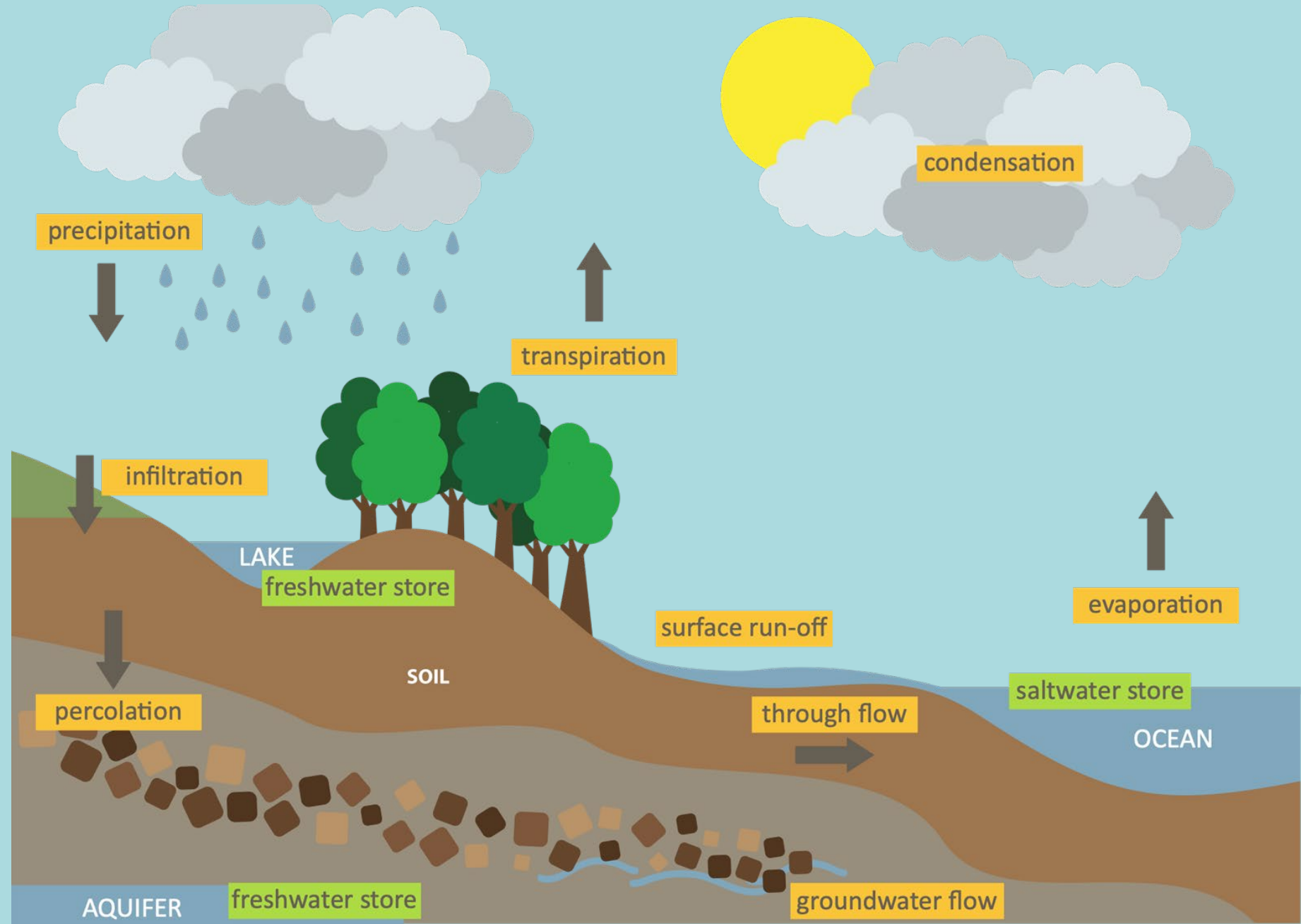
Hydrological Cycle

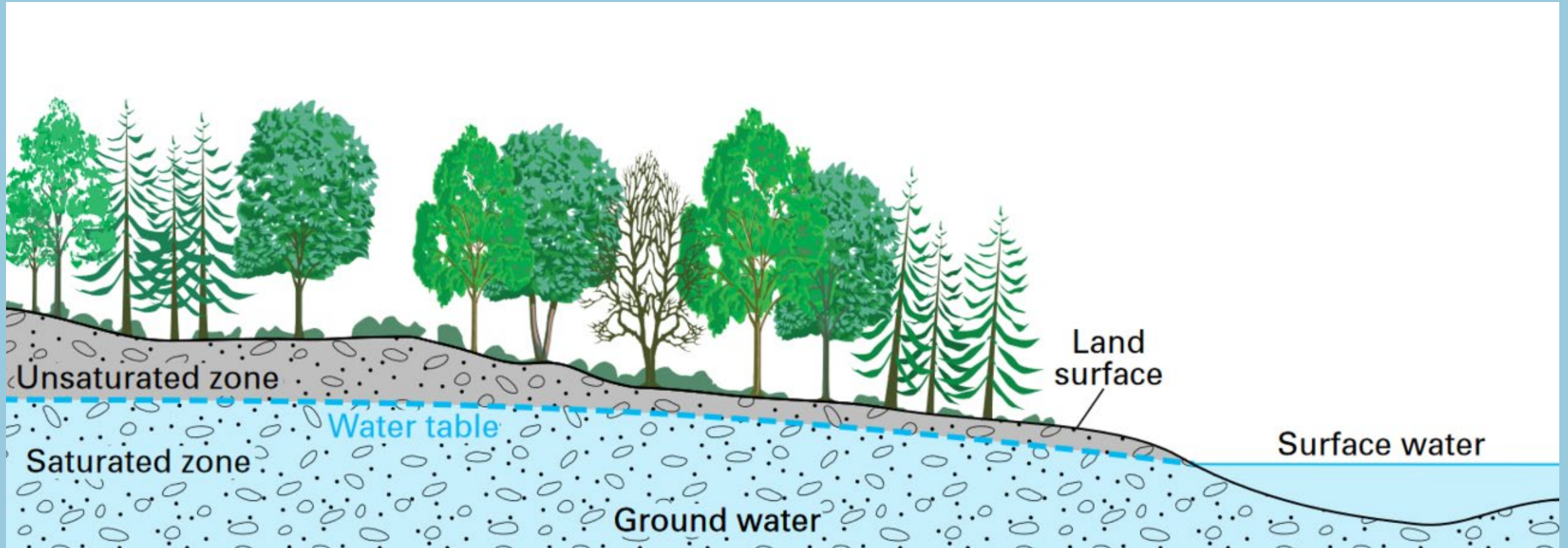
Groundwater is formed when rainwater and other surface water percolate through the ground, seeping down through the soil and rock.

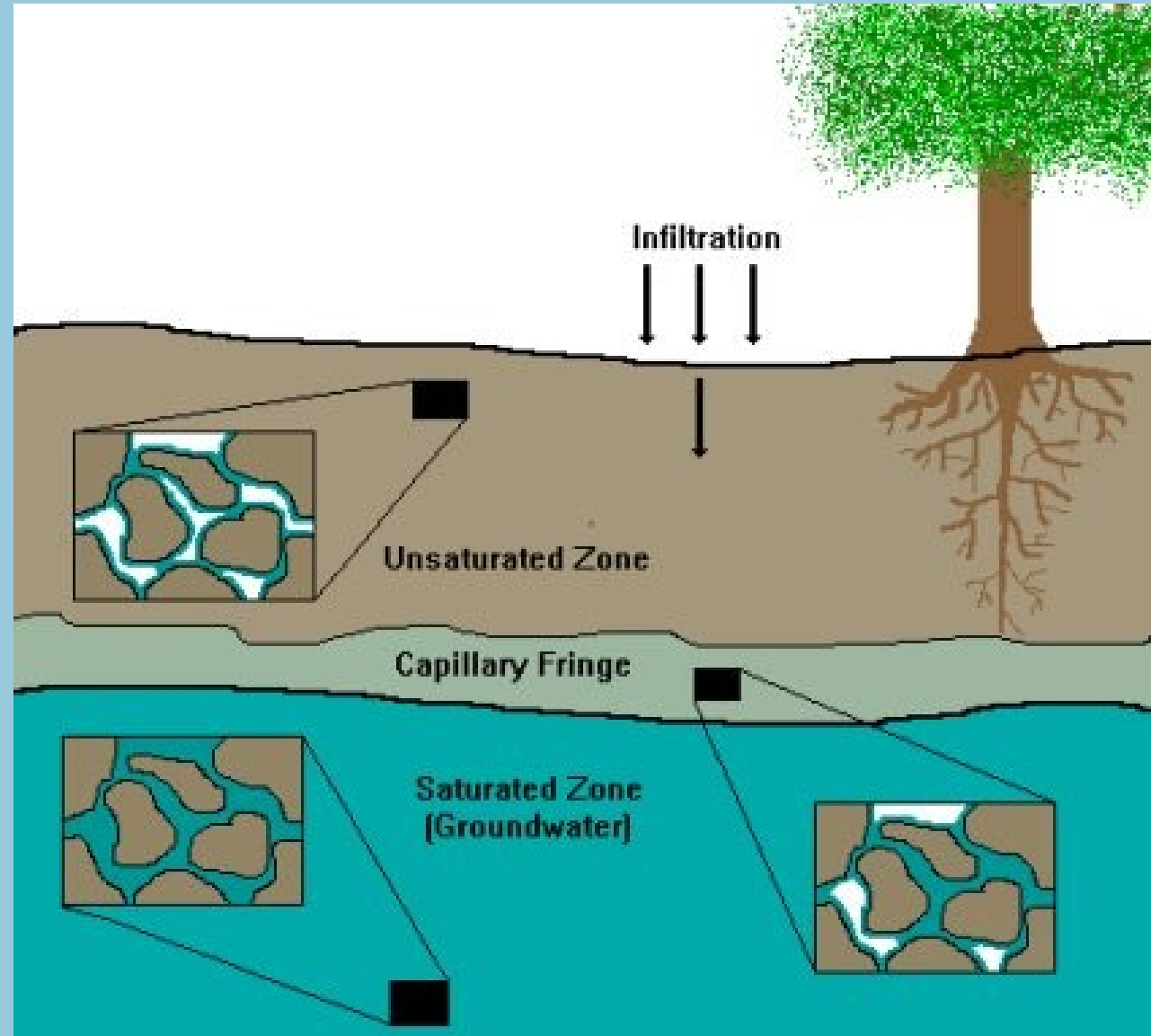


Hydrological Cycle

As the water percolates through the soil and rock, it fills the spaces between particles, eventually collecting in aquifers.

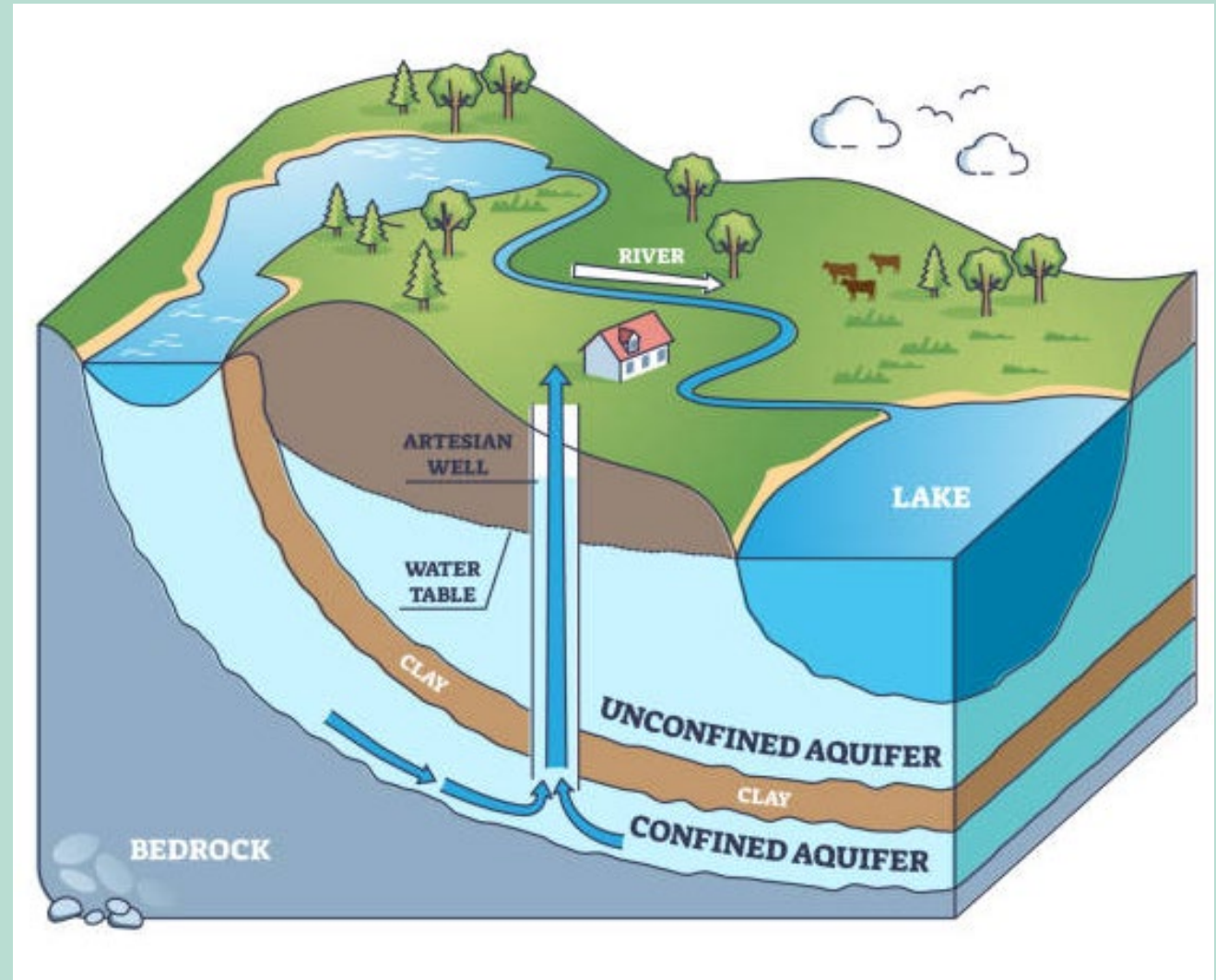






Aquifers

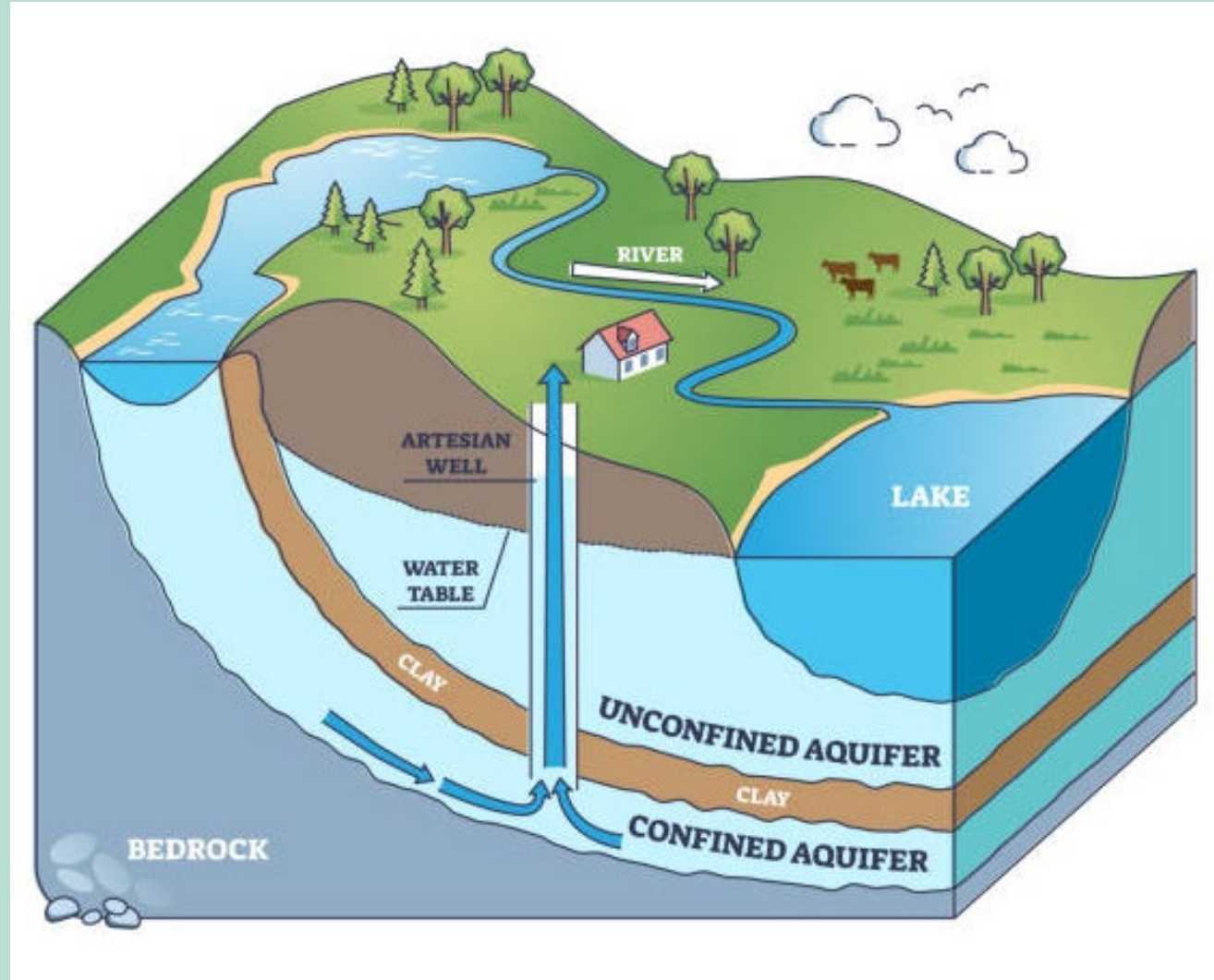
An aquifer is an underground layer of permeable rock, sediment or soil that contains and transmits groundwater.



Types of Aquifers

Unconfined Aquifers

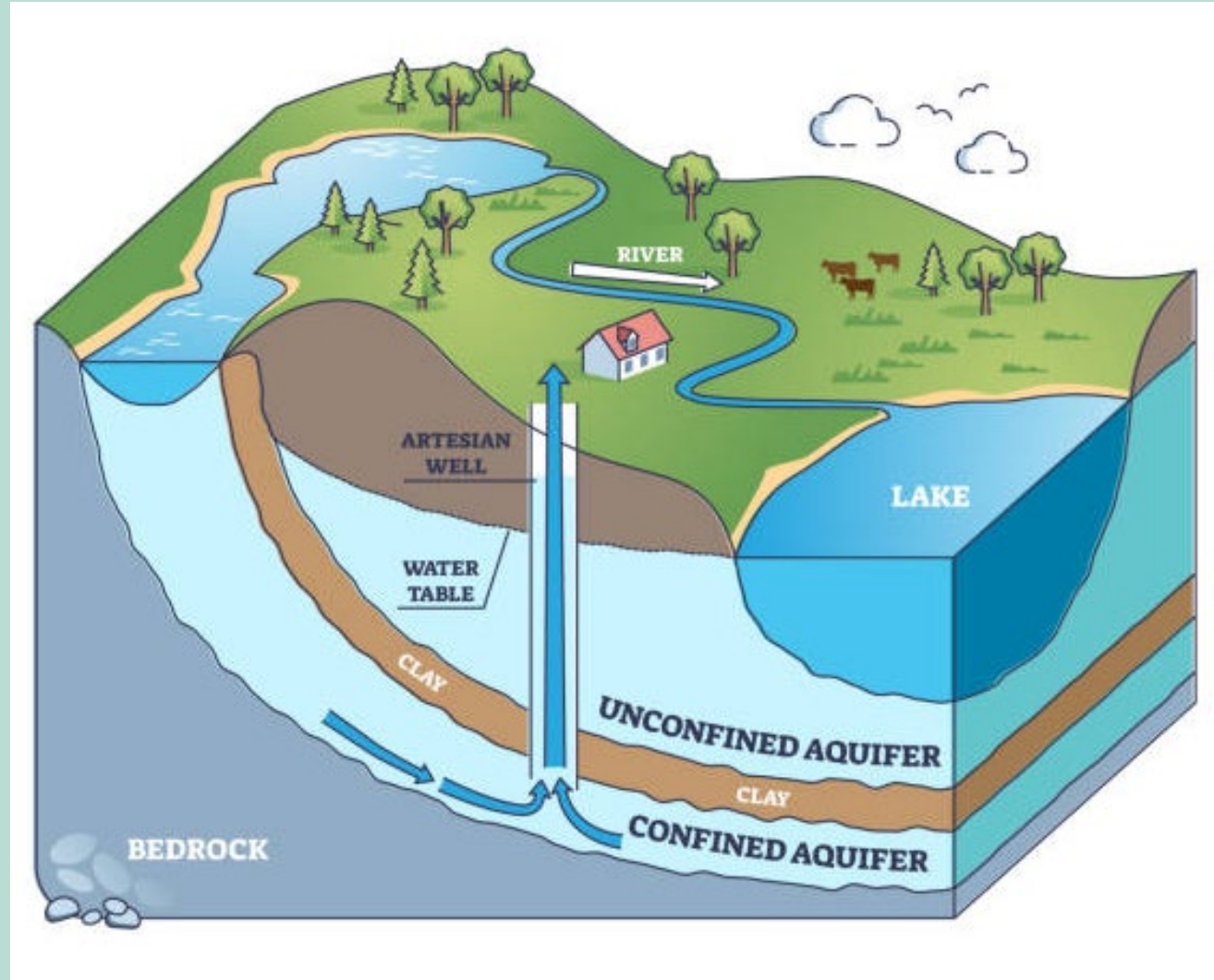
- These aquifers have a permeable layer above them and are recharged directly by rainwater or other surface water.
- They are typically closer to the surface, making them more accessible but also more susceptible to contamination.



Types of Aquifers

Confined Aquifers

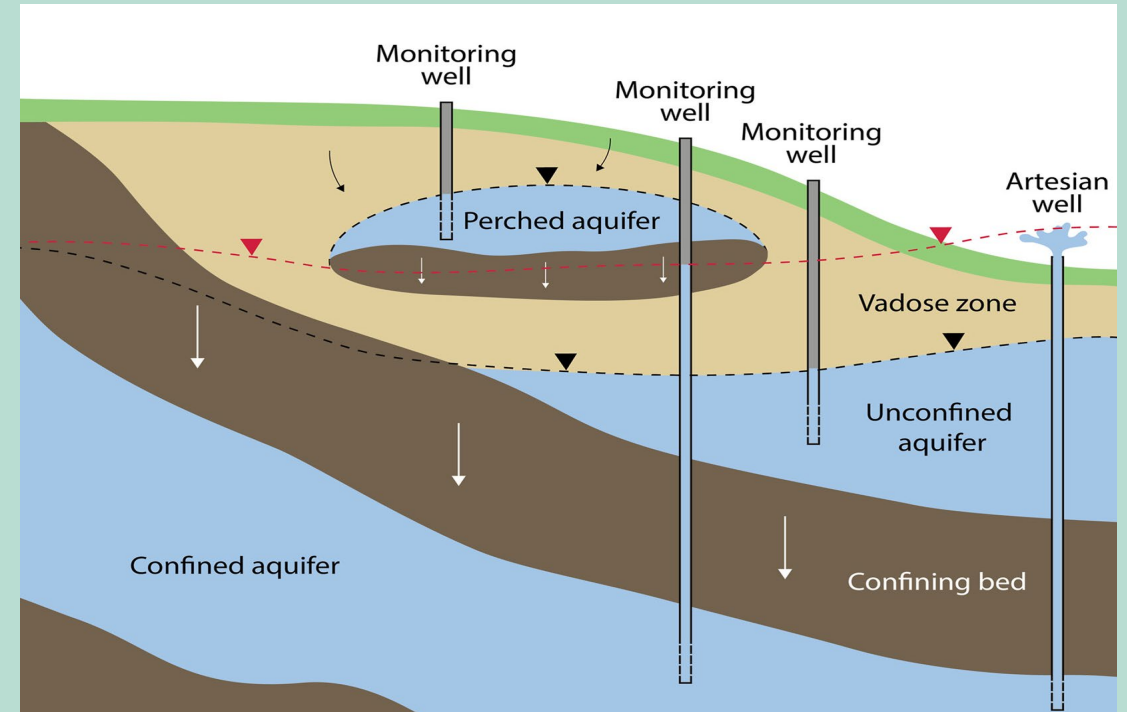
- These are found beneath an impermeable layer of rock or clay, which protects them from direct surface contamination.
- Confined aquifers are usually under pressure, so when they are tapped, the water may rise on its own in an artesian well.



Types of Aquifers

Perched Aquifers

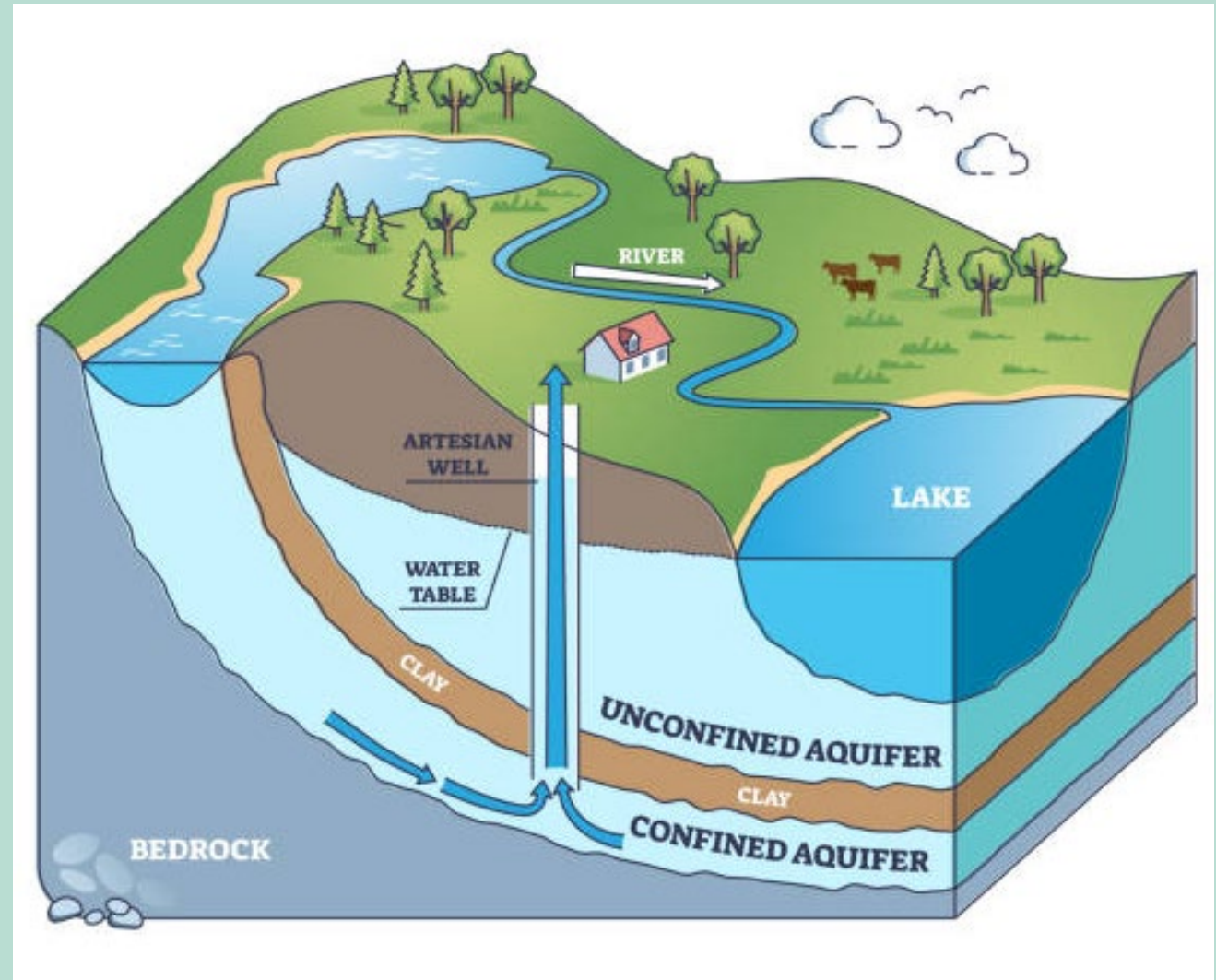
- A perched aquifer is a localised body of groundwater sitting above the main regional water table, formed when rainwater saturates permeable soil or rock until it hits a layer of impermeable material.



Aquitard & Aquiclude

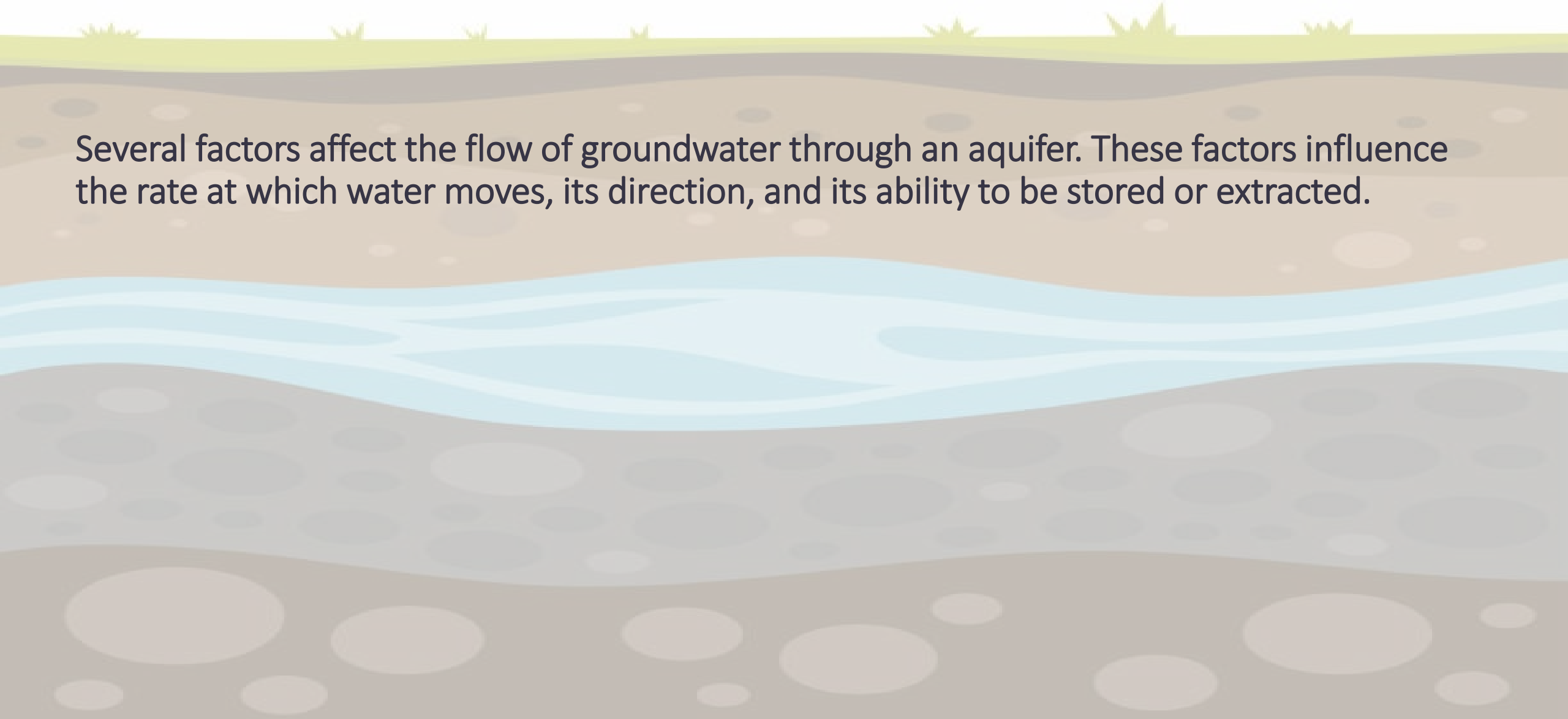
An aquitard is a geologic layer with low permeability that slows groundwater flow but does not completely stop it. Water can pass through an aquitard, just very slowly.

An aquiclude is a layer with extremely low permeability that effectively prevents groundwater flow under practical engineering time scales.

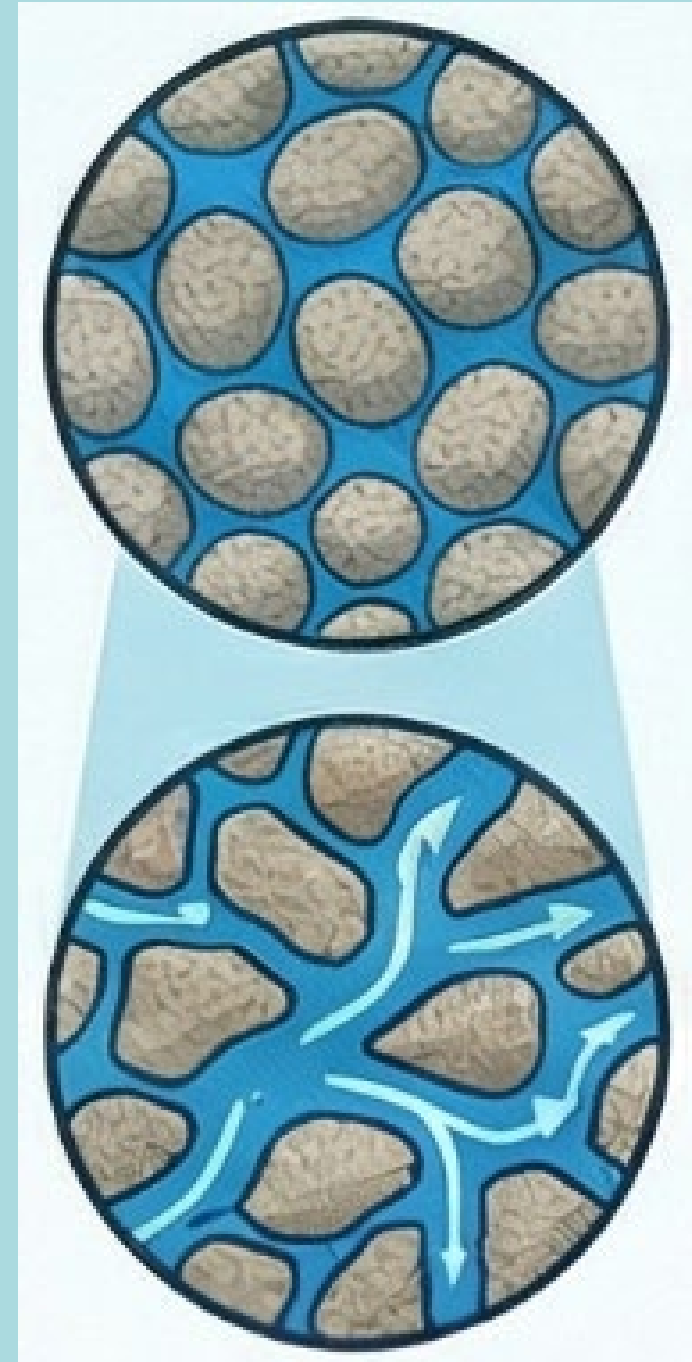


Properties of Groundwater

Several factors affect the flow of groundwater through an aquifer. These factors influence the rate at which water moves, its direction, and its ability to be stored or extracted.



Porosity vs Permeability



Porosity

Porosity is the measure of the amount of open space in a rock or sediment that can hold water.

It determines how much water can be stored in an aquifer and how easily it can flow through it.



Porosity

We define porosity as the ratio of the volume of voids in the rock to the total volume of rock.

$$n = \frac{V_p}{V_b}$$

where

n = Porosity

V_p = Volume of Voids

V_b = Bulk Volume of Rock



Porosity



Imagine you have a sample of sand with the following measurements:

The total volume of the sand sample is 500cm^3 .

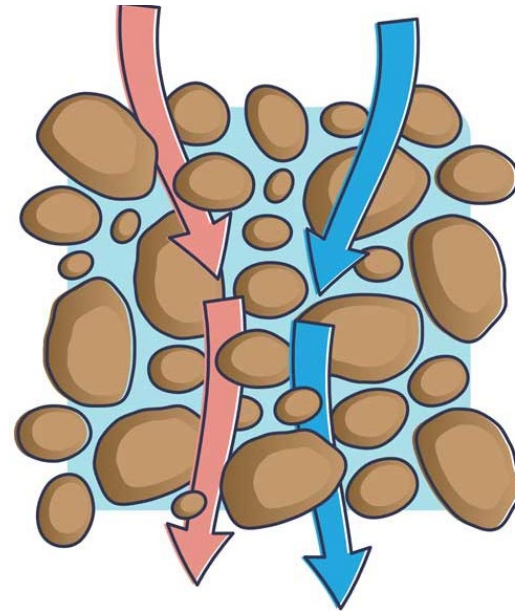
The volume of void spaces (pores) is 150cm^3 .

$$n = \frac{V_p}{V_b} = \frac{150}{500} = 0.3 \rightarrow 30\%$$

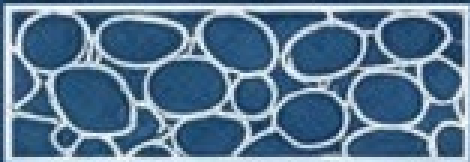
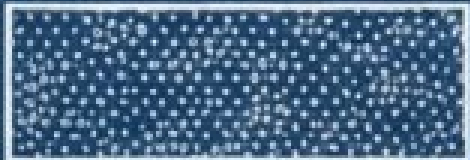
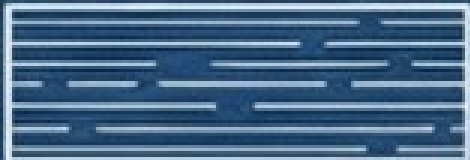
Permeability

Permeability is the measure of well the pores are interconnected and therefore how easily water can move through a rock or sediment.

Materials that allow water to pass easily are said to be permeable. Those in which it is difficult are impermeable.



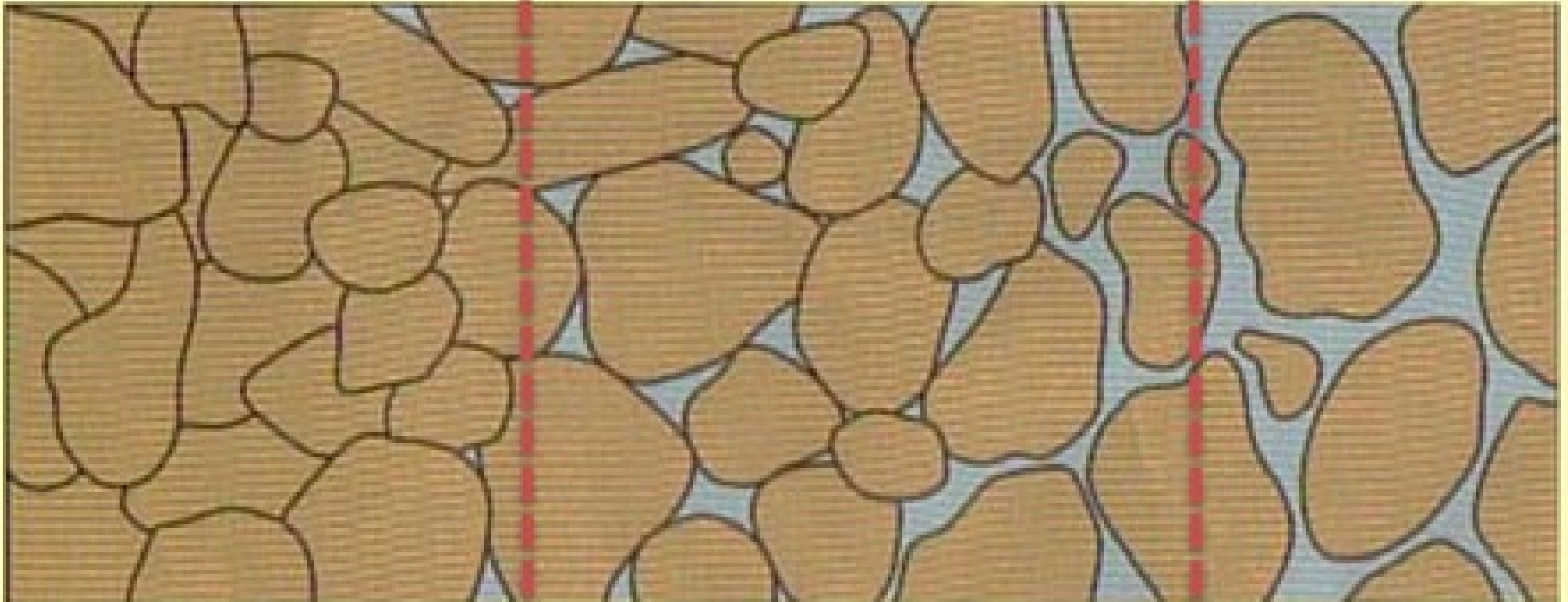
SOIL PERMEABILITY DATA

Soil Type		Permeability (K) Range	Engineering Impact
	Gravel	10^{-2} to 10^{-1} m/s	Very high flow; dangerous in excavations.
	Sand	10^{-6} to 10^{-6} m/s	Moderate flow; requires dewatering design.
	Clay	10^{-6} to 10^{-7} m/s	Low permeability; holds water but drains slowly.

**Non-porous
Non-permeable**

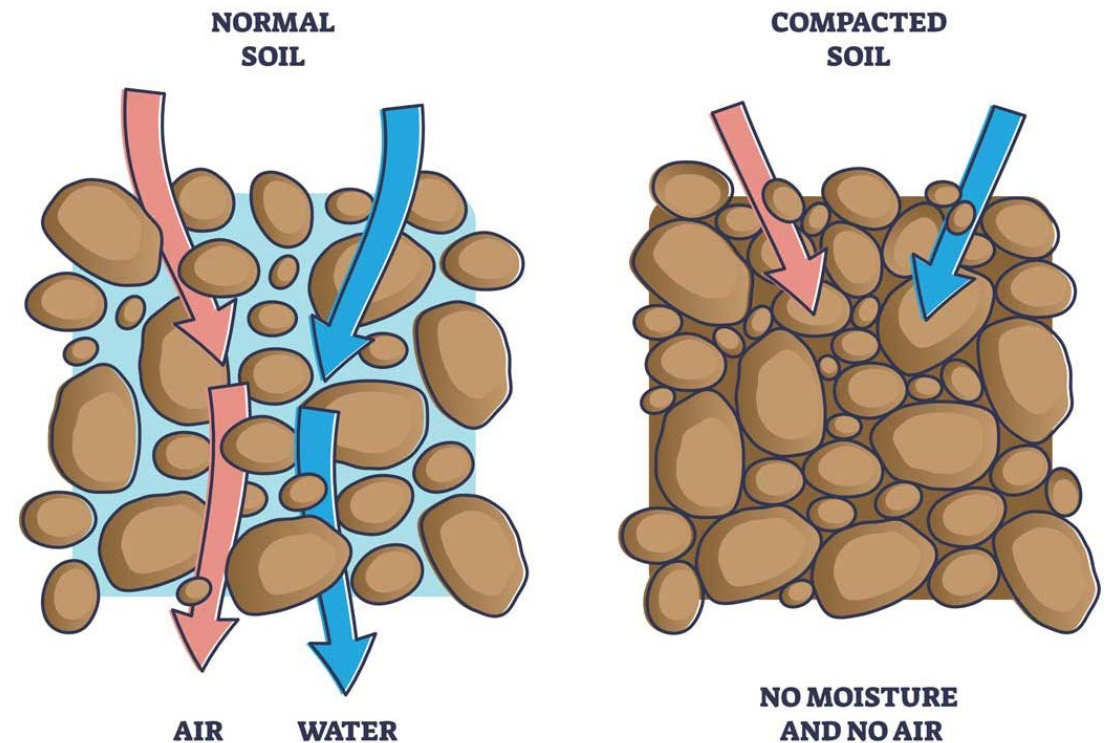
**Porous
Non-permeable**

**Porous
Permeable**



Compaction

Compaction reduces the overall porosity (pore volume) of materials like soil and sediment by forcing particles into closer contact and collapsing pore spaces



Hydraulic Head

- Hydraulic head is a measure of the total energy per unit weight of water at a particular point within a fluid system, and it determines the direction and potential for fluid flow.

Hydraulic Head

Elevation Head

- This is the height of a point in the fluid above a reference level (often taken as sea level or another fixed baseline).
- The higher a point is, the more potential energy it has due to gravity, like how water at a high elevation in a tank has more potential energy than water at a lower elevation.

Hydraulic Head

Pressure Head

- This represents the energy from fluid pressure at a point in the system.
- The pressure head depends on the pressure at a given point and varies based on the depth within a fluid column, in a groundwater system, deeper points usually experience higher pressure due to the weight of the water above them.

Hydraulic Head

The formula for hydraulic head, h , at any point in a fluid system is therefore:

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

Where:

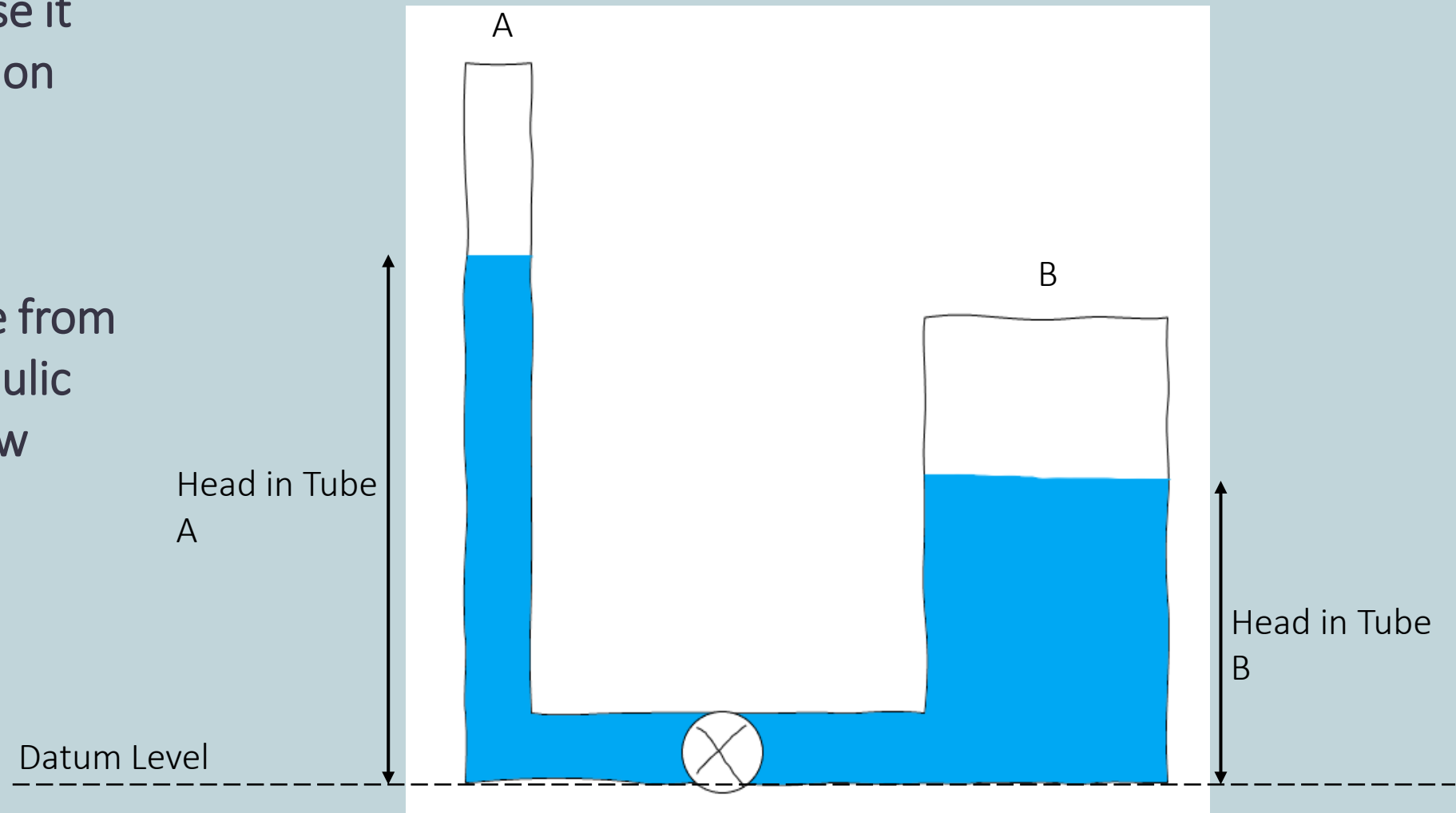
h is hydraulic head

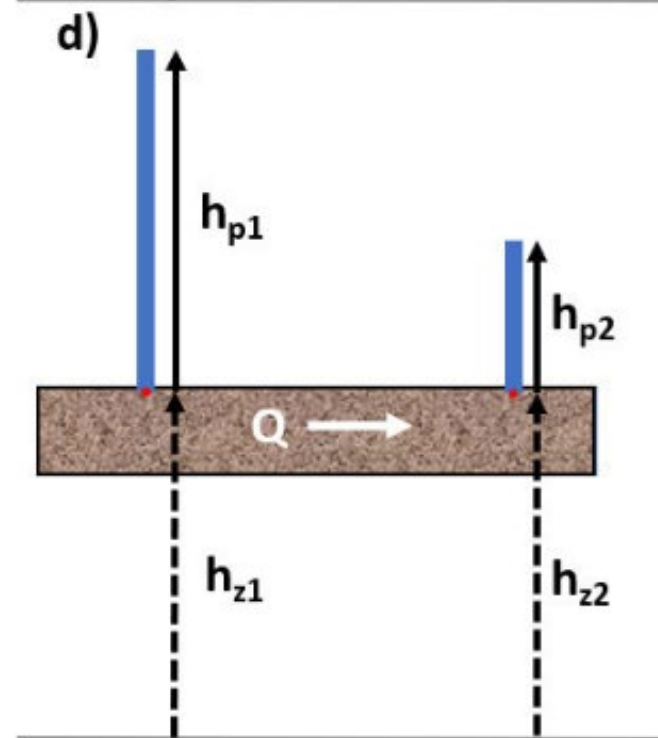
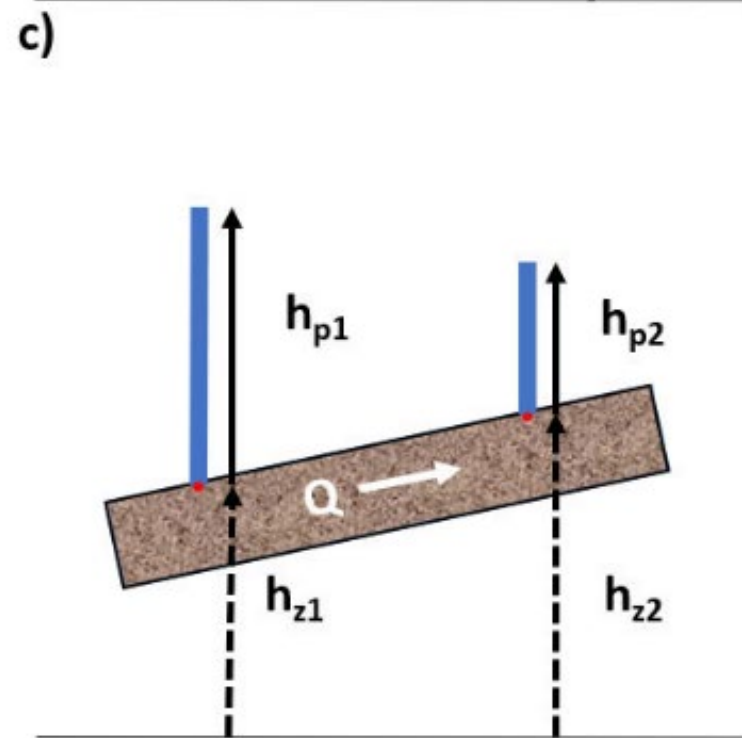
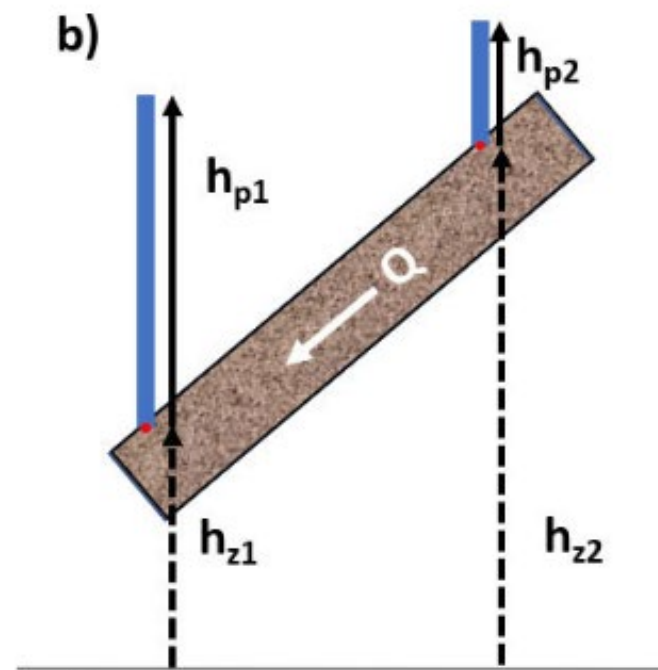
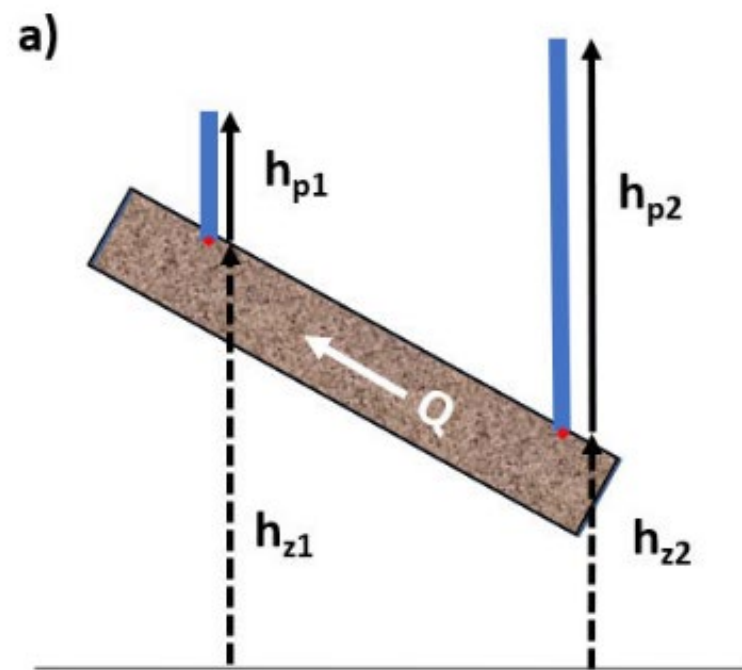
z is the elevation head

$\frac{P}{\rho g}$ is the pressure head, where P is fluid pressure, ρ is fluid density and g is acceleration due to gravity

Hydraulic head is key to understanding fluid flow in porous media because it influences the direction and speed of fluid movement.

Fluids naturally move from regions of high hydraulic head to regions of low hydraulic head





Hydraulic Gradient

When comparing two points in a fluid system, the difference in hydraulic head between these points creates what's called a hydraulic gradient:

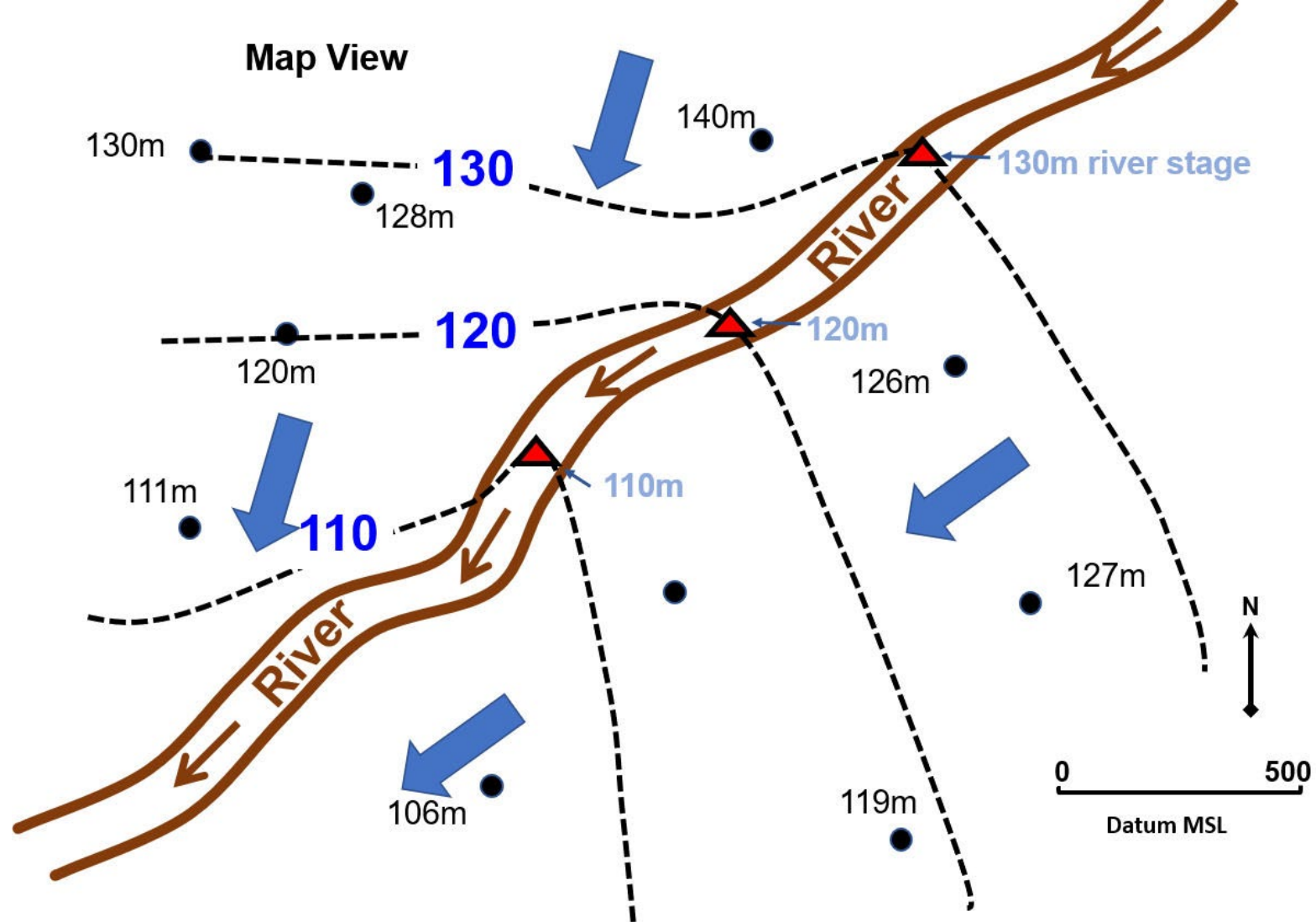
$$i = \frac{h_1 - h_2}{\Delta x} = \frac{\Delta h}{\Delta x}$$

Where:

i is hydraulic gradient

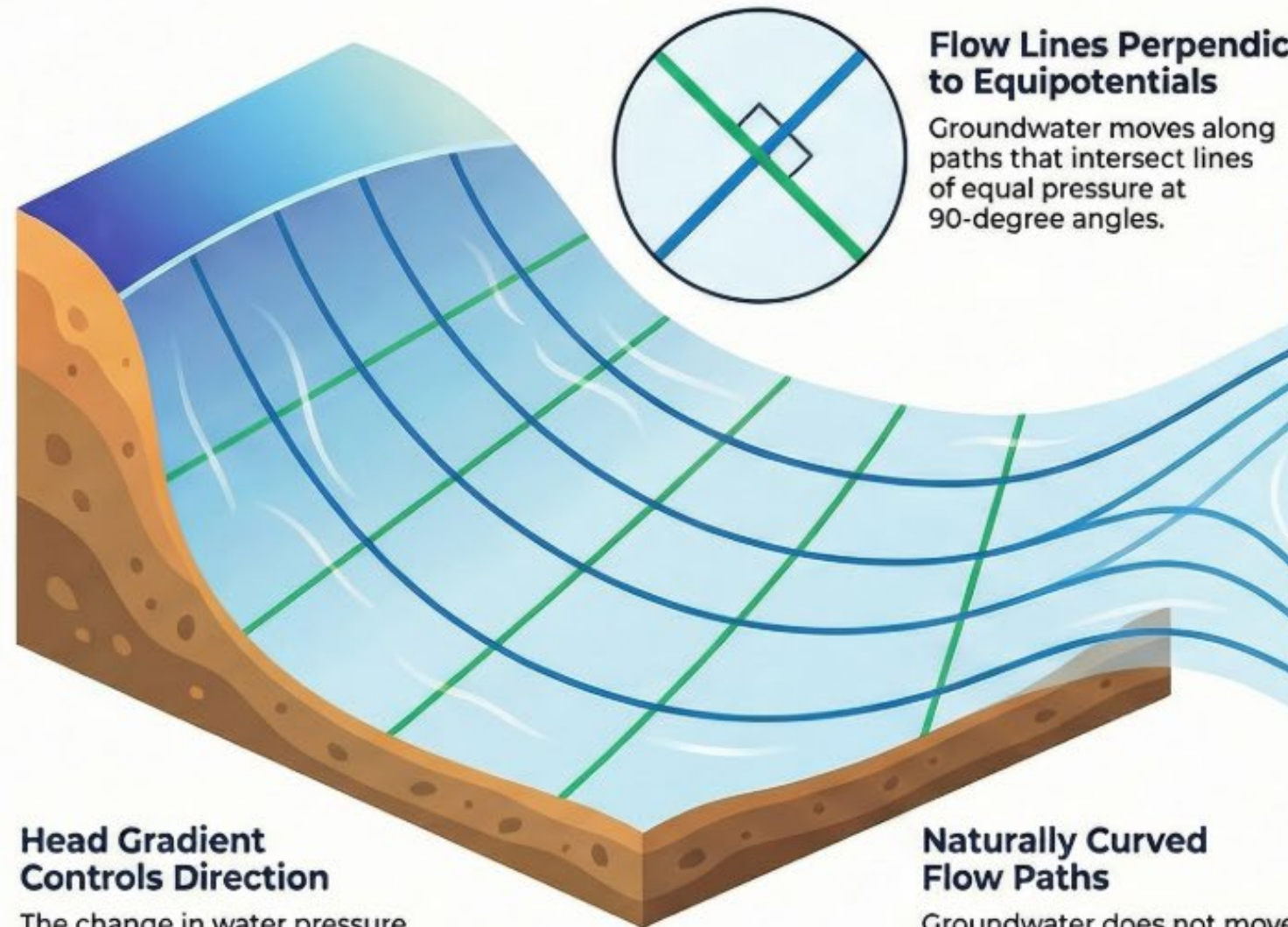
Δh is change in hydraulic head

Δx is horizontal distance



In hydrogeology, knowing the hydraulic head at multiple locations in an aquifer allows scientists to map the flow patterns, predict where water and dissolved substances will move, and understand how water might interact with surface water bodies, like rivers and lakes.

Fundamental Flow Principles



Flow Lines Perpendicular to Equipotentials

Groundwater moves along paths that intersect lines of equal pressure at 90-degree angles.

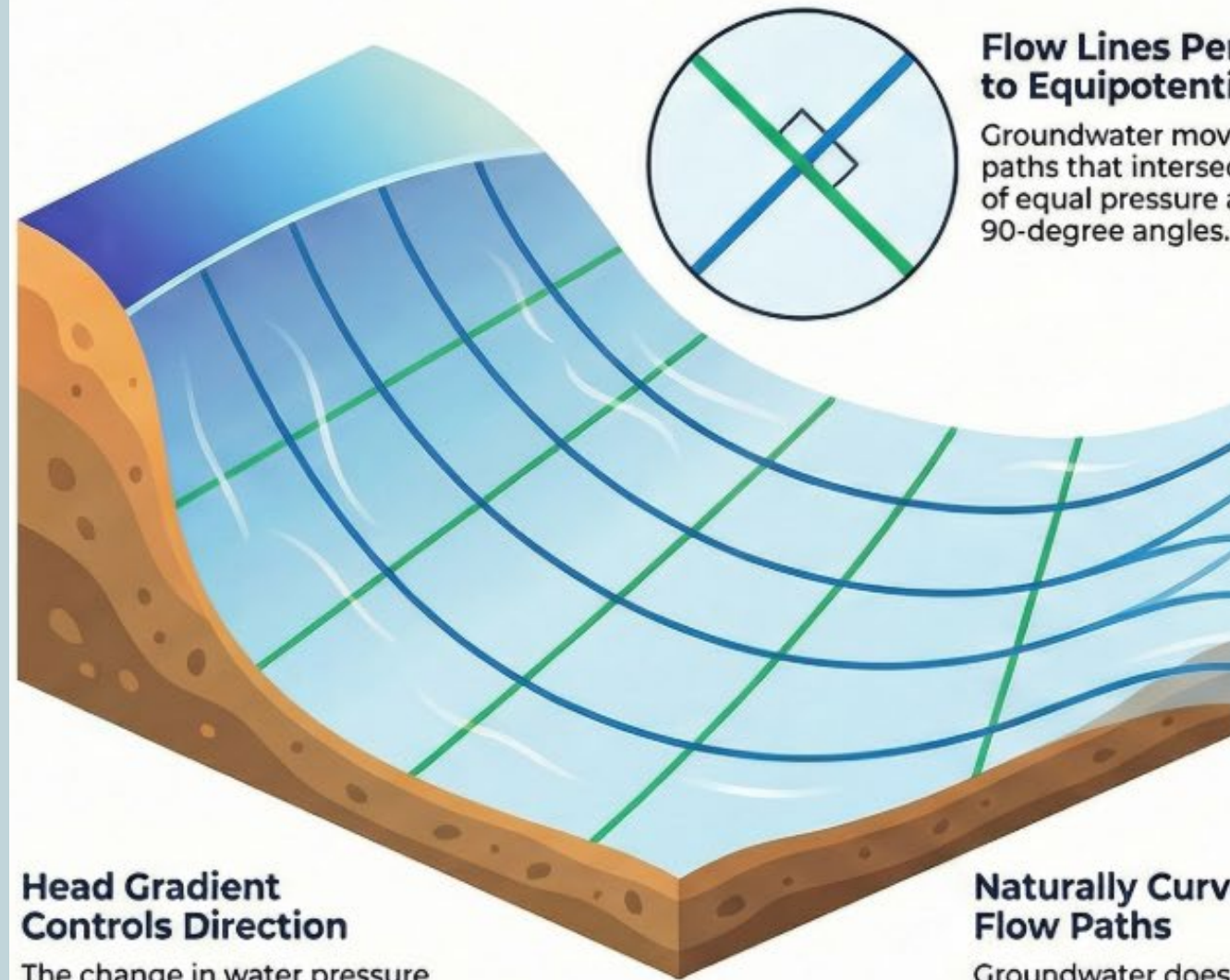
Head Gradient Controls Direction

The change in water pressure levels dictates the overall direction of the flow

Naturally Curved Flow Paths

Groundwater does not move in straight lines but follows curved trajectories.

Fundamental Flow Principles



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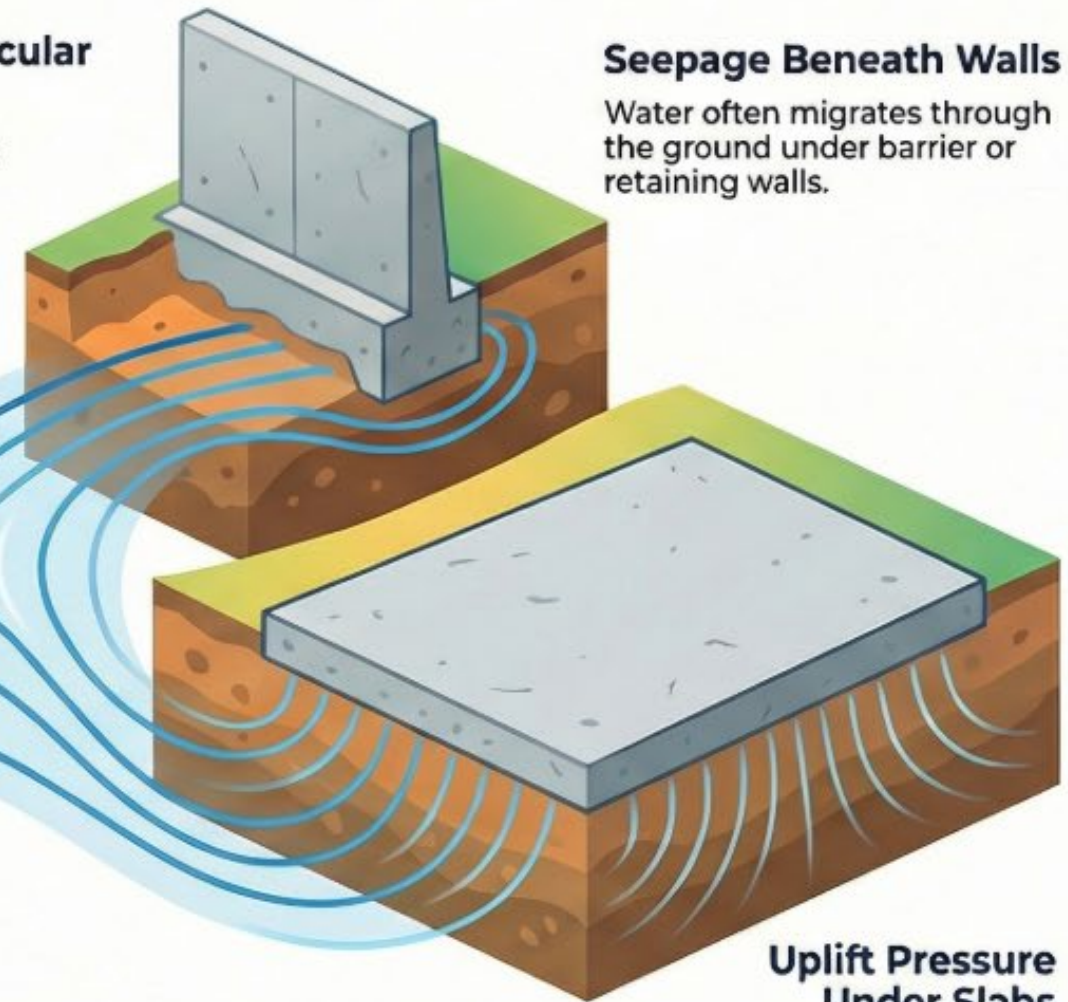
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Naturally Curved Flow Paths

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Civil Engineering Relevance



Seepage Beneath Walls

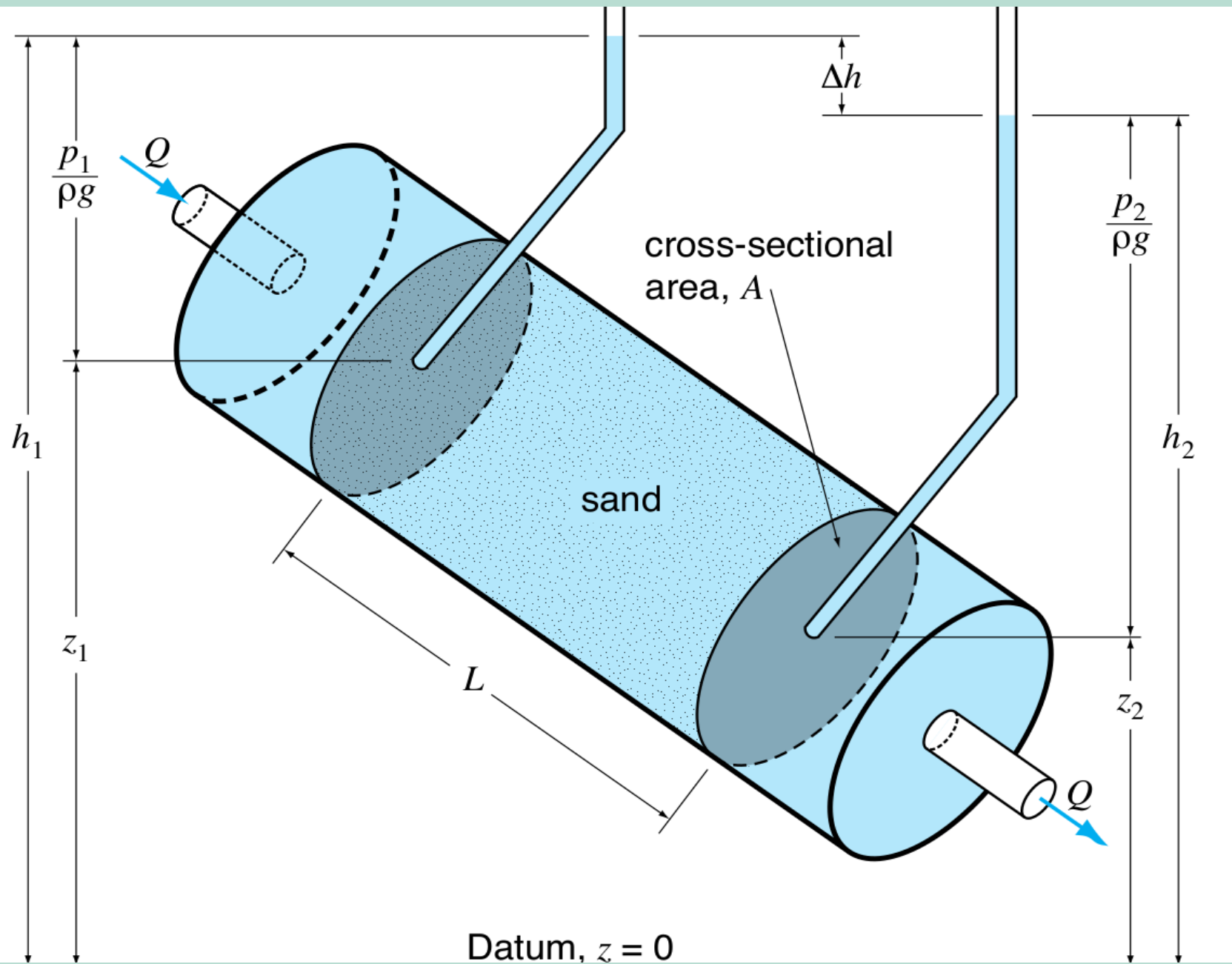
Water often migrates through the ground under barrier or retaining walls.

Uplift Pressure Under Slabs

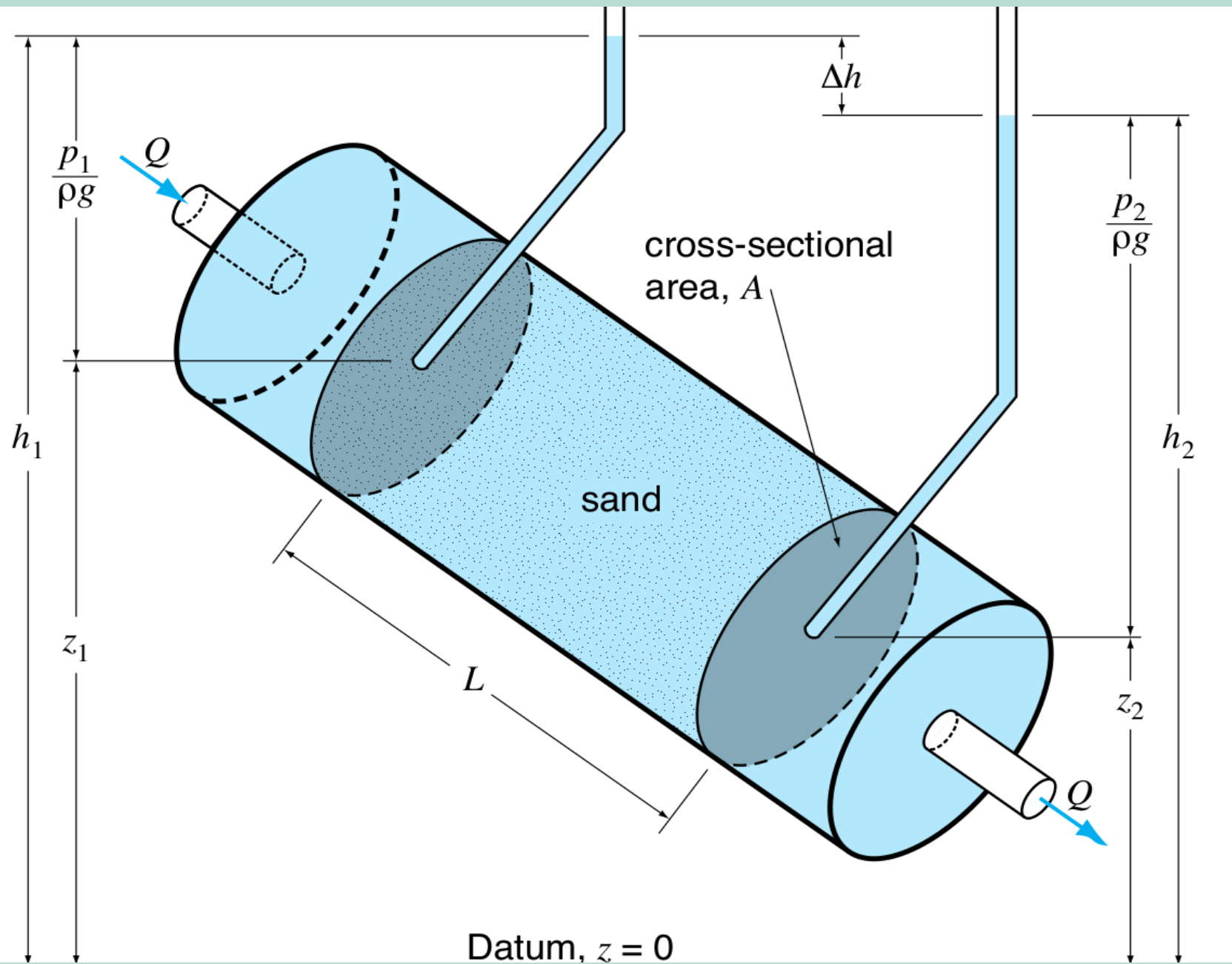
Seepage creates upward pressure that can destabilize or lift concrete foundation slabs.

Darcy's Law

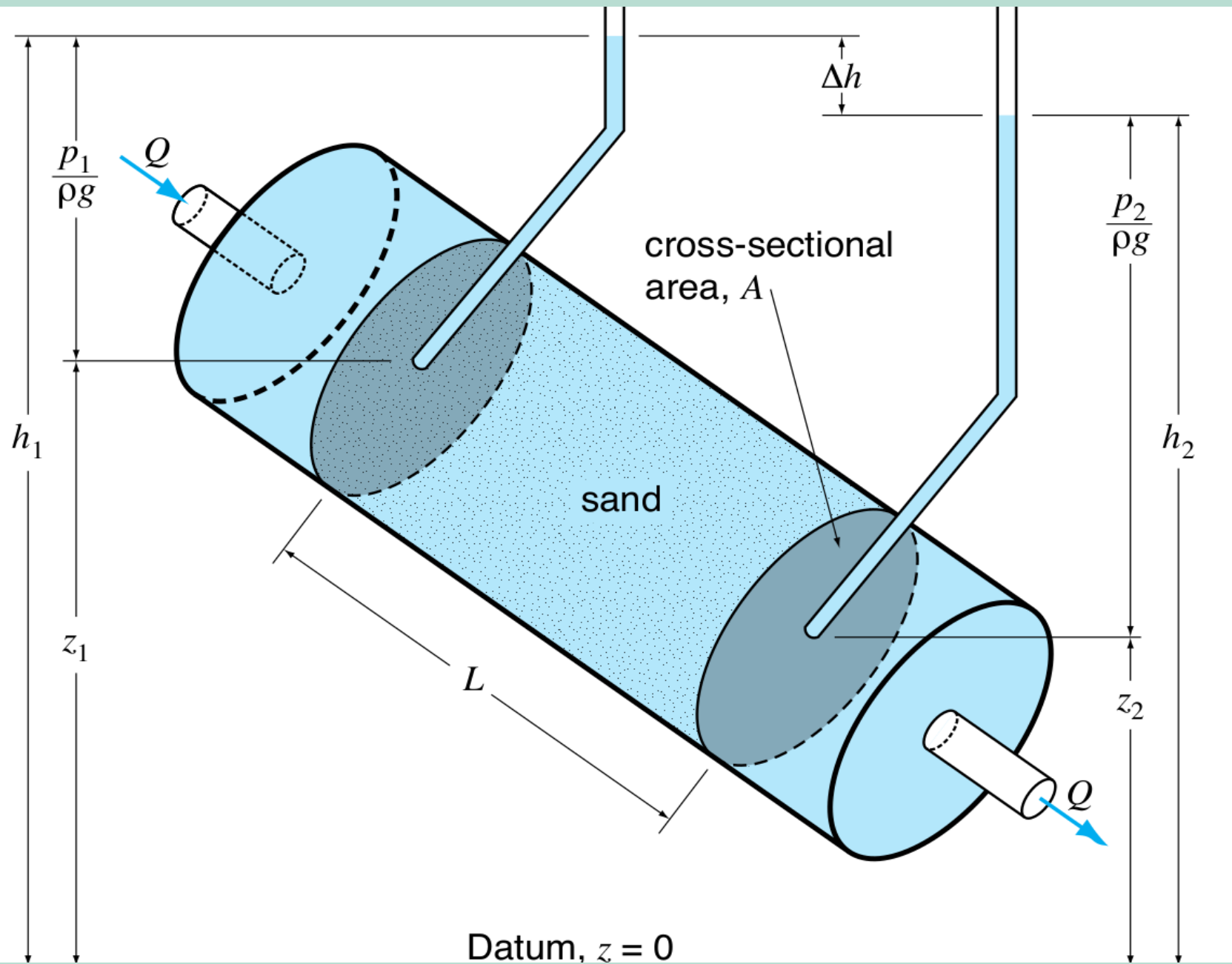
- In studying the flow of water (or any other fluid) through rock (or any other porous media), we make use of Darcy's Law.
- It was formulated by the French engineer Henry Darcy in 1856 while studying water flow through sand filters.



Darcy's Law



Darcy's Law



Darcy's Law

Darcy's Law

Darcy observed that the flow rate was directly proportional to:

- The hydraulic head difference (driving force)
- The cross-sectional area of the column
- The characteristics of the sand.

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He proposed the relationship:

$$Q = -KA \frac{\Delta h}{L}$$

Q is Flow Rate

K is Hydraulic Conductivity

A is the Cross-Sectional Area

$\frac{\Delta h}{L}$ is the Hydraulic Gradient:

Darcy's Law

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DARCY'S LAW ($q = KiA$)



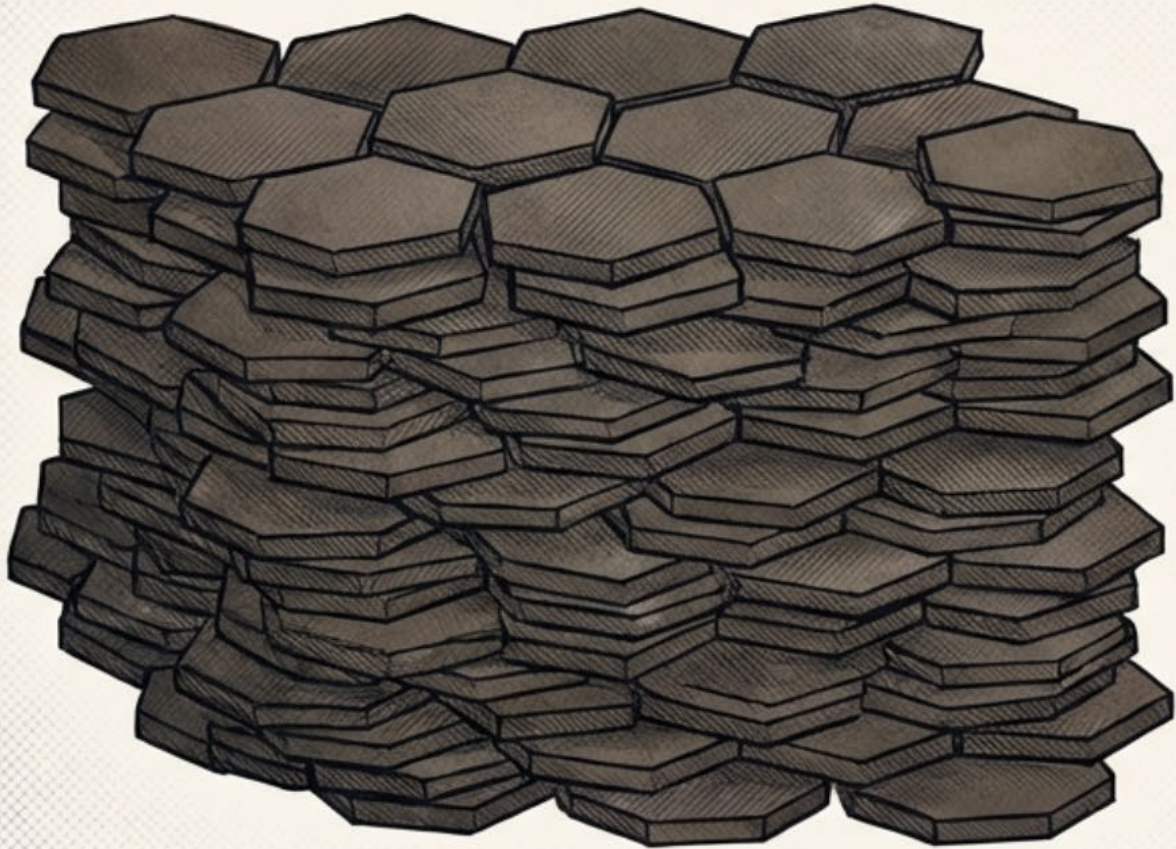
Flow volume (q) increases with higher soil permeability (K), steeper gradients (i), and larger areas (A).

Hydraulic Conductivity

- As fluid moves through the pores of a medium, it encounters resistance due to friction with the solid particles in the medium.
- Hydraulic conductivity (K) is a property that measures how easily fluid can flow through the medium.
- It depends on both the properties of the fluid (like viscosity) and the porous medium (like pore size and shape)

Clay: The Barrier

$$K = 10^{-9} - 10^{-7} \text{ m/s}$$



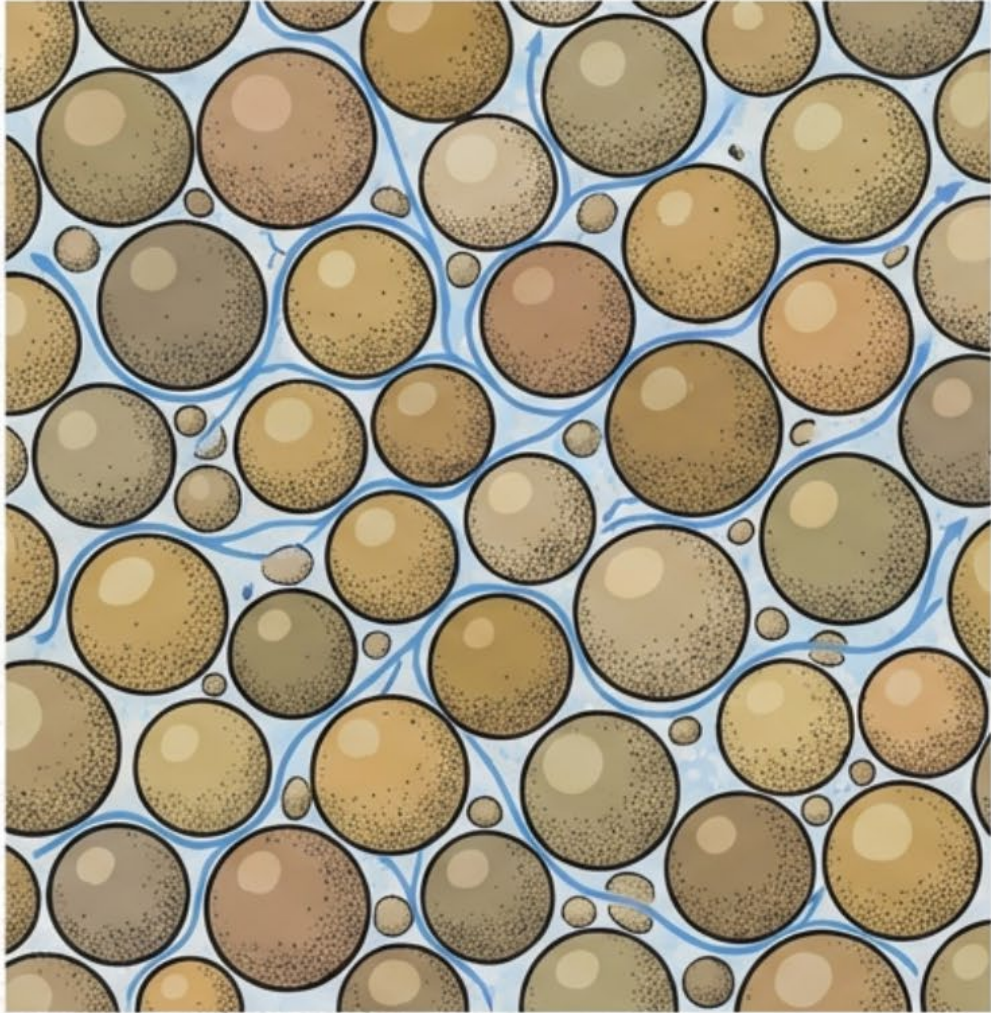
At this magnitude, water movement is **negligible on human time scales**. This is the **domain of containment**.

Application:
Liners, Cores,
Aquicludes



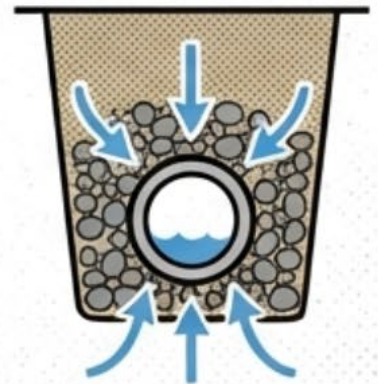
Sand: The Filter

$$K = 10^{-5} - 10^{-3} \text{ m/s}$$



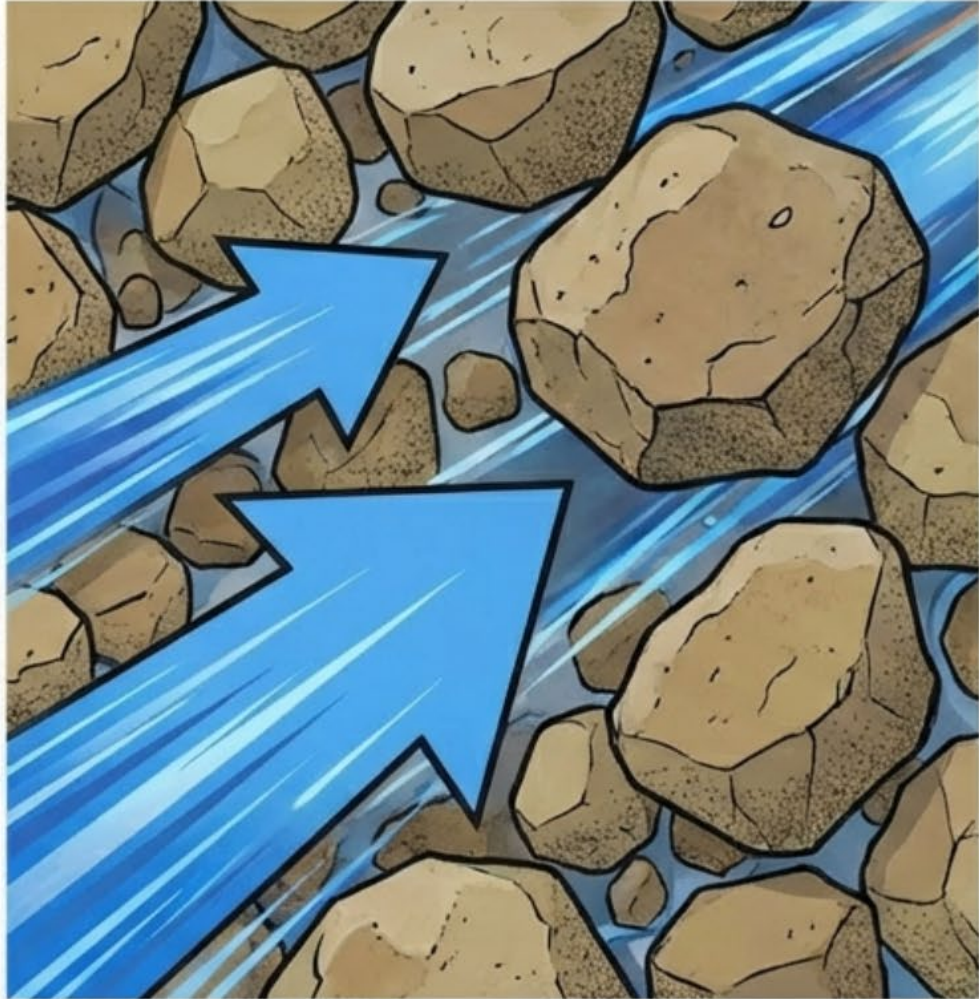
A transition zone where flow becomes a calculated active variable. The timeframe is manageable but consequential.

Application: Filtration Layers, Standard Drainage.



Gravel: The Conduit

$$K = 10^{-2} - 10^{-1} \text{ m/s}$$



High energy flow. Immediate hydraulic response. At this magnitude, the ground behaves less like a solid and more like a pipe.

Application: Rapid Recharge,
Dewatering Risk.



Material	Saturated hydraulic conductivity (ms^{-1})	Comments
Gravel	10^{-2} – 10^{-3}	Values based on “clean” soils;
Sand	10^{-3} – 10^{-5}	variation in k_{sat} based on particle size distribution
Silt	10^{-5} – 10^{-8}	Variation in k_{sat} based on mineralogical composition of silt particles
Clay	10^{-8} – 10^{-12}	Variation in k_{sat} based on mineralogical composition of clay particles
Geosynthetic clay liner	10^{-10} – 10^{-11}	Values based on sodium bentonite sandwiched between two geotextiles
Sand–bentonite mixture	10^{-9} – 10^{-10}	Values based on a mixture of clean sand (w/o fines) and 4–10% (w/w) sodium bentonite

Speed of Groundwater

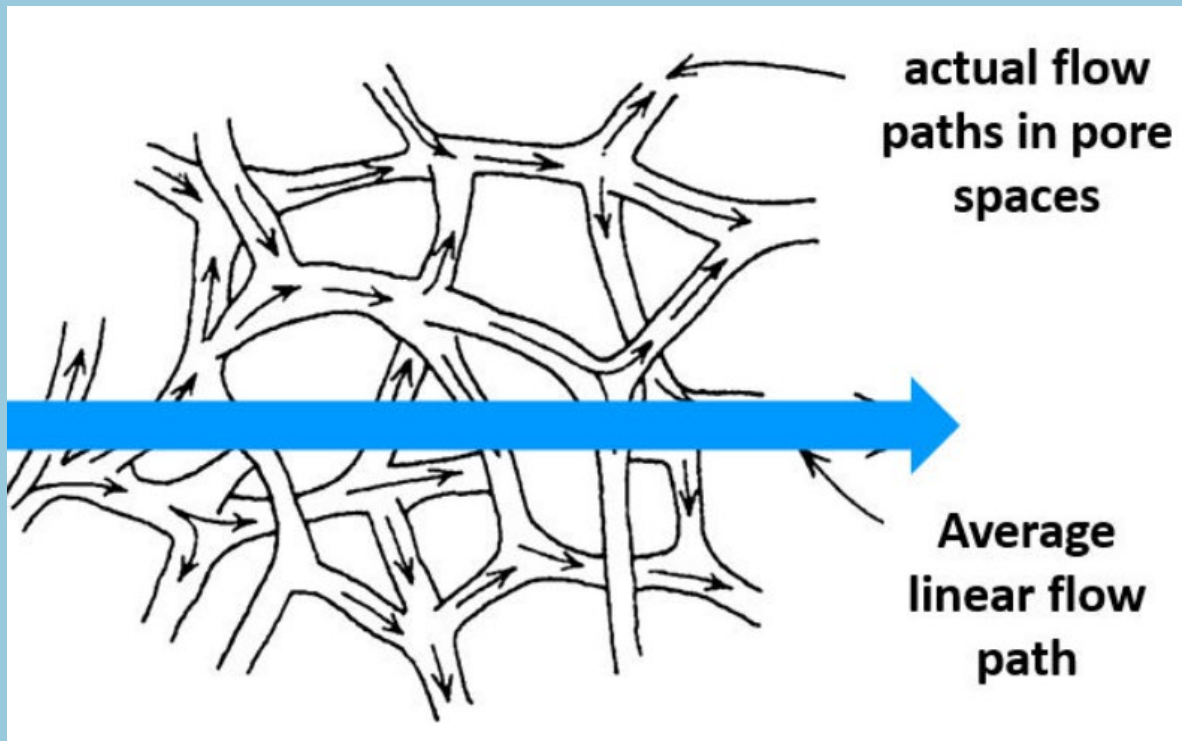
- But what if we're not interested in the volume , but how fast that water is flowing?



Speed of Groundwater

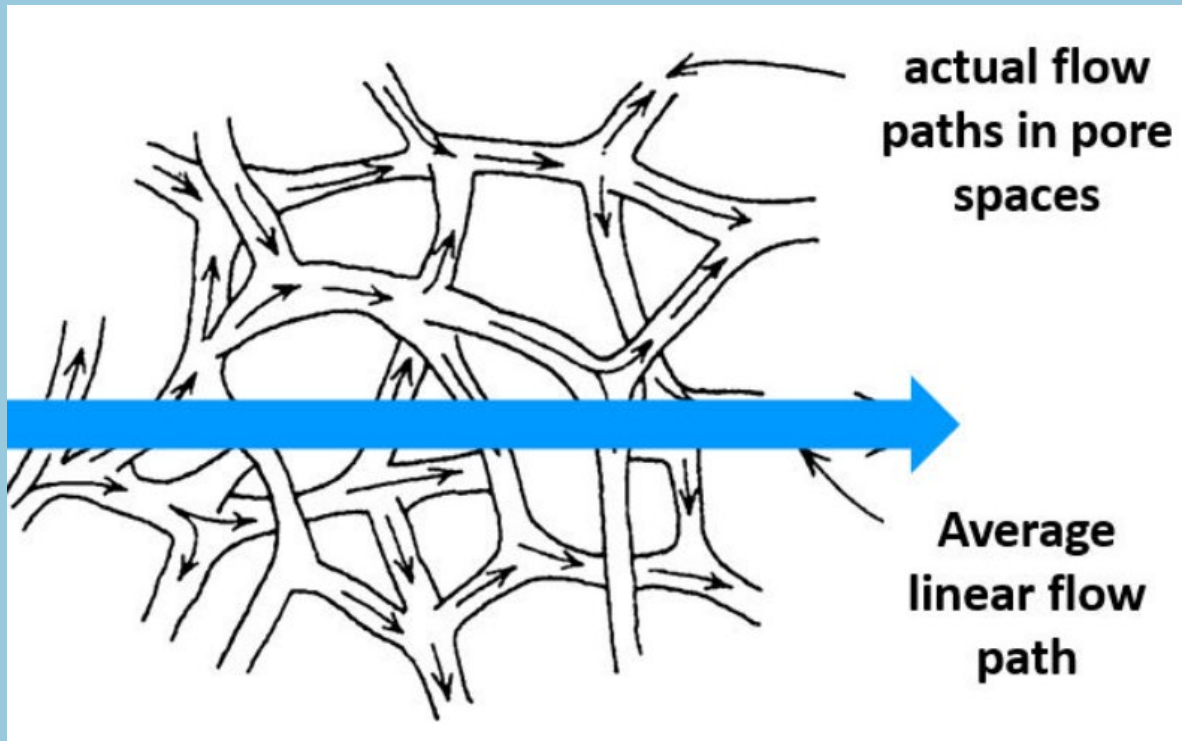
- But what if we're not interested in the volume , but how fast that water is flowing?
- This question may arise , if a potentially harmful substance has entered groundwater and is travelling towards a borehole.

Apparent Velocity



- In an aquifer we use the idea of apparent velocity.
- Apparent velocity refers to the speed at which a fluid appears to move through a porous medium, calculated as if it were flowing through the entire cross-sectional area of the medium (like soil or rock), including both solid and pore spaces

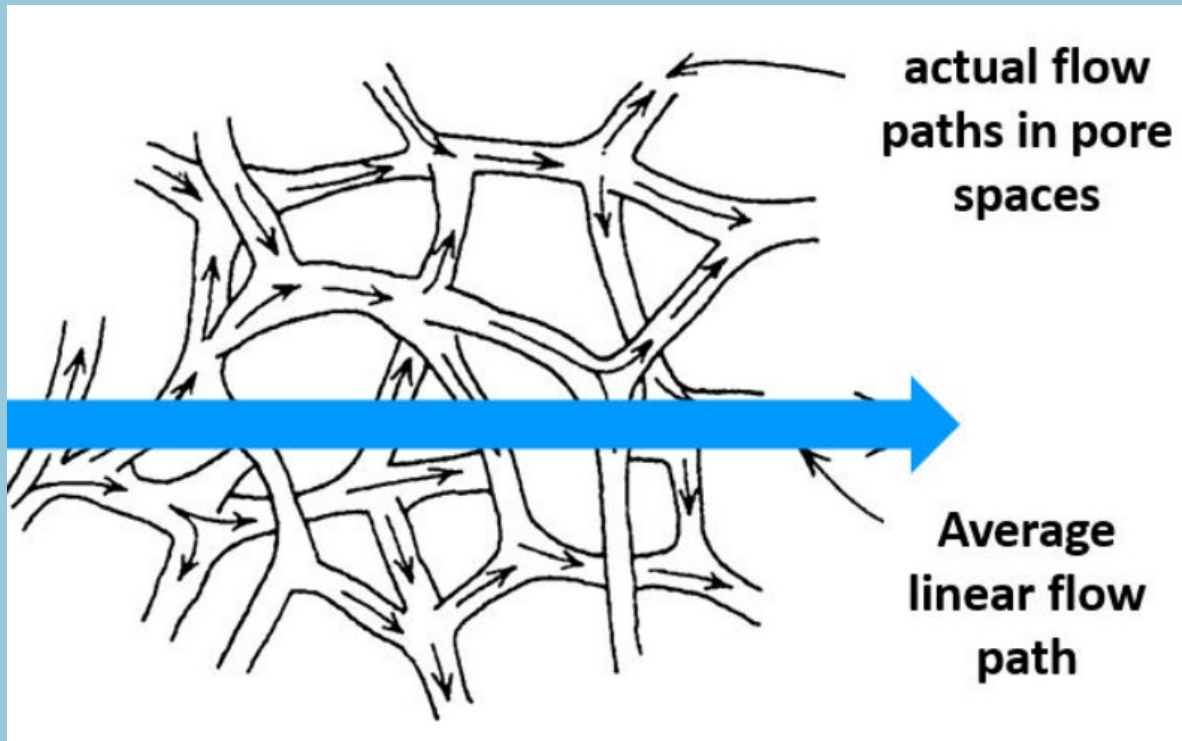
Apparent Velocity



This apparent velocity is given the symbol, q and is called Specific Discharge.

$$q = \frac{Q}{A}$$

Apparent Velocity

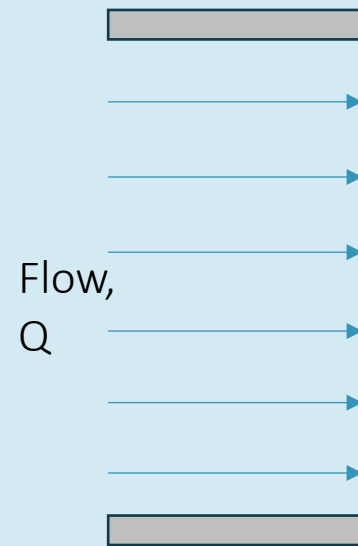


We can then re-write Darcy's Law as:

$$q = -ki$$

- Although these are the same units as velocity, q is not the true speed of groundwater.
- This is because A , the cross-sectional area is of the whole of the aquifer, however the water is only moving through the pore space.

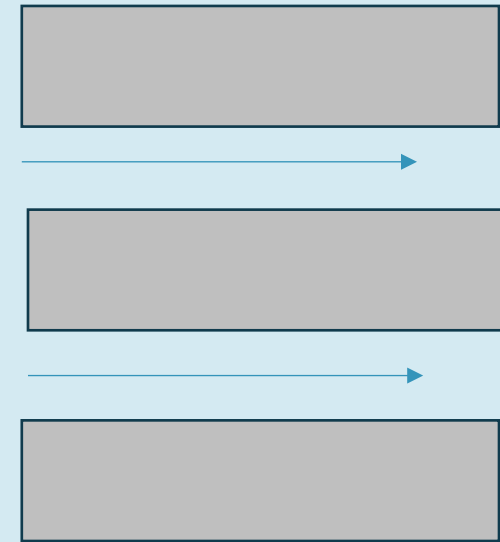
- For the same flow rate to occur through a smaller cross-sectional area, the flow speed must increase.
- If the flow speed through area, A_1 is q , when the total area is available for flow, then the flow speed through the reduced area A_2 will have to be v (speed of flow).



Flow speed q
through A_1

Area,
 A_1

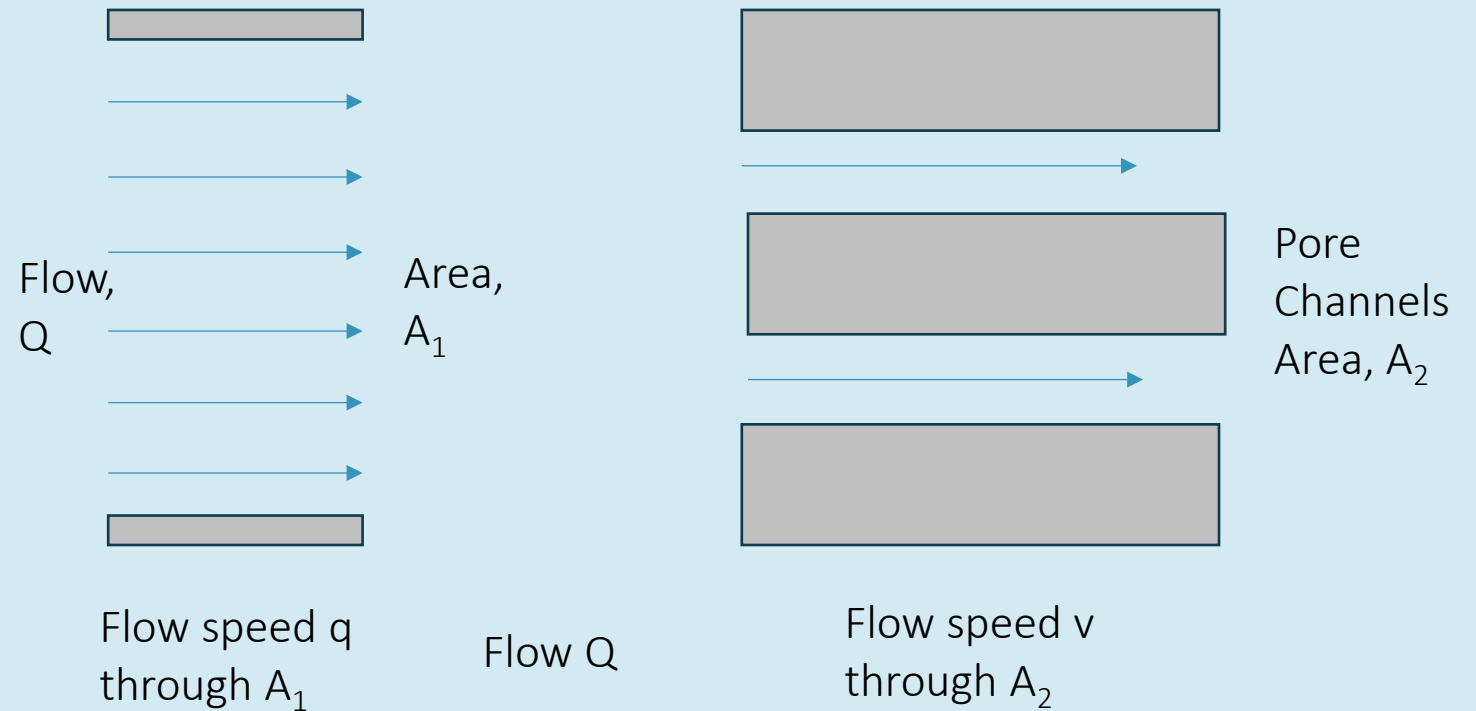
Flow Q



Flow speed v
through A_2

$$qA_1 = vA_2 = Q$$

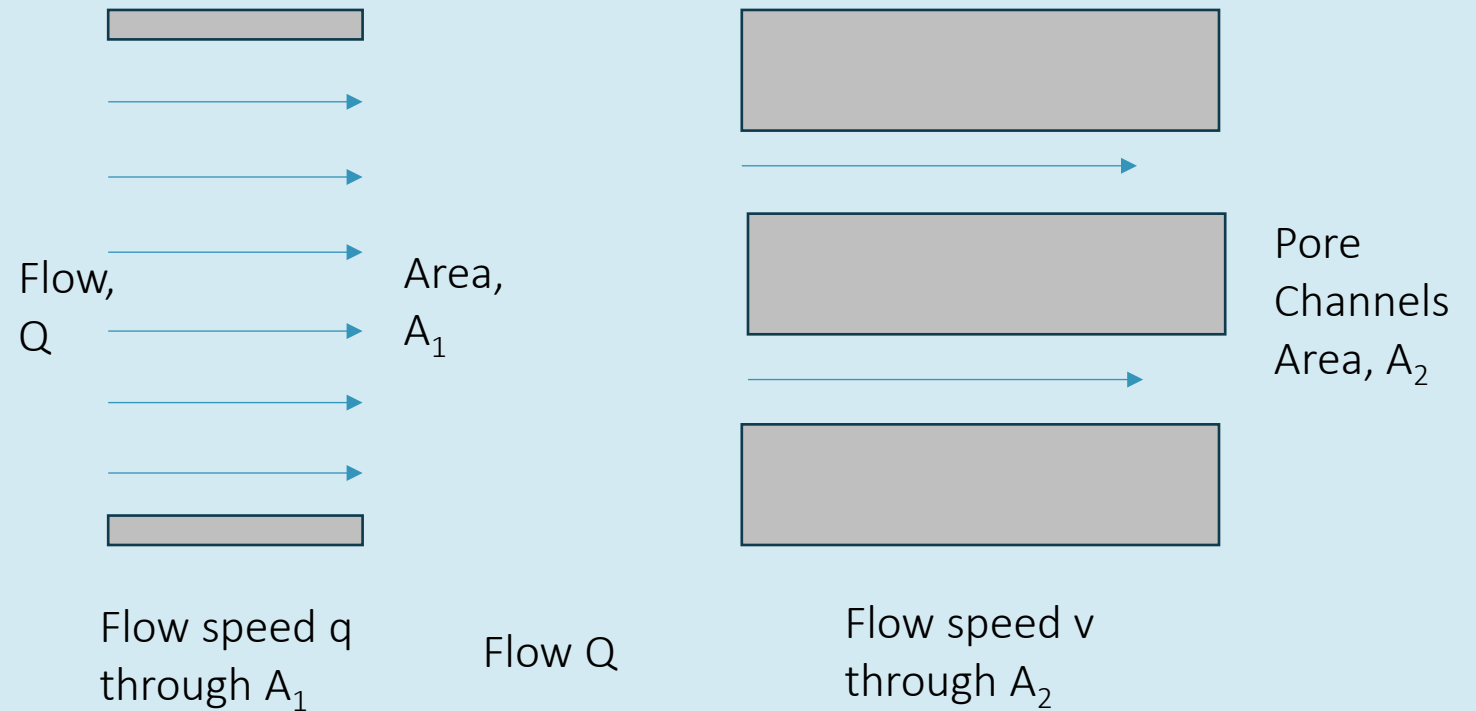
- The ratio A_2/A_1 is the same as the ratio of volume of the pores to total volume.



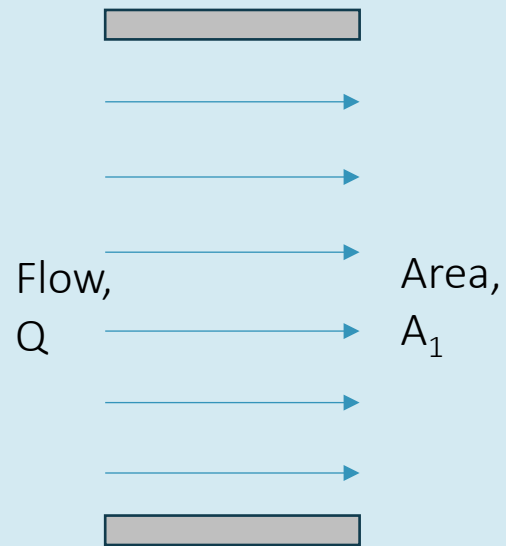
$$qA_1 = vA_2 = Q$$

- The ratio A_2/A_1 is the same as the ratio of volume of the pores to total volume.

POROSITY

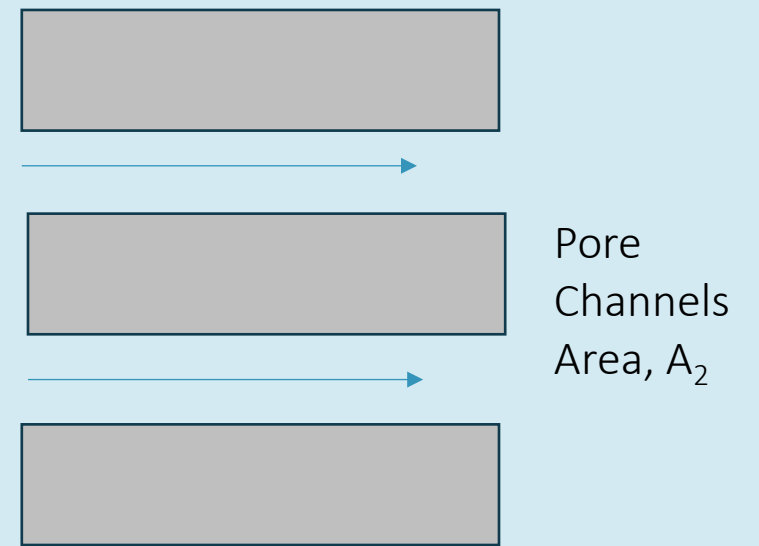


$$v = \frac{Q}{A_2} = \frac{Q}{nA_1} = \frac{q}{n}$$



Flow speed q
through A_1

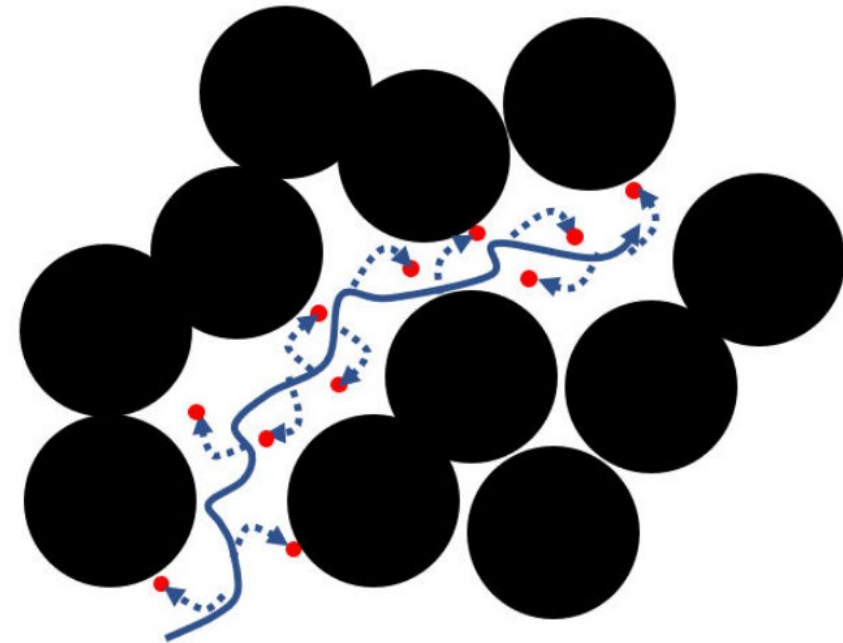
Flow Q



Flow speed v
through A_2

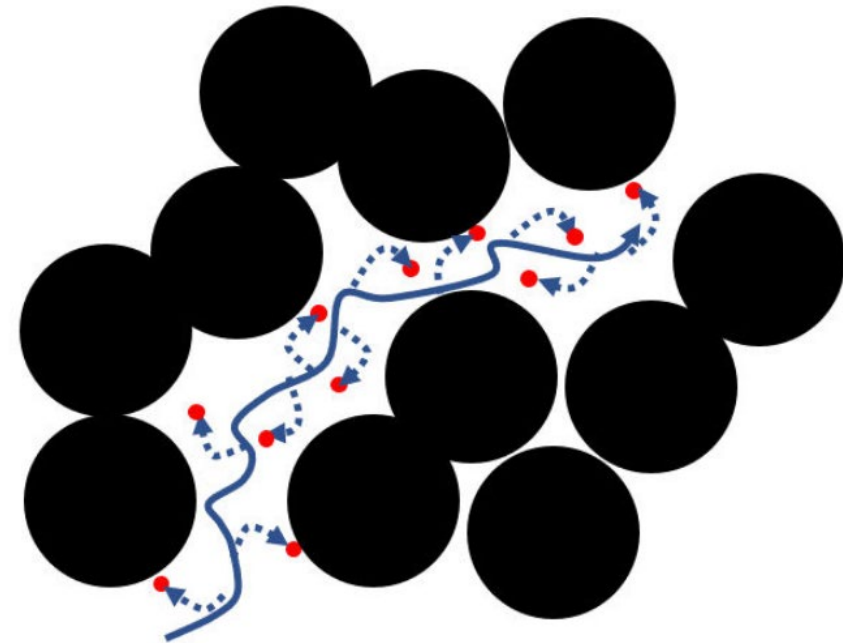
In an aquifer the pores are not neat cylindrical tubes but much more variable, plus not all pores will be flow paths.

The water also will not make full use of the width of the pore channels due to a boundary layer around the grains.



The effect of this means we need to talk about mean flow speed – the flow speed that would occur if the pores were all the same size.

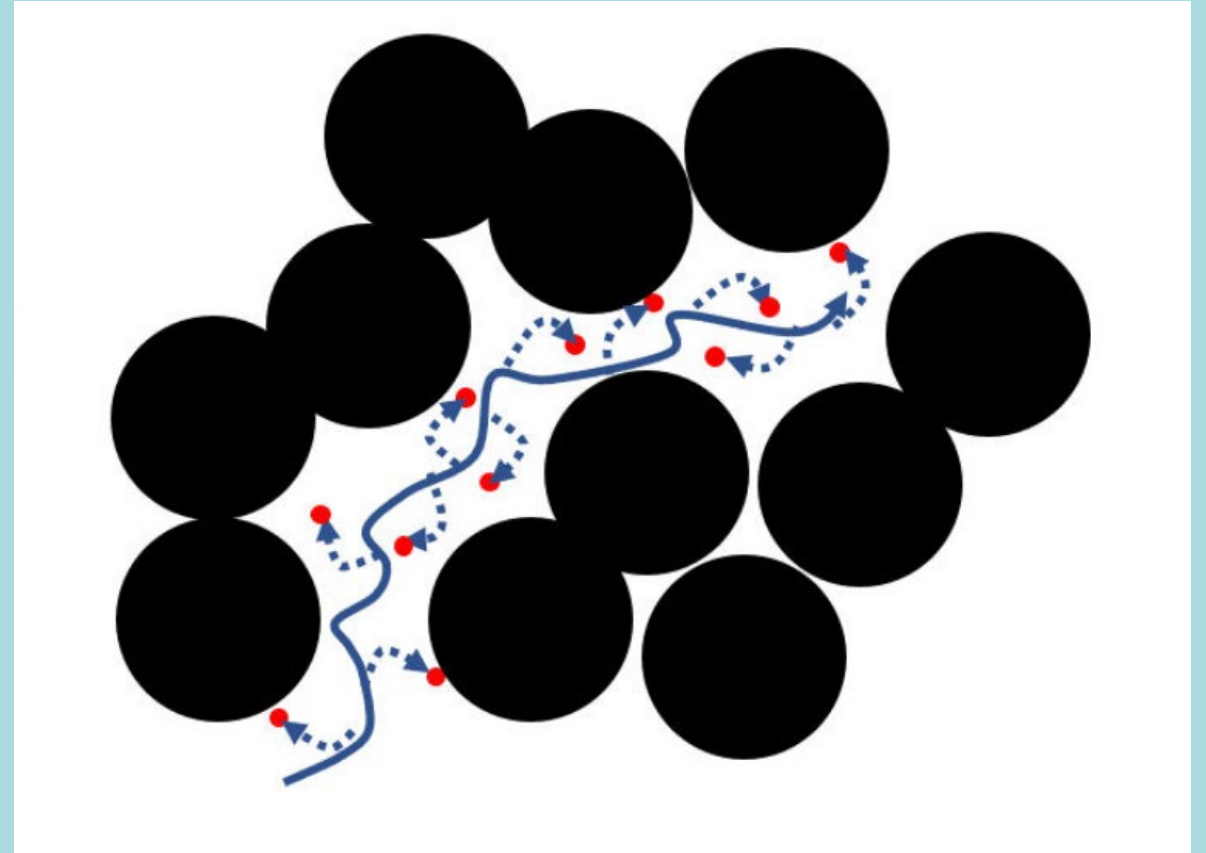
This results in a porosity slightly lower than that calculated using the porosity equation.



- The result of this is that our equation for the speed of groundwater movement becomes:

$$v_i = \frac{q}{n_d} = \frac{Ki}{n_d}$$

- Where v_i is the average speed of groundwater movement
- n_d is the kinematic (or dynamic) porosity





ANISOTROPY AND HETEROGENEITY

Flow prefers horizontal paths and high-permeability sand seams over vertical or clay-heavy routes.