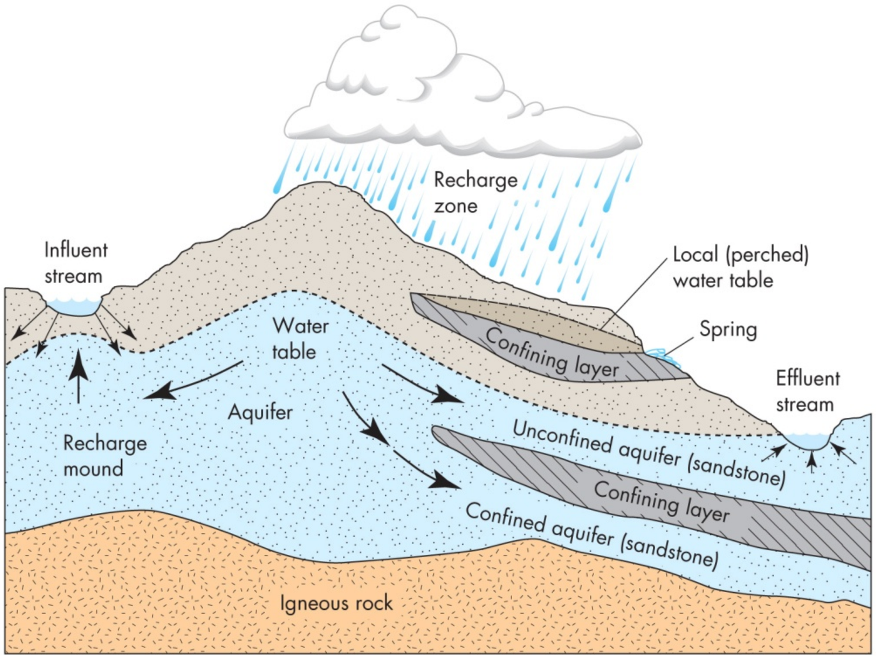
Lecture 20: Groundwater Introduction

Key Questions for Groundwater

1. What is an aquifer?
2. What is an unconfined aquifer?
3. What is groundwater recharge?
4. What is porosity? What determines the magnitude of porosity?
5. What causes groundwater to move?
6. What quantifies the hydraulic gradient?
7. What is hydraulic conductivity?
8. What is Darcy's Law?



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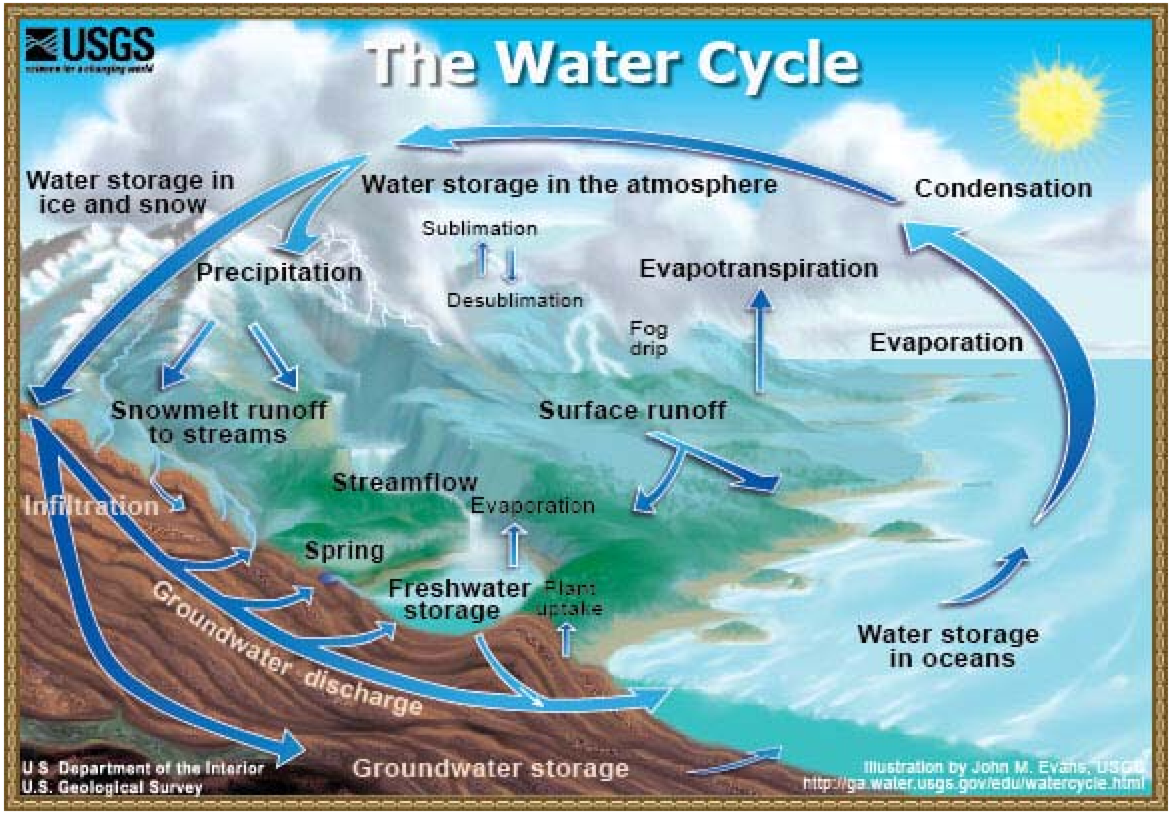
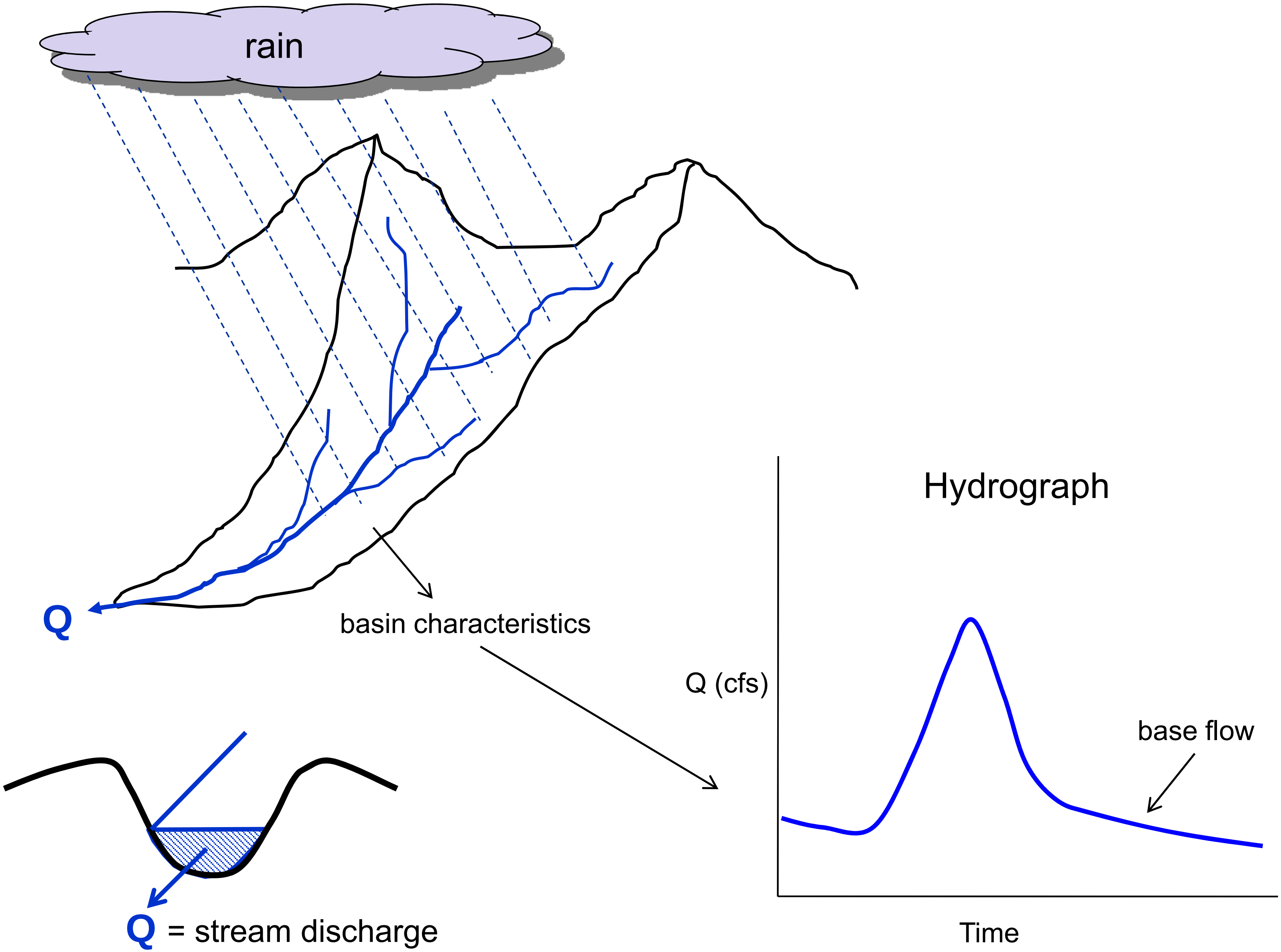
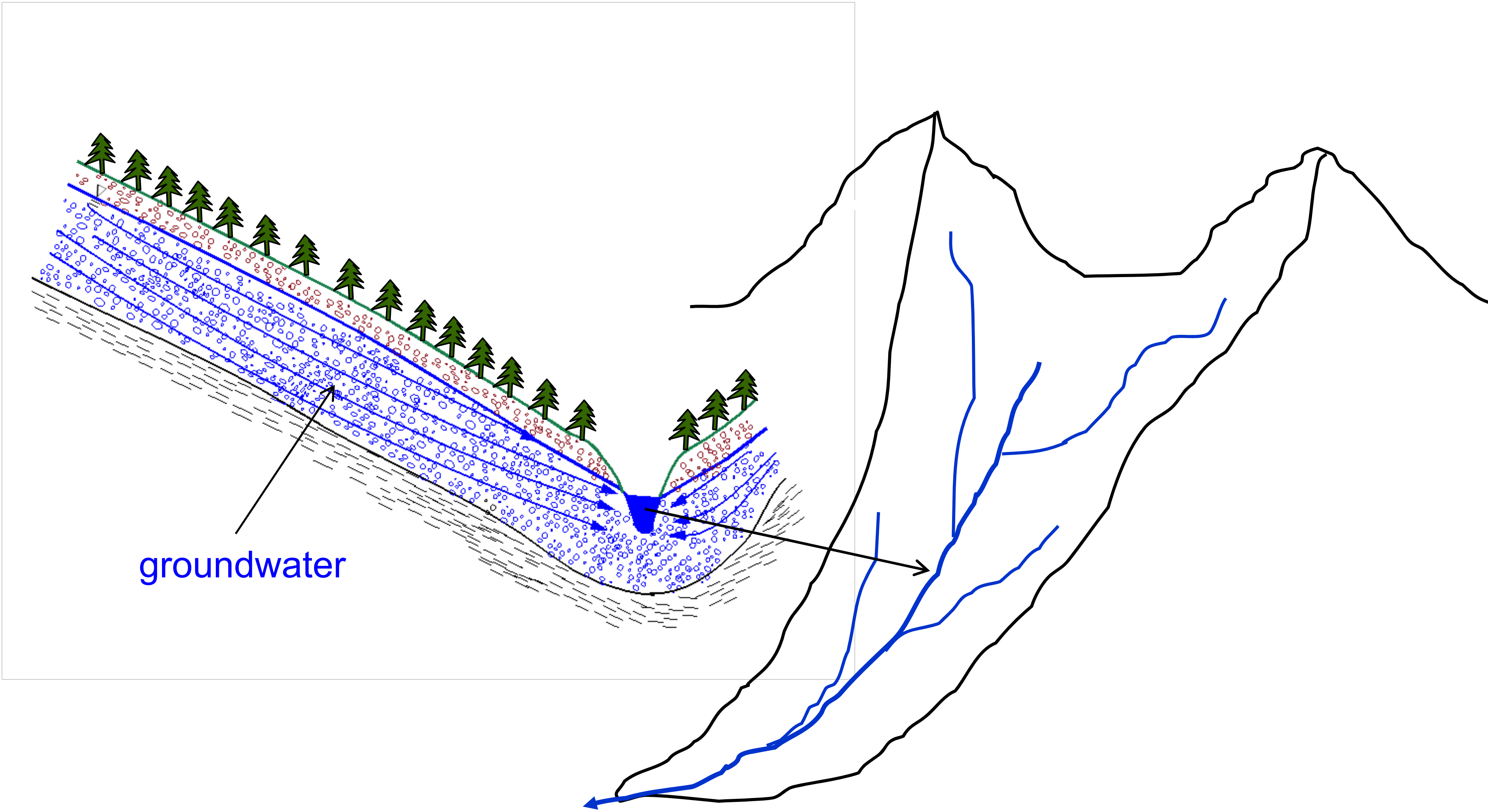
The **Hydrologic (or water) Cycle** describes the distribution of water among the oceans, land and atmosphere.

Read the Groundwater Discharge section

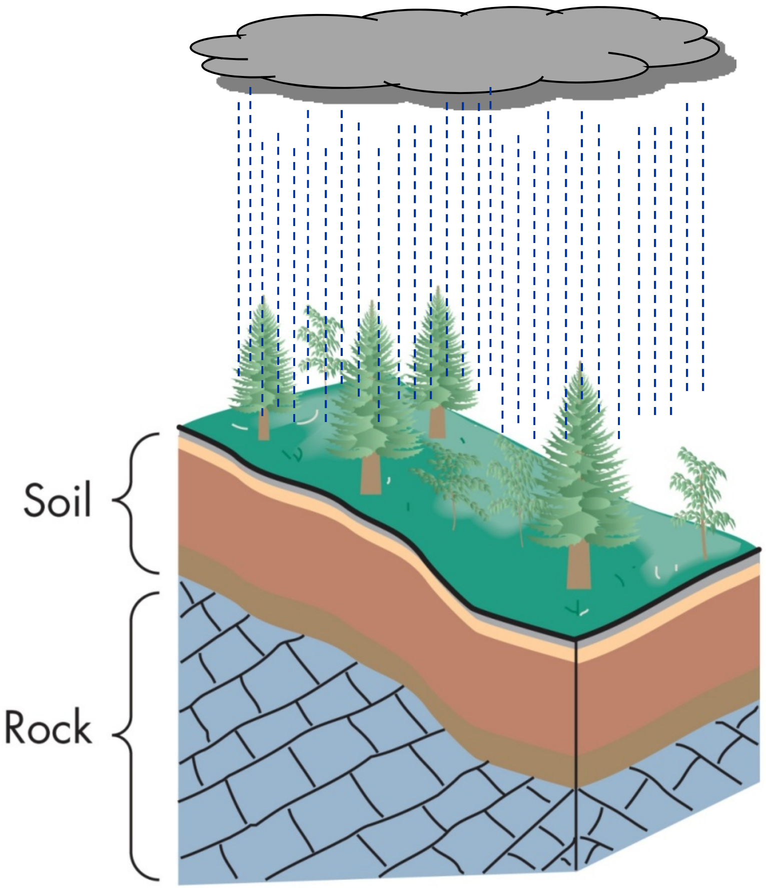



rain
Q
basin characteristics
Hydrograph
Q (cfs)
base flow
Time
Q = stream discharge

Groundwater supports streamflow in between rain events (baseflow)



Infiltration (and runoff) is controlled by soil type, thickness, original water content, and precipitation characteristics



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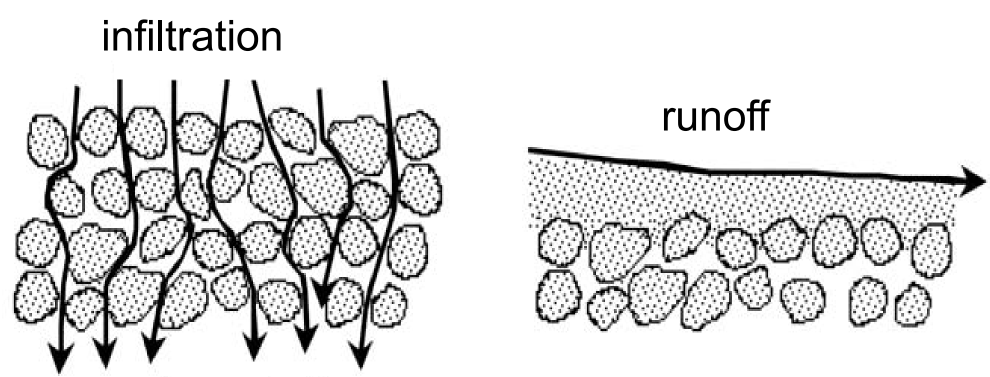
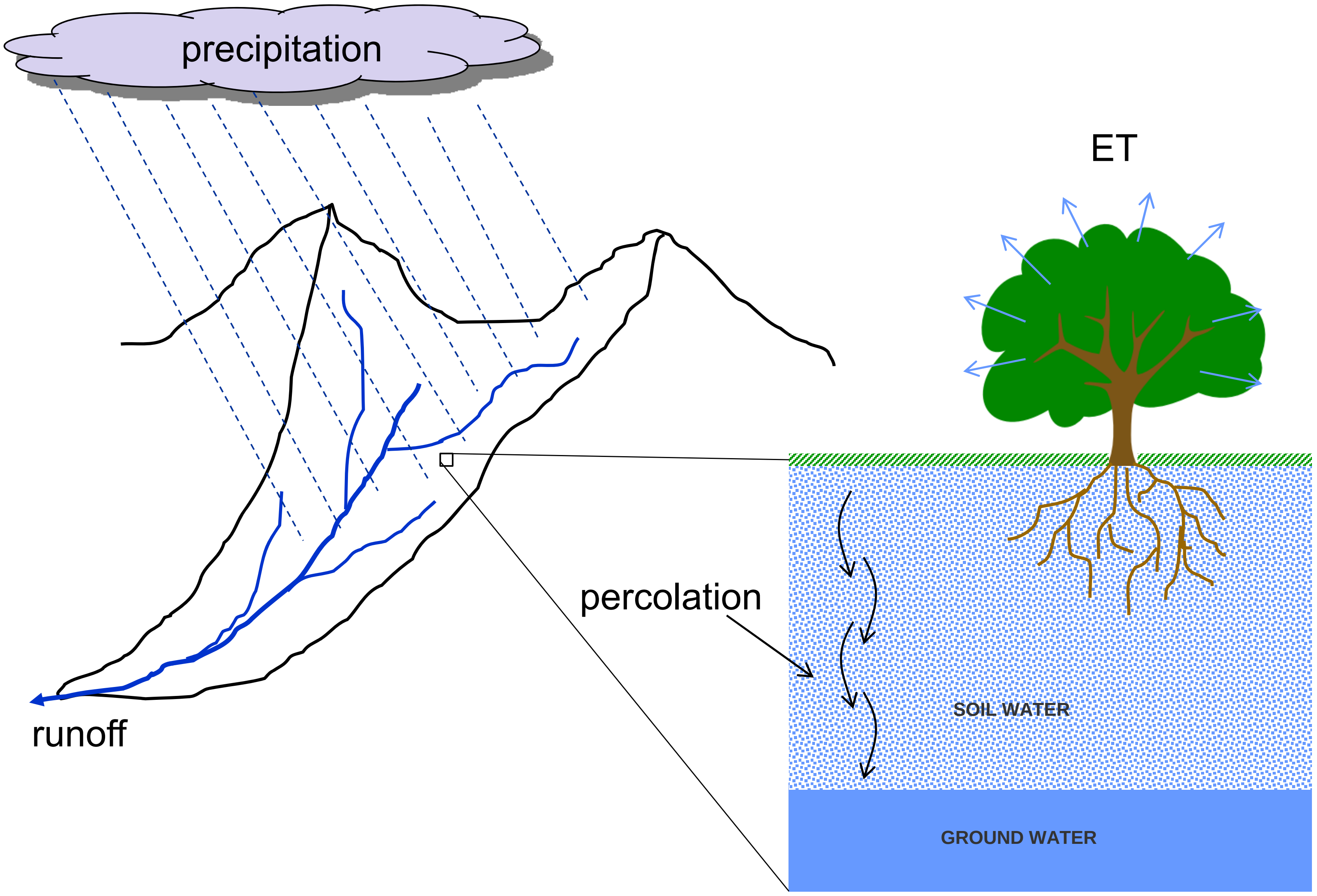
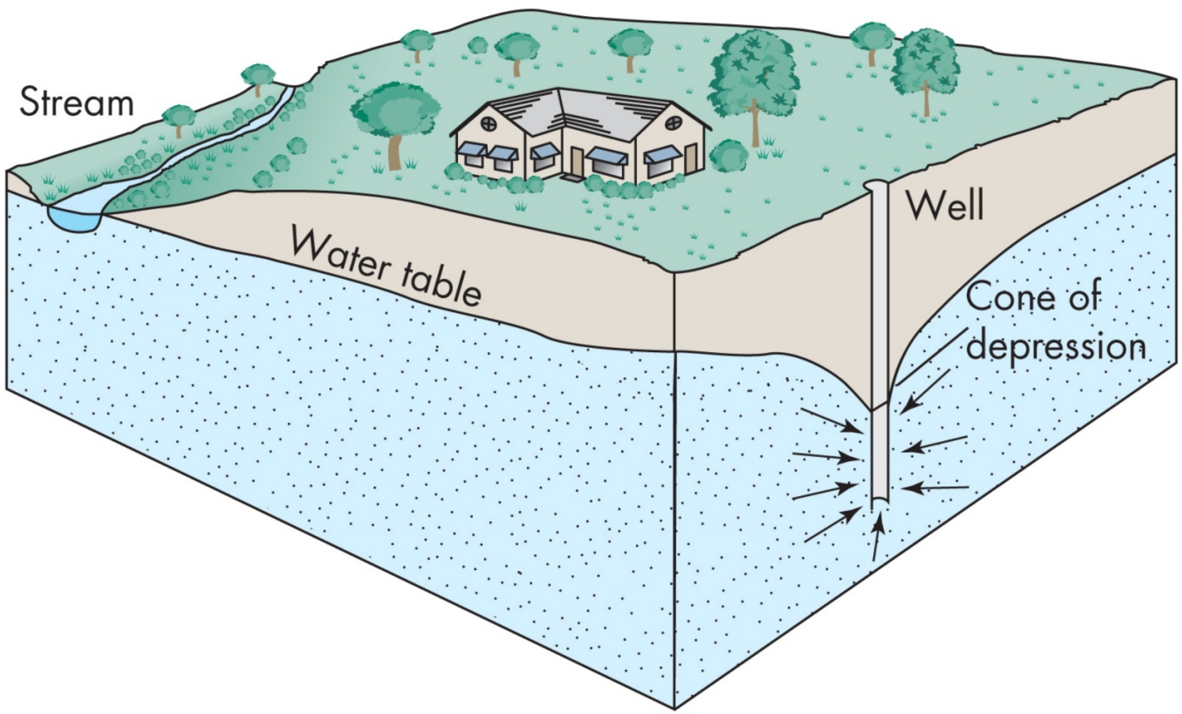




Groundwater Recharge = precipitation – evapotranspiration - runoff

An **aquifer** is a geologic unit that can store and transmit water at rates fast enough to supply reasonable amounts to wells.



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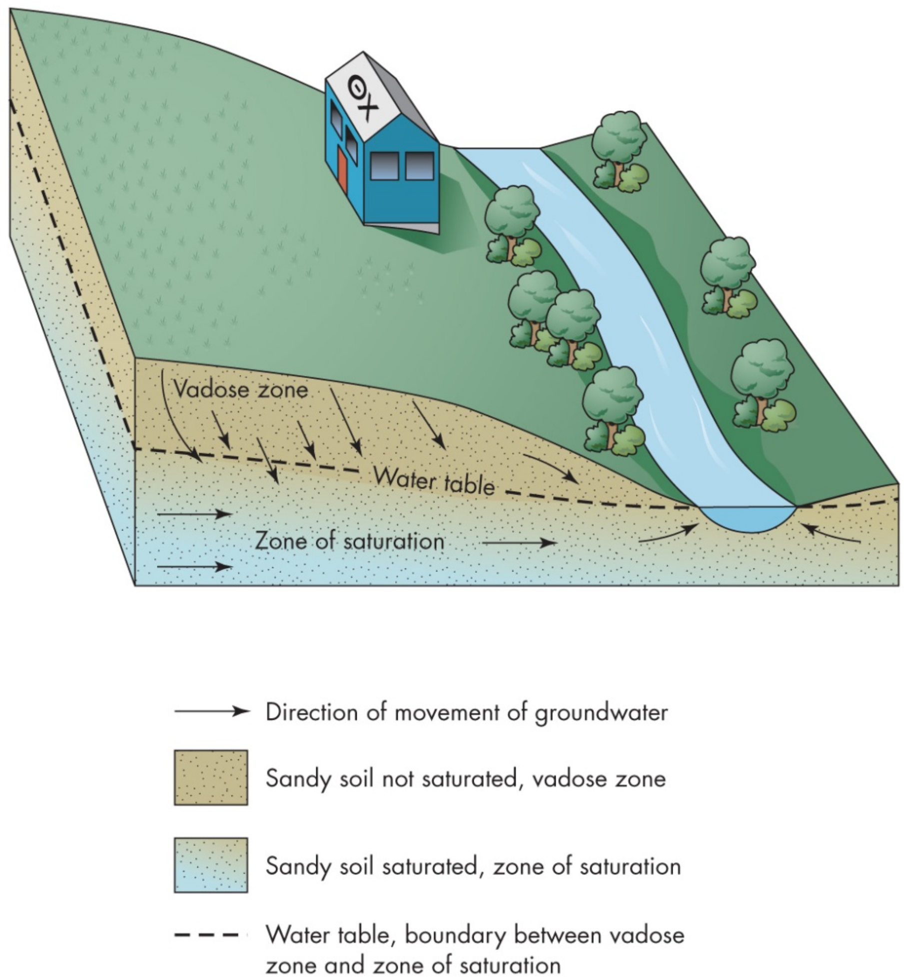
An **unconfined aquifer** is an aquifer that has the ground surface as an upper bound.



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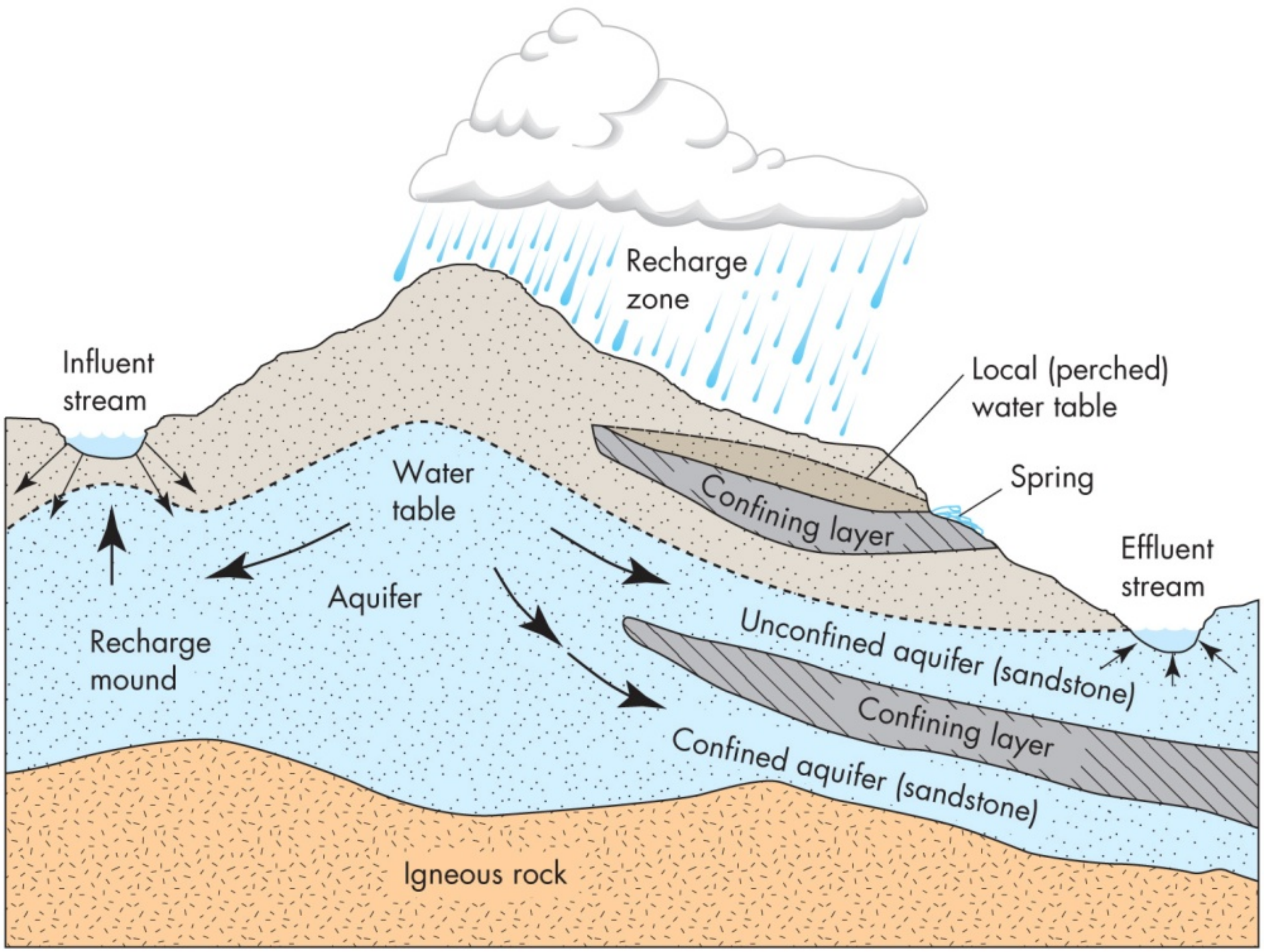
A **confined aquifer** is an aquifer that has a confining unit (low conductivity) as an upper bound and lower bound.



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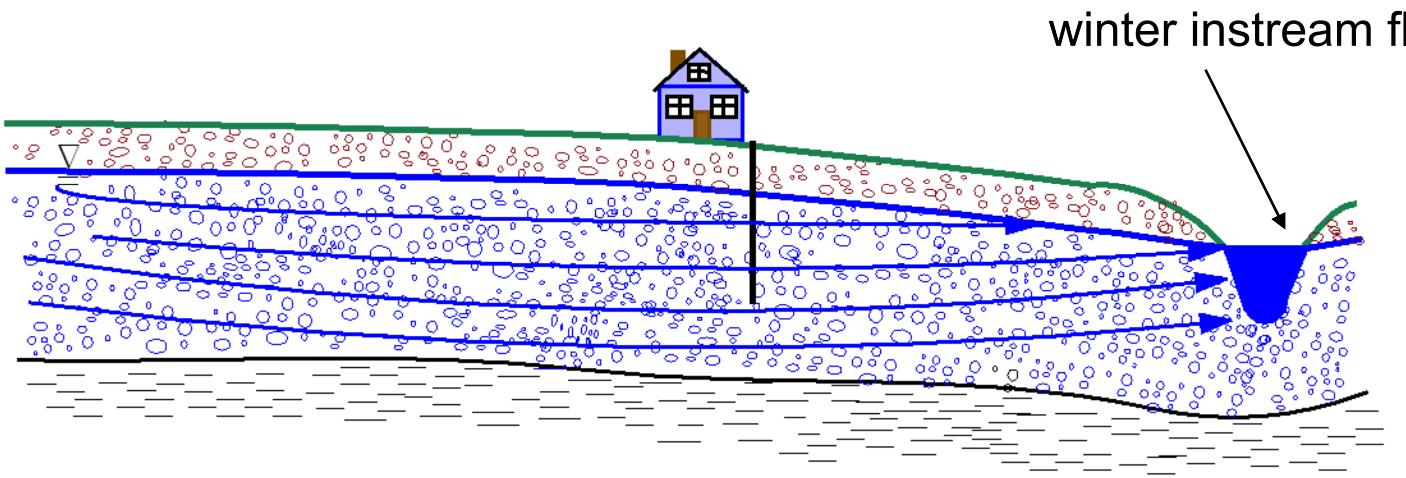
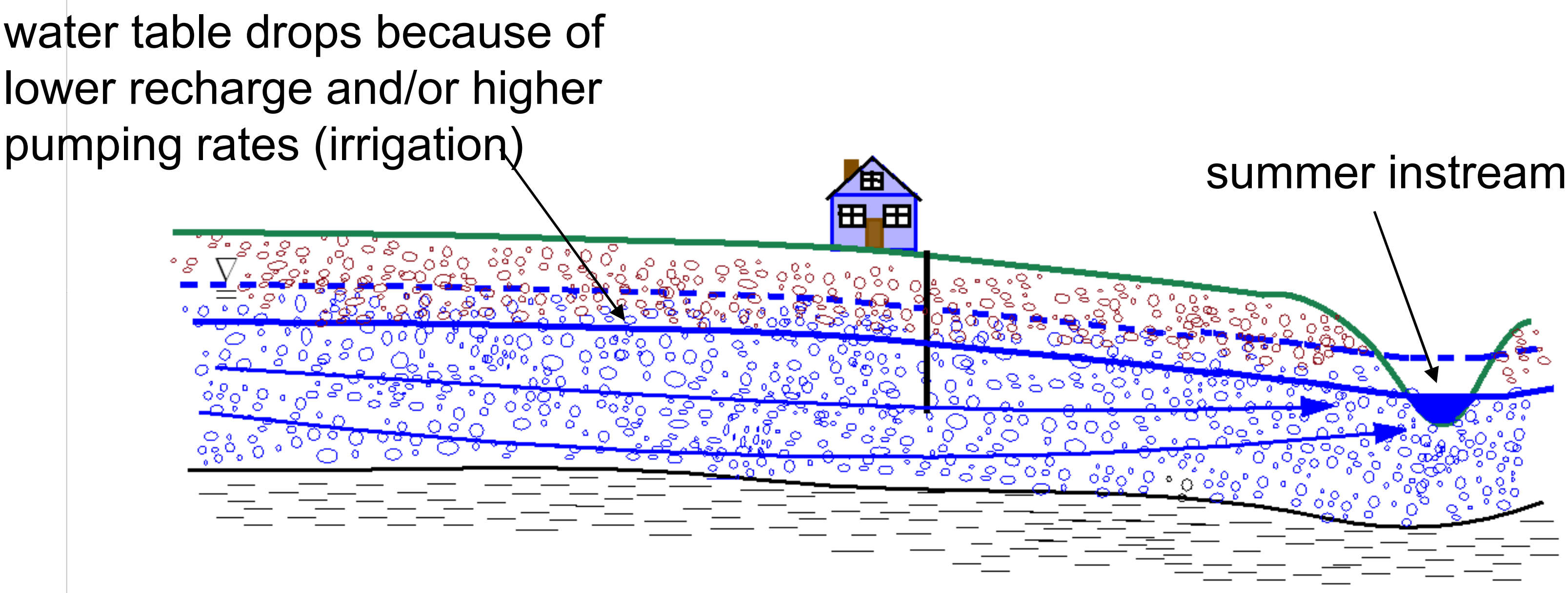
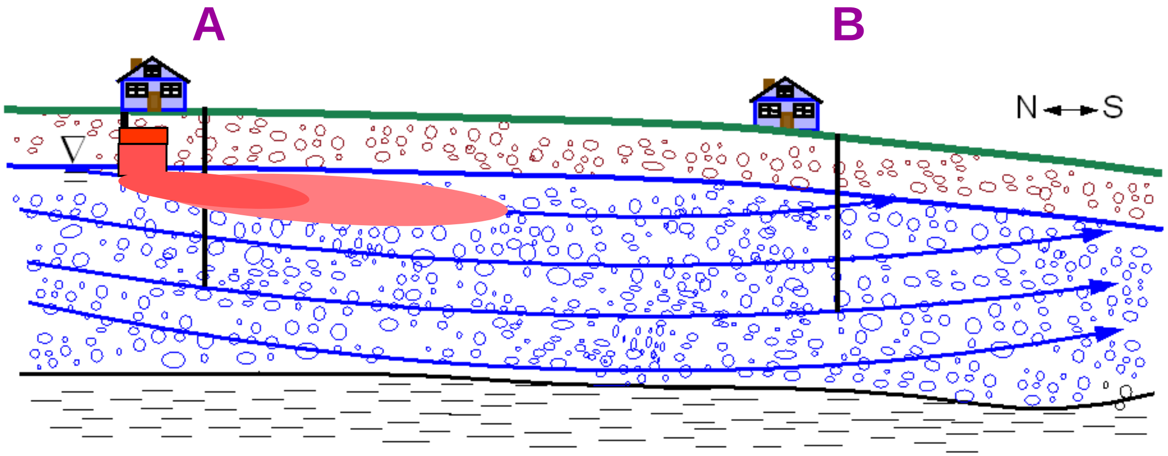
Unconfined aquifers interact with surface water streams (i.e., groundwater surface water interactions)



Groundwater surface water interactions

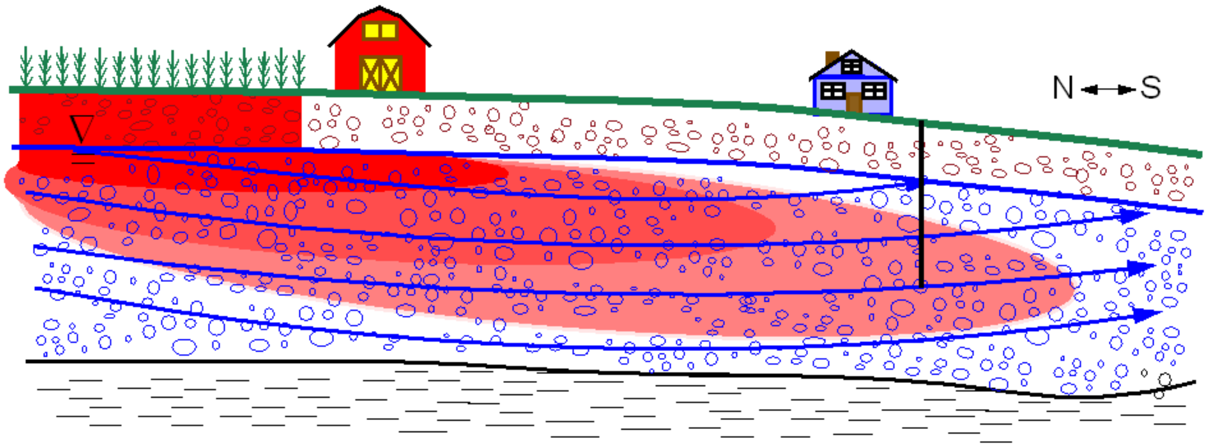


Unconfined aquifers are more susceptible to groundwater contamination

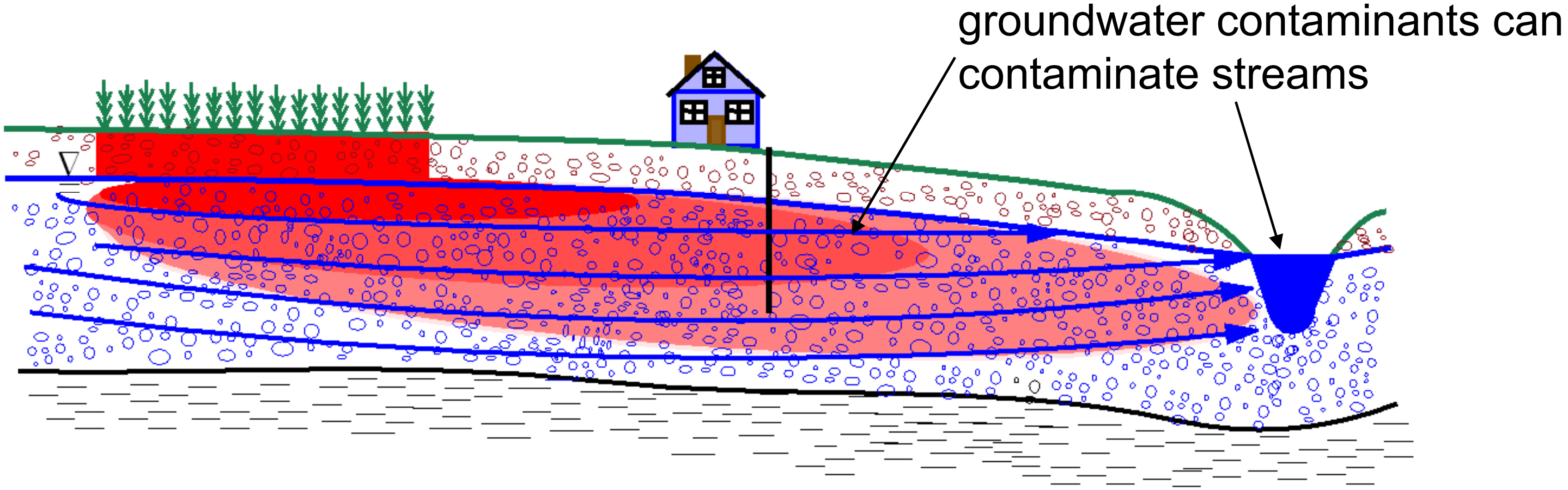


Unconfined aquifers are more susceptible to groundwater contamination.

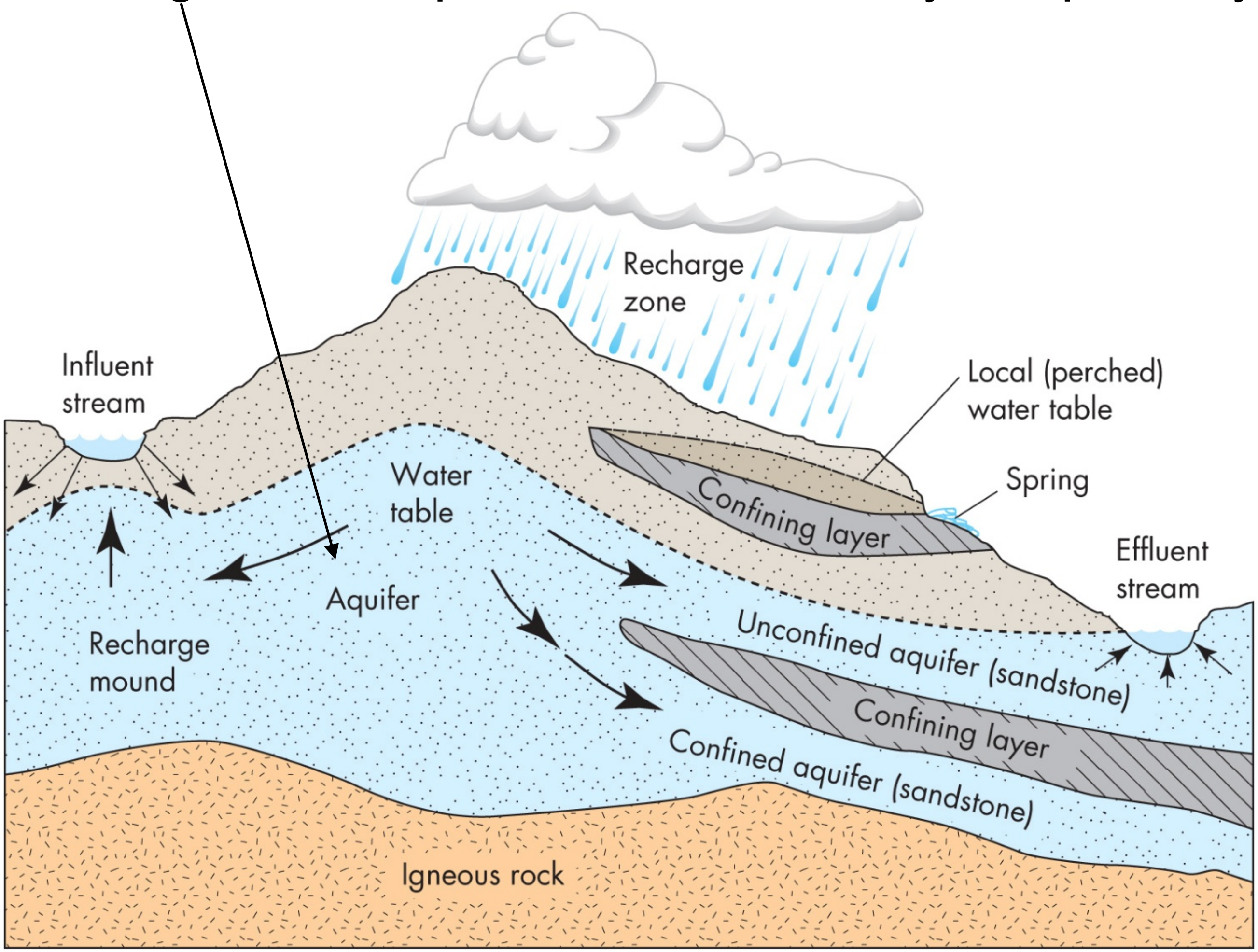
Contaminants are transported by groundwater flow



Groundwater surface water interactions



Water storage in an aquifer is controlled by the porosity



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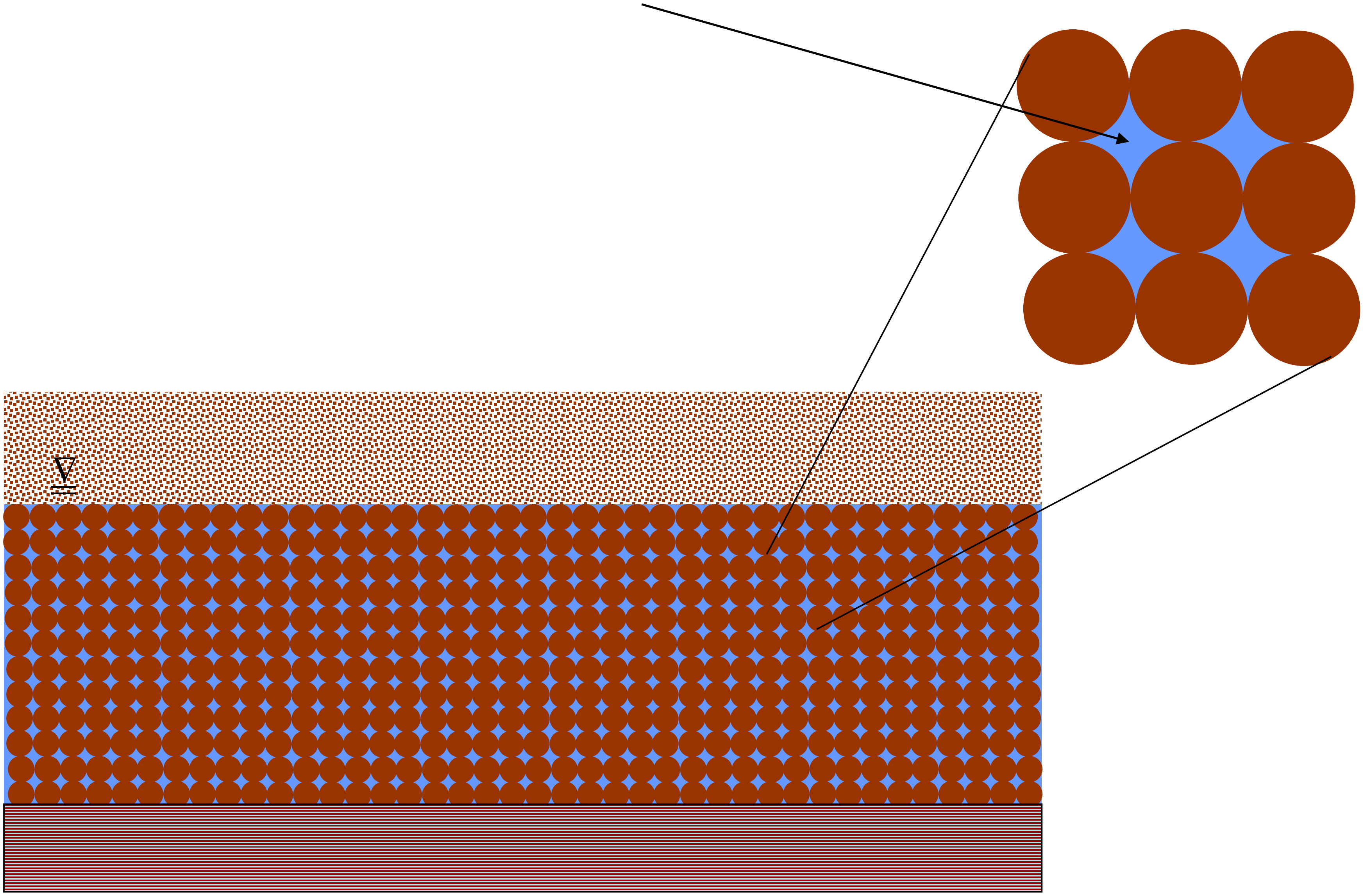
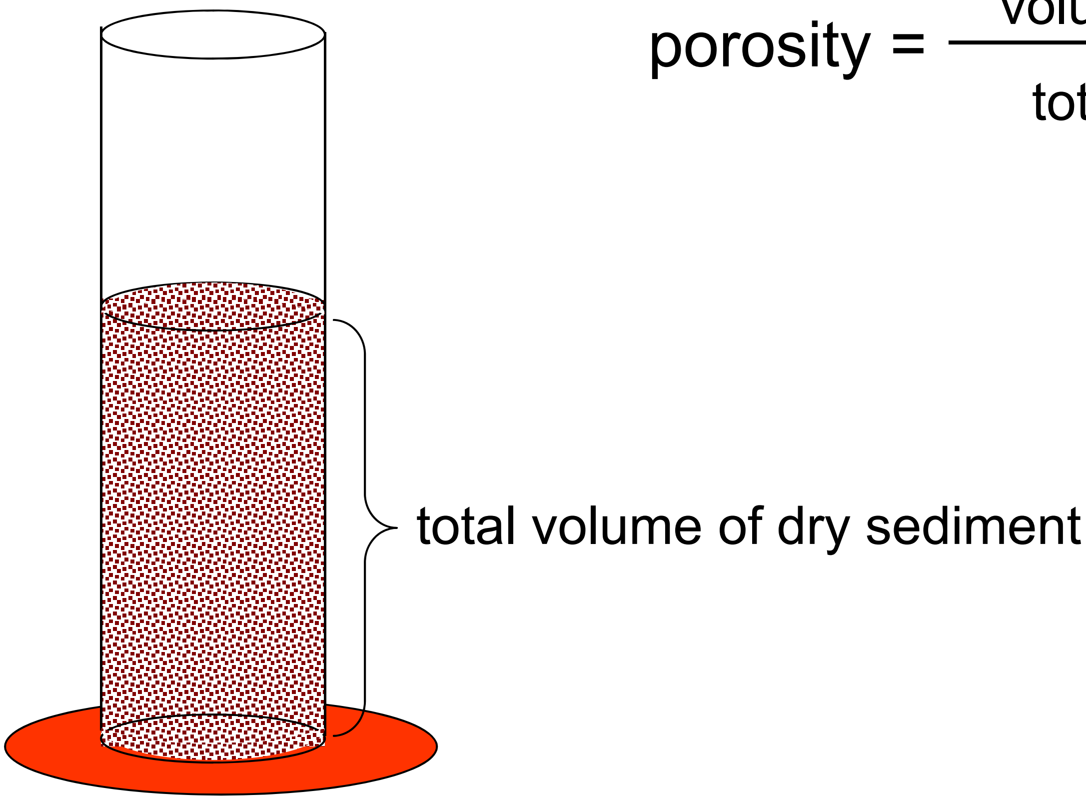
Porosity is a measure of void space in a geologic material



$$\text{porosity} = \frac{\text{volume of voids}}{\text{total volume}}$$



	Material	average Porosity (%)
Unconsolidated	Clay	50
	Sand	35
	Gravel	25
	Gravel and sand	20
Rock	Sandstone	15
	Dense limestone or shale	5
	Granite	1

What controls the magnitude of porosity?

1. Grain shape and packing

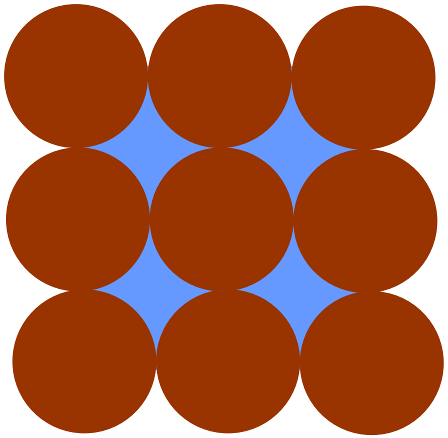
2. Grain-size distribution

3. Degree of compaction

4. Degree of cementation

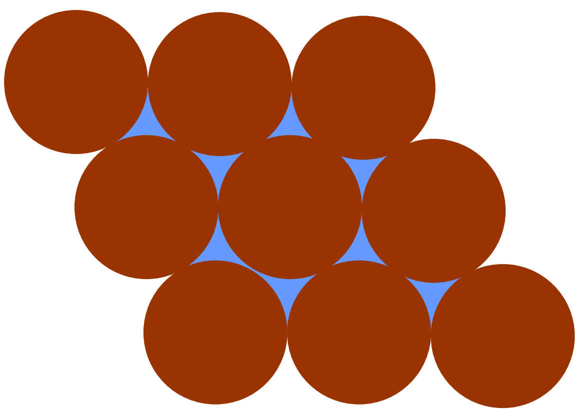
1. Grain Packing

cubic packing (loosest possible packing)



porosity = n = 47.64%

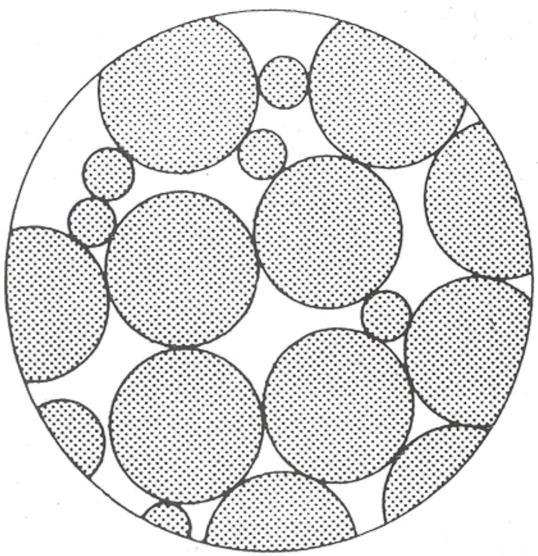
rhombohedron packing (tightest possible packing)



porosity = 25.95%

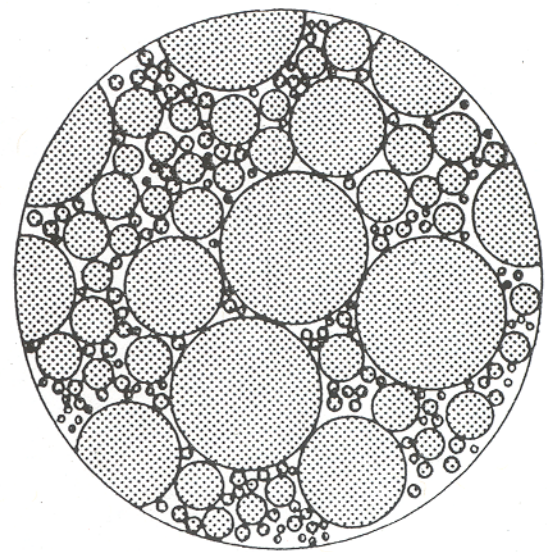
2. Grain-Size Distribution

uniform grain sizes



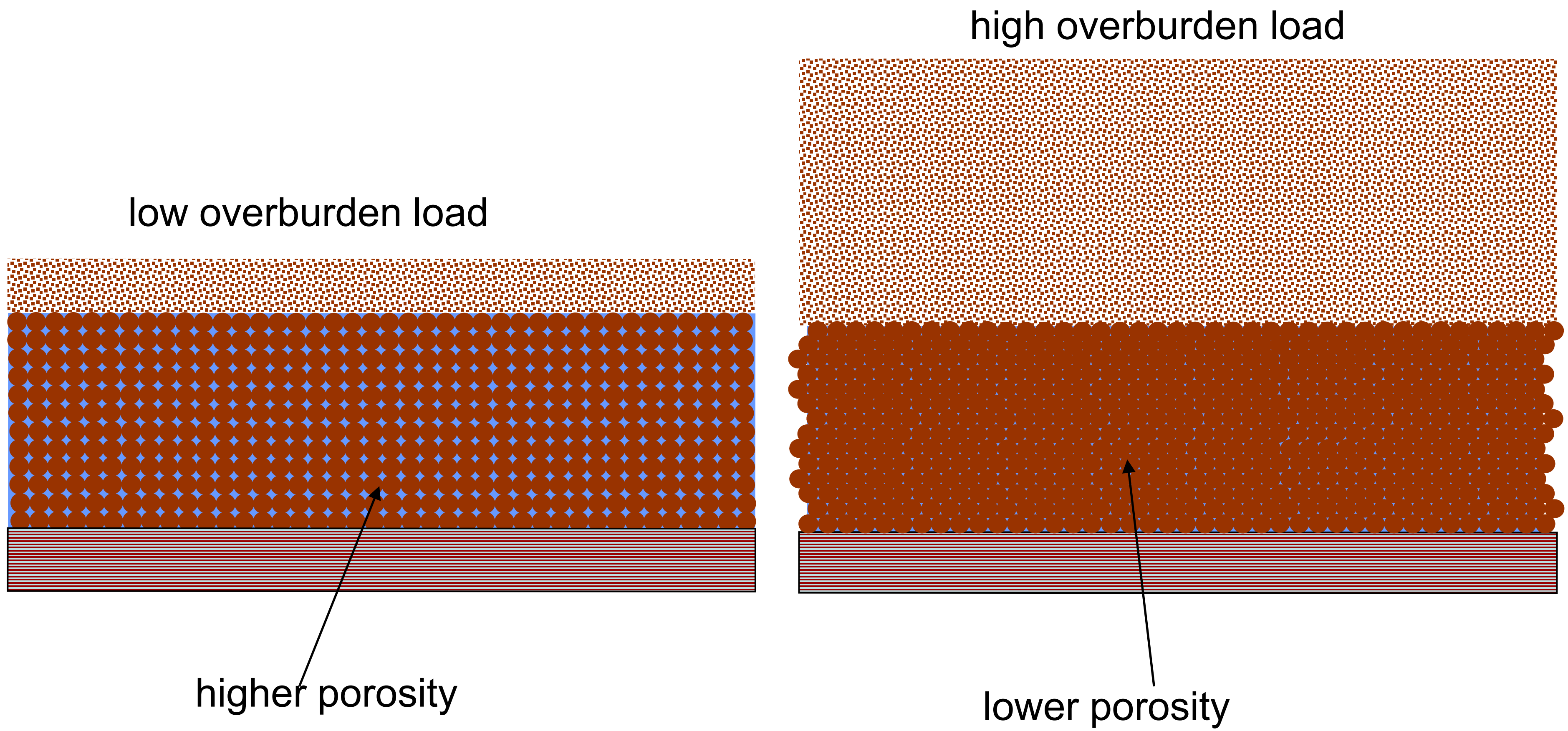
porosity ≈ 40%

mixture of grain sizes



porosity ≈ 25%

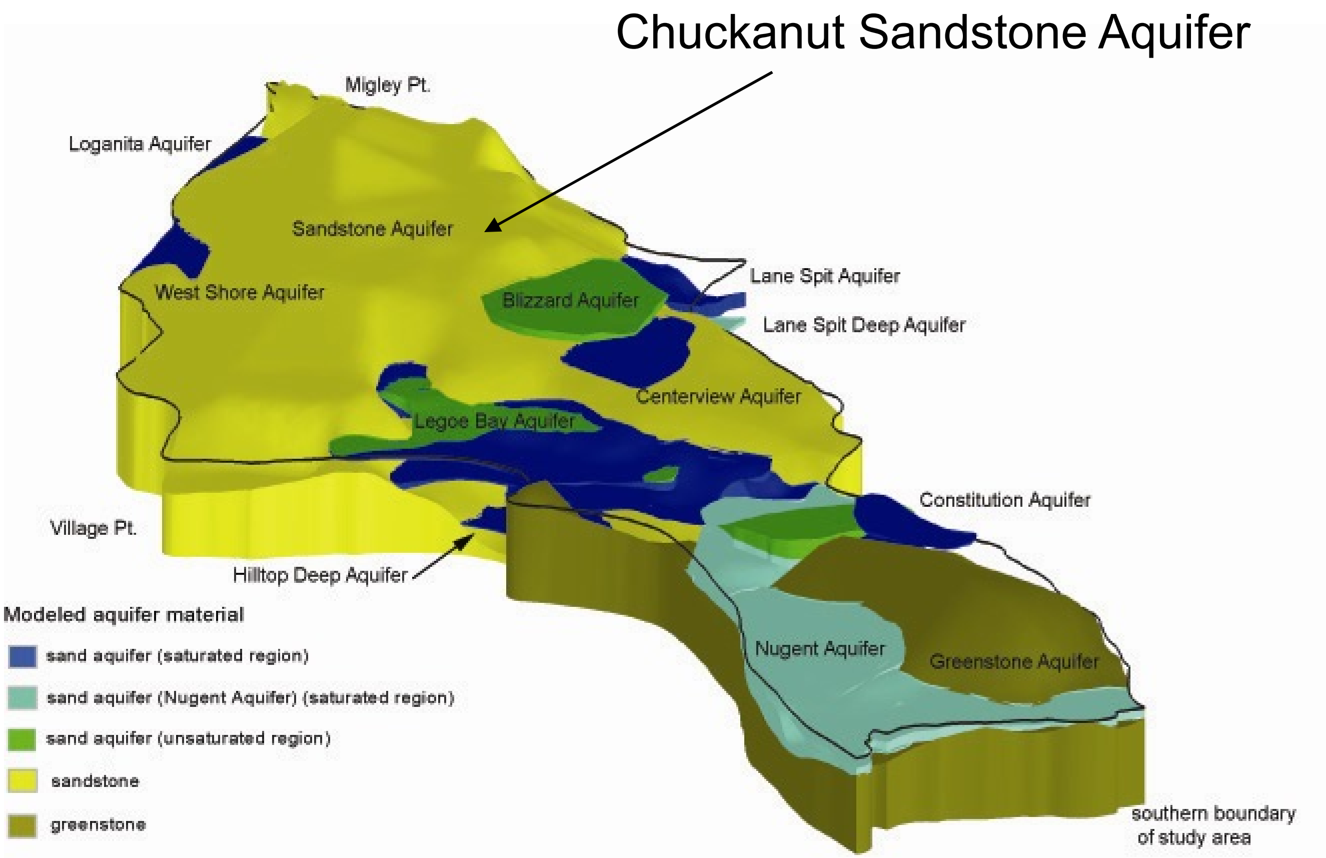
3. Degree of Compaction



4. Degree of Cementation

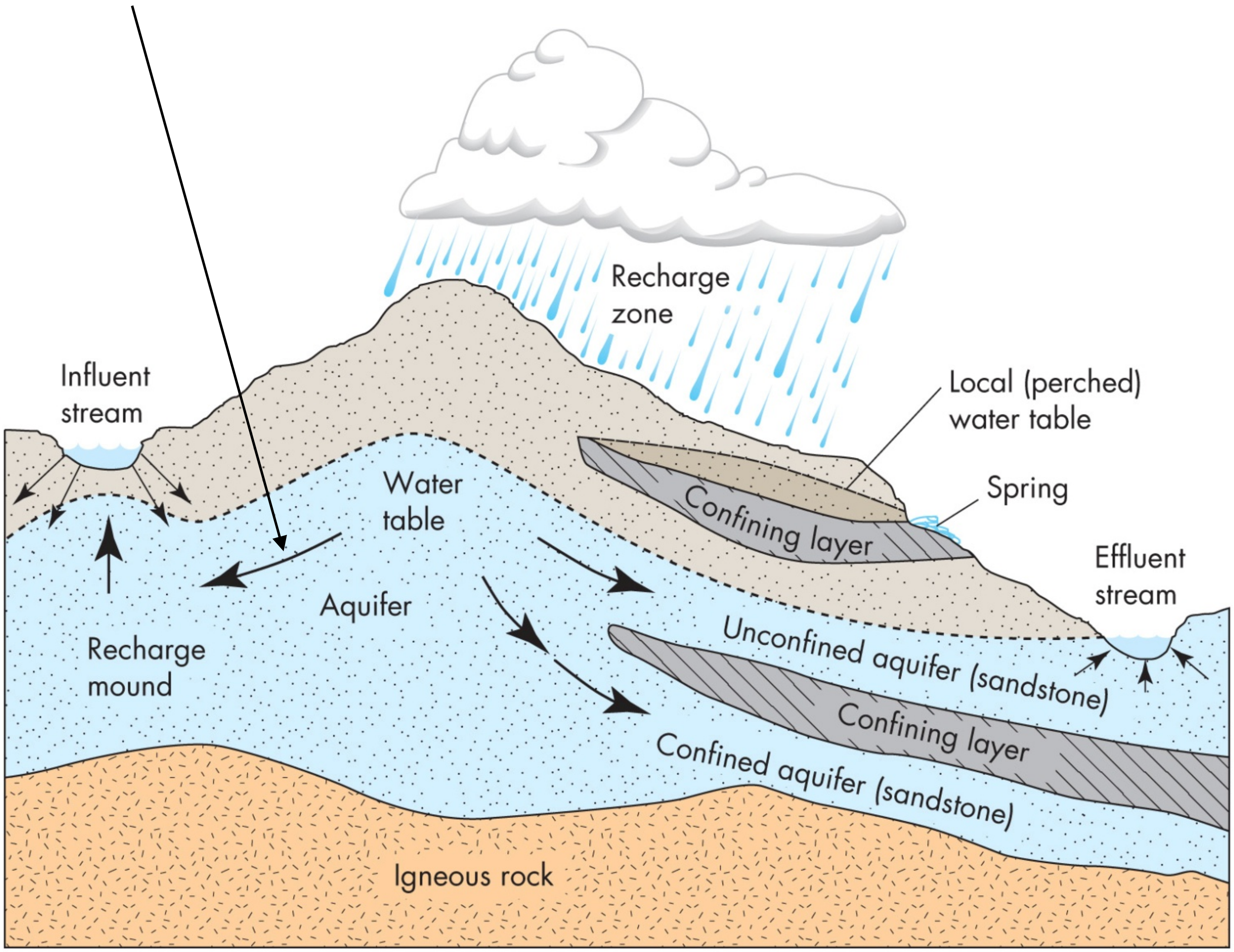
Calcite and silica cements can bind minerals together and hence, reduce porosity

4. Degree of Cementation



Lummi Island Aquifers

What controls groundwater movement?



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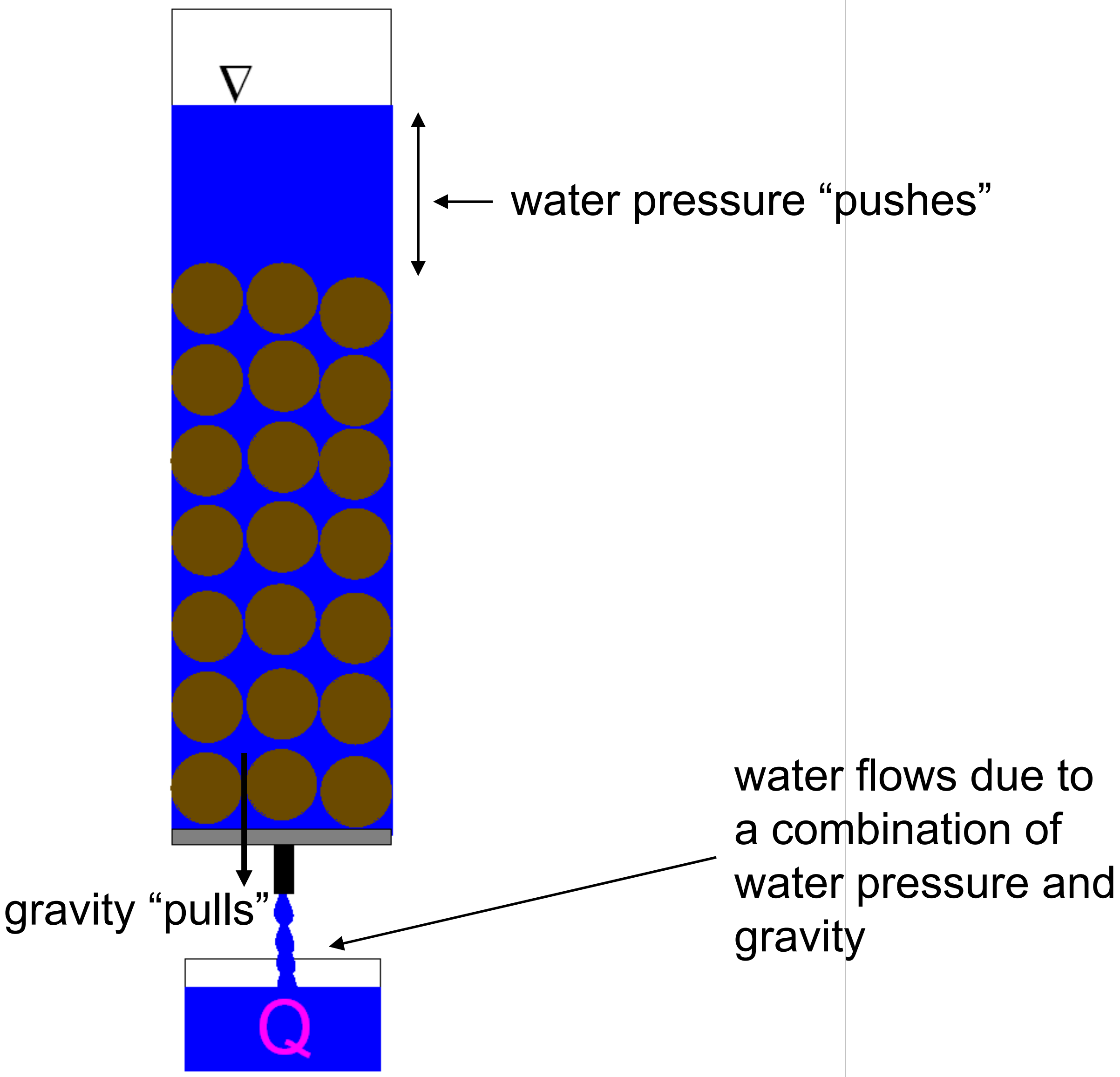
Groundwater movement depends on

1. The type of geologic material
    - porosity
    - hydraulic conductivity

2. Energy gradients caused by
    - water pressure
    - gravity



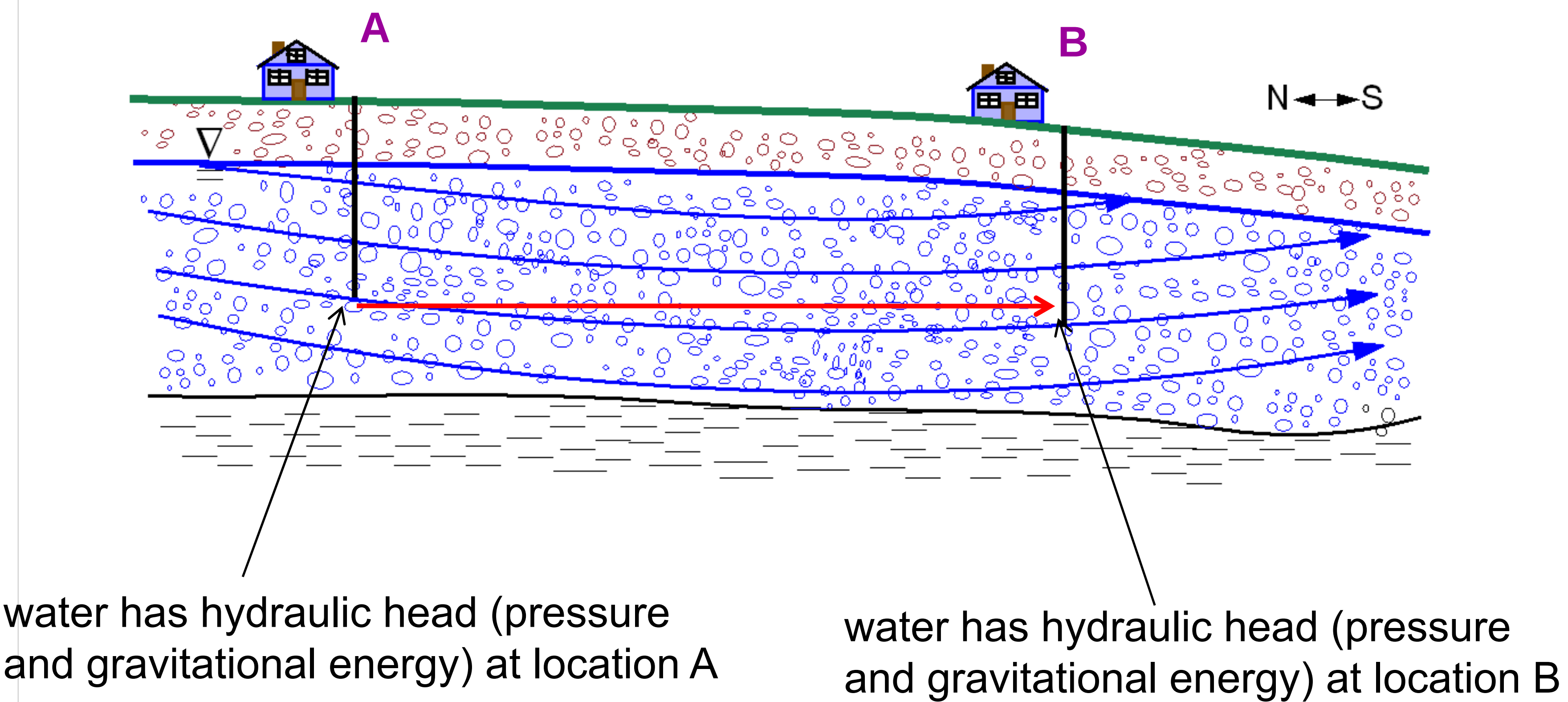
water pressure “pushes”
gravity “pulls”
water flows due to a combination of water pressure and gravity
Q

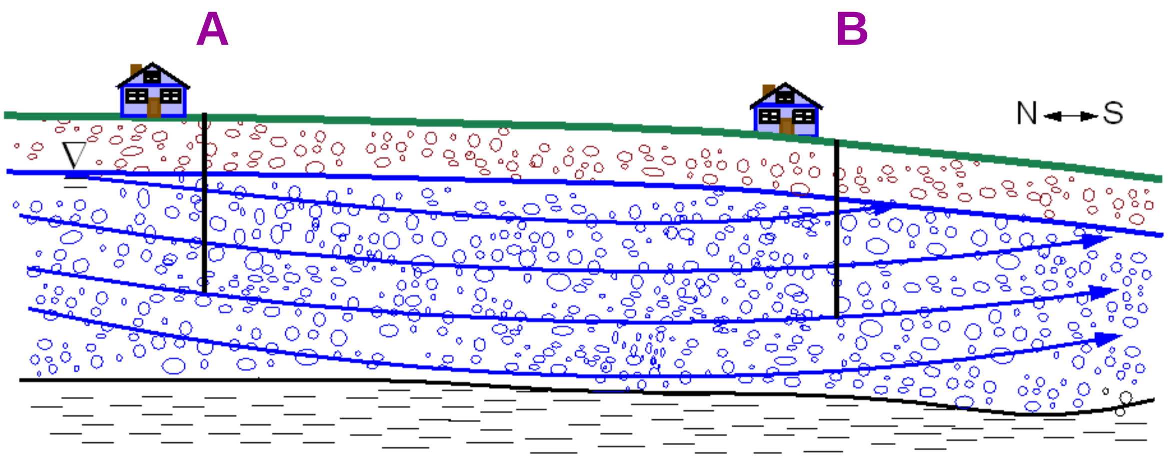
Water pressure “pushes” and gravity “pulls”

The combination of these two quantities is called the **hydraulic head**

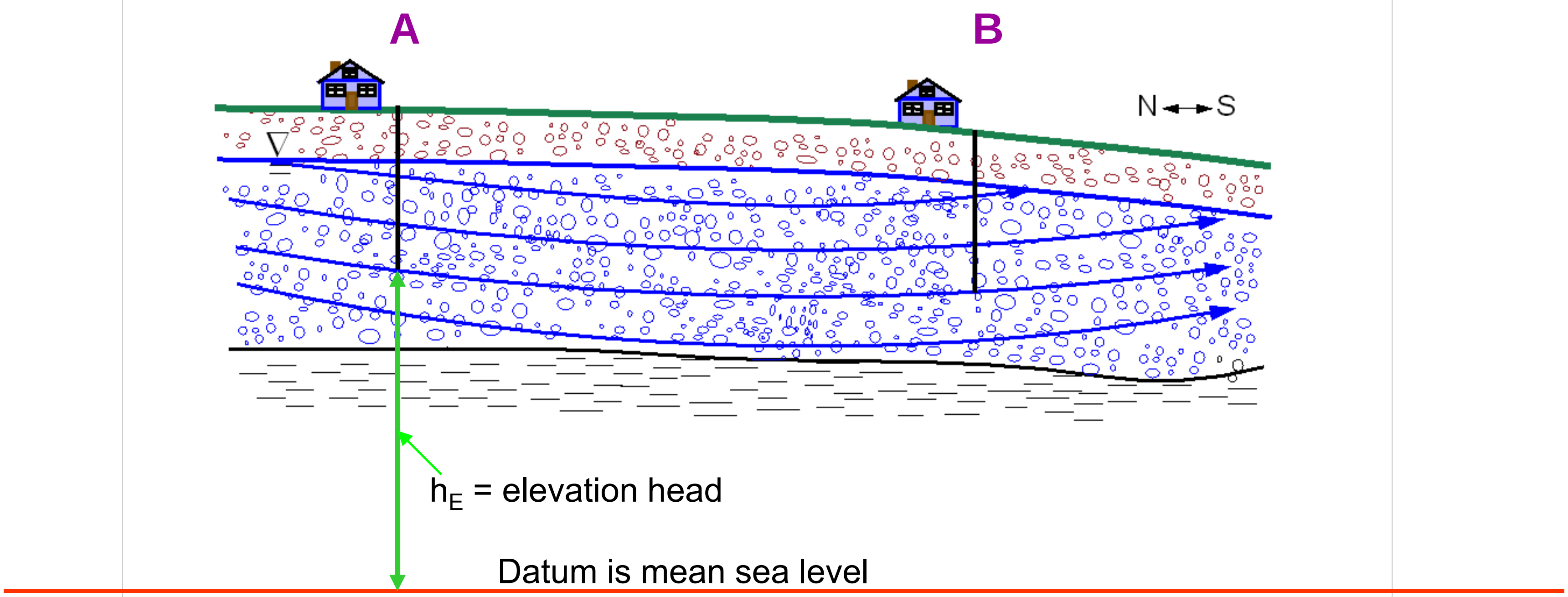
Water moves due to a difference in hydraulic head between two locations

The change in hydraulic head over a distance is called the **hydraulic gradient**



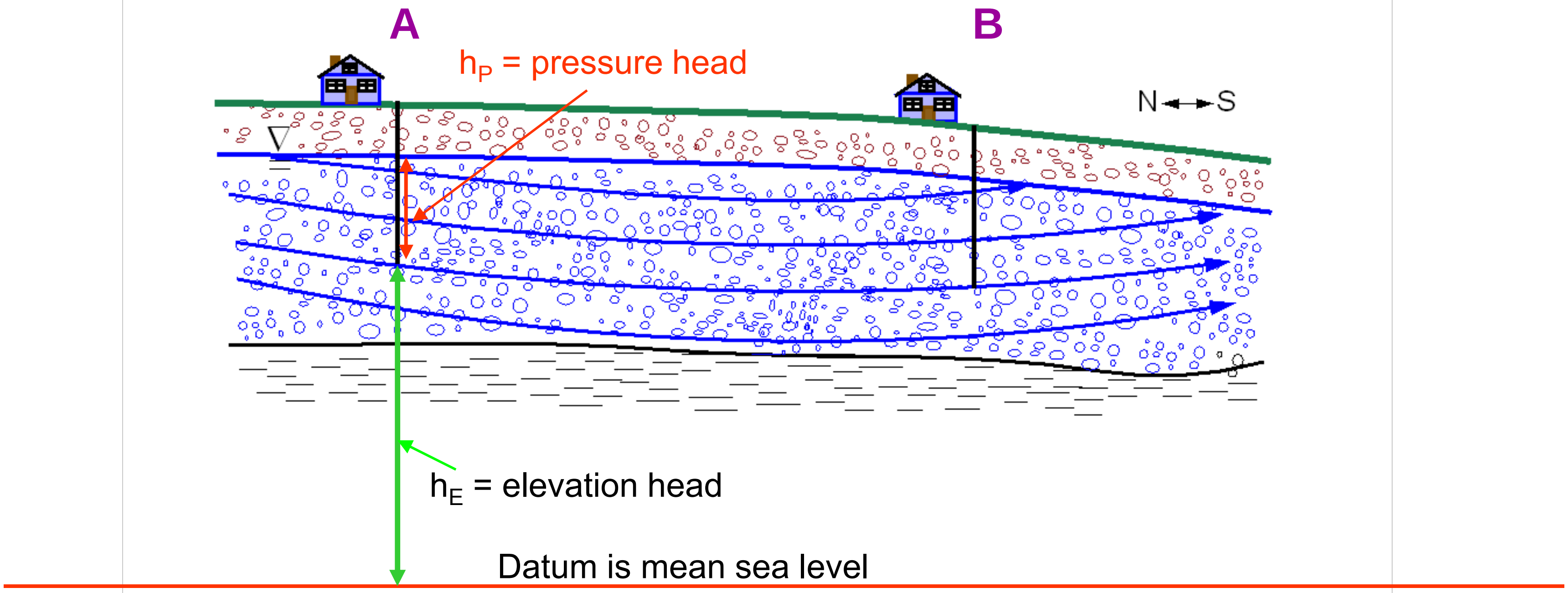


A
B
N
S

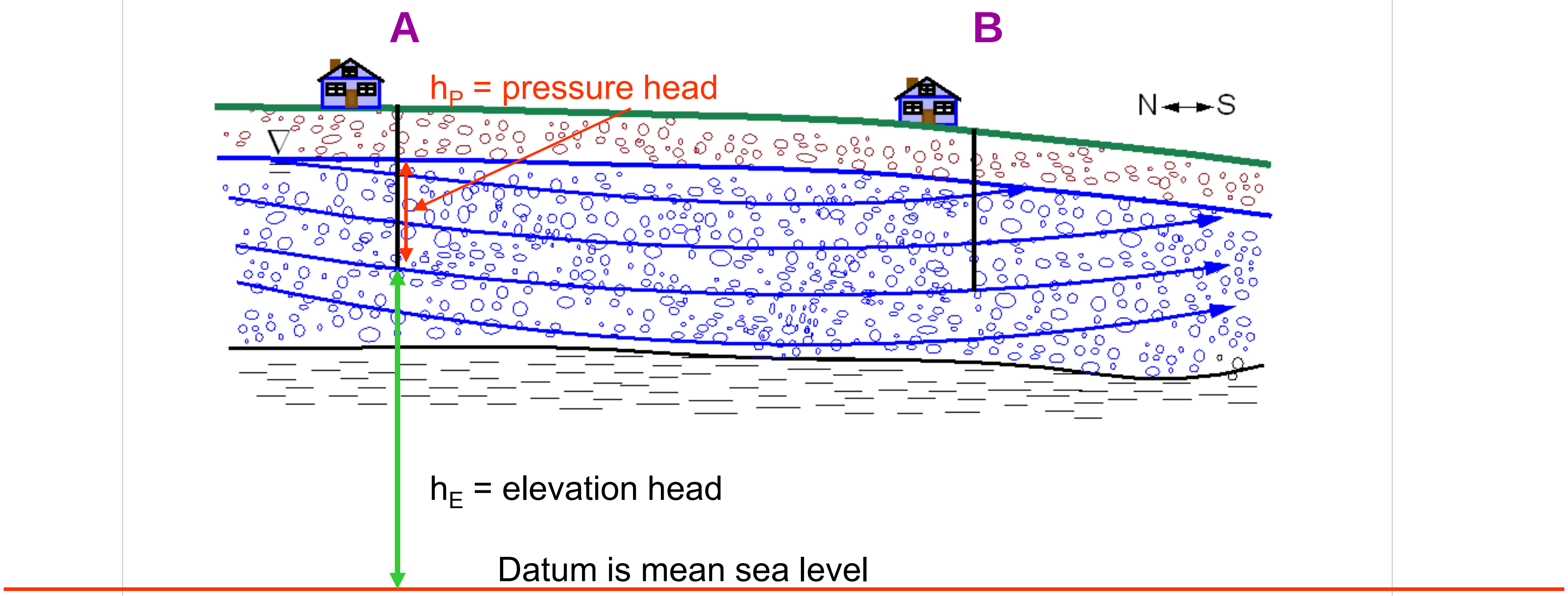


Note: elevation head is the gravitational head

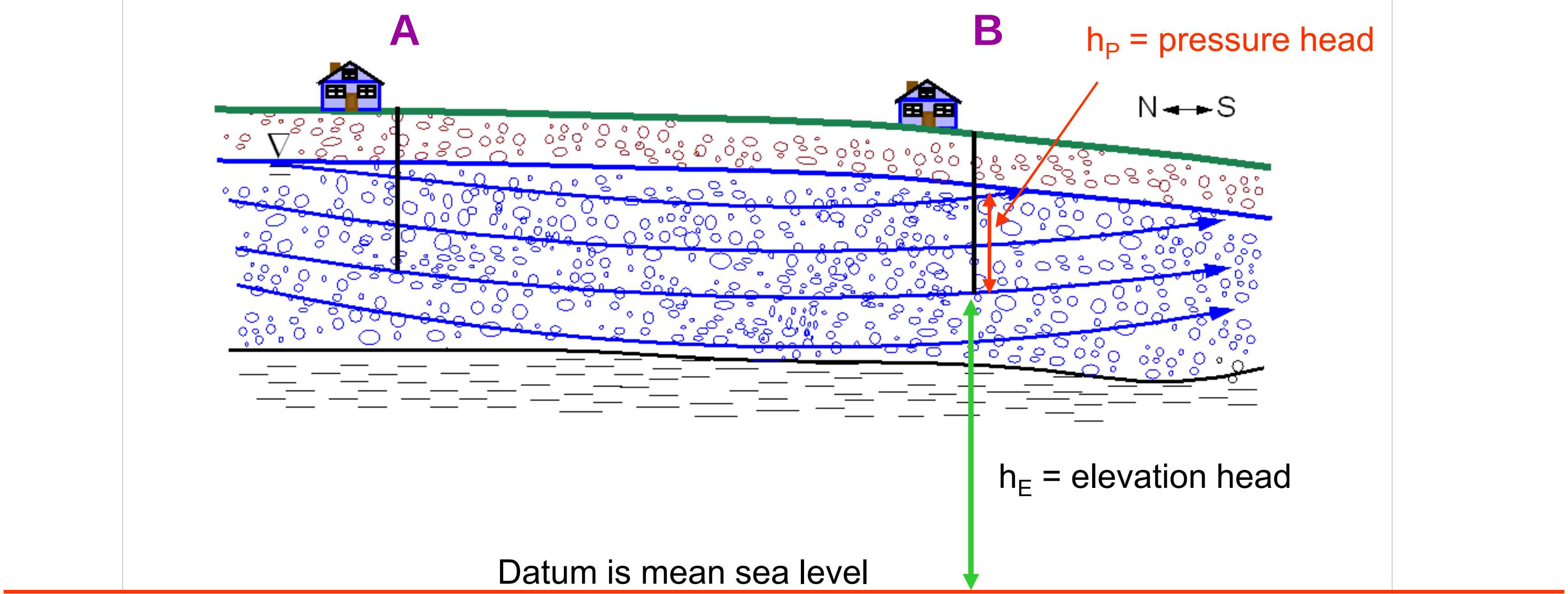
Note: pressure head is the height to which water will rise in a well



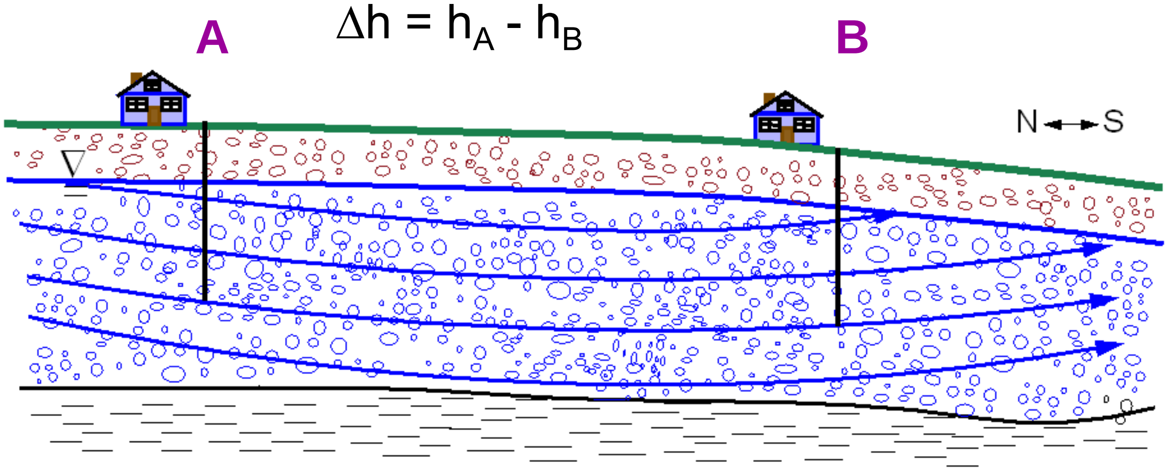
h_A = total head = pressure head + elevation head



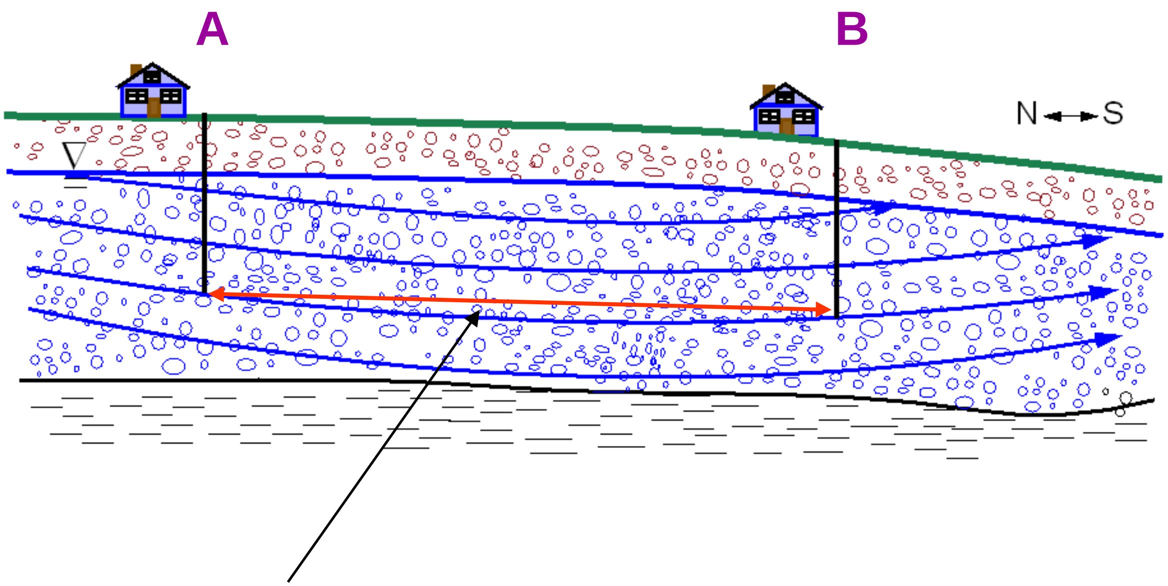
h_B = total head = pressure head + elevation head



The change in total head (Δh) between A and B is what causes water to flow.



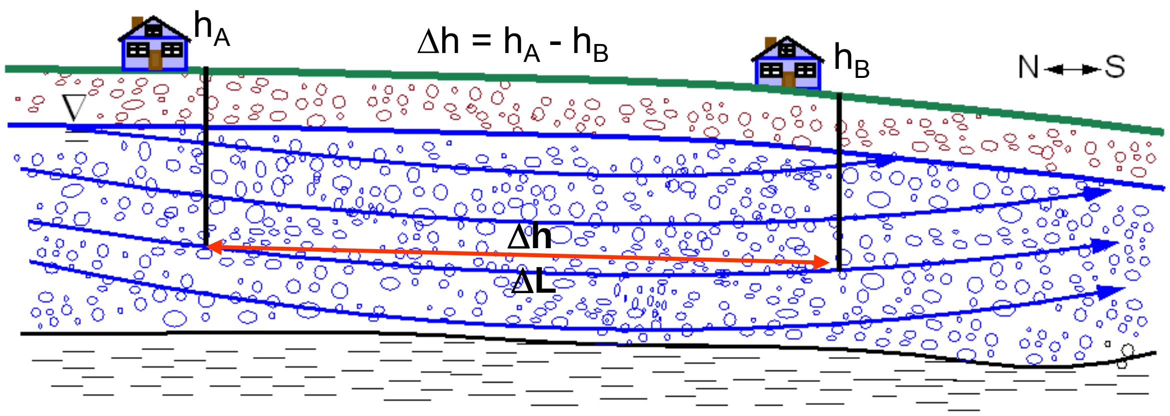
Datum is mean sea level

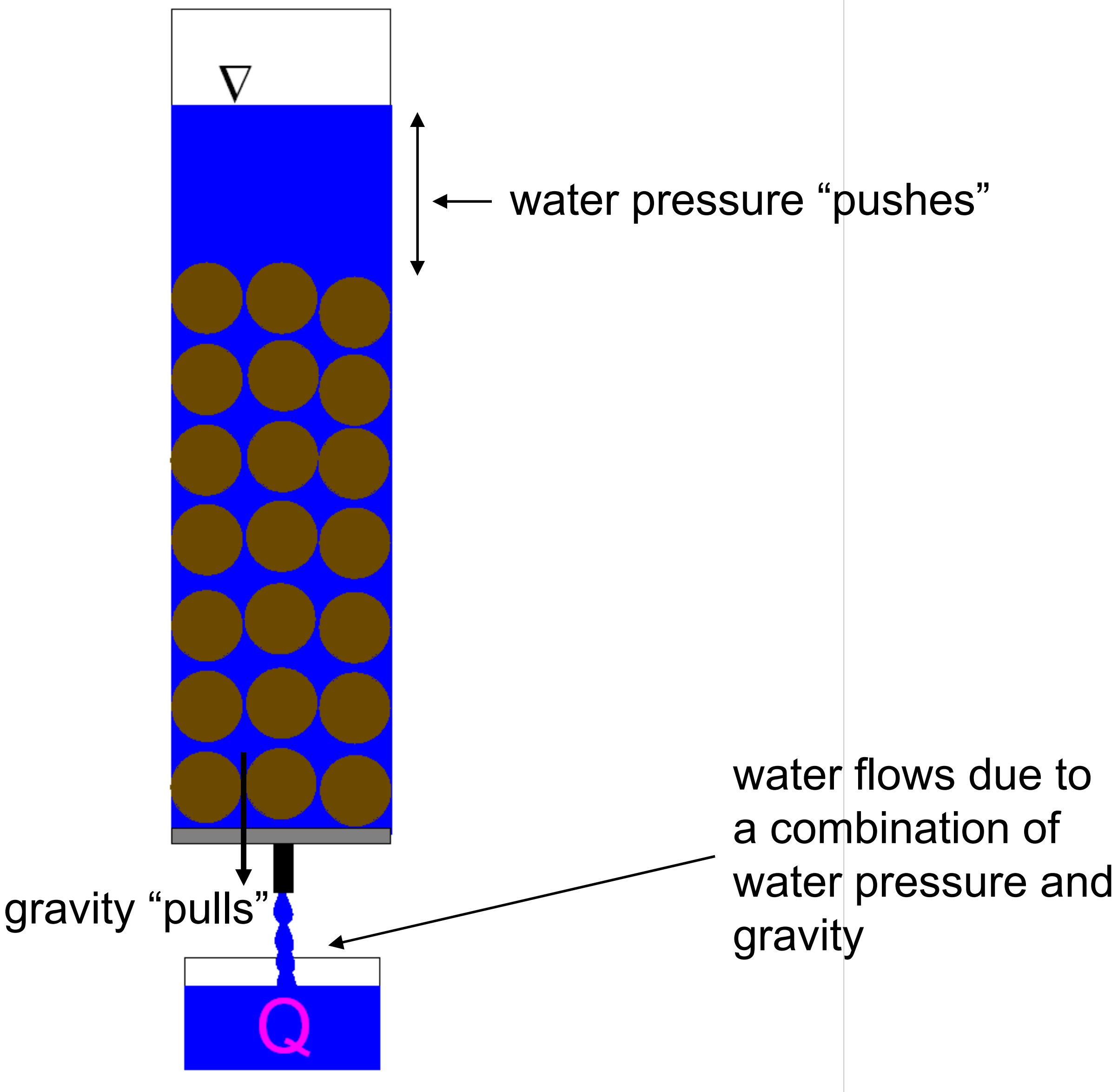


Distance between wells is ΔL

The hydraulic gradient between wells A and B is equal to the magnitude of the change in total head divided the distance over which the change occurs.

hydraulic gradient = $\Delta h/\Delta L$

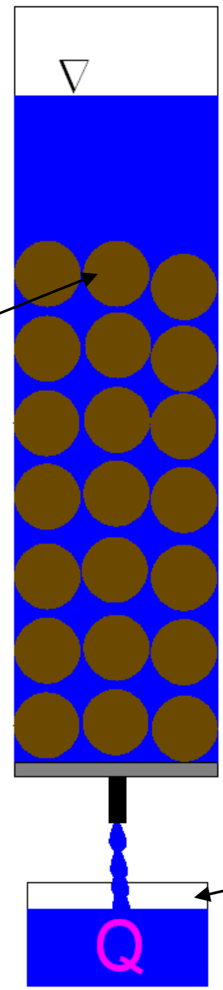




water pressure “pushes”
gravity “pulls”
water flows due to a combination of water pressure and gravity
Q

The hydraulic gradient DRIVES water flow and porous media RESISTS flow

friction along the grain surfaces will resist water flow



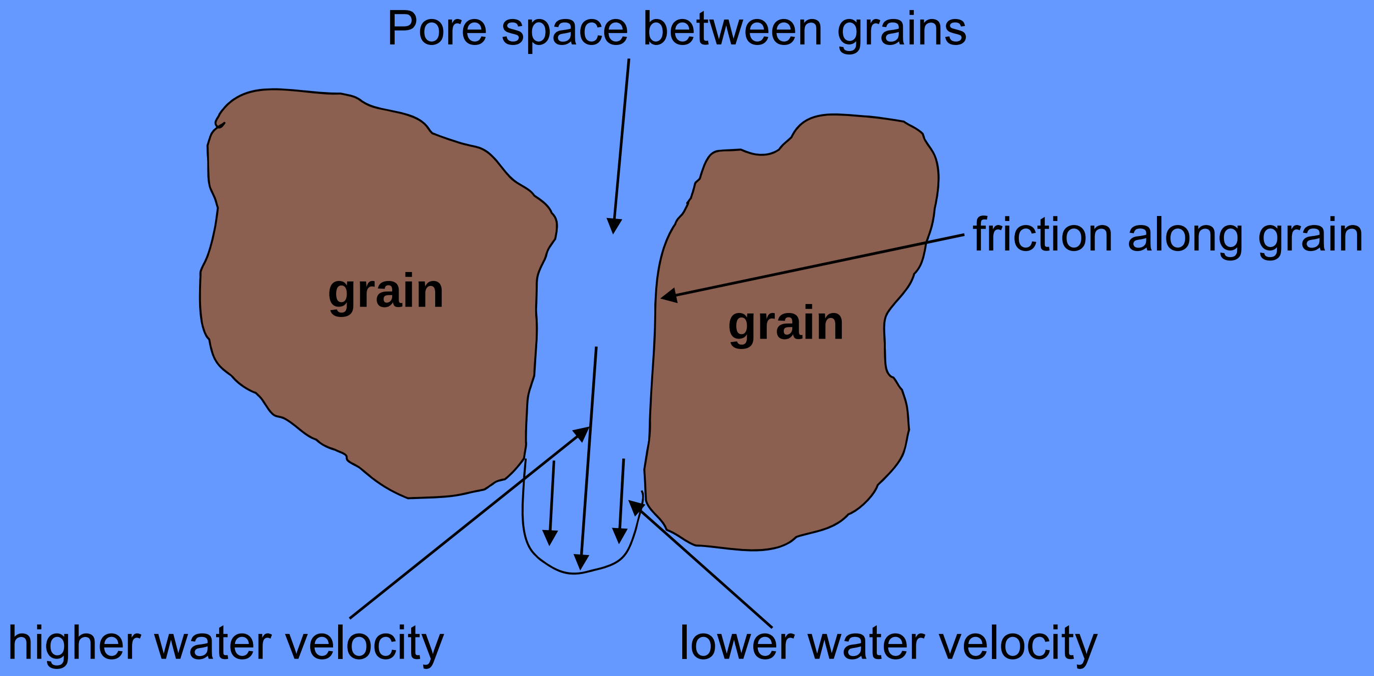
water flows due to a combination of water pressure and gravity

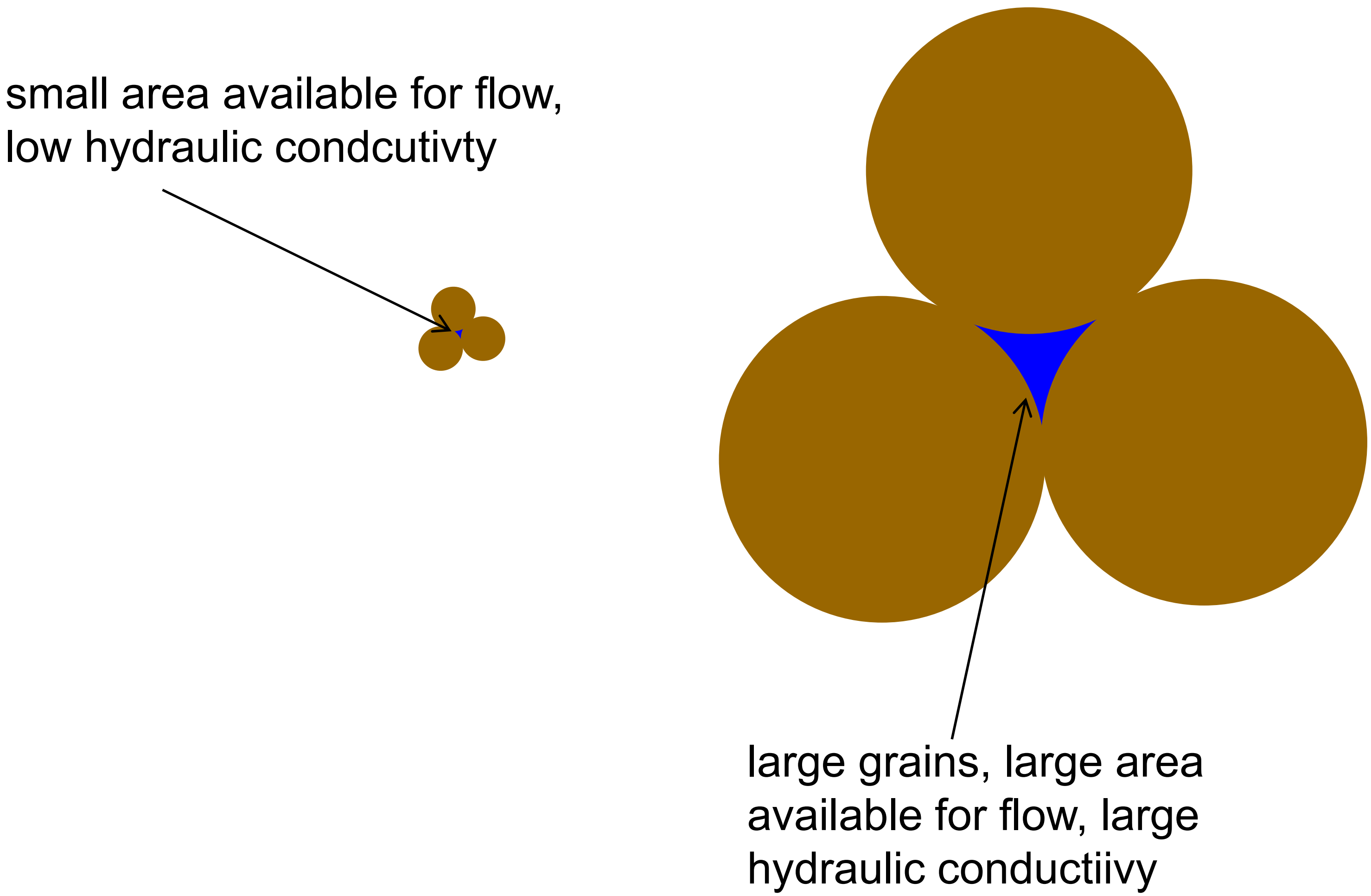
The hydraulic conductivity (K) is a measure of the sediments ability to transmit fluid.

It’s magnitude is controlled by the grain size (or pore size) which determines the amount of frictional resistance and the area available for flow.

The units of hydraulic conductivity are length per time (e.g., cm/s)

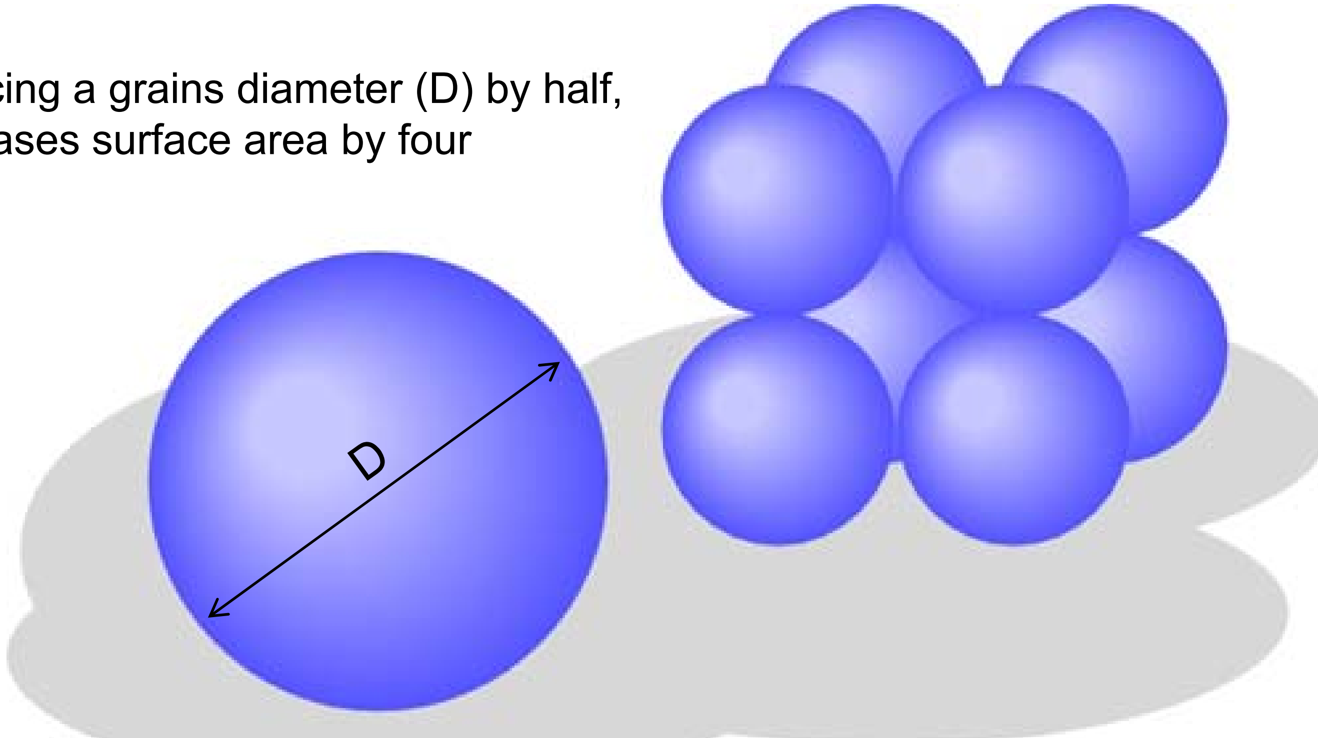
Water Flow in Porous Media




small area available for flow,
low hydraulic condcutivty
large grains, large area
available for flow, large
hydraulic conductiivy

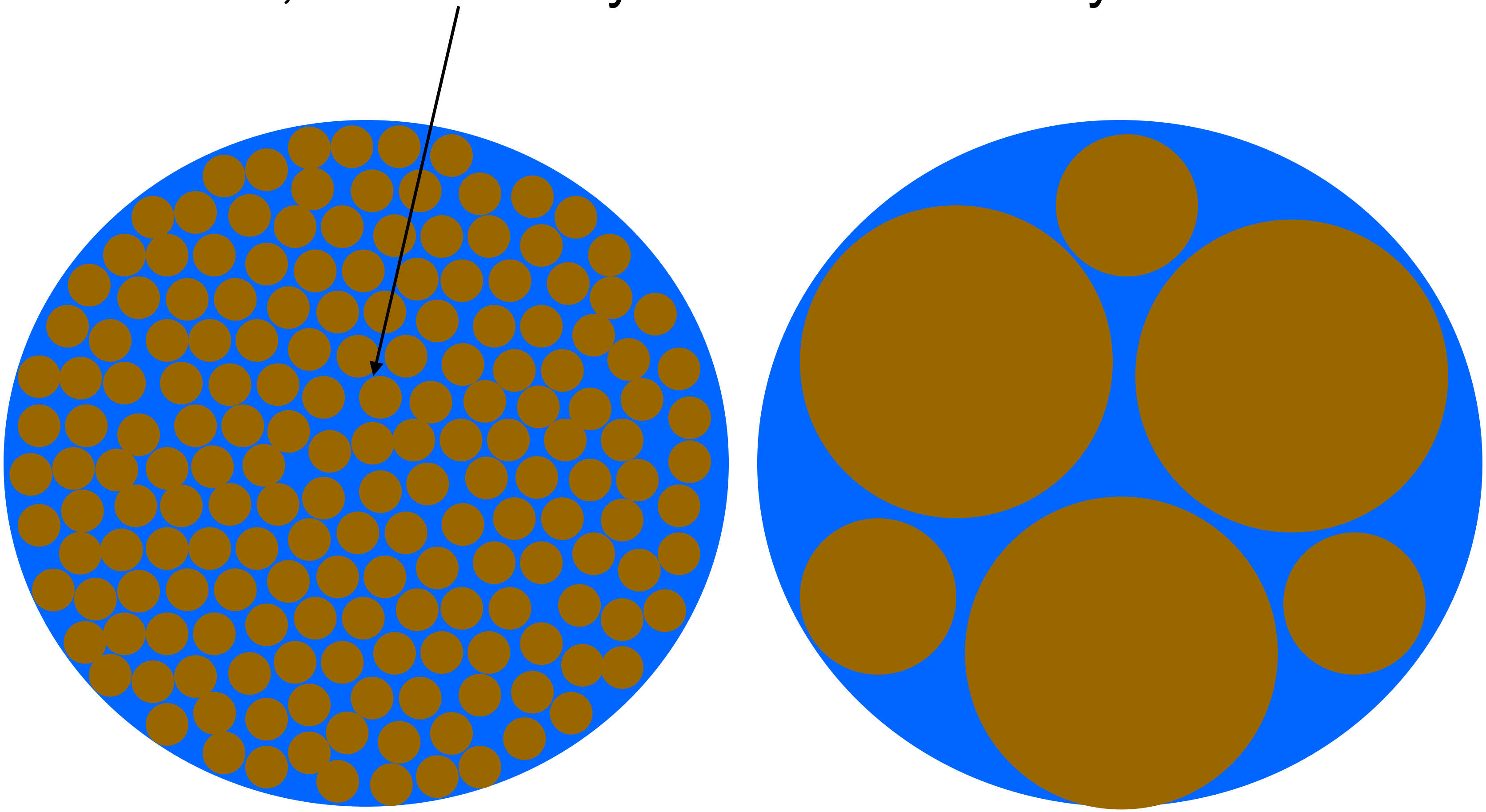
The amount of friction along grain boundaries depends on the surface area of the sediment

reducing a grains diameter (D) by half, increases surface area by four

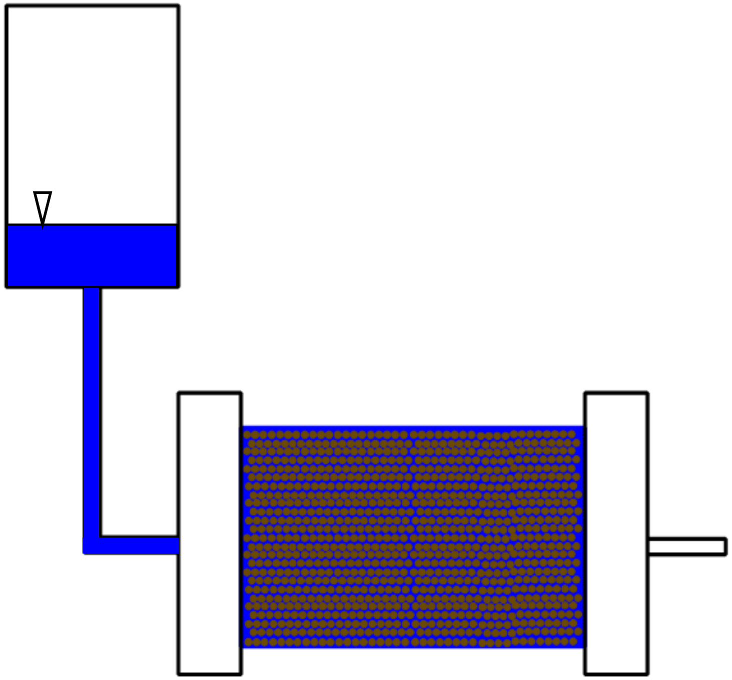


surface area of a sphere = πD^2

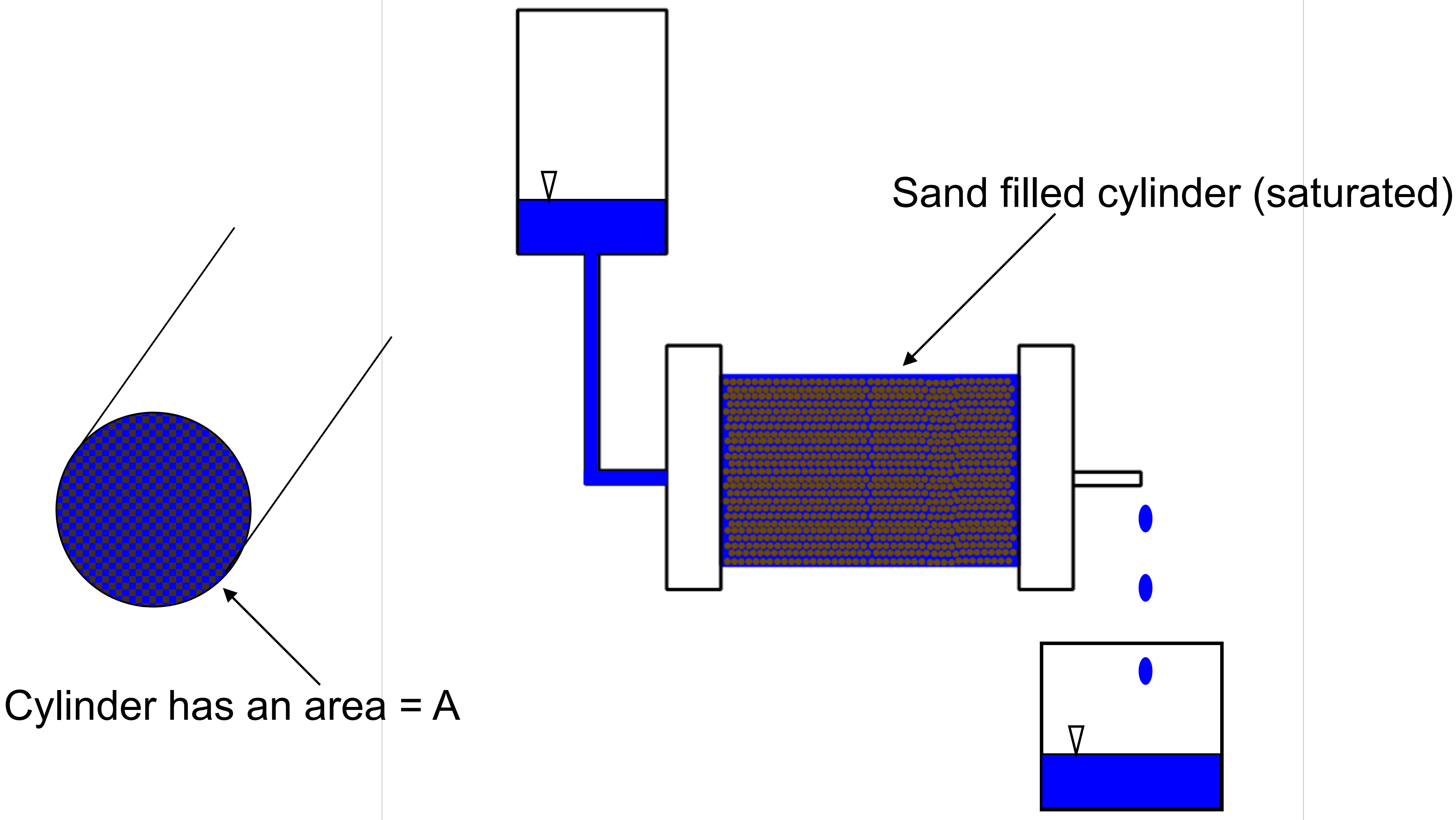
Smaller grains, means smaller pores, more frictional resistance, and lower hydraulic conductivity



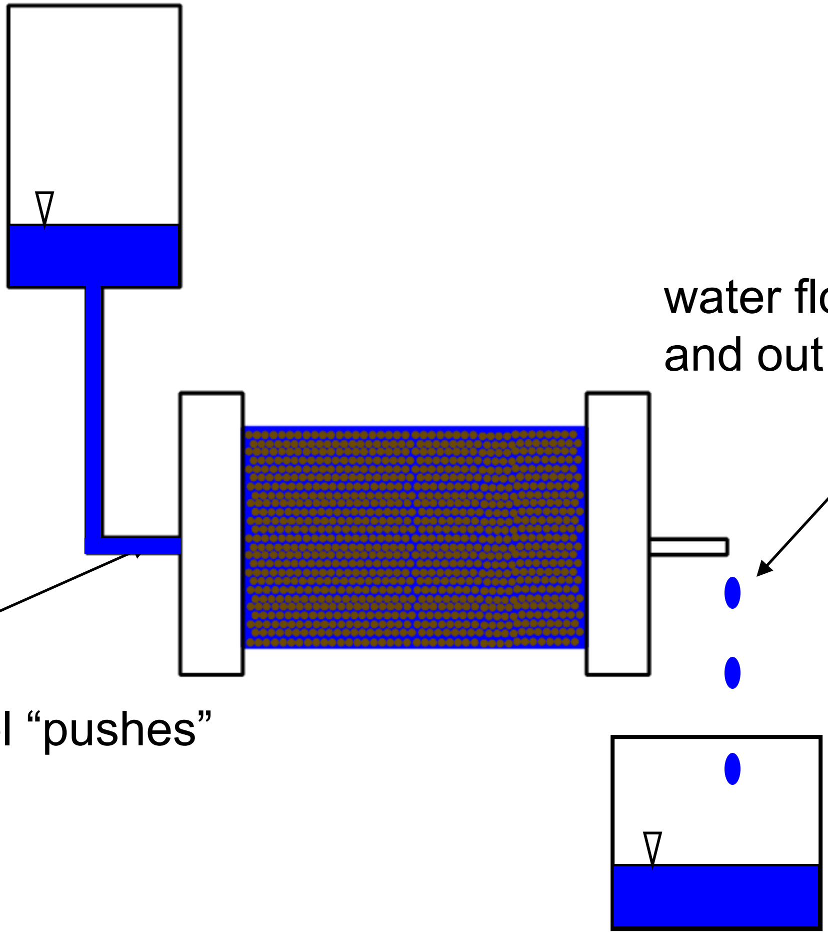
Hydraulic conductivity is measured with a permeameter



Permeameter



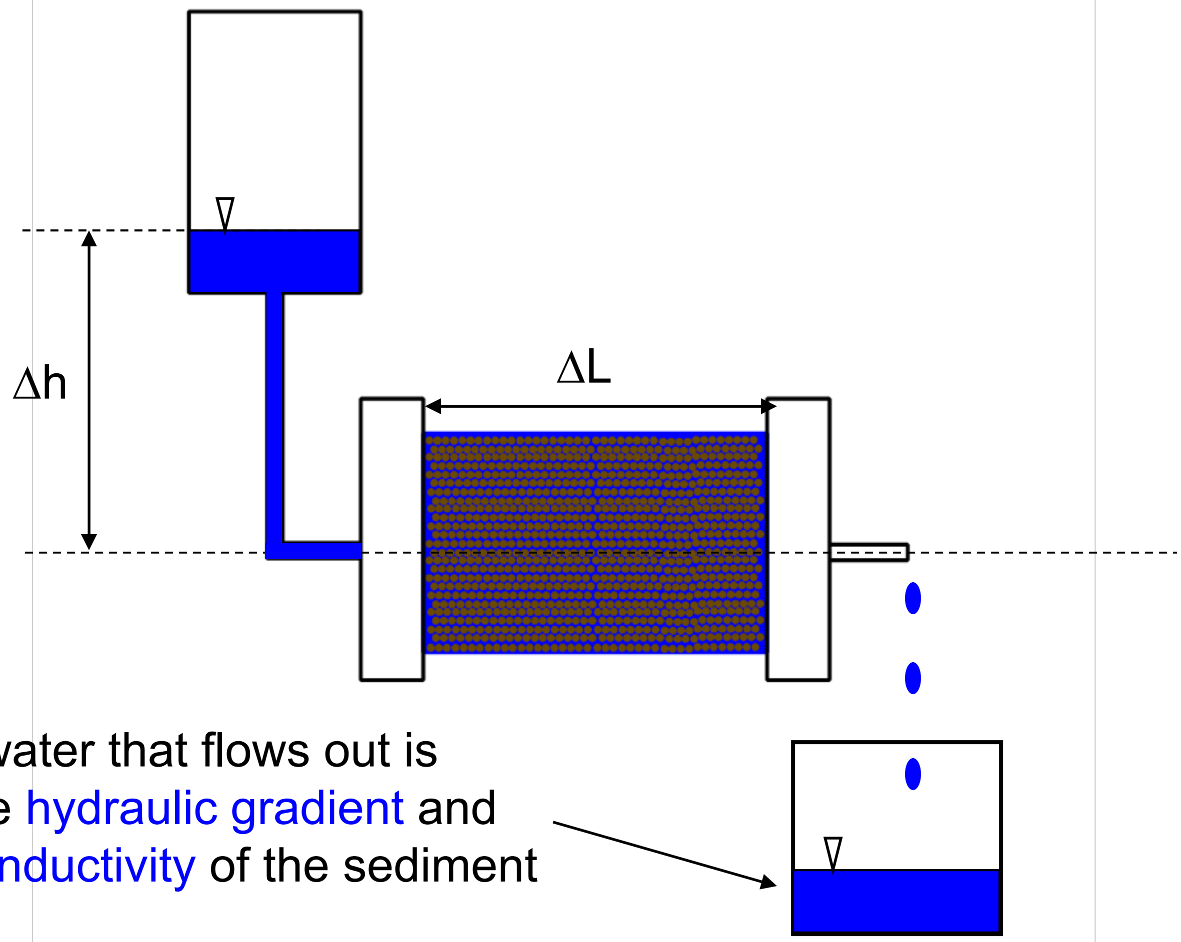
Permeameter



water flows through the sand
and out the valve

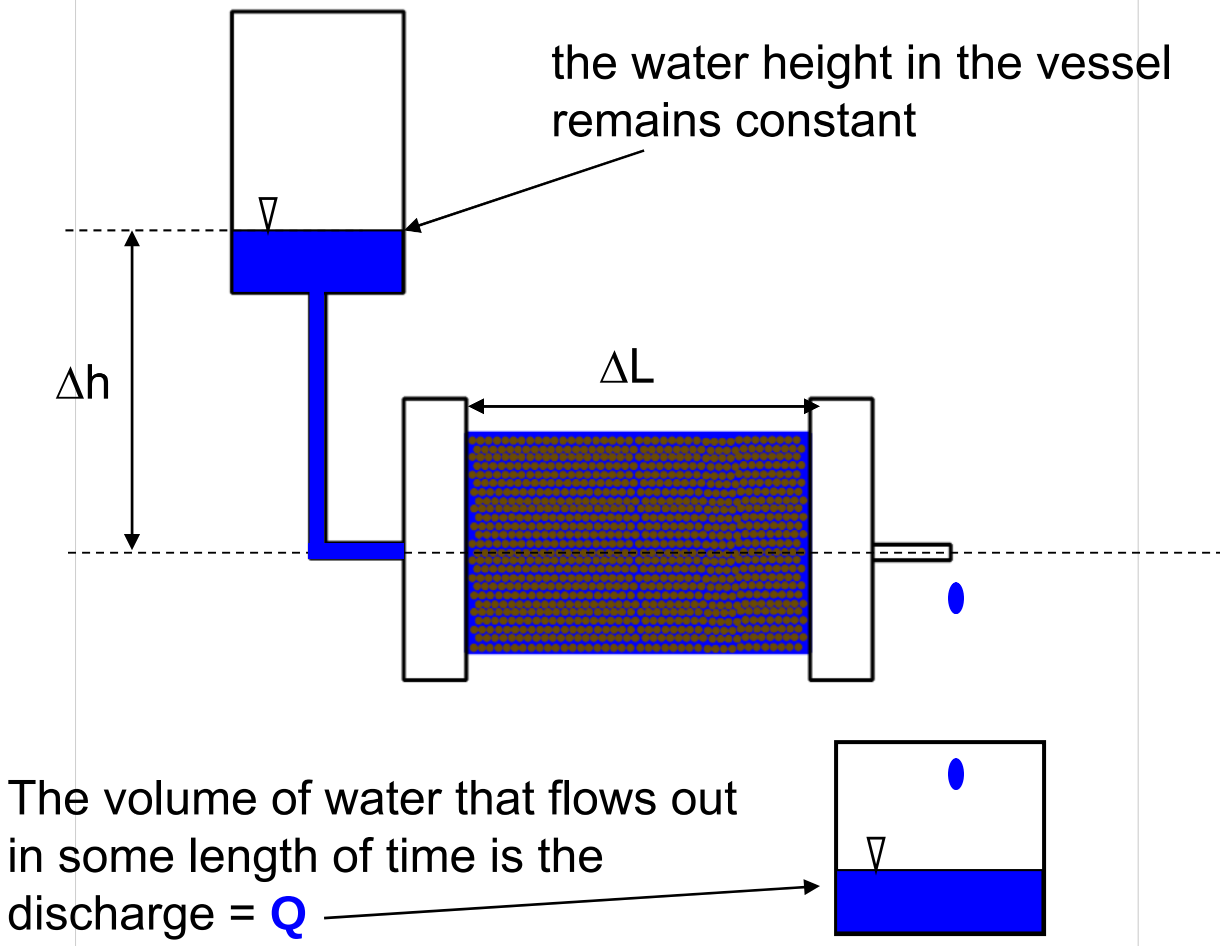
water pressure in the vessel “pushes”
water into the sand

Permeameter

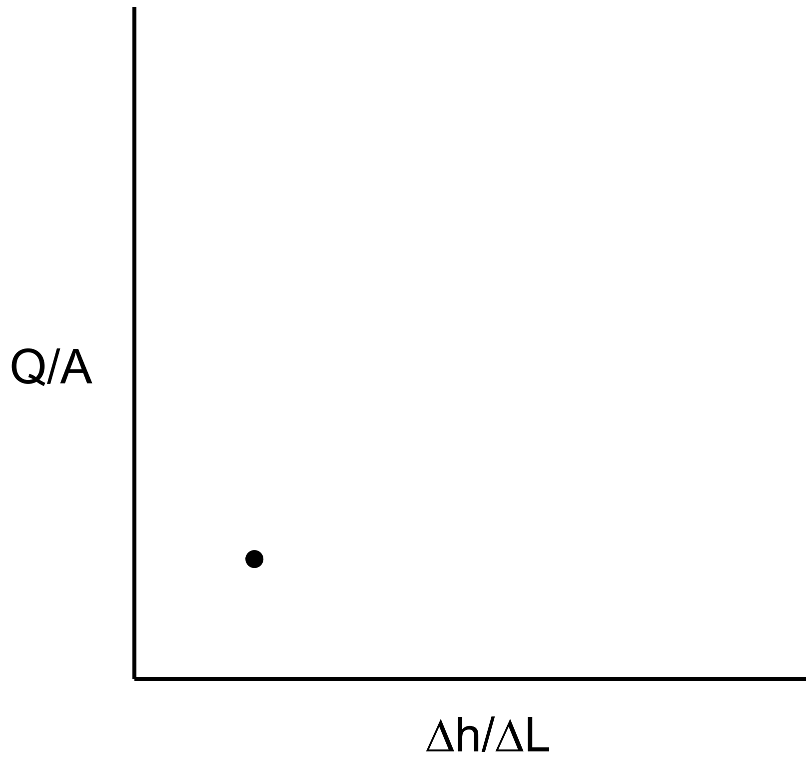


The volume of water that flows out is controlled by the hydraulic gradient and the hydraulic conductivity of the sediment

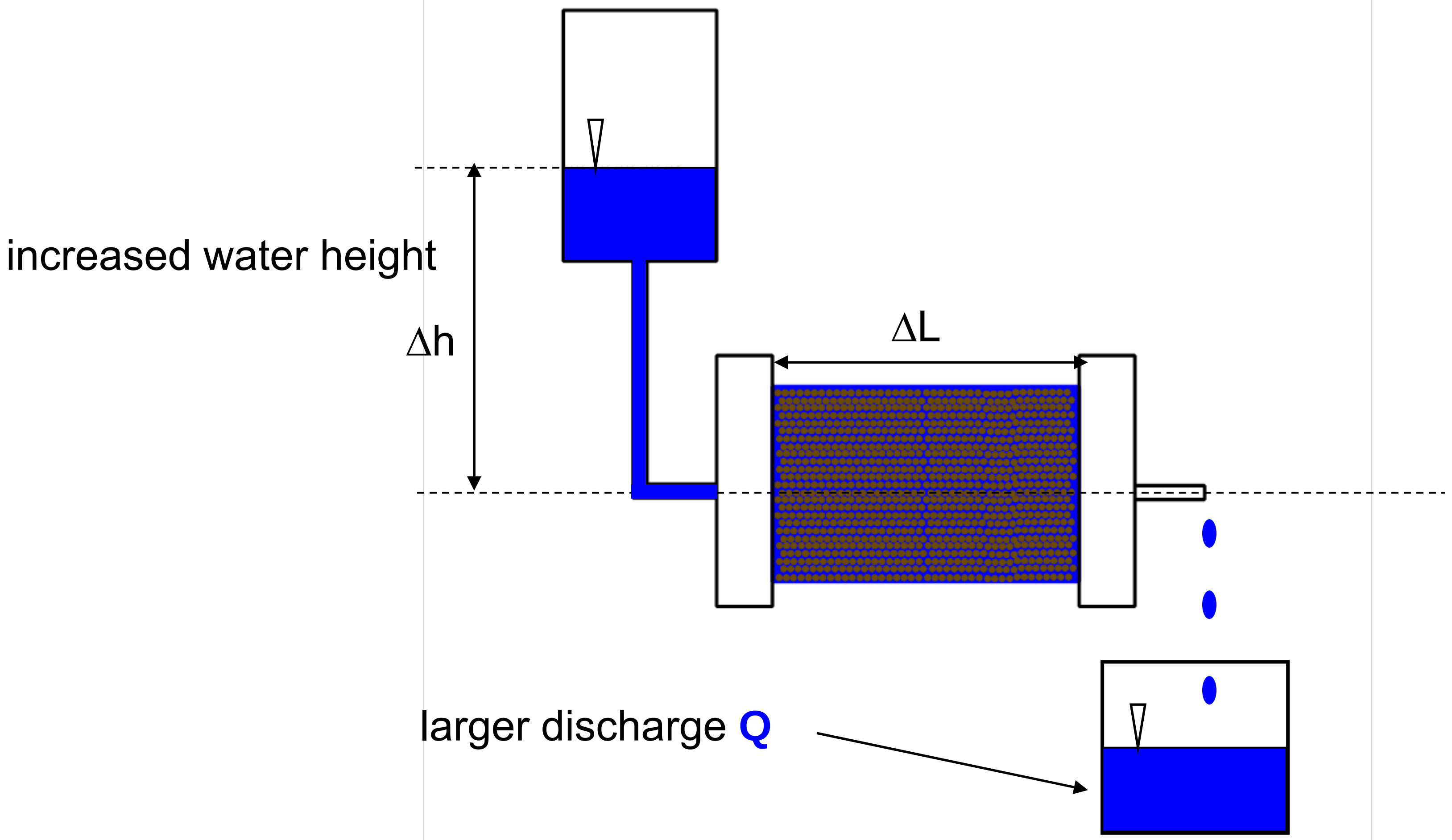
First Experiment



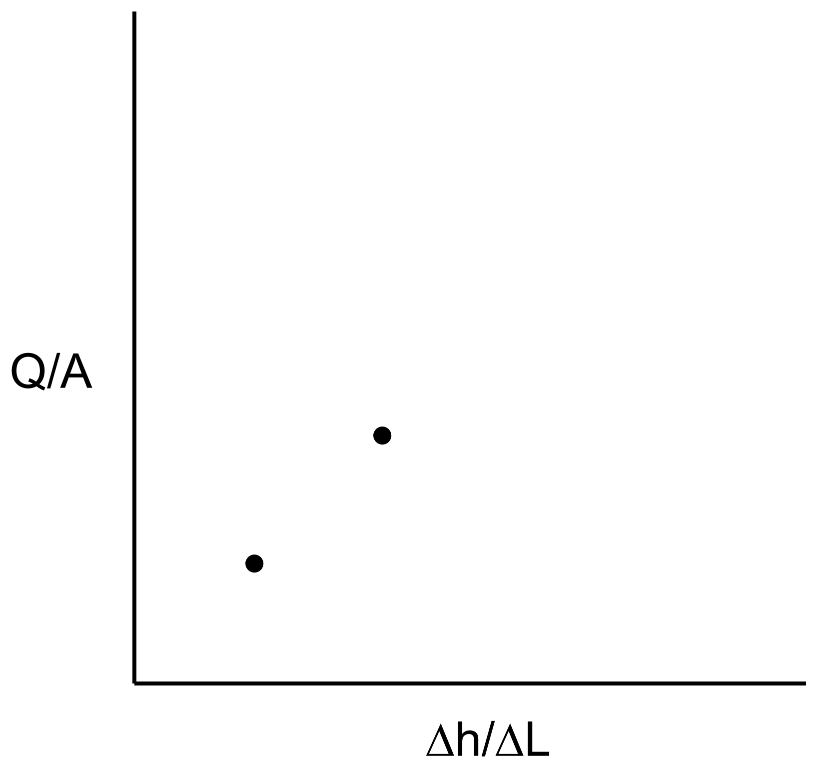
Plot the results of the 1st experiment



Second Experiment



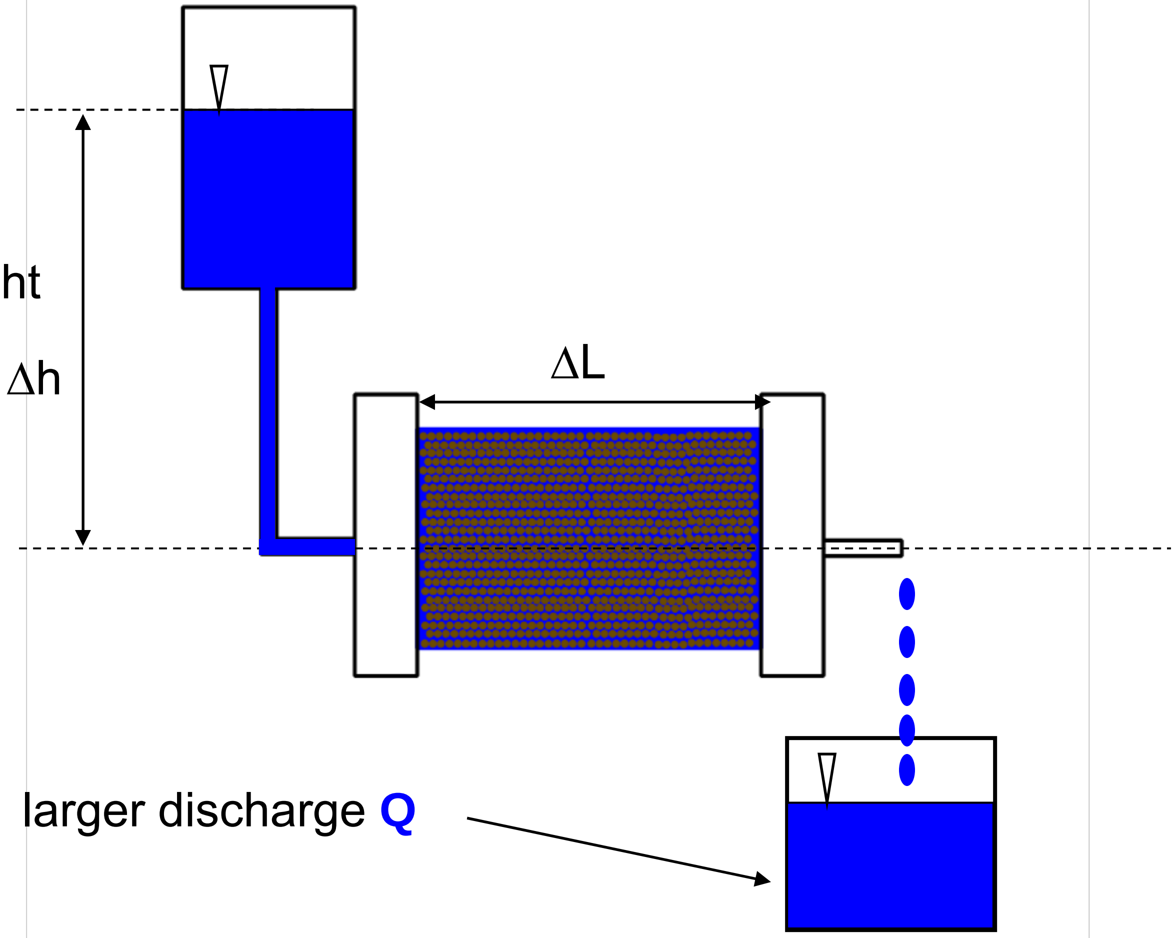
Plot the results of the 2nd experiment



Third Experiment

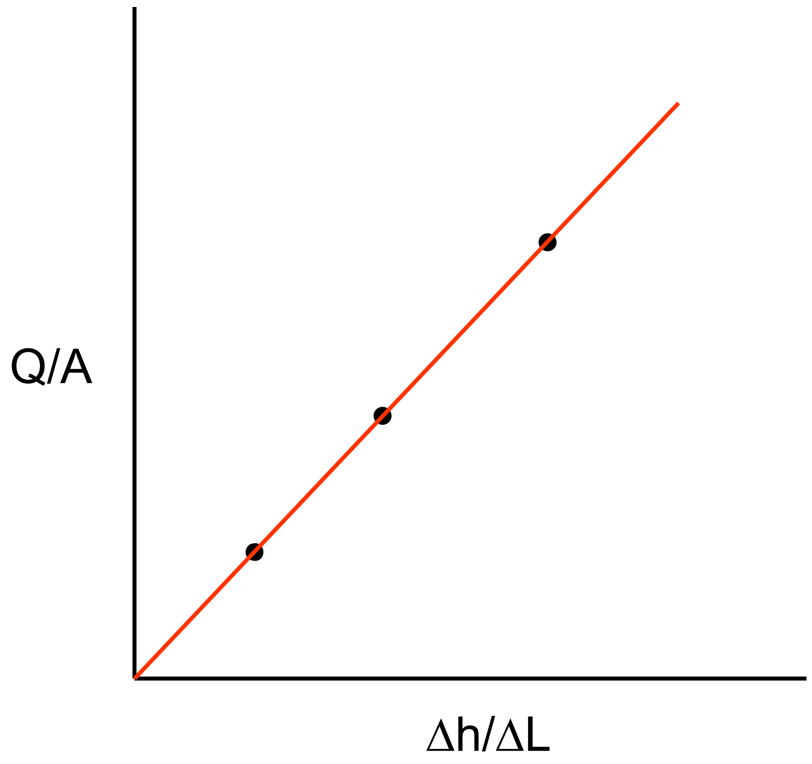
in all experiments the Δh is kept constant

increased water height



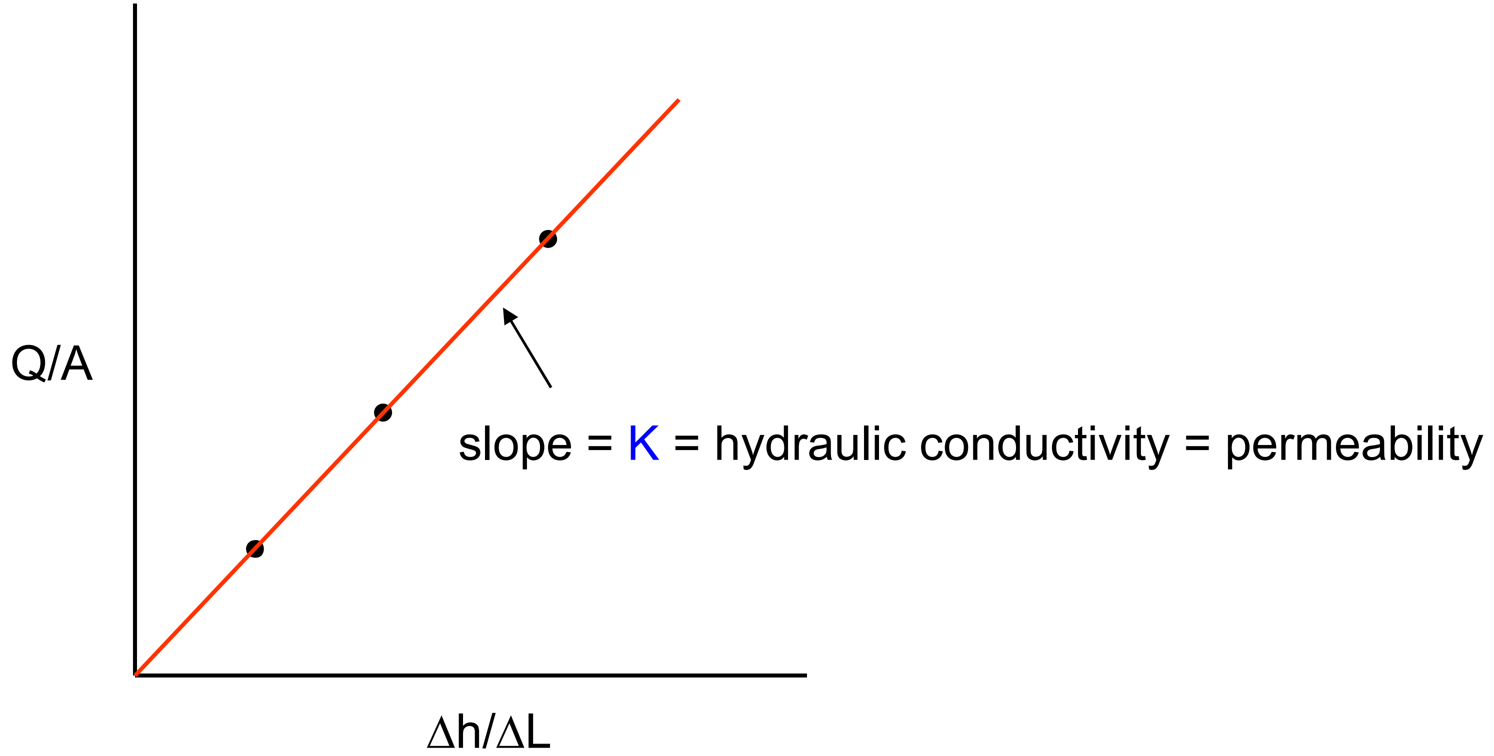
larger discharge **Q**

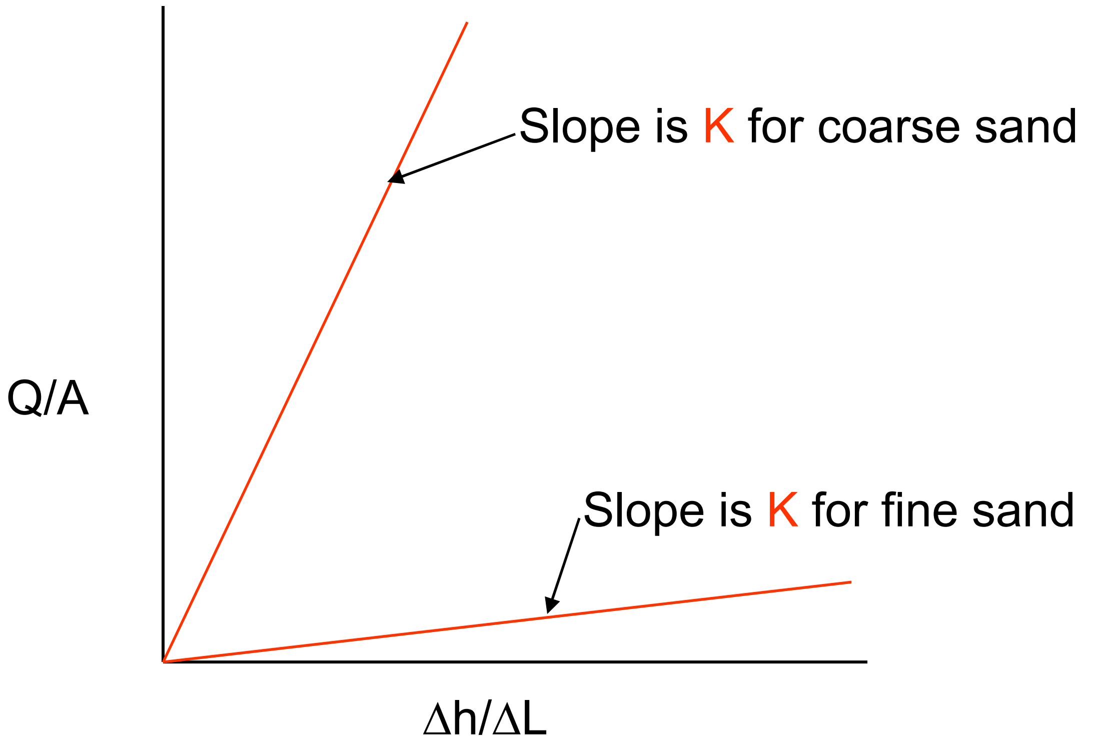
Plot the results of the 3rd experiment

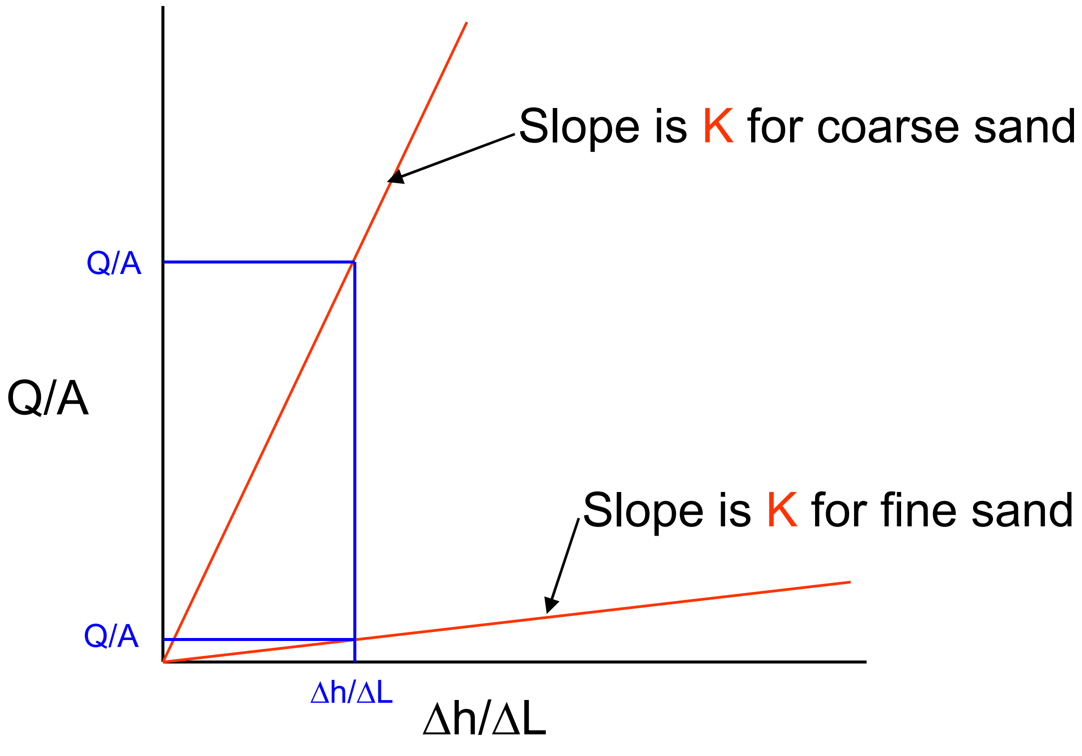


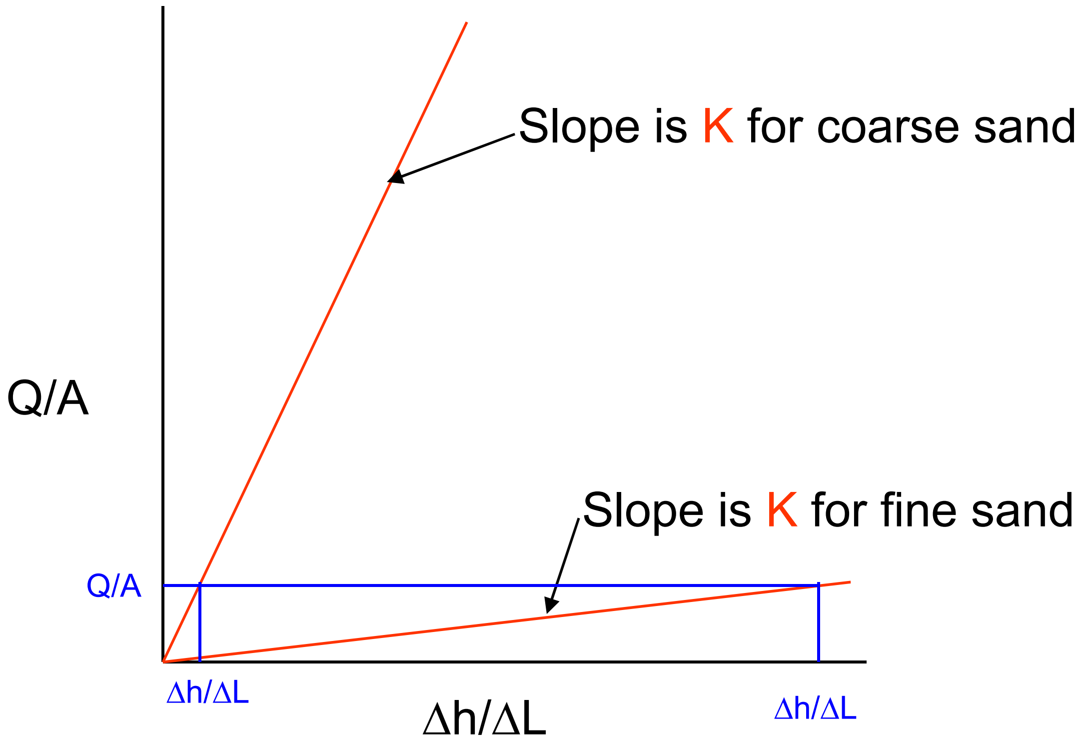
Darcy's Law

$$Q/A = -K(\Delta h/\Delta L)$$



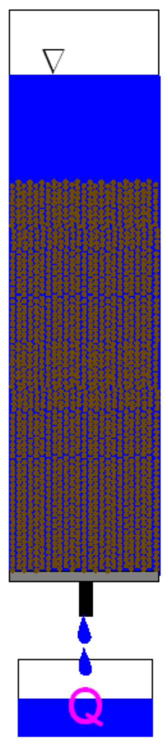

Slope is K for coarse sand
Q/A
Slope is K for fine sand
Δh/ΔL


Slope is K for coarse sand
Q/A
Q/A
Slope is K for fine sand
Q/A
Δh/ΔL
Δh/ΔL


Slope is K for coarse sand
Q/A
Slope is K for fine sand
Q/A
Δh/ΔL
Δh/ΔL
Δh/ΔL

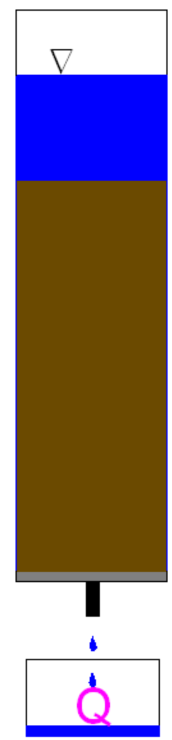
Sand

$K \approx 1 \times 10^{-3}$ cm/s

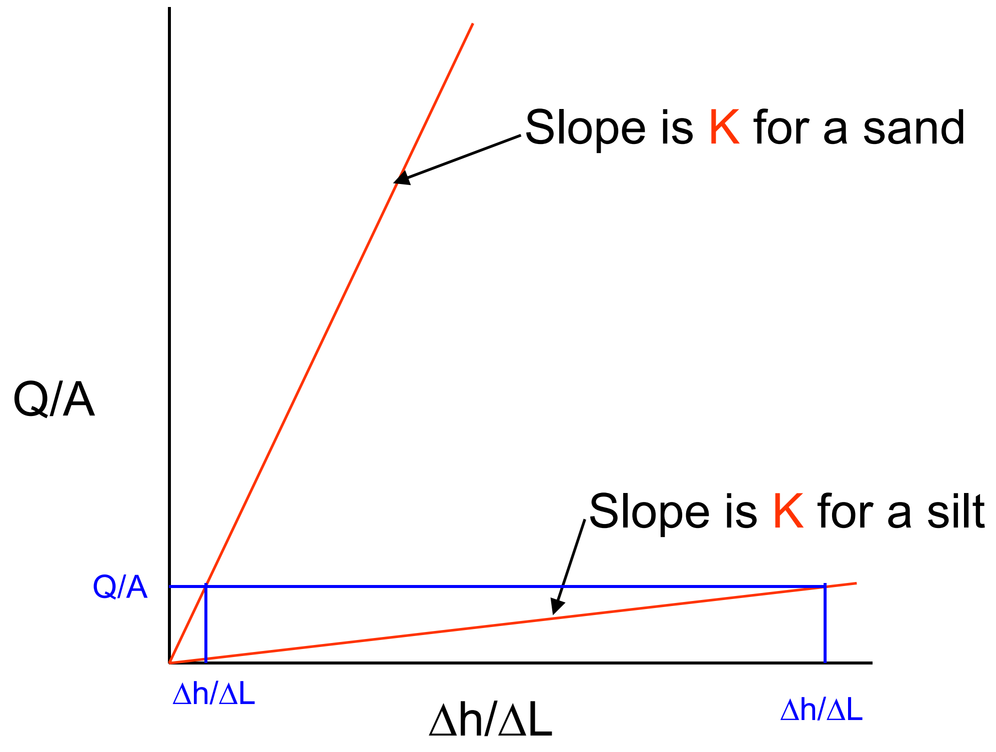


Silt

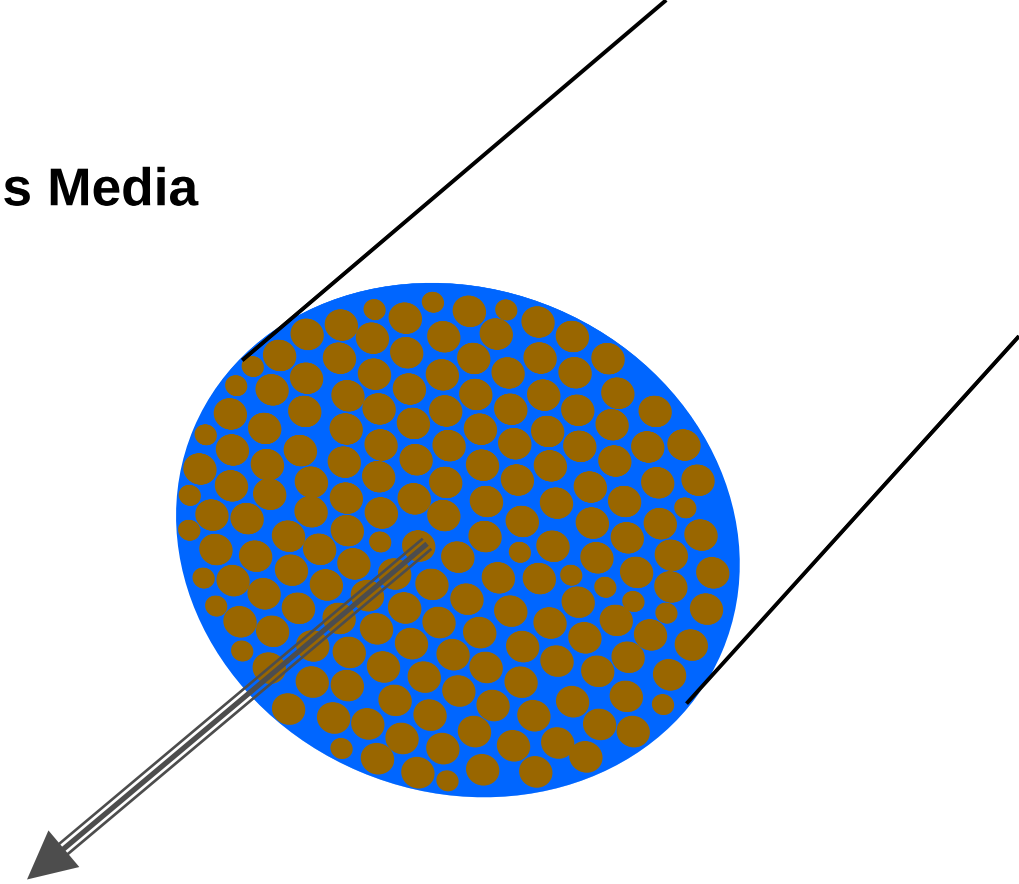
$K \approx 1 \times 10^{-6}$ cm/s



To get the same amount of Q out of both cylinders in the same amount of time, the Δh for the silt would have to be 1000 times that of the sand.



Saturated Flow in Porous Media



average pore water velocity = v = q/n

or $v = -K/n(\Delta h/\Delta L)$

The average velocity of the water is the Darcy equation divided by the porosity of the sediment.