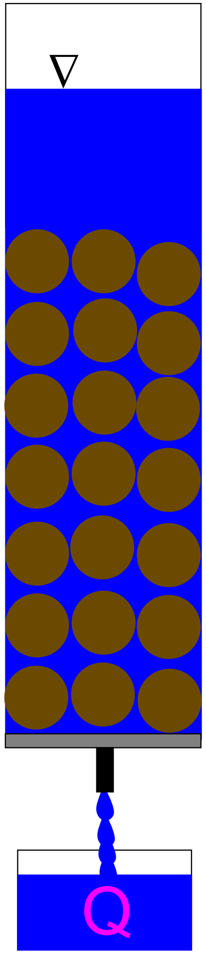
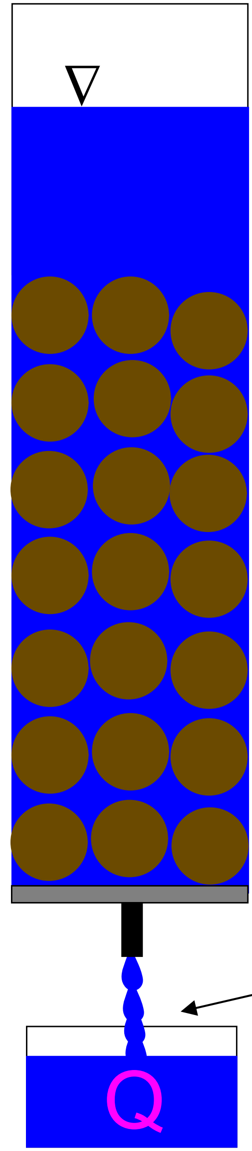
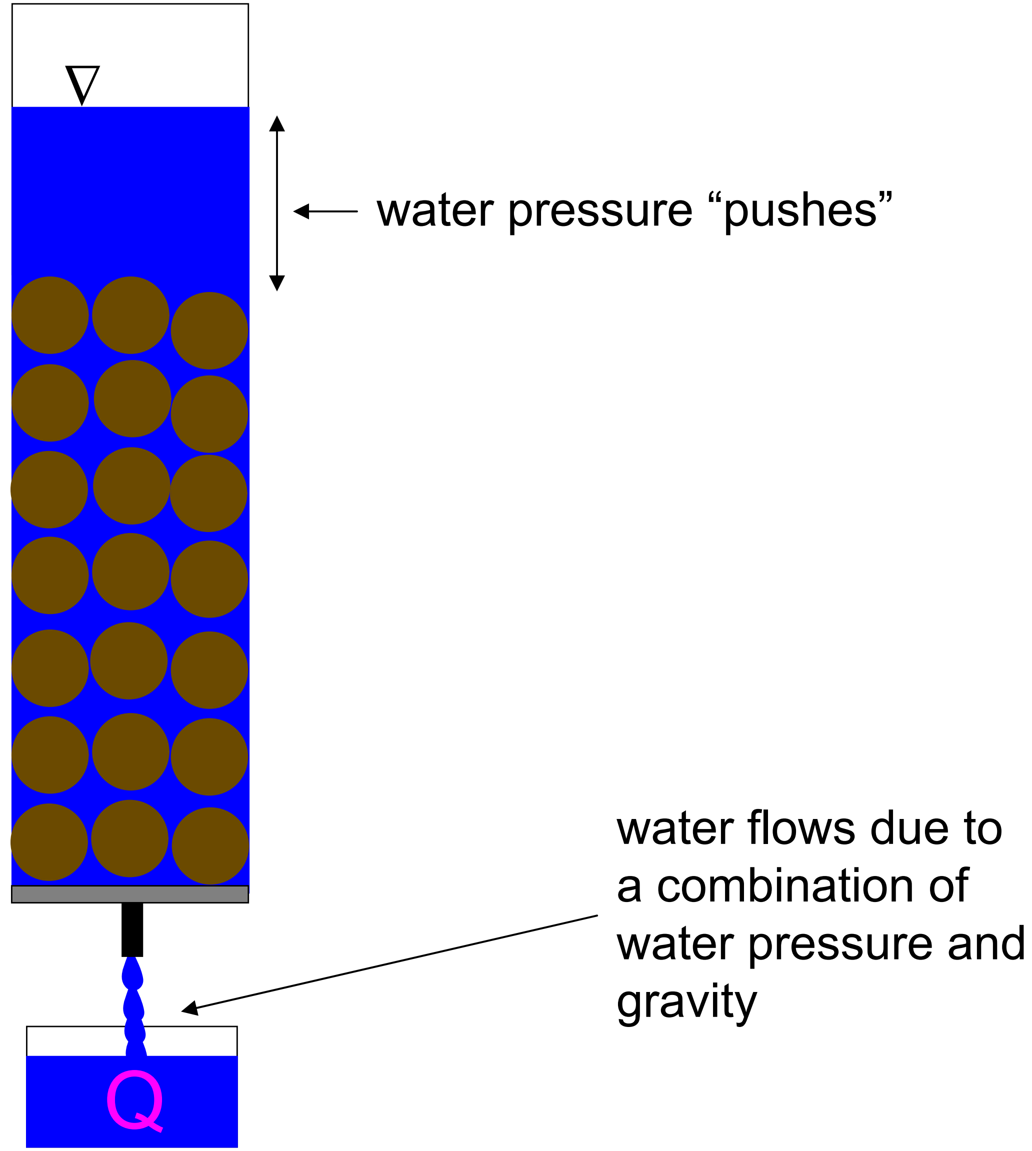
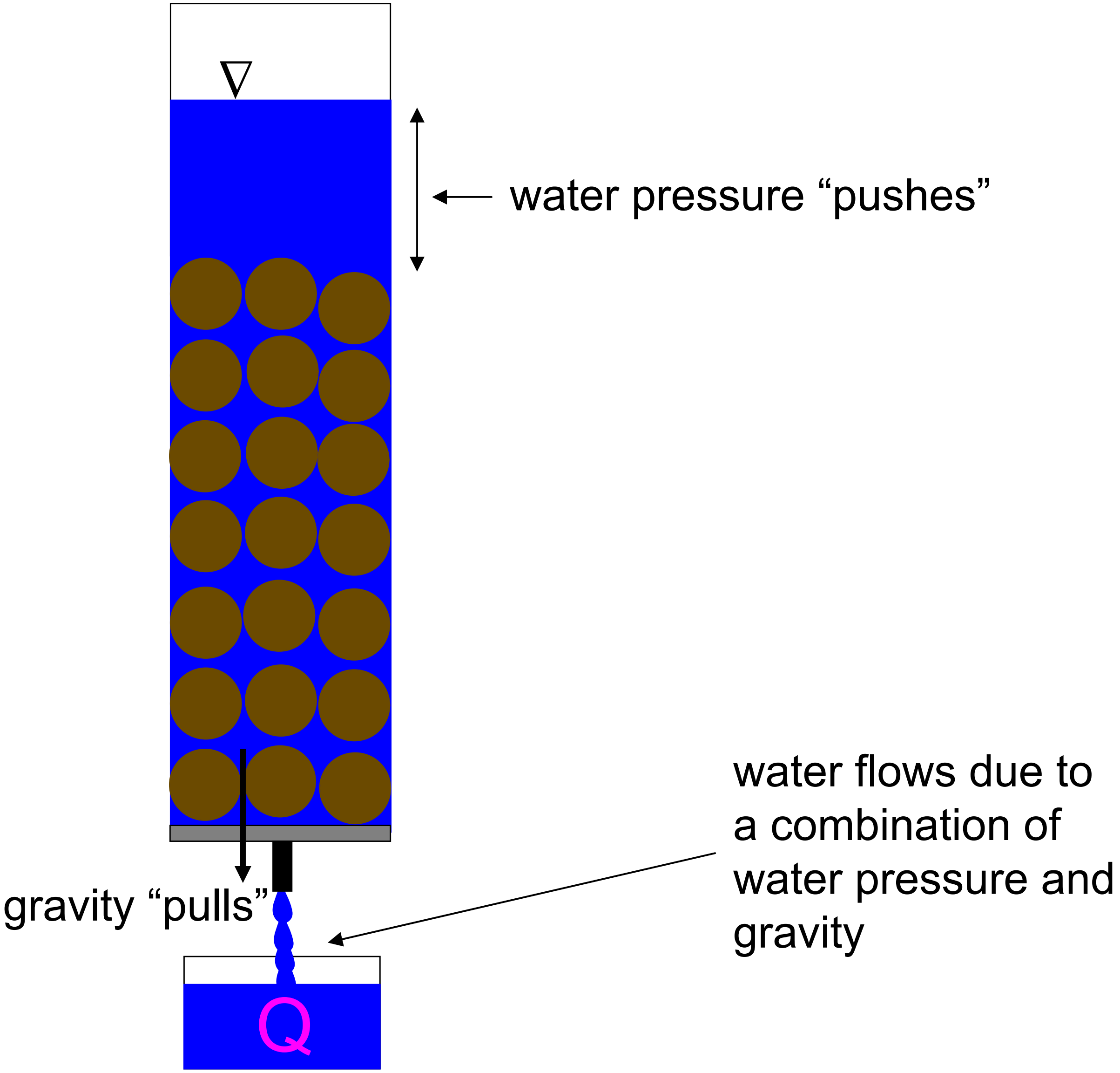
Water Flow in Porous Media





water flows due to
a combination of
water pressure and
gravity


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


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

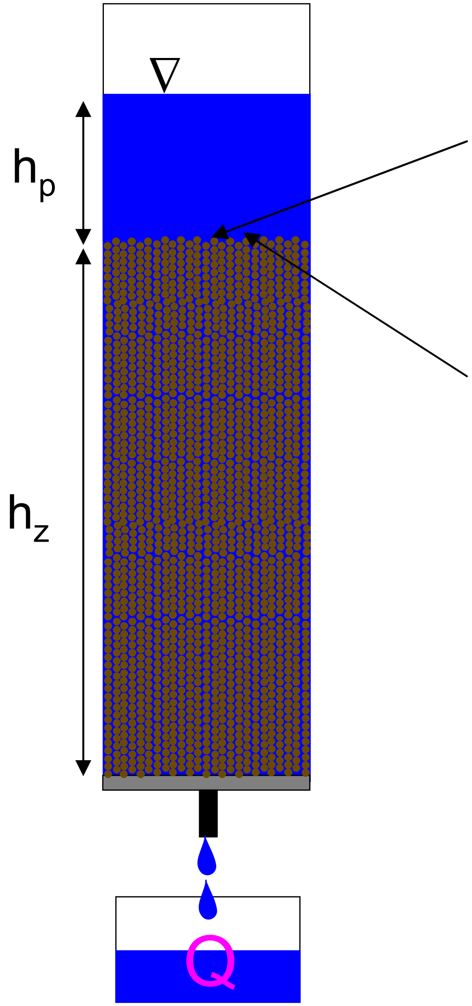
Water pressure “pushes” and gravity “pulls”

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 some distance is called the **hydraulic gradient**.

The total head at the surface of the sand



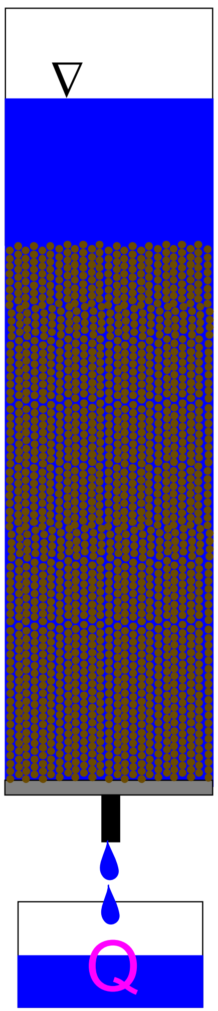
A water molecule at the surface of the sand senses a water pressure due to the height of the water above the sand. It is called the pressure head or h_p

A water molecule at the surface wants to “fall” to the bottom of the sand due to gravity. This is called elevation head or h_z

The total head at the surface of the sand is

$$h = h_p + h_z$$

The total head at the bottom of the sand



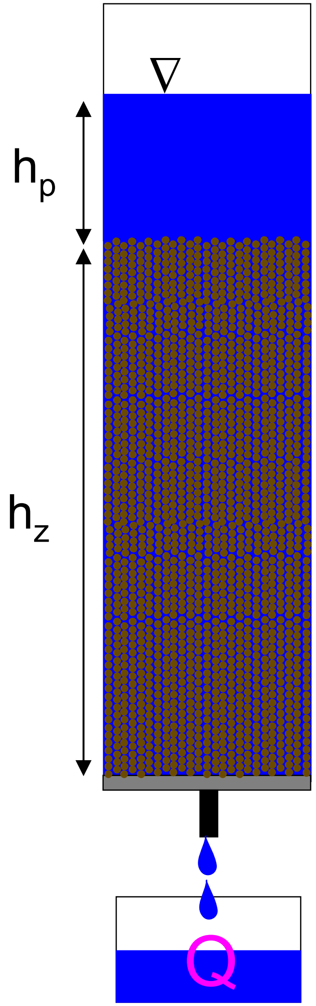
A water molecule at the bottom of the sand senses no water pressure because the valve opening is exposed to the atmosphere, therefore $h_p = 0$

A water molecule at the bottom doesn’t fall any distance because it is already at the bottom! Therefore, $h_z = 0$

The total head at the bottom of the sand is

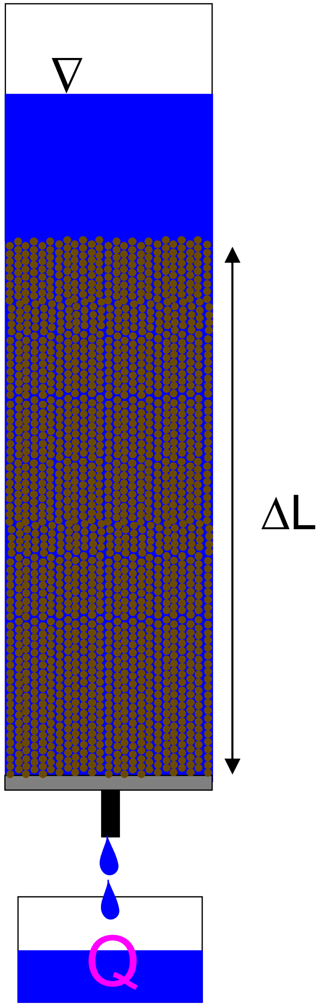
$$h = 0$$

The change in total head (Δh)



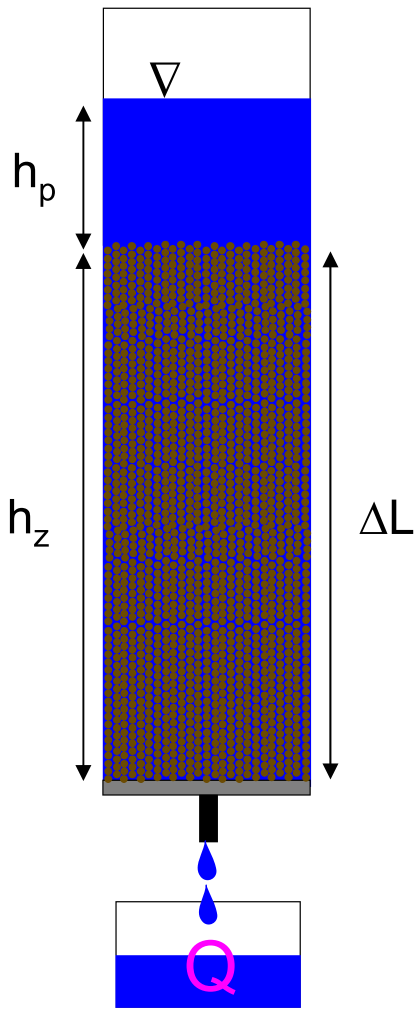
Δh = head at the top “minus” the head at the bottom

$$\Delta h = h - 0 = h_p + h_z$$



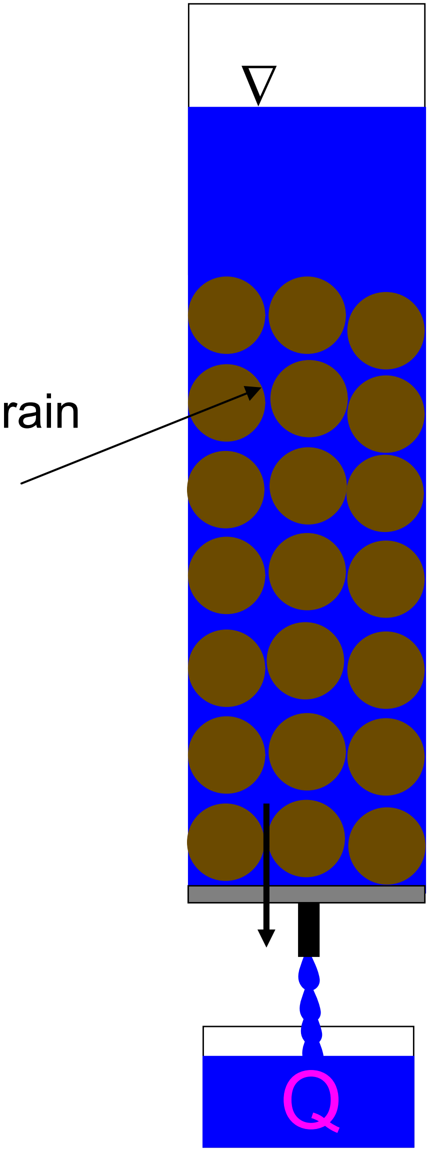
The length of the sand is defined as ΔL

The hydraulic gradient

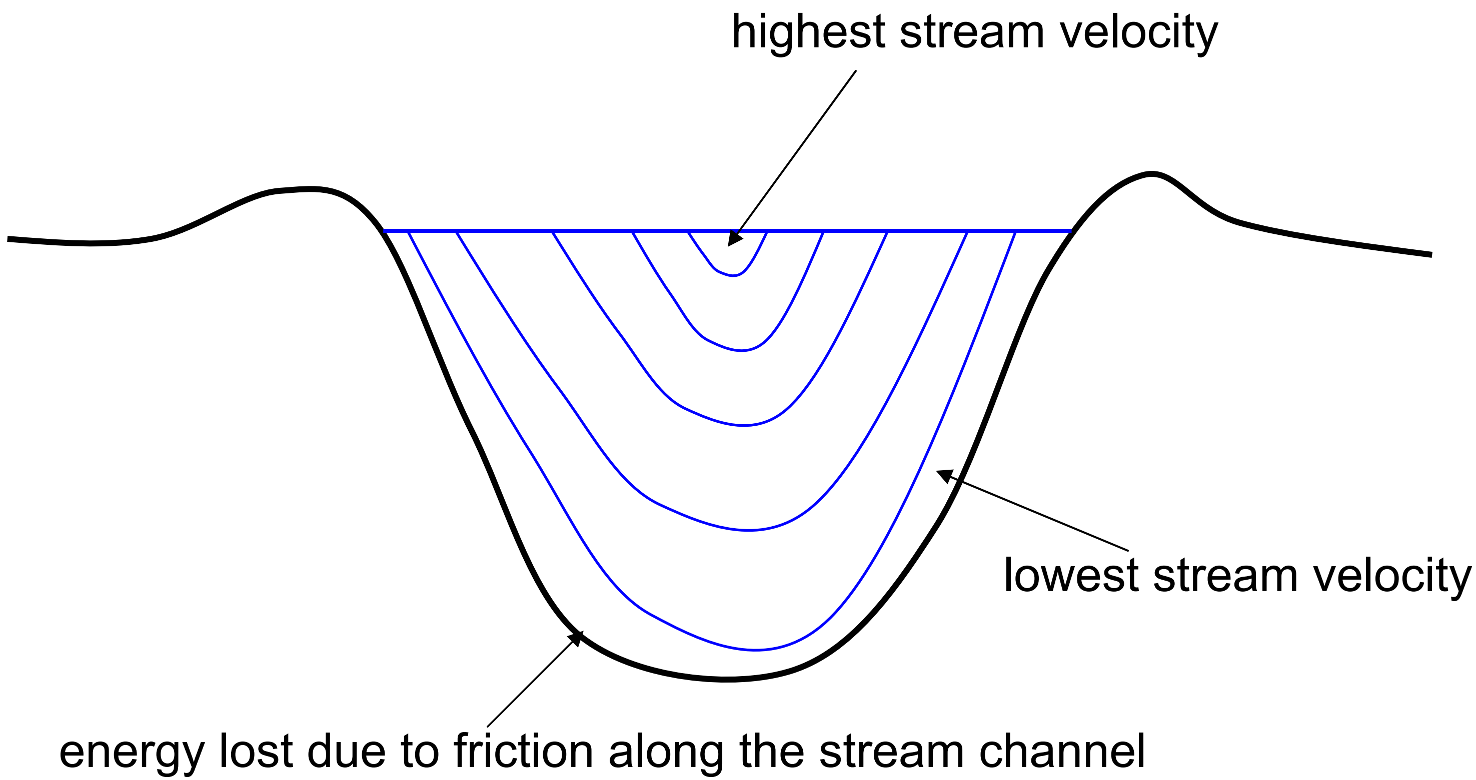


The hydraulic gradient is $\Delta h/\Delta L$

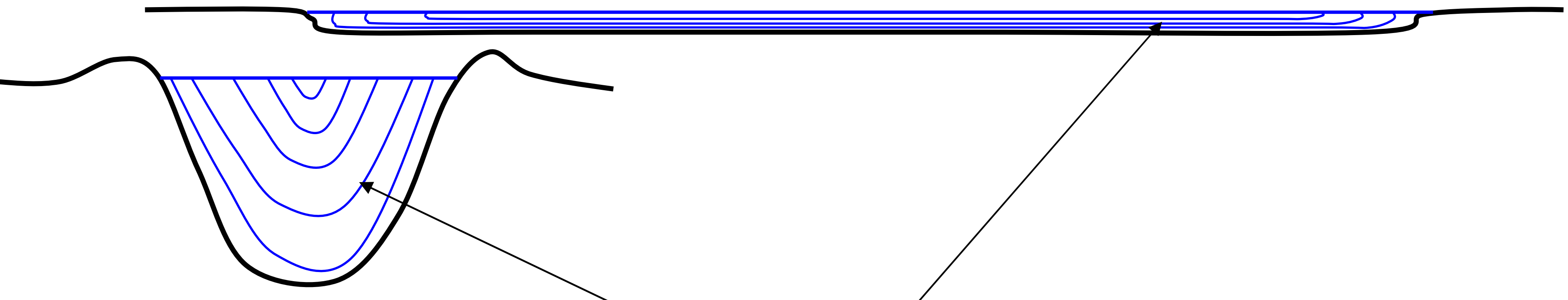
friction along the grain surfaces will resist water flow



Stream-Flow Analogy



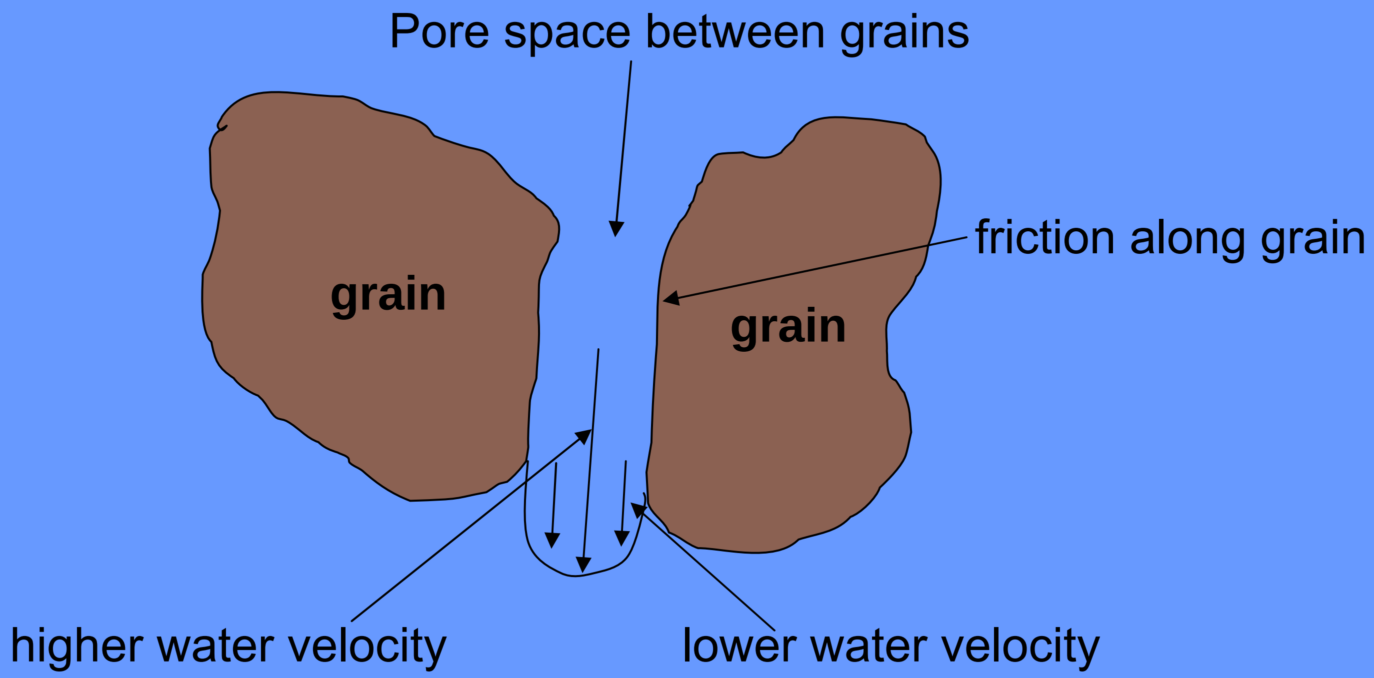
Stream-Flow Analogy



Equivalent stream-channel volumes.

Which one has the lower velocity? Why?

Water Flow in Porous Media

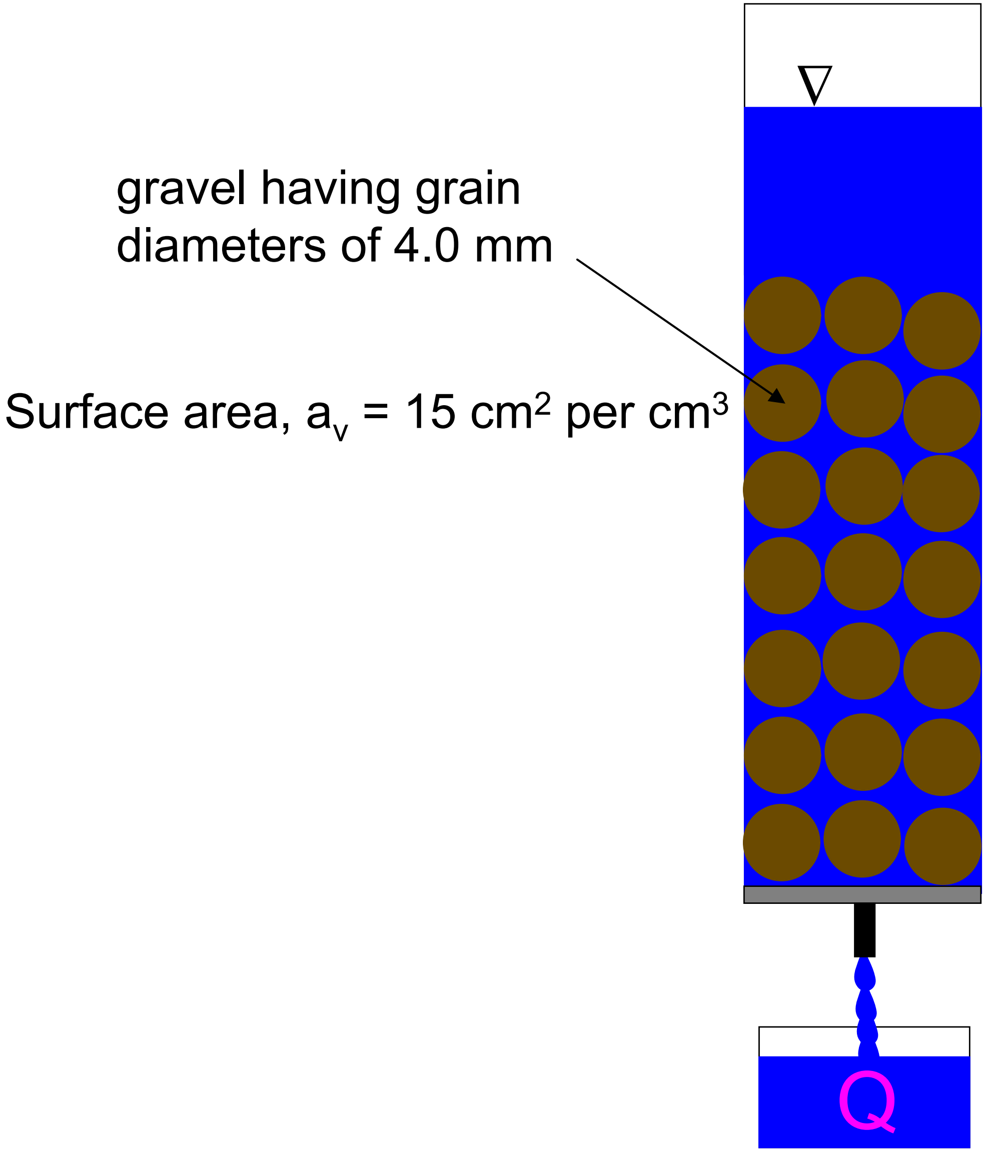


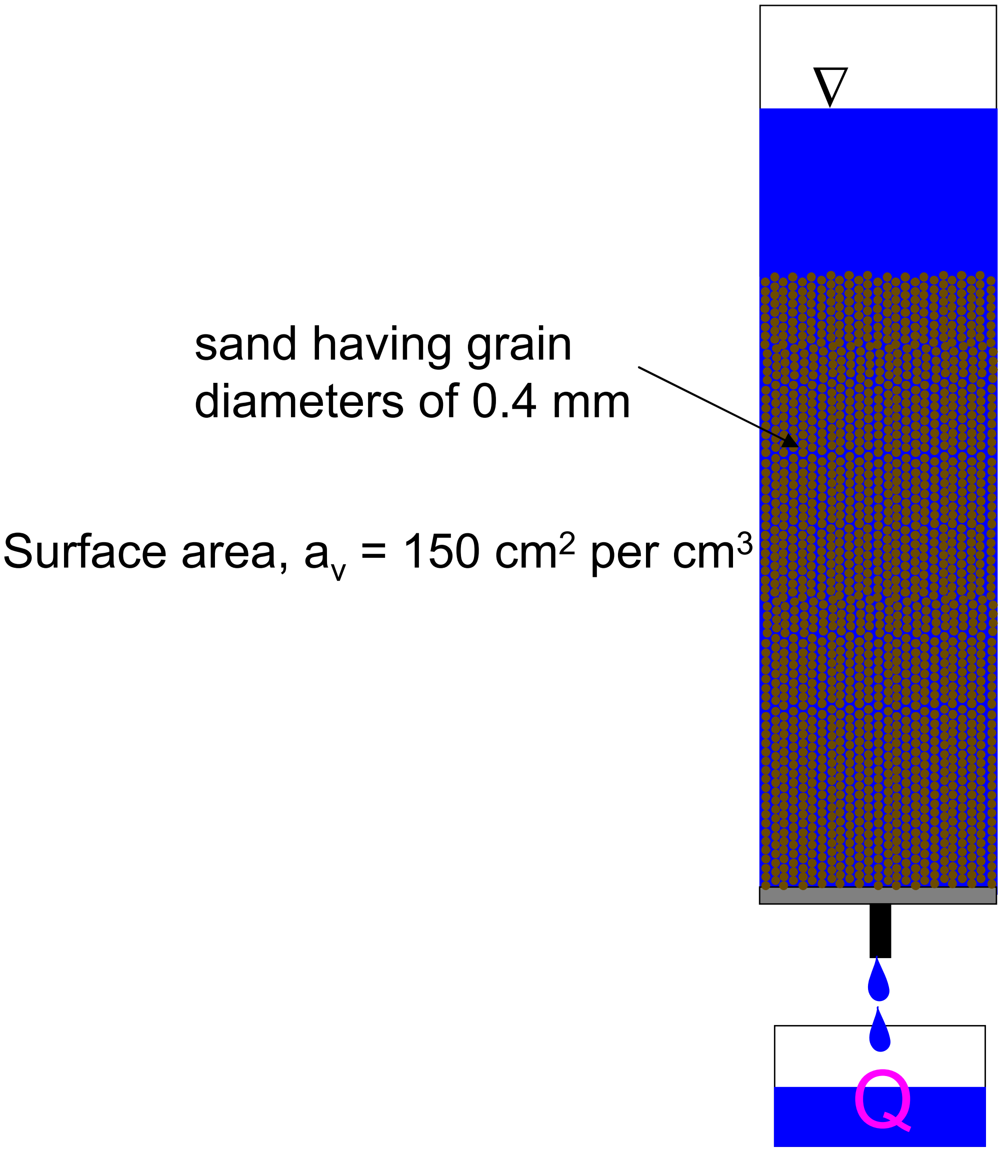
The amount of friction along grain boundaries depends on the surface area of the sediment

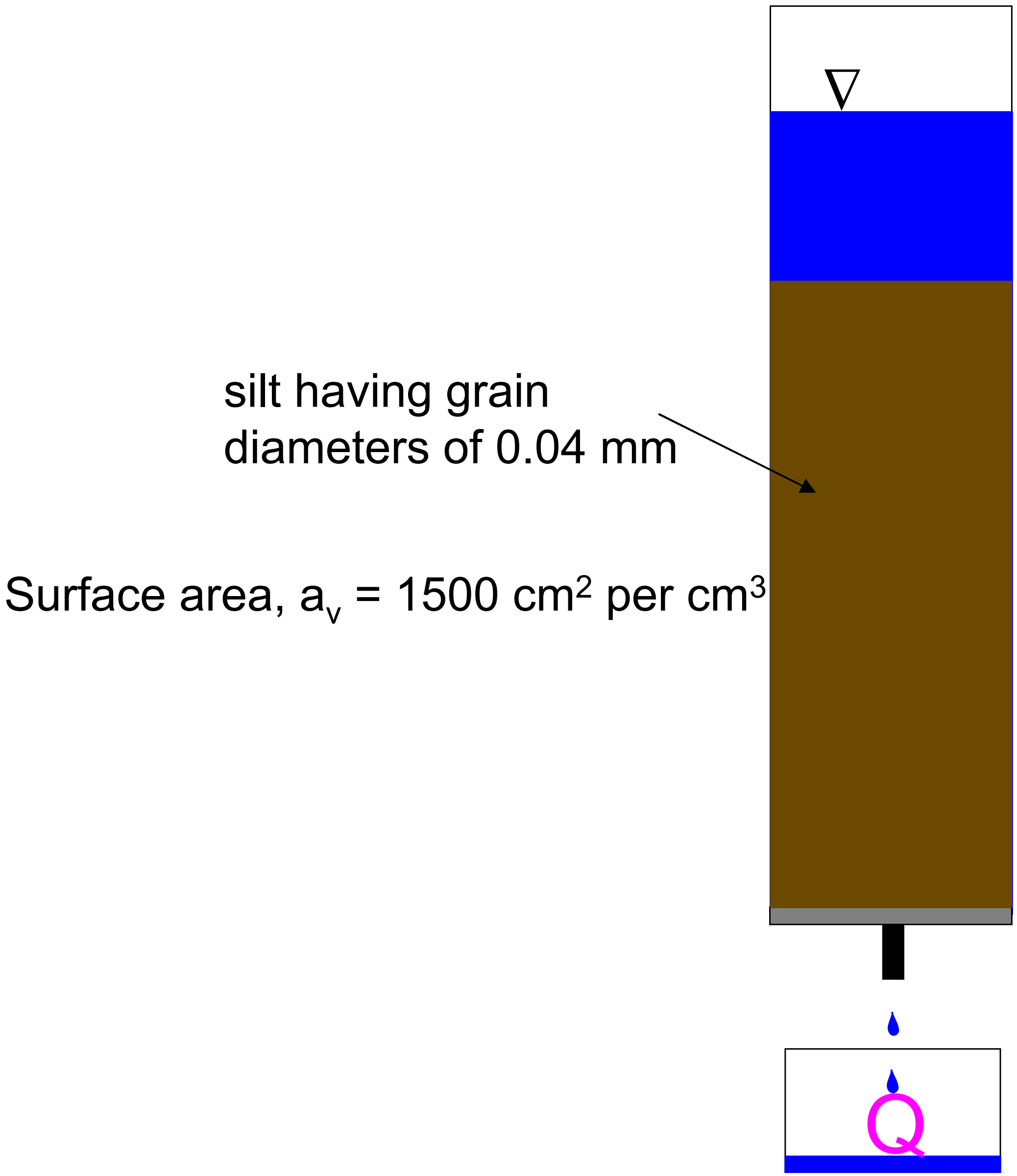
Assuming spherical sediments, the surface area per volume is given as

$$a_v = 6/d$$

where d = grain diameter


gravel having grain
diameters of 4.0 mm
Surface area, a_v = 15 cm^2 per cm^3
Q


sand having grain diameters of 0.4 mm
Surface area, a_v = 150 cm^2 per cm^3
Q



silt having grain diameters of 0.04 mm
Surface area, a_v = 1500 cm^2 per cm^3
Q

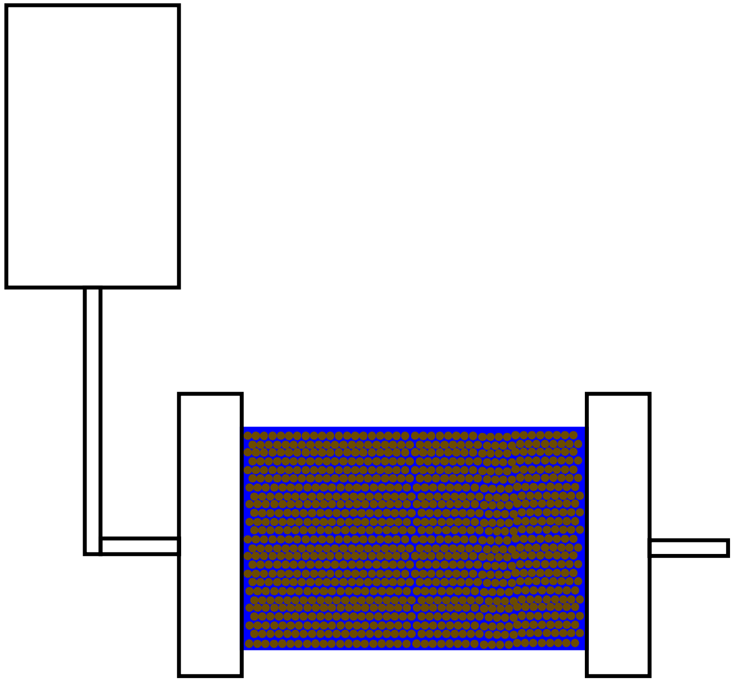
1 gram of smectite clay has 8,000,000 cm^2 of surface area

or

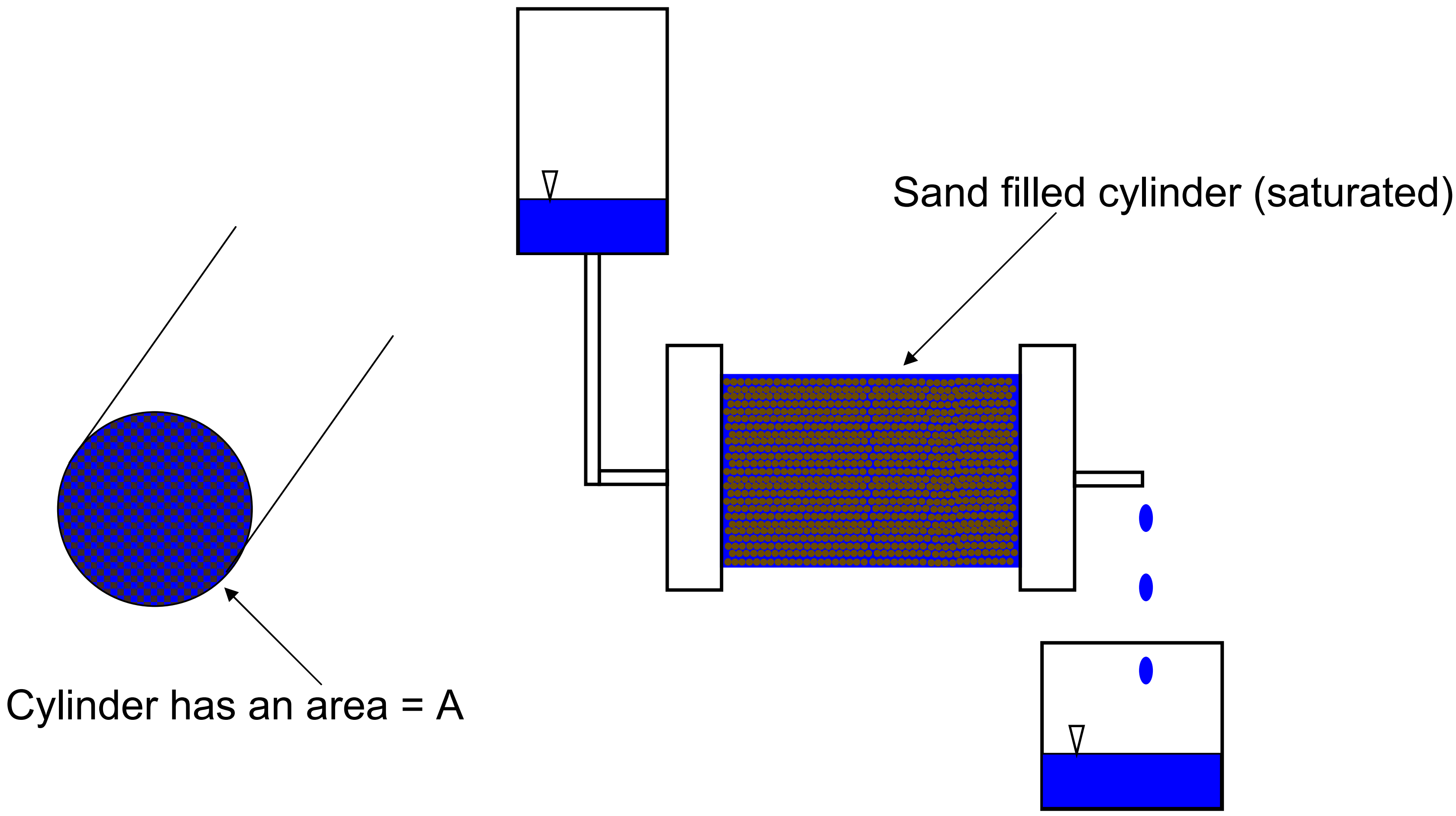
5 grams of smectite clay has the surface area of a football field!

smectite is a common name for montmorillonite clay, the clay that attracts water and “swells”

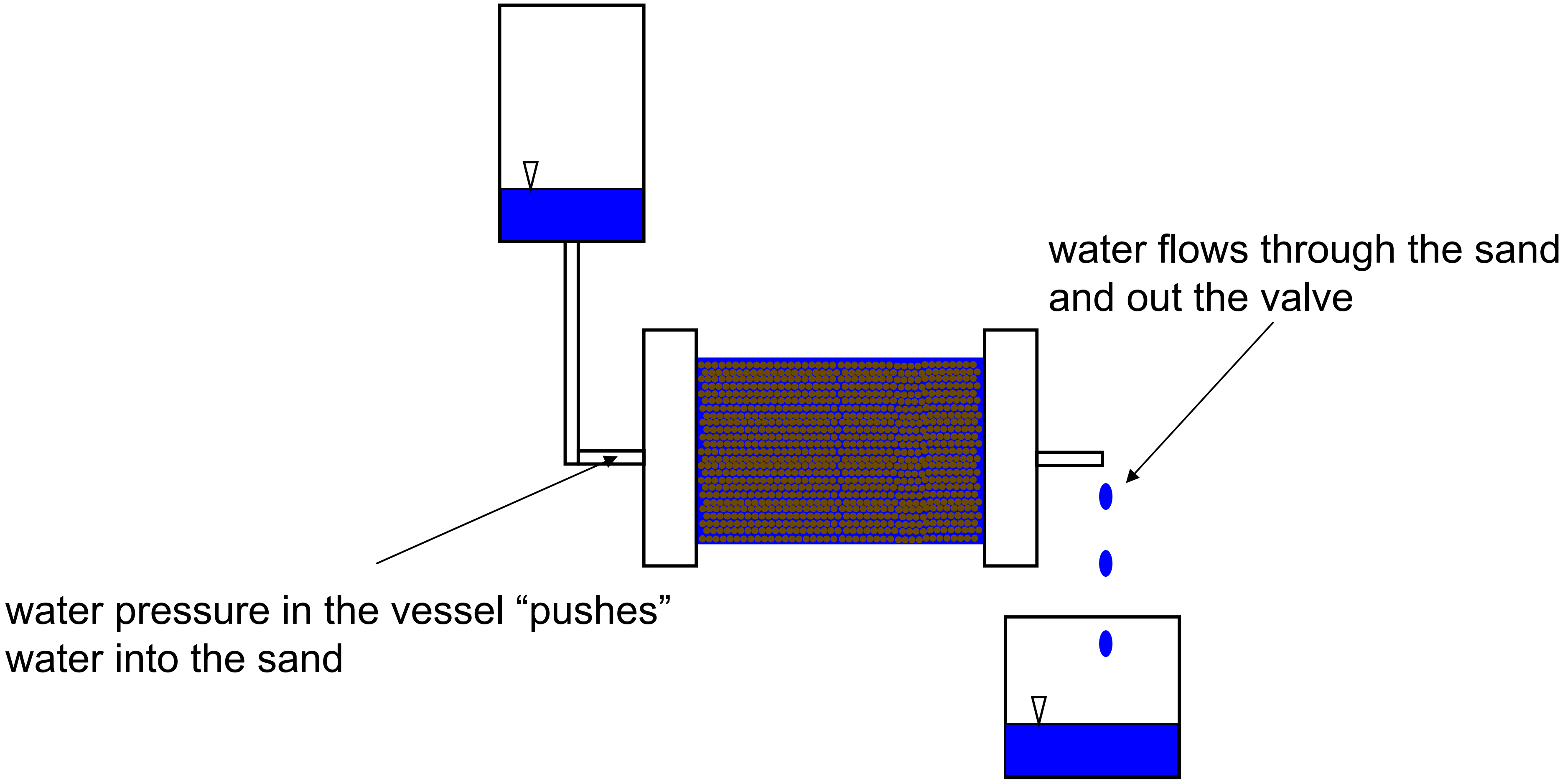
Water flow in porous media is measured with a permeameter



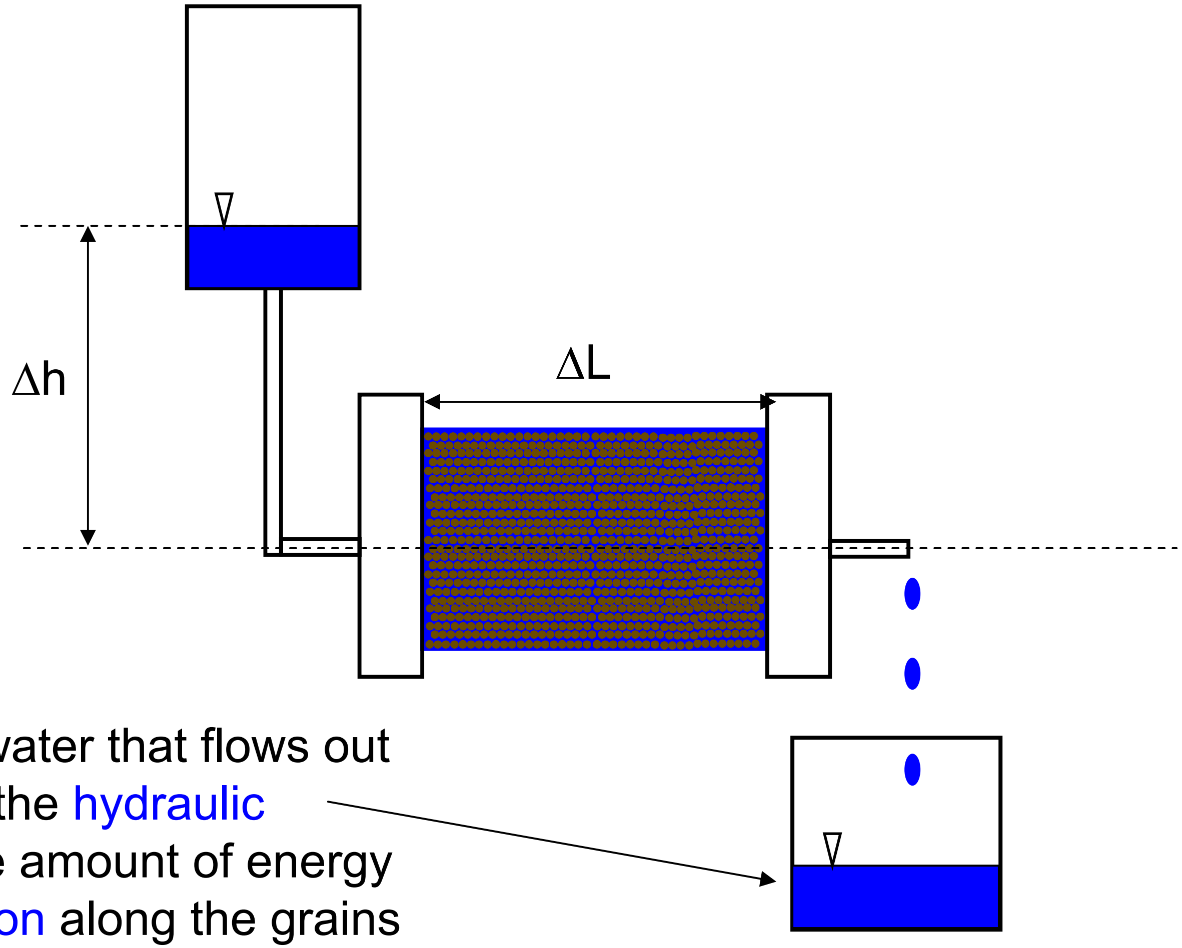
Permeameter



Permeameter

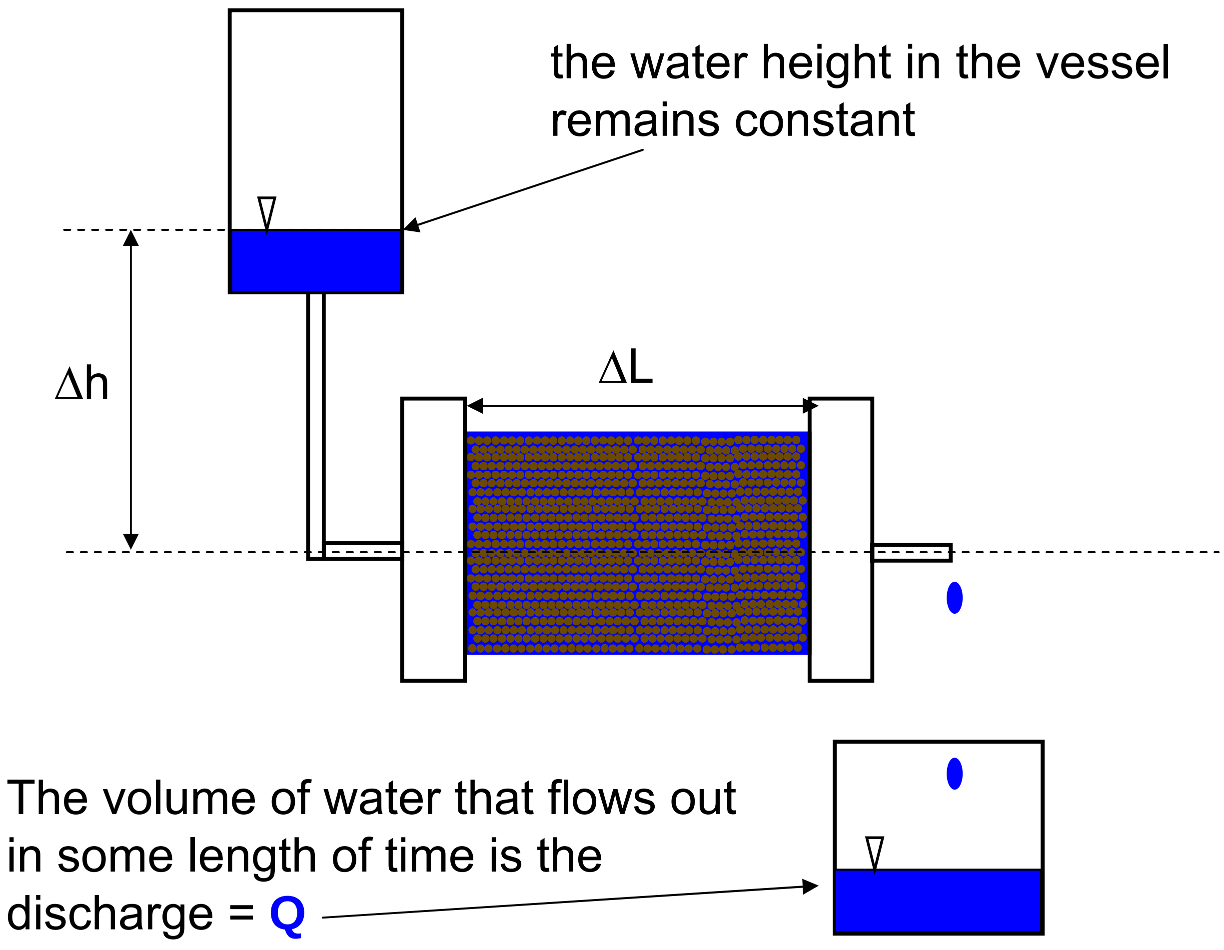


Permeameter

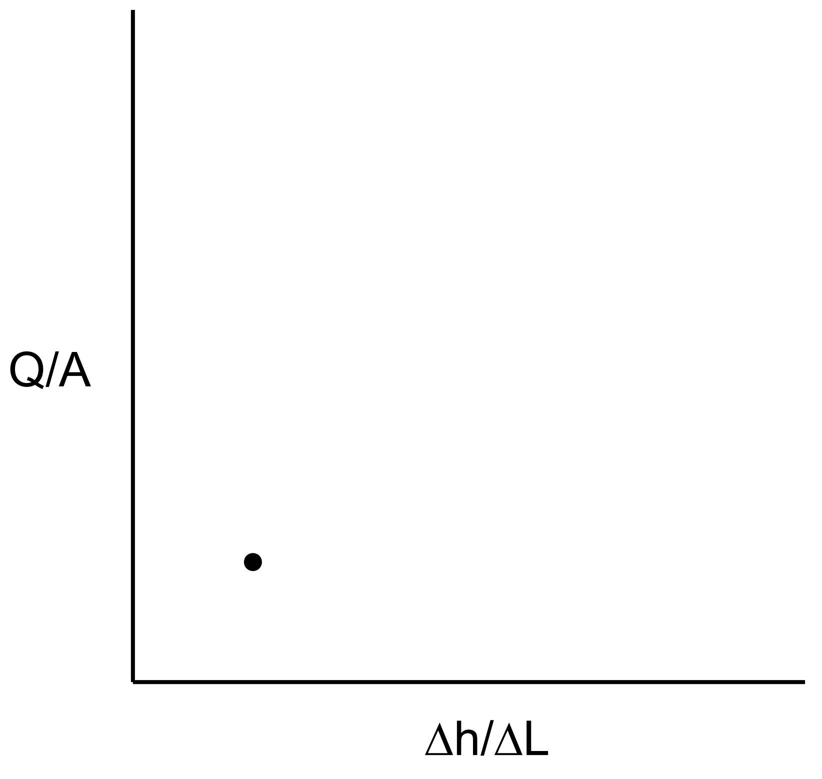


The volume of water that flows out is controlled by the hydraulic gradient and the amount of energy loss due to friction along the grains

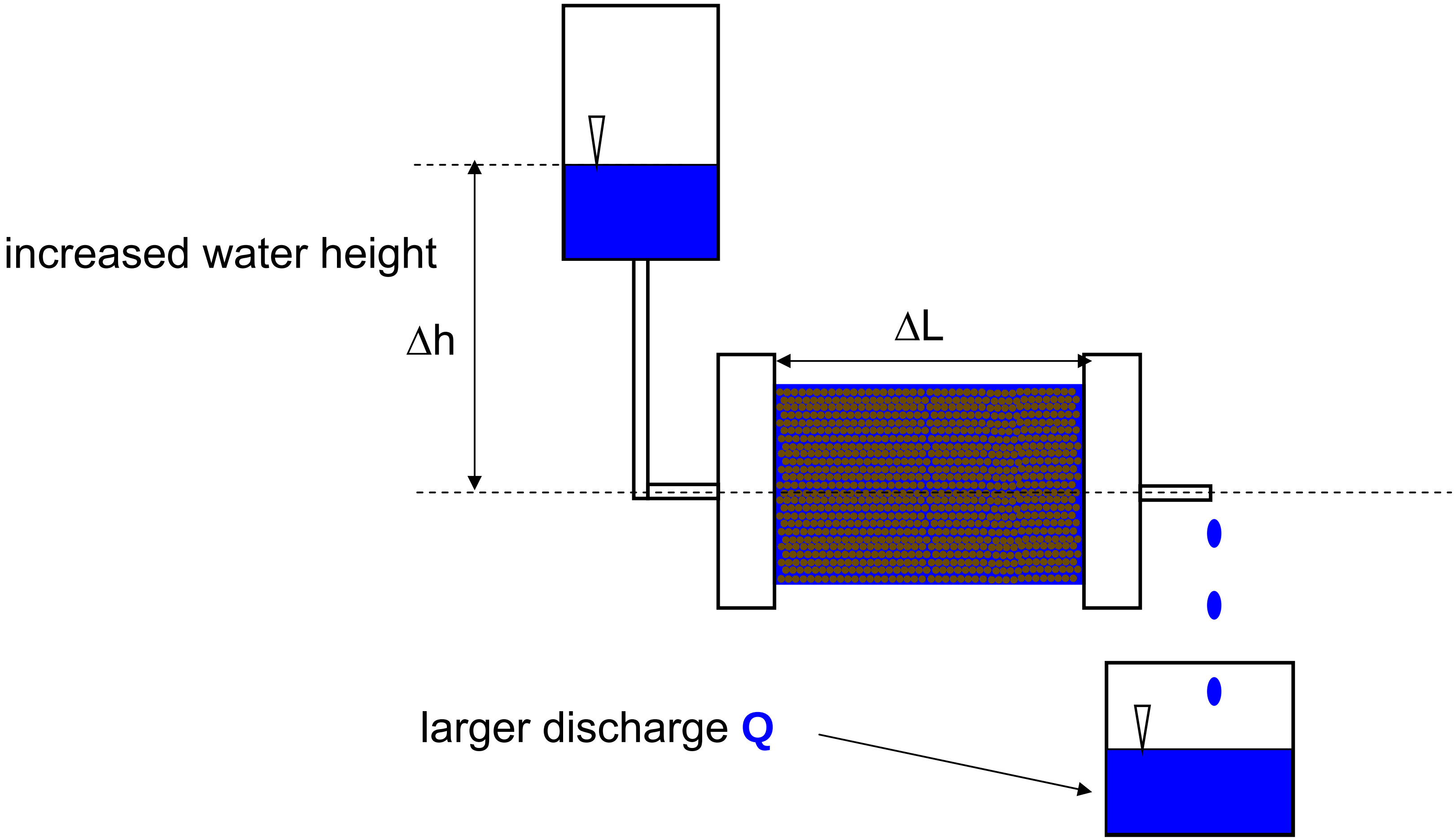
First Experiment



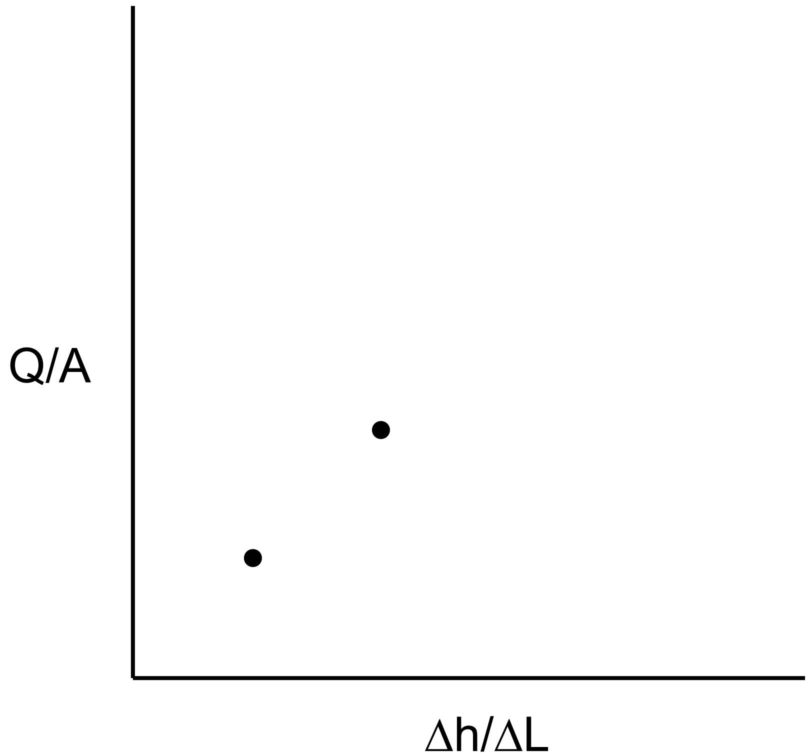
Plot the results of the 1st experiment



Second Experiment



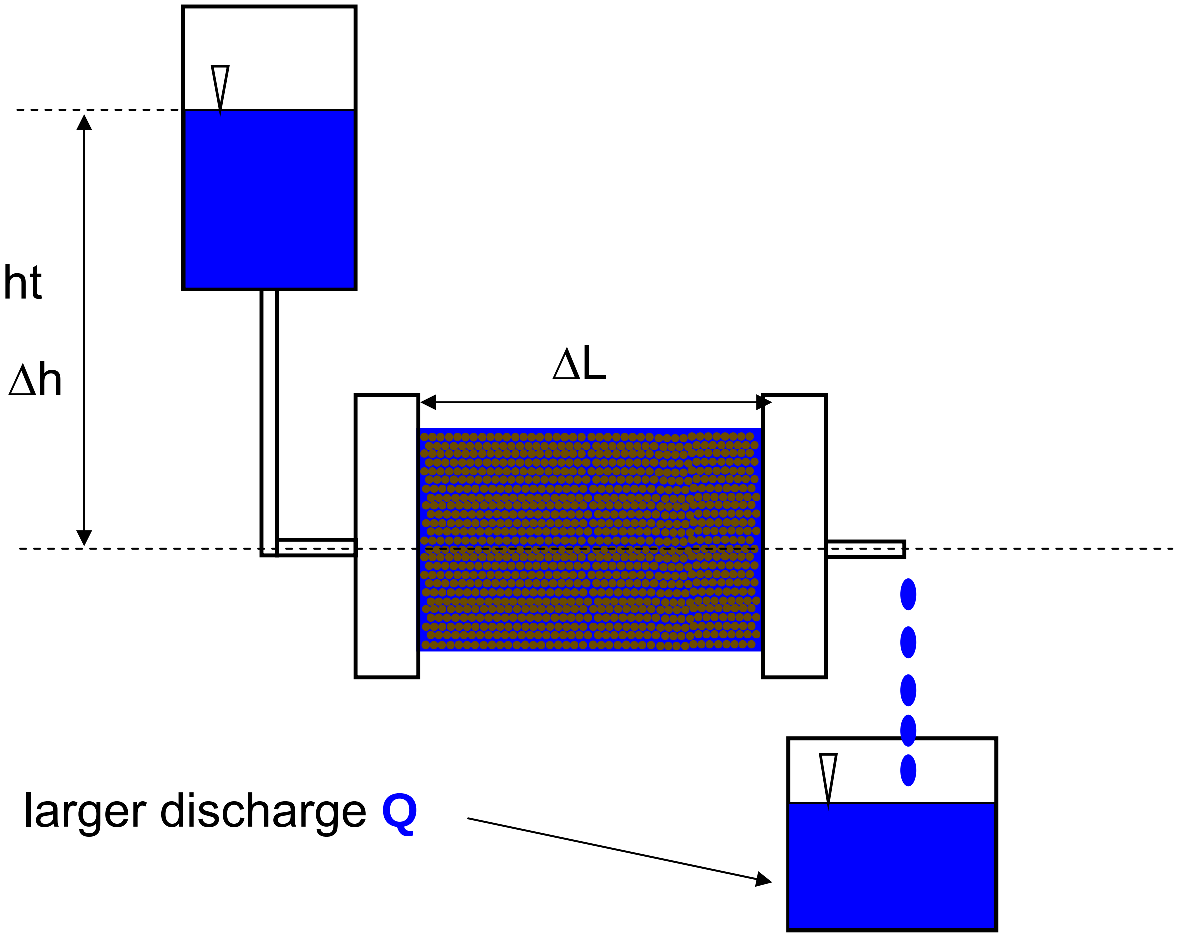
Plot the results of the 2nd experiment



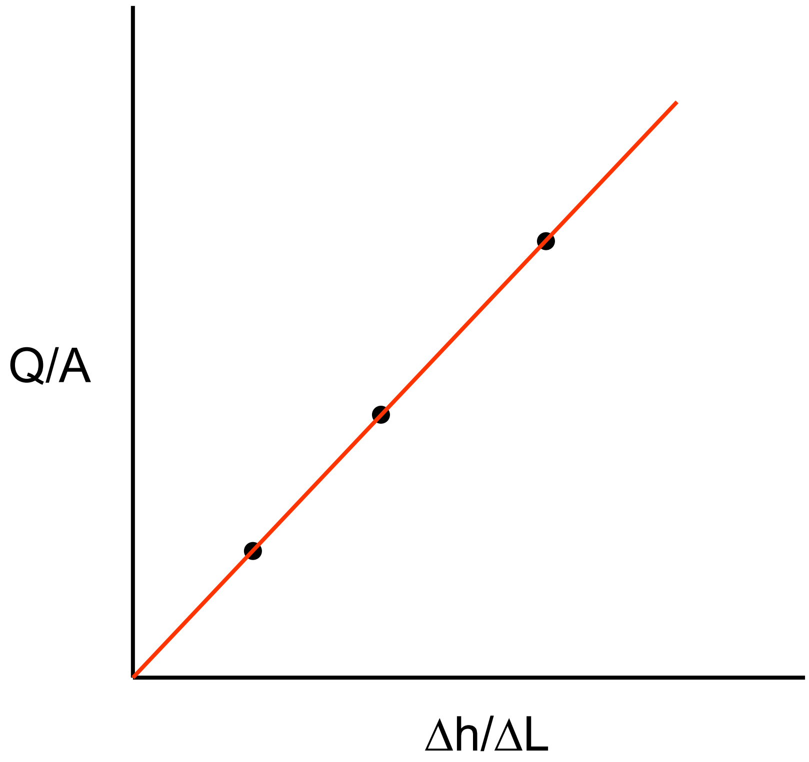
Third Experiment

in all experiments the Δh is kept constant

increased water height

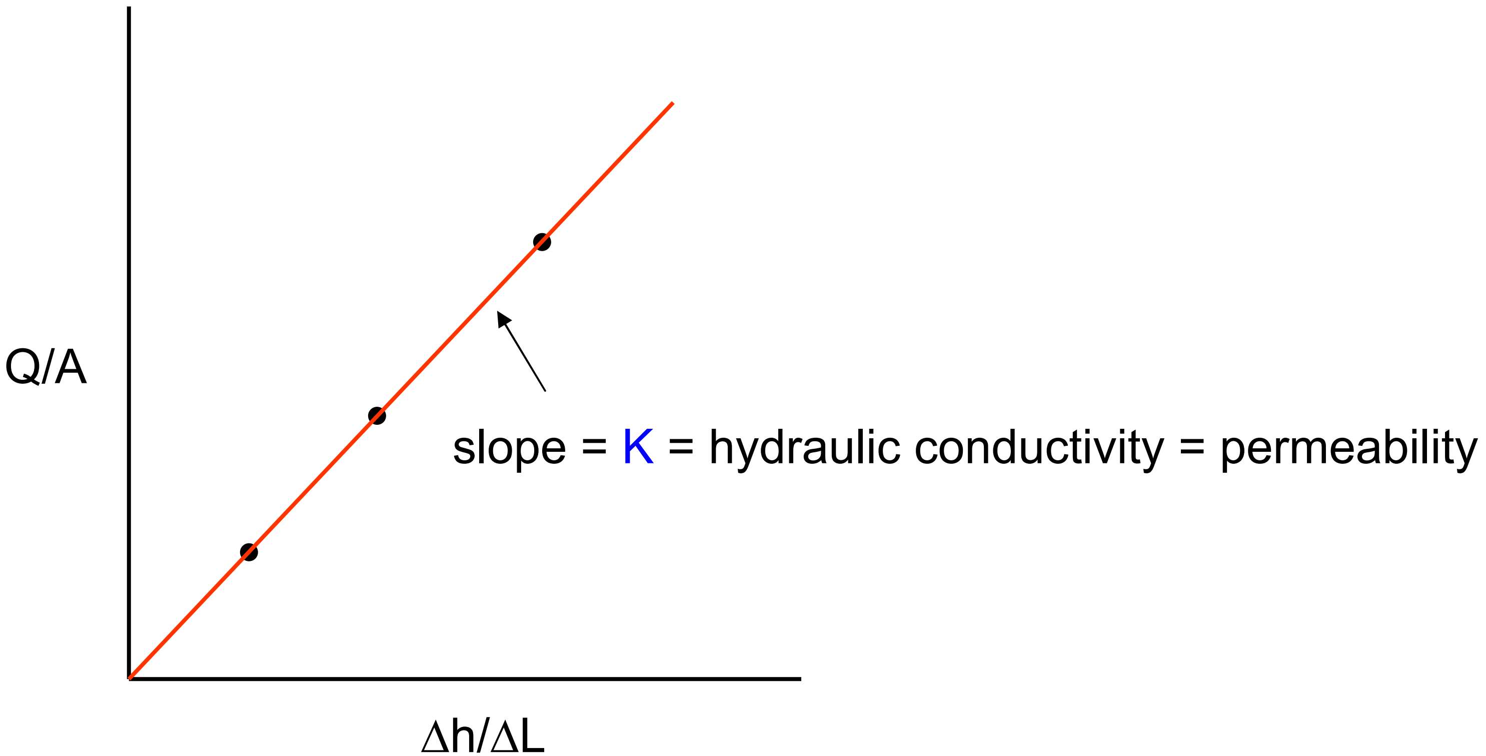


Plot the results of the 3rd experiment



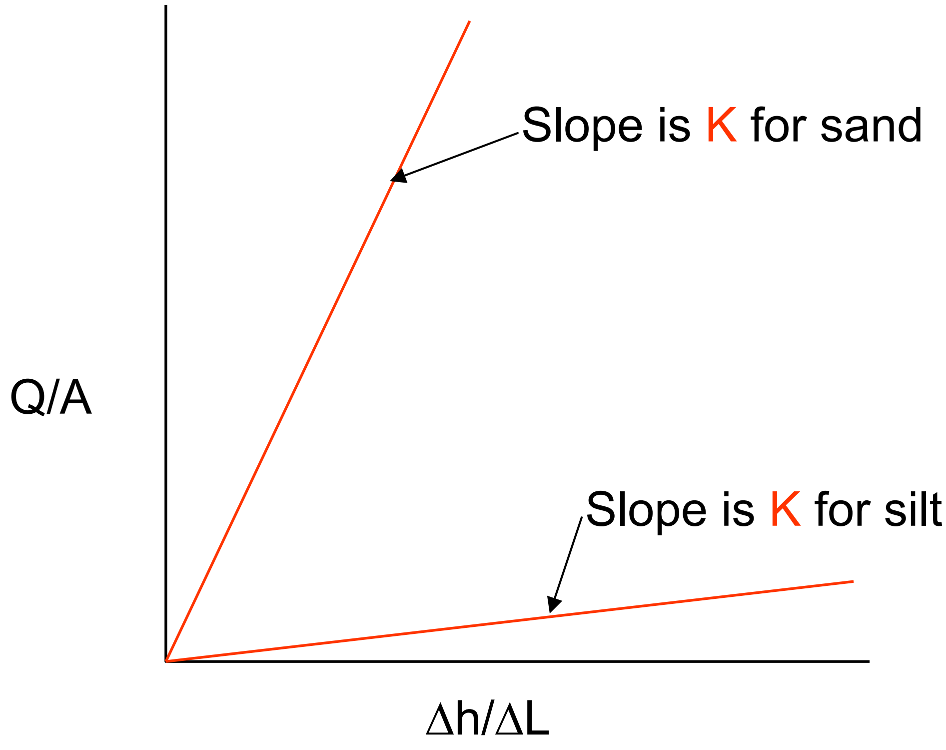
Darcy's Law

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

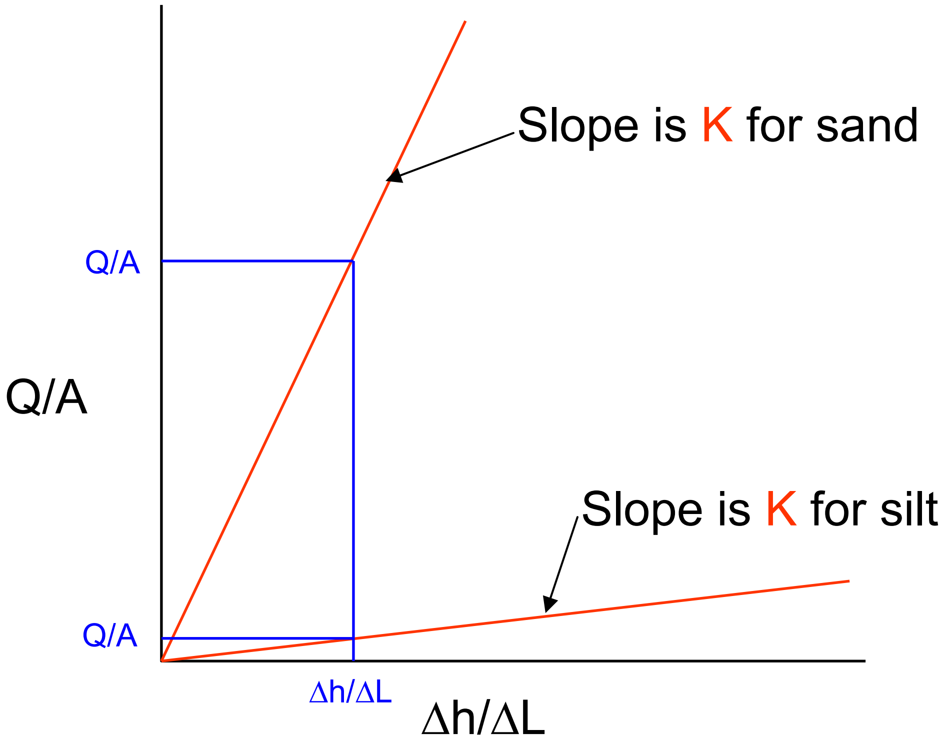


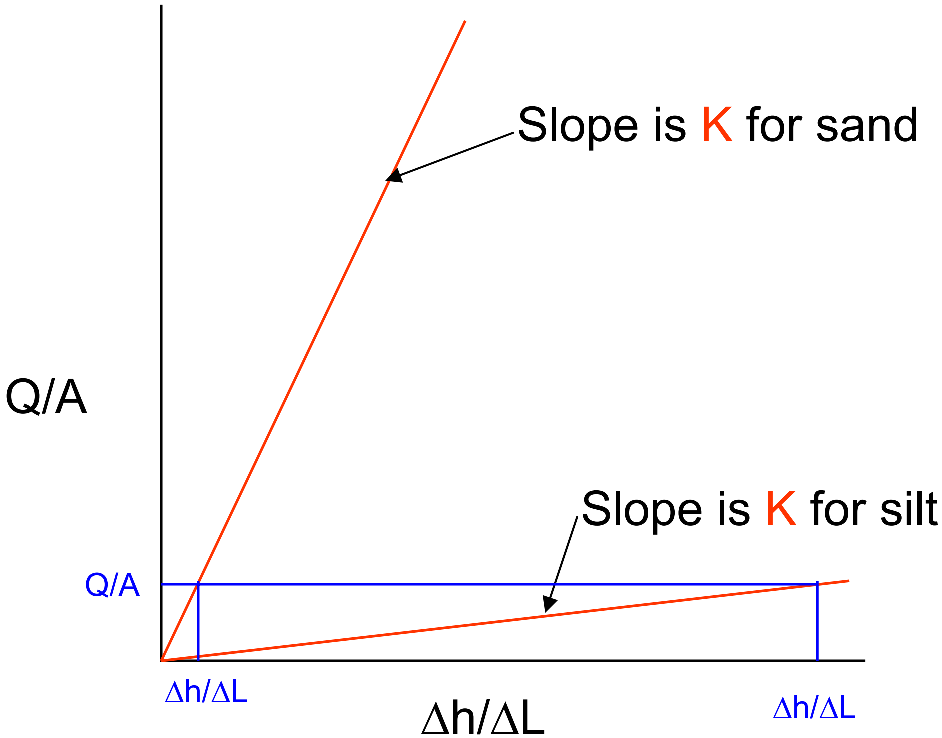
The hydraulic conductivity is a measure of the sediments ability to transmit fluid.

It's magnitude is controlled by the grain size (or pore size) which determines the amount of frictional resistance



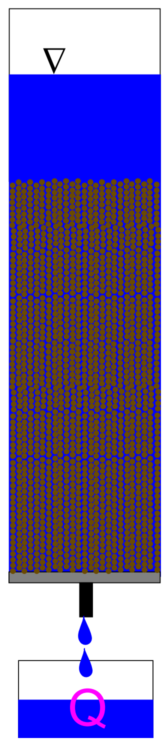
Slope is K for sand
Q/A
Slope is K for silt
Δh/ΔL


Slope is K for sand
Q/A
Q/A
Slope is K for silt
Q/A
Δh/ΔL
Δh/ΔL


Slope is K for sand
Q/A
Slope is K for silt
Q/A
Δh/ΔL
Δh/ΔL
Δh/ΔL

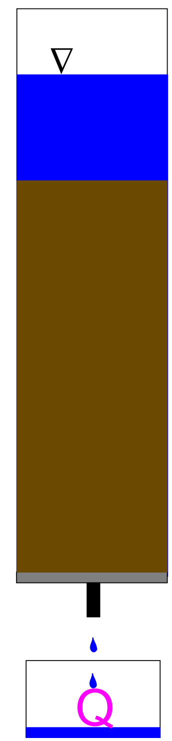
Sand

K ≈ 1 x 10^{-3} cm/s

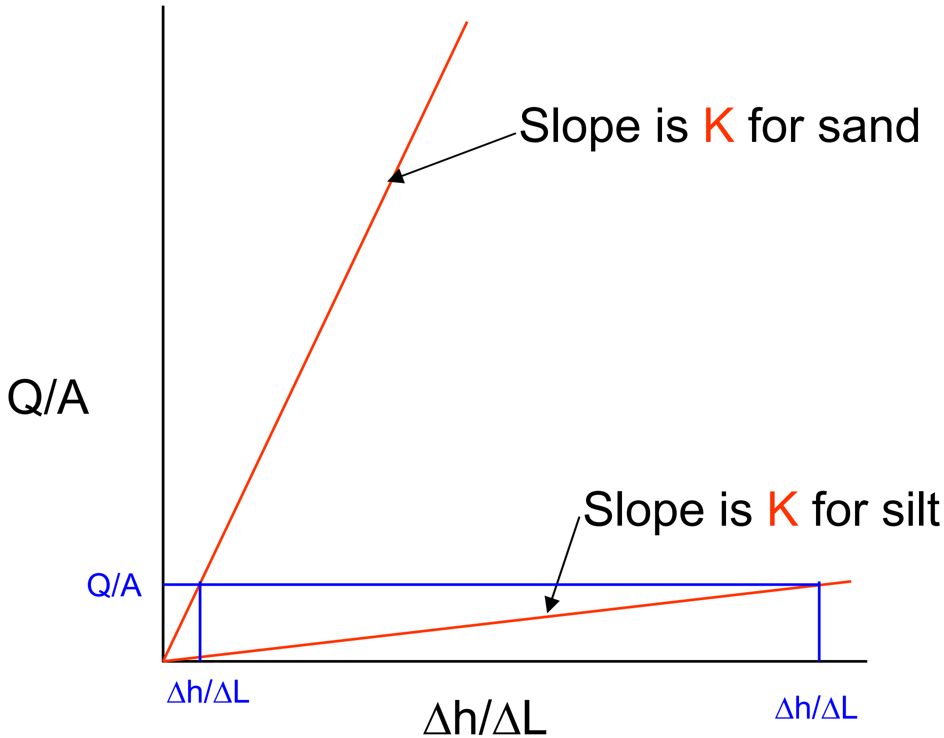


Silt

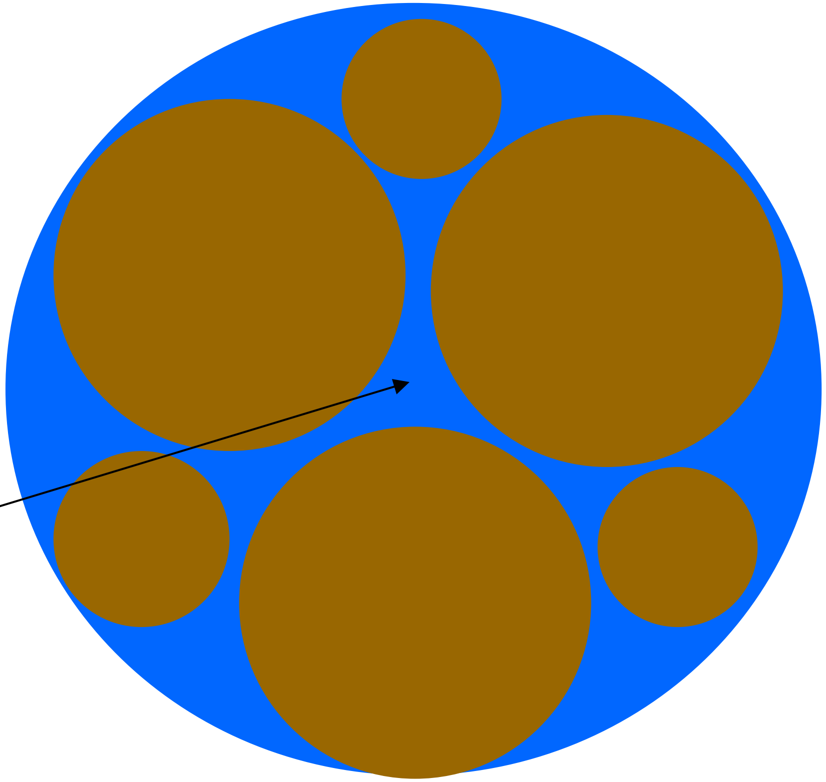
K ≈ 1 x 10^{-6} cm/s



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.

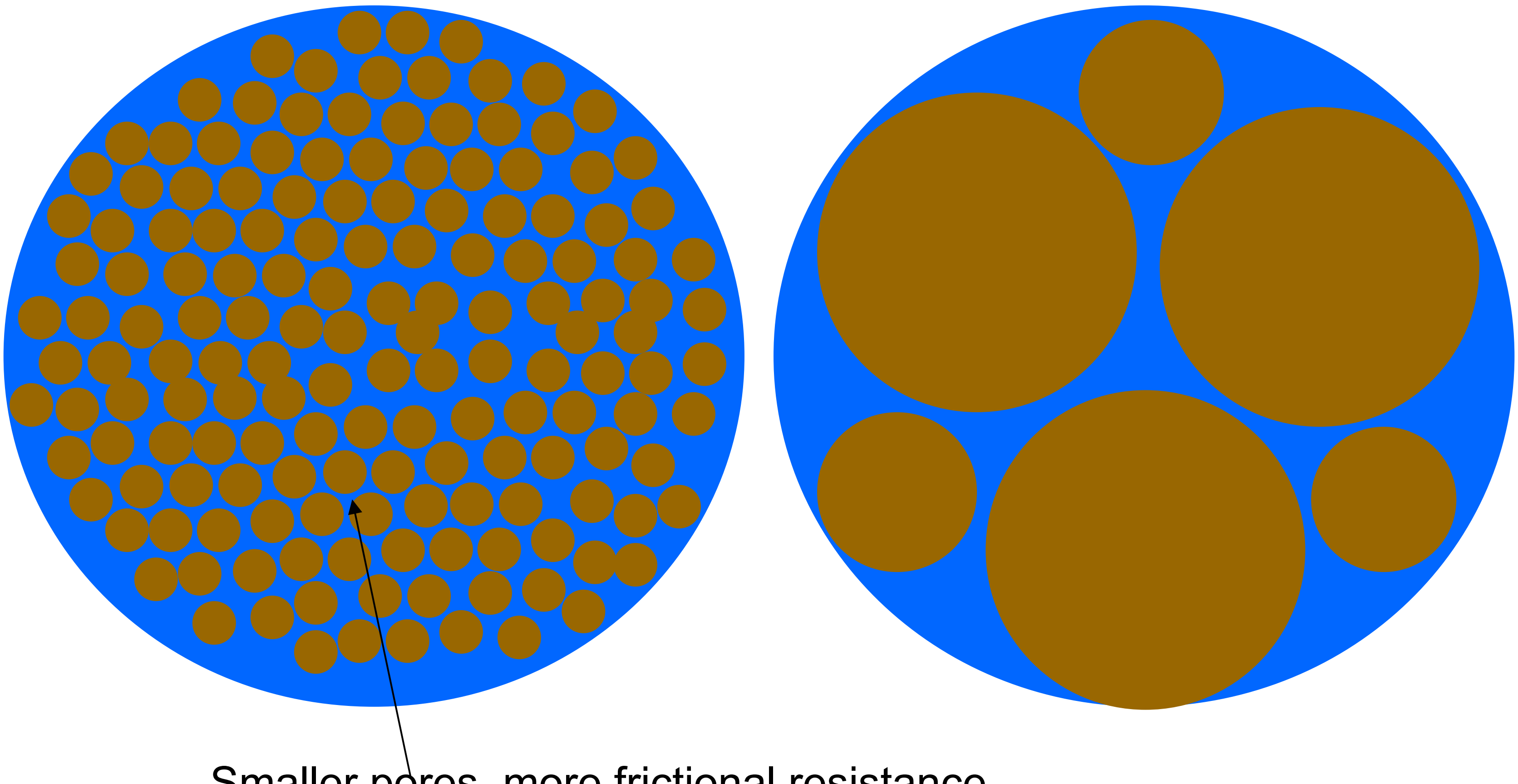


Saturated Flow in Porous Media



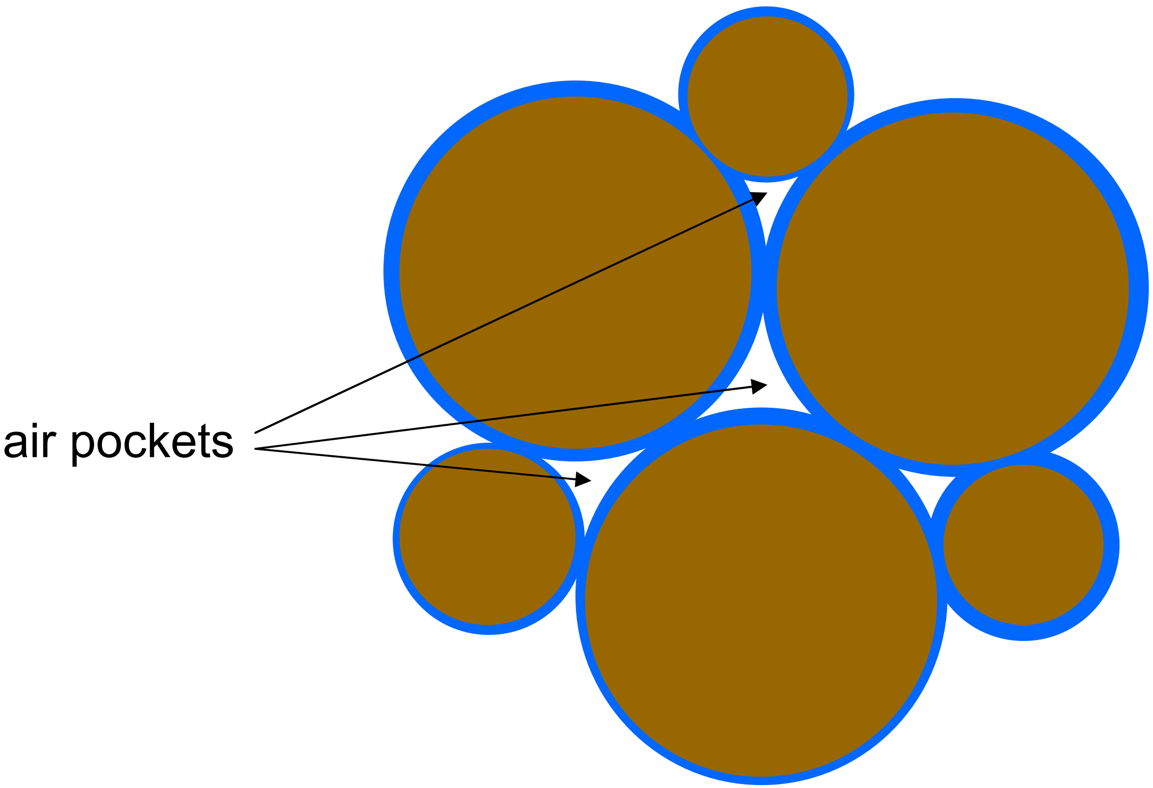
water moves fastest in
the center of the pore

Saturated Flow in Porous Media

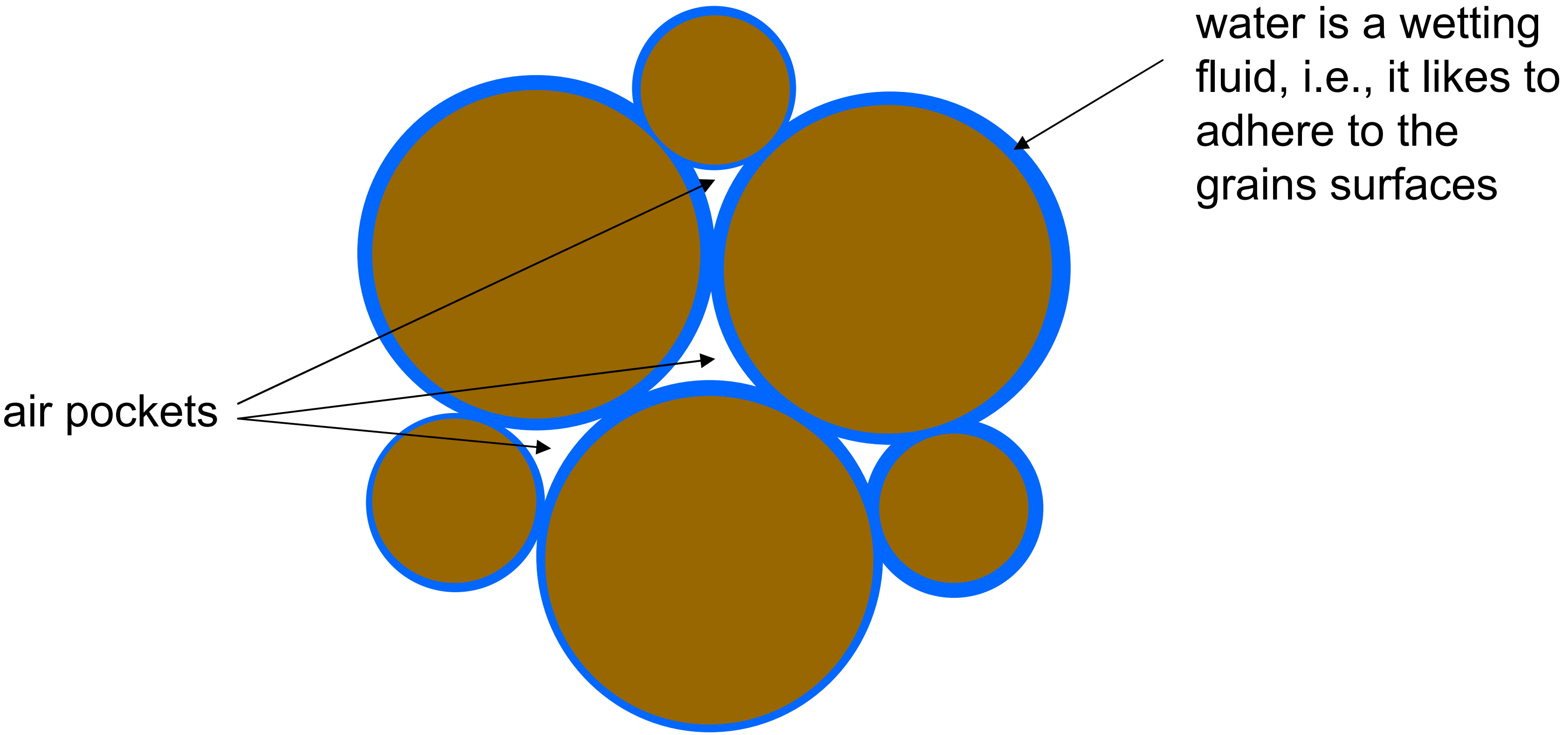


Smaller pores, more frictional resistance, lower hydraulic conductivity

Unsaturated Flow in Porous Media

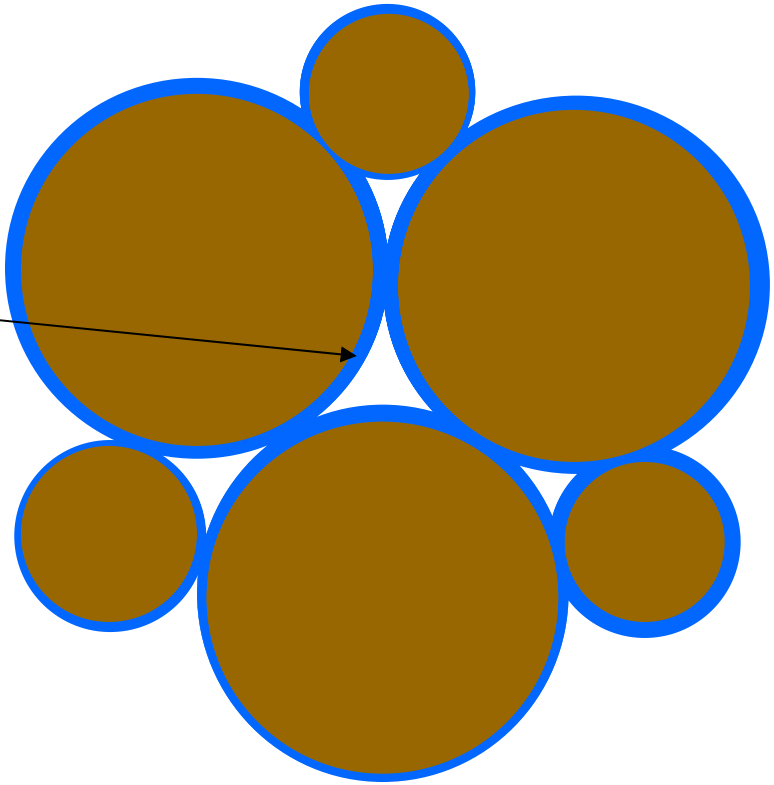


Unsaturated Flow in Porous Media

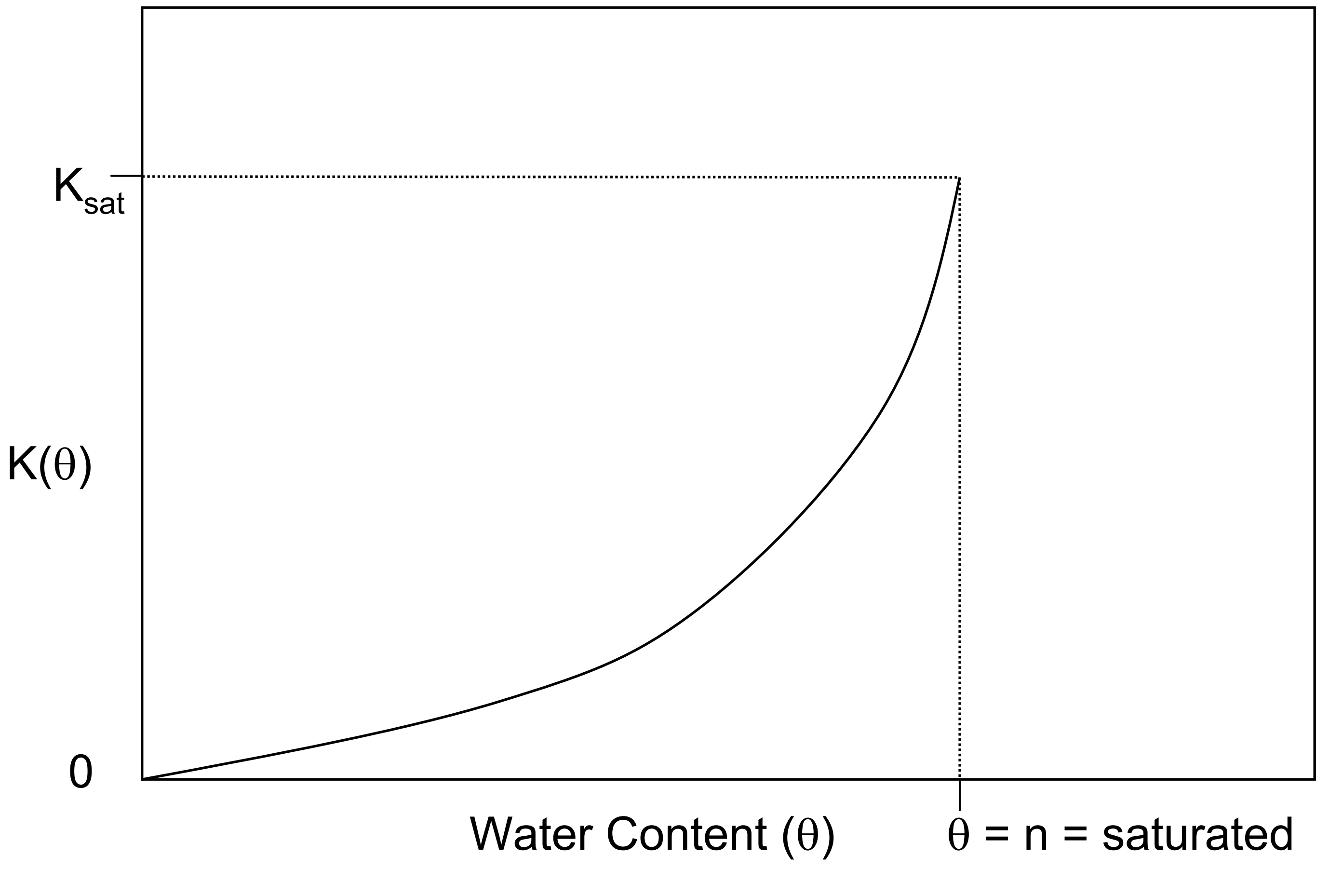


Unsaturated Flow in Porous Media

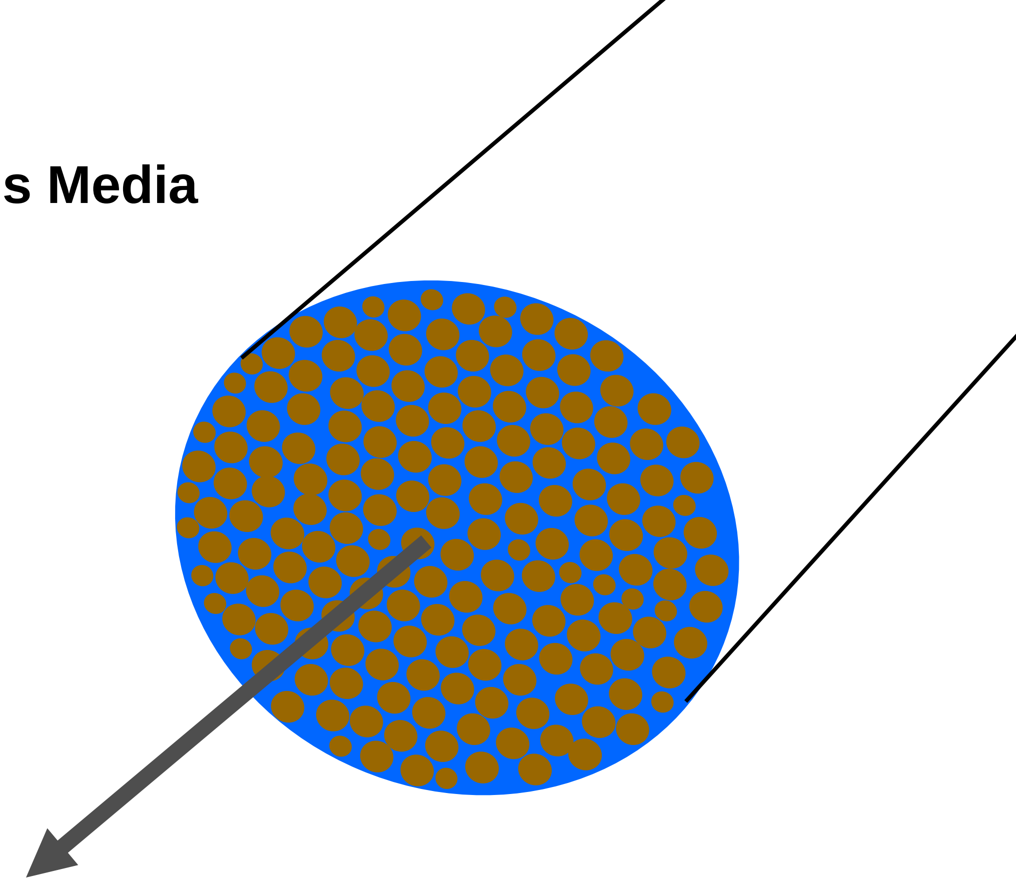
Water flows through a smaller available area—as such there is more frictional resistance and the rate at which water can flow decreases—i.e., the hydraulic conductivity decreases with water content.



Unsaturated Flow in Porous Media



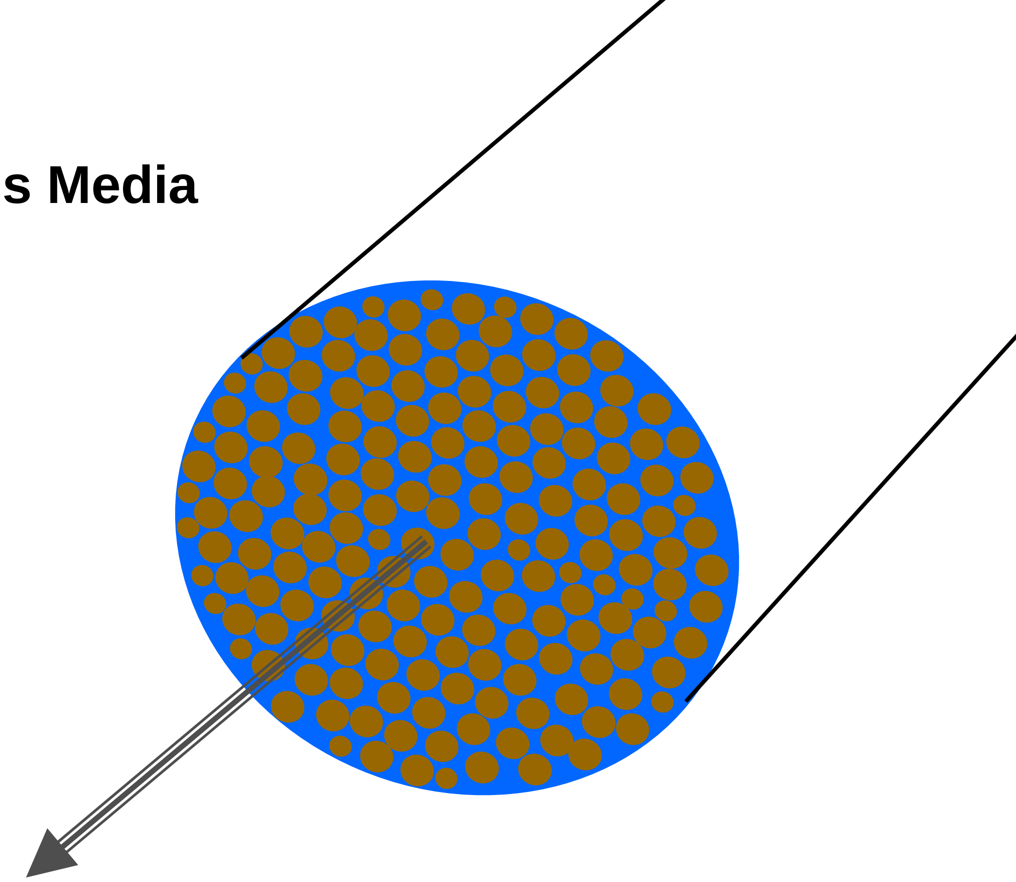
Saturated Flow in Porous Media



Darcy Flux = q = Q/A = -K(Δh/ΔL)

Darcy Flux is the average flux of water discharging through the entire cross sectional area of the conduit.

Saturated Flow in Porous Media



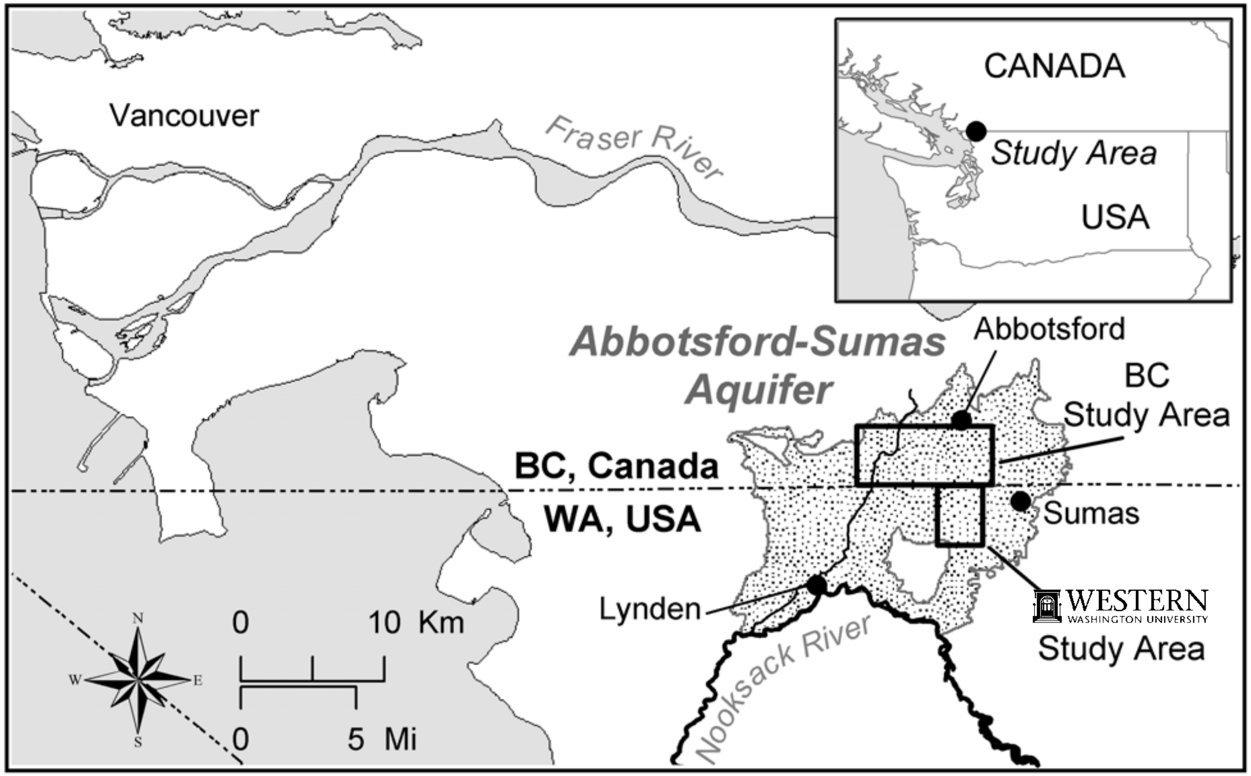
average pore water velocity = v = q/n

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

In actuality, water is only flowing through the available pore space in the porous media. Therefore, the average velocity of the water is the Darcy Flux divided by the porosity of the sediment.

Abbotsford-Sumas Aquifer

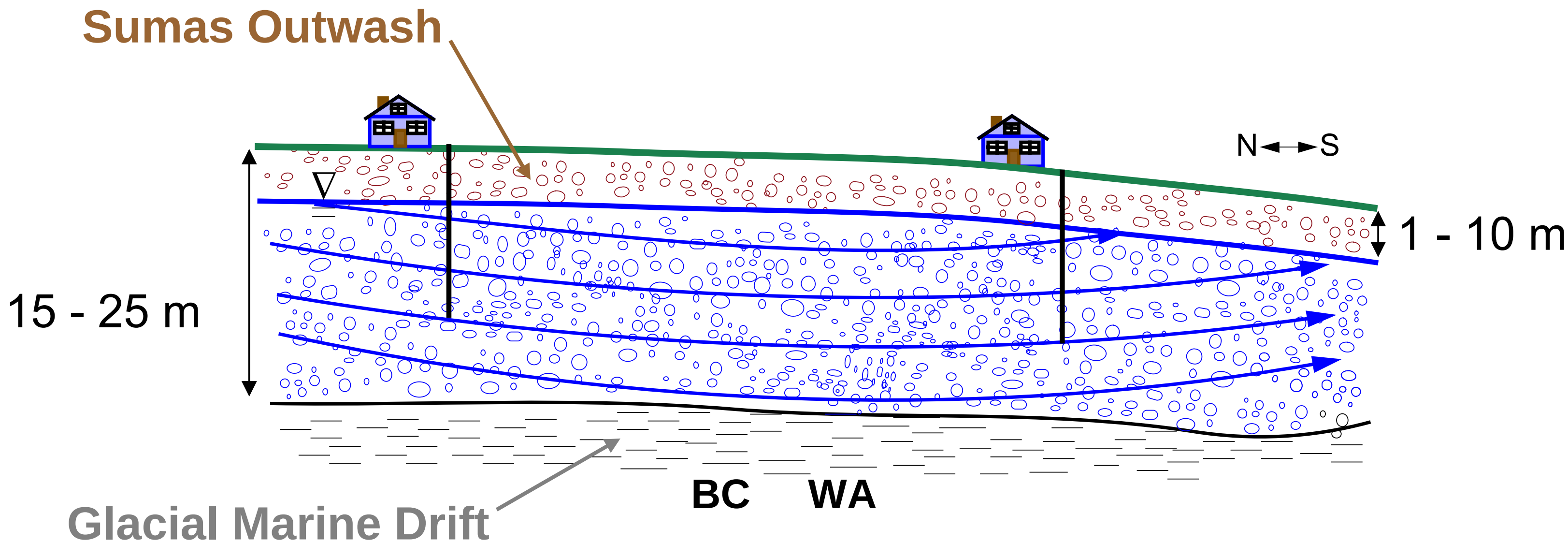
The aquifer covers approximately 200 km^2 and serves as a water supply for approximately 110,000 people in BC and WA.



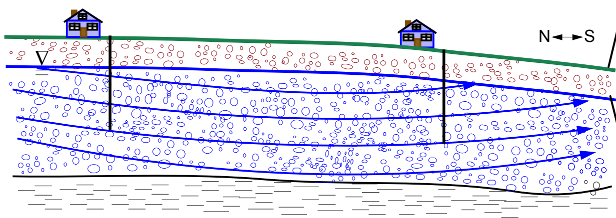
Ground Water Flow is from North-to-South

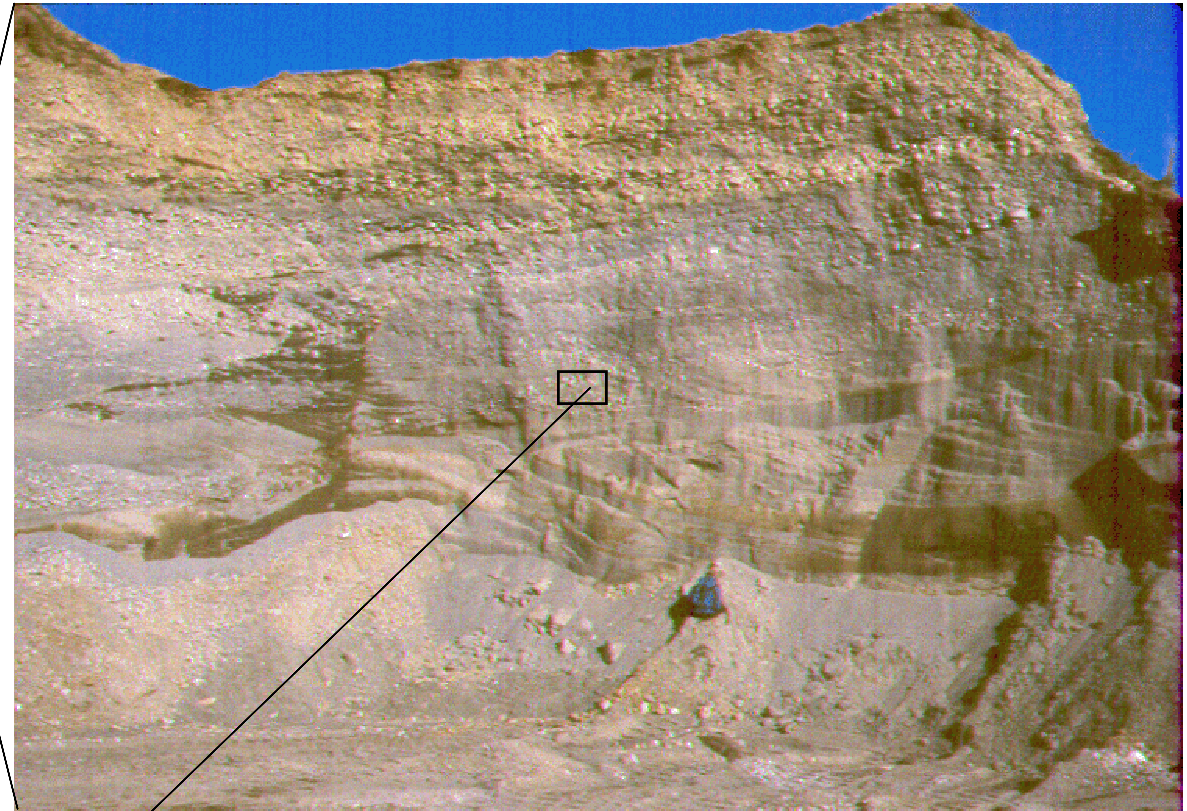
Abbotsford-Sumas Aquifer

The aquifer is unconfined and comprised of glacial outwash sands and gravels (Sumas Outwash) deposited about 10,000 years ago.

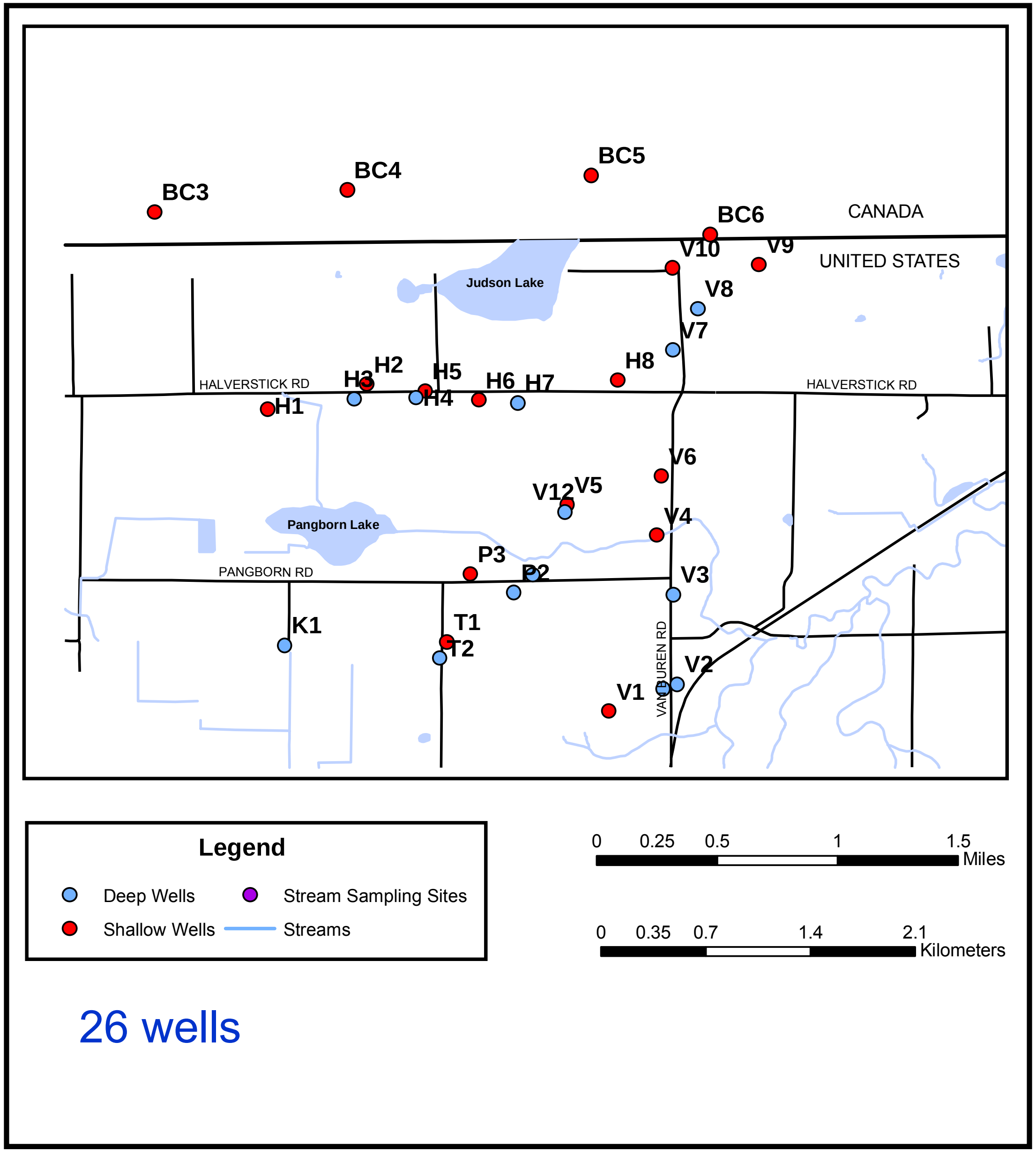


Sumas Outwash





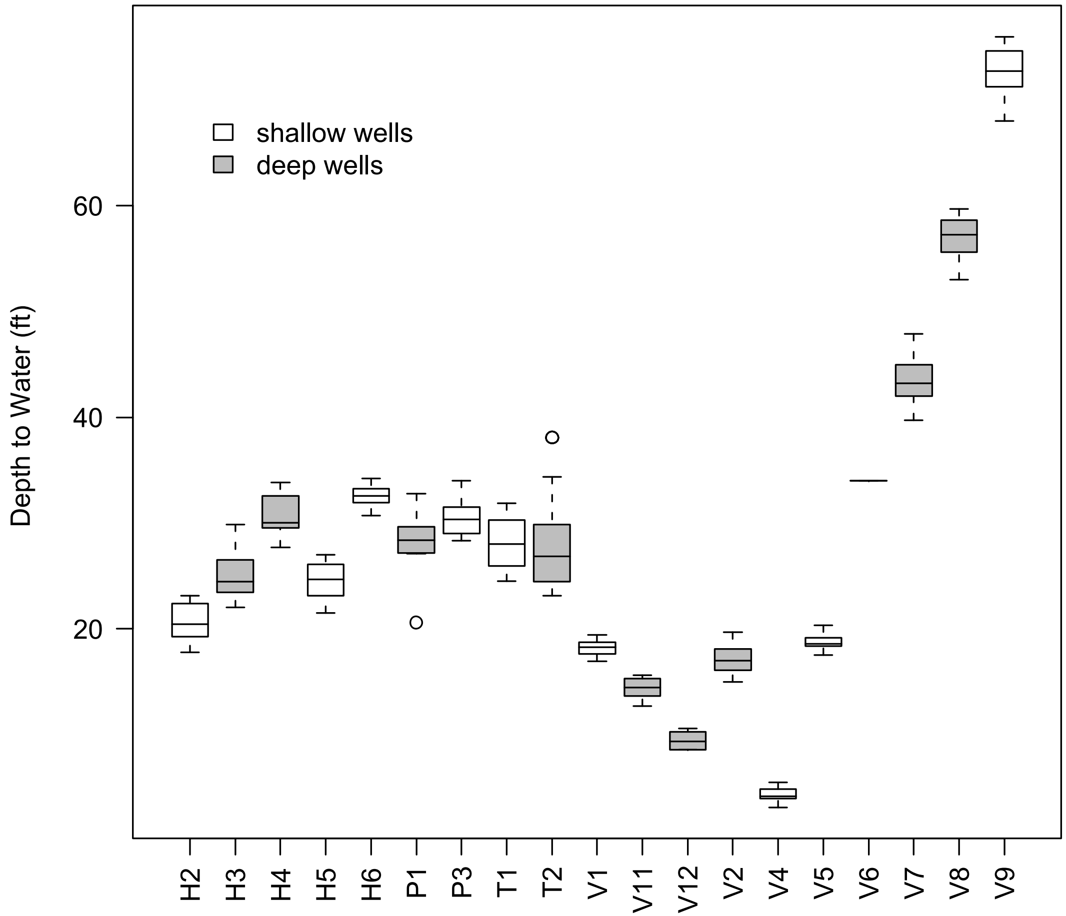
Well Sampling Sites



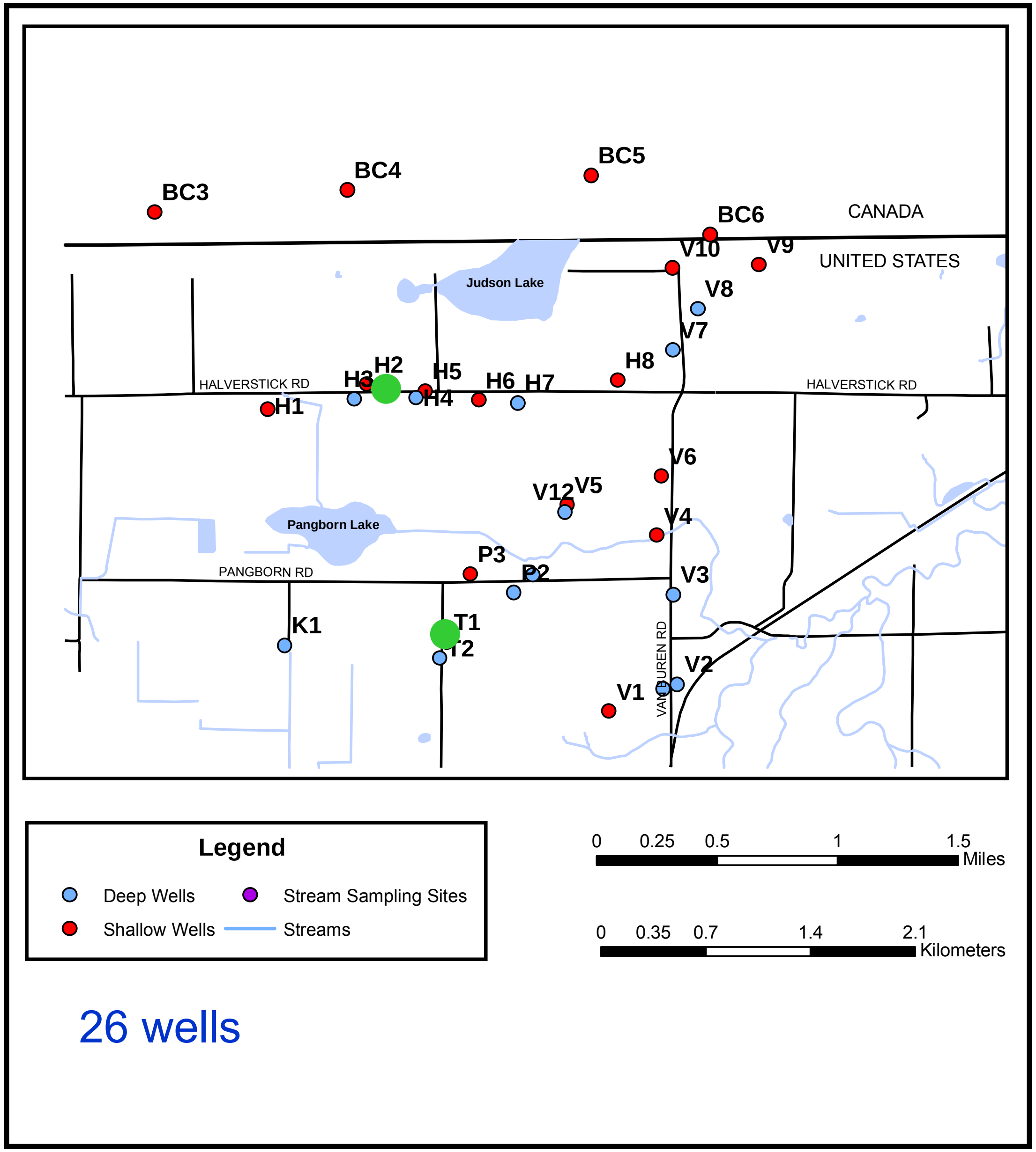
26 wells

Water-level measurements and sampling

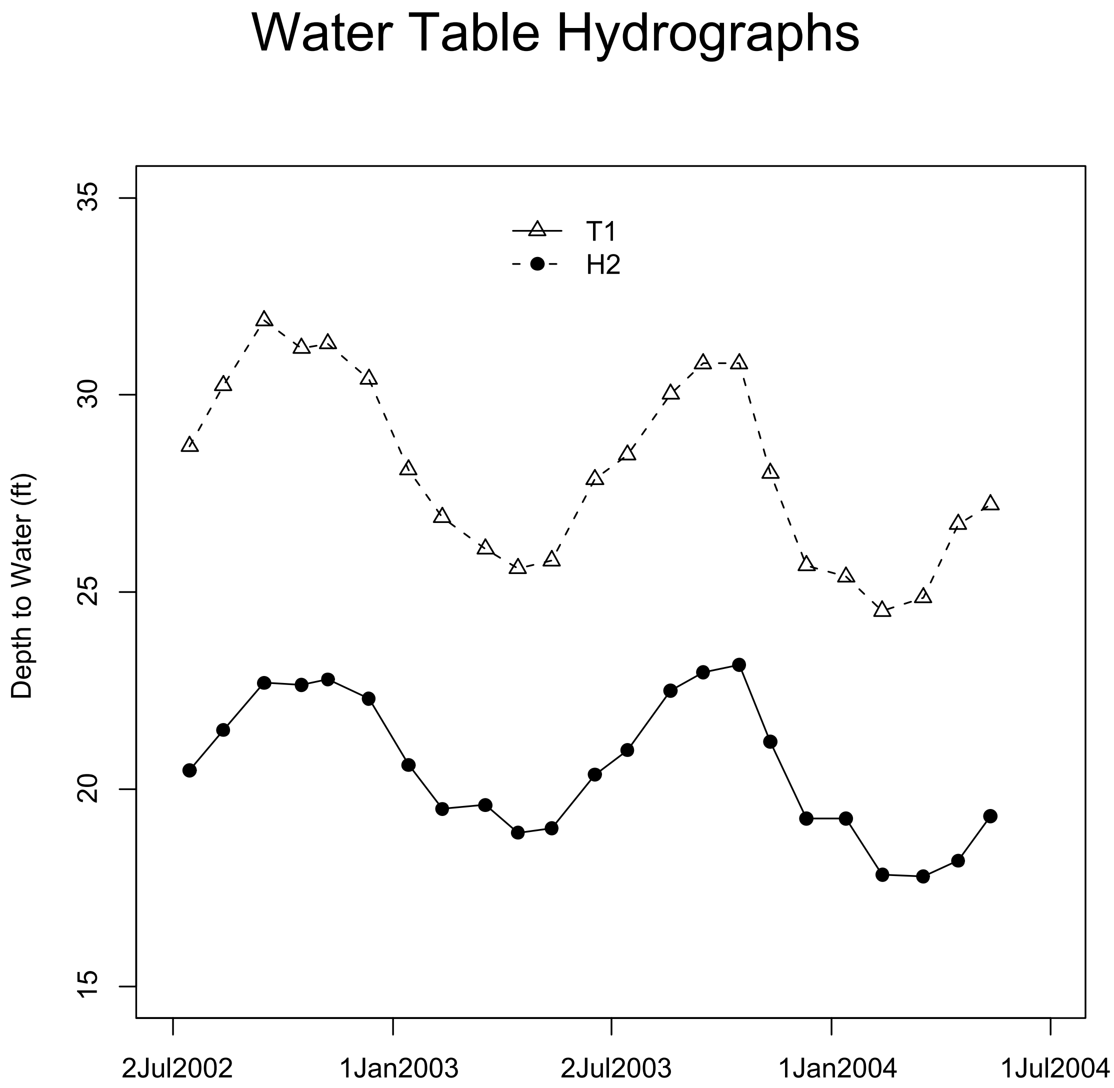
Depth to Water Table



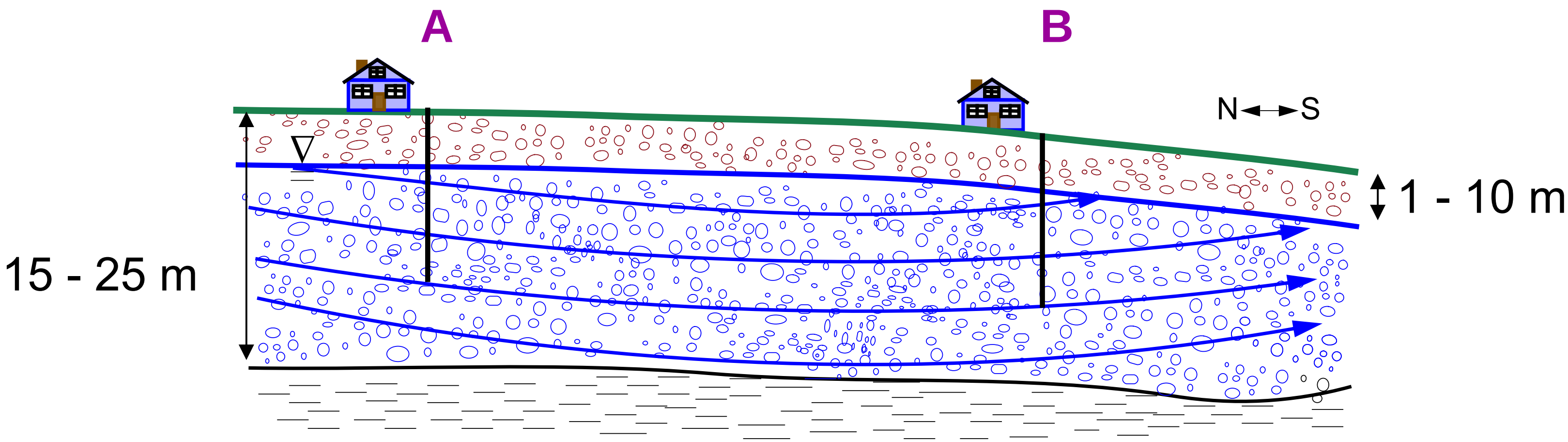
Well Sampling Sites

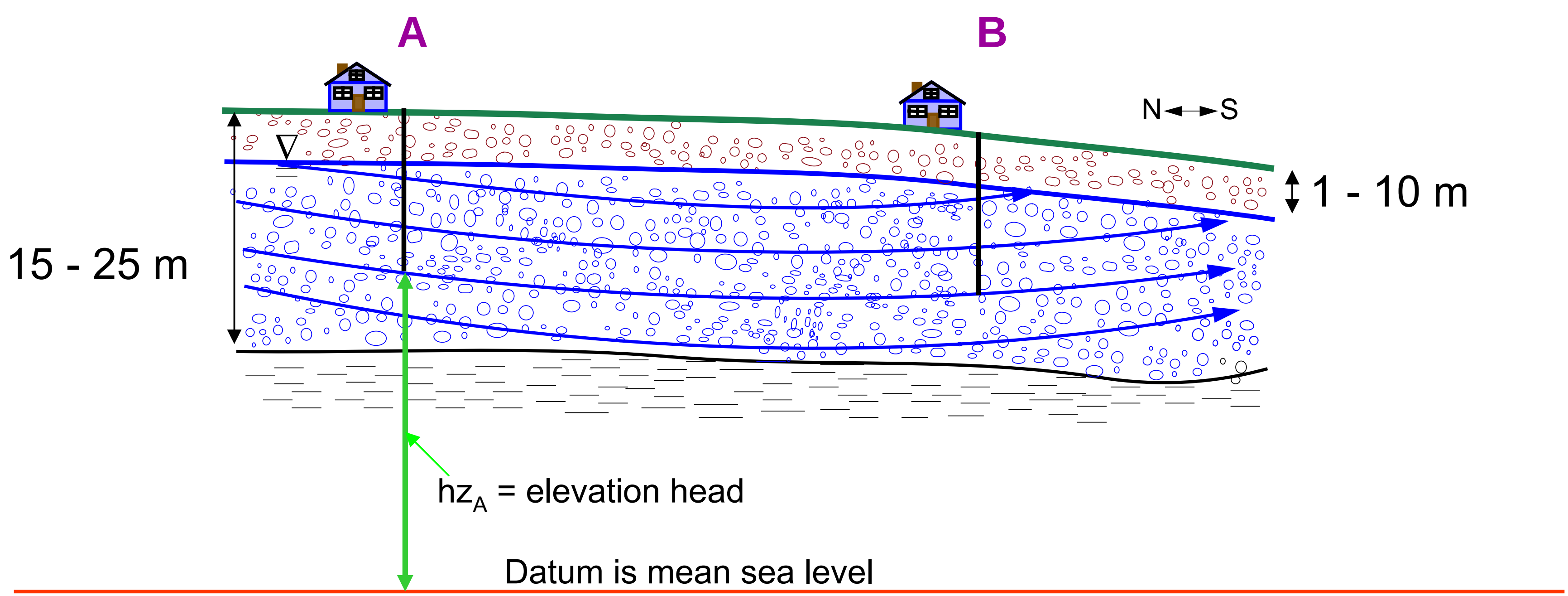


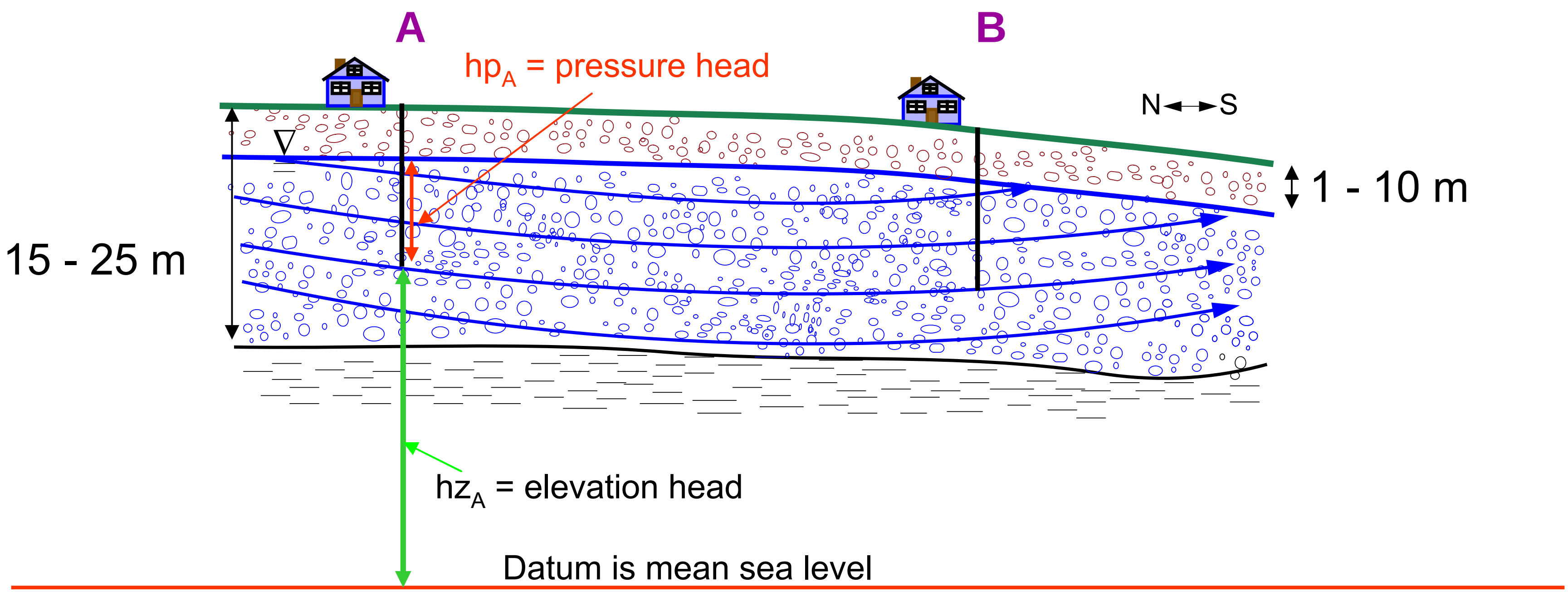
26 wells



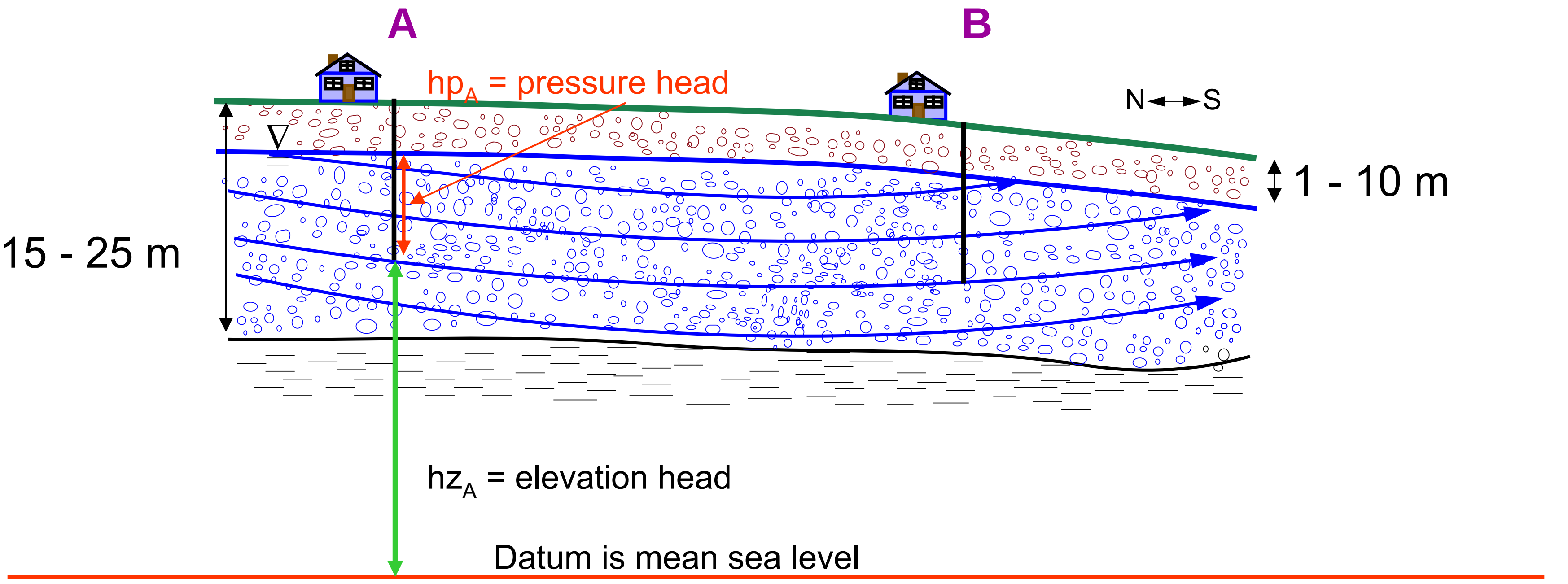
Water Table Hydrographs
T1
H2
Depth to Water (ft)
15
20
25
30
35
2Jul2002
1Jan2003
2Jul2003
1Jan2004
1Jul2004


A
B
N
S
1 - 10 m
15 - 25 m

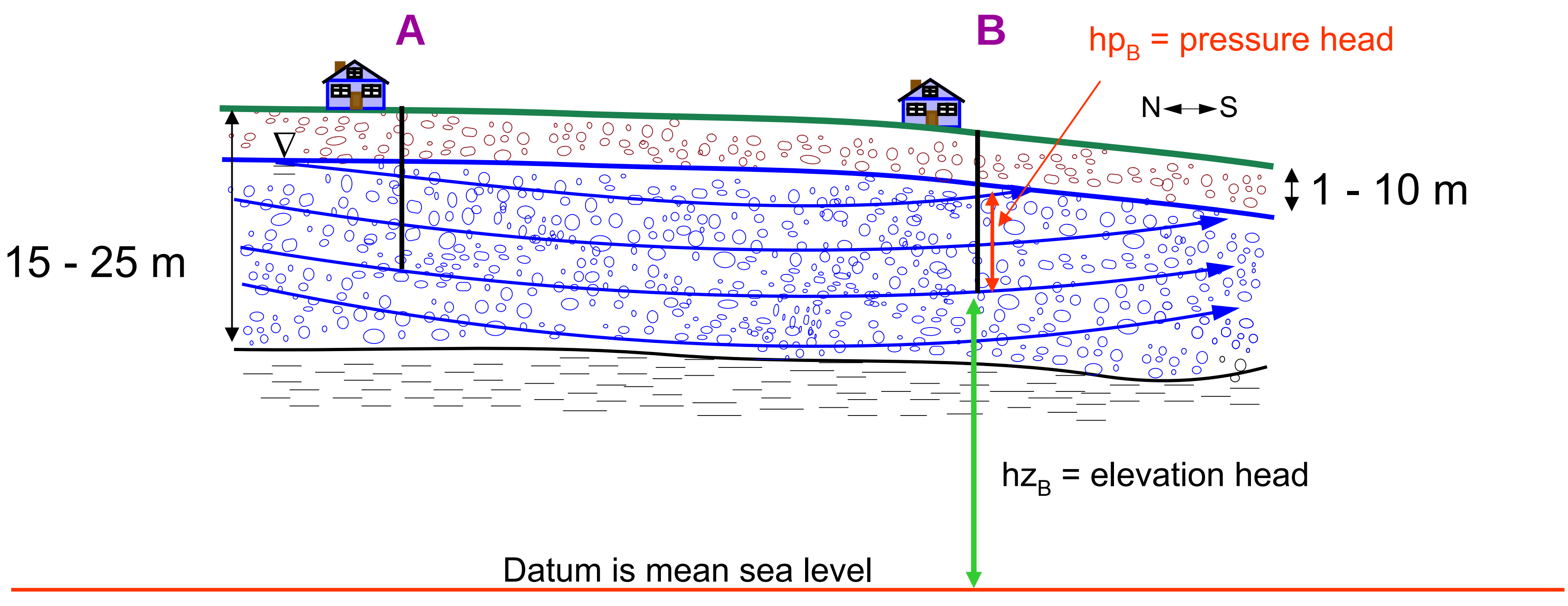

A
B
N S
15 - 25 m
1 - 10 m
hz_A = elevation head
Datum is mean sea level


A
B
hpA = pressure head
N S
1 - 10 m
15 - 25 m
hzA = elevation head
Datum is mean sea level

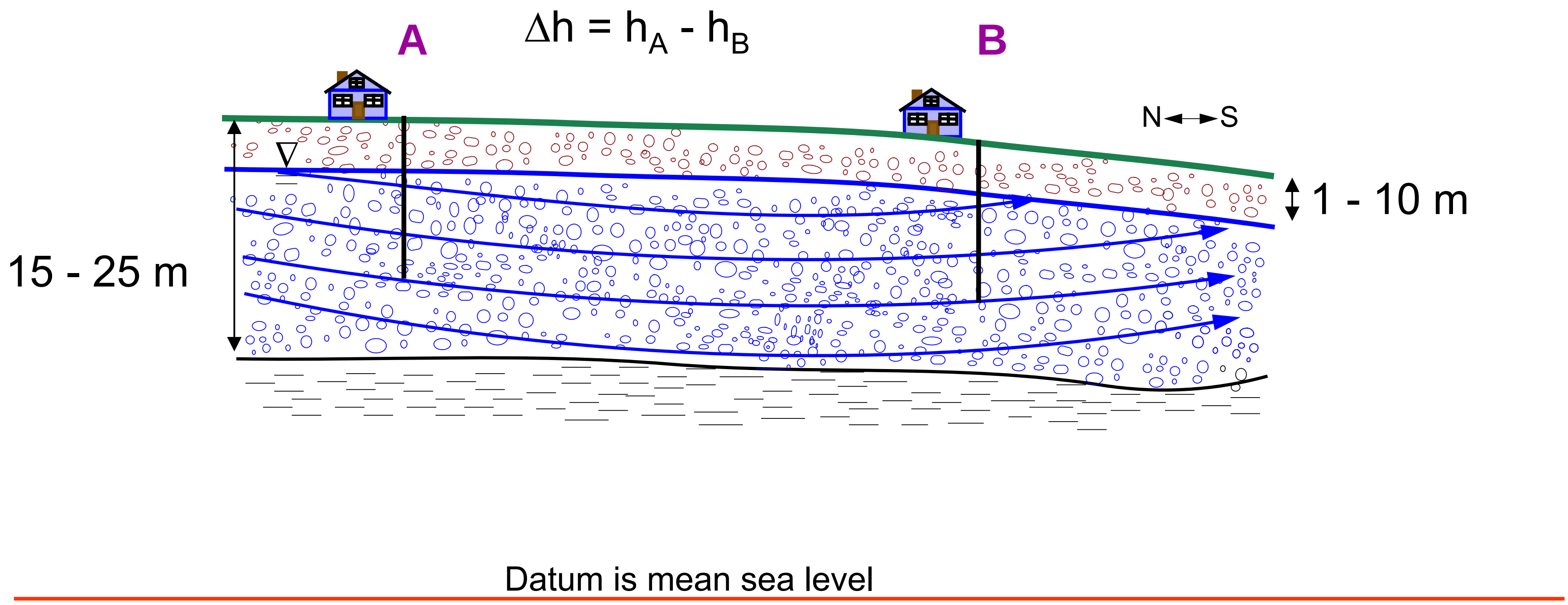
h_A = total head = pressure head + elevation head

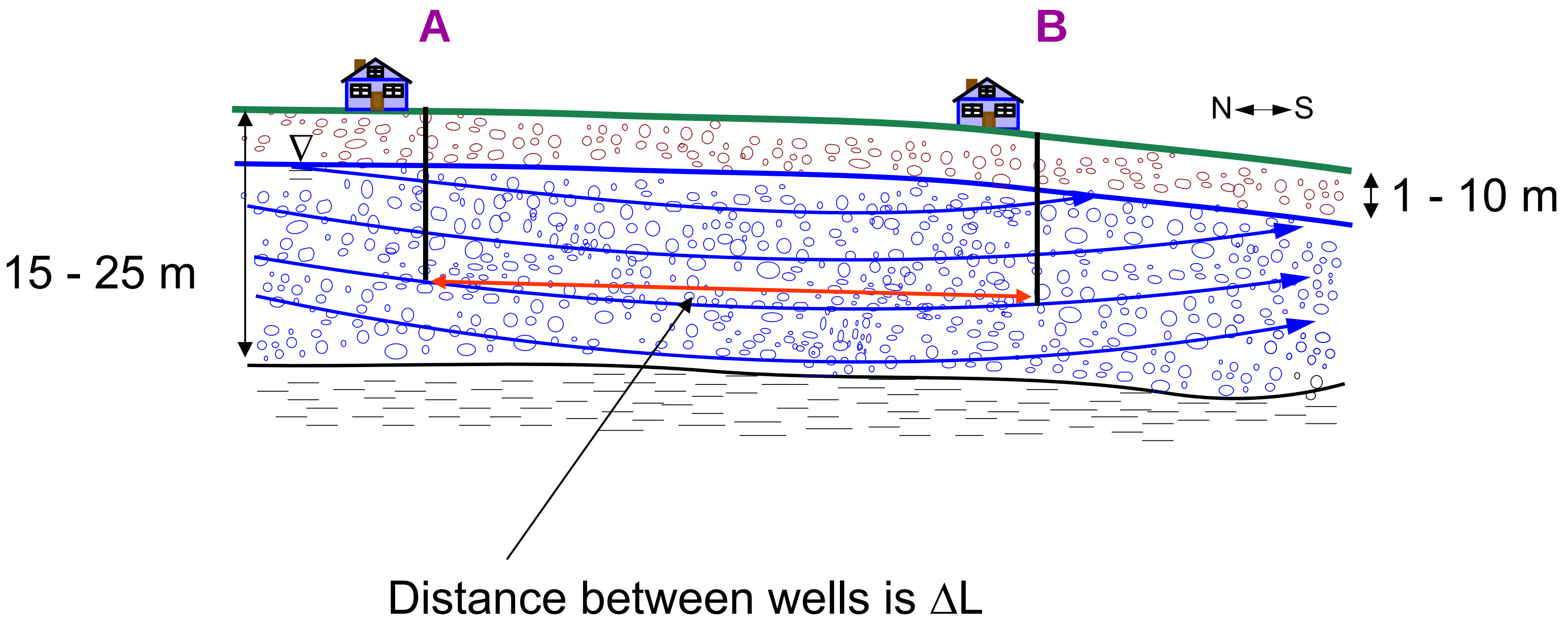


h_B = total head = pressure head + elevation head



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





A
B
N S
1 - 10 m
15 - 25 m
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.

$$\text{hydraulic gradient} = \Delta h/\Delta L$$

The hydraulic gradient ($\Delta h/\Delta L$) between wells A and B is what drives water through the pore spaces. The hydraulic conductivity (K) will resist the fluid flow because of friction along the grain surfaces. The average velocity (v) at which water flows in the media is quantified by:

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

where n = porosity

The average hydraulic gradient in the Abbotsford-Sumas aquifer is

$$\Delta h/\Delta L = -0.0055$$

The average hydraulic conductivity of the glacial sediments is

$K = 545$ ft/day or $K = 0.187$ cm/sec

The average porosity of the glacial sediments is

$$n = 0.30$$

The average pore-water velocity can be determined using Darcy's Law

$$\text{velocity} = v = -K/n\ (\Delta h/\Delta L)$$

Using the aquifer parameters in the equation above yields

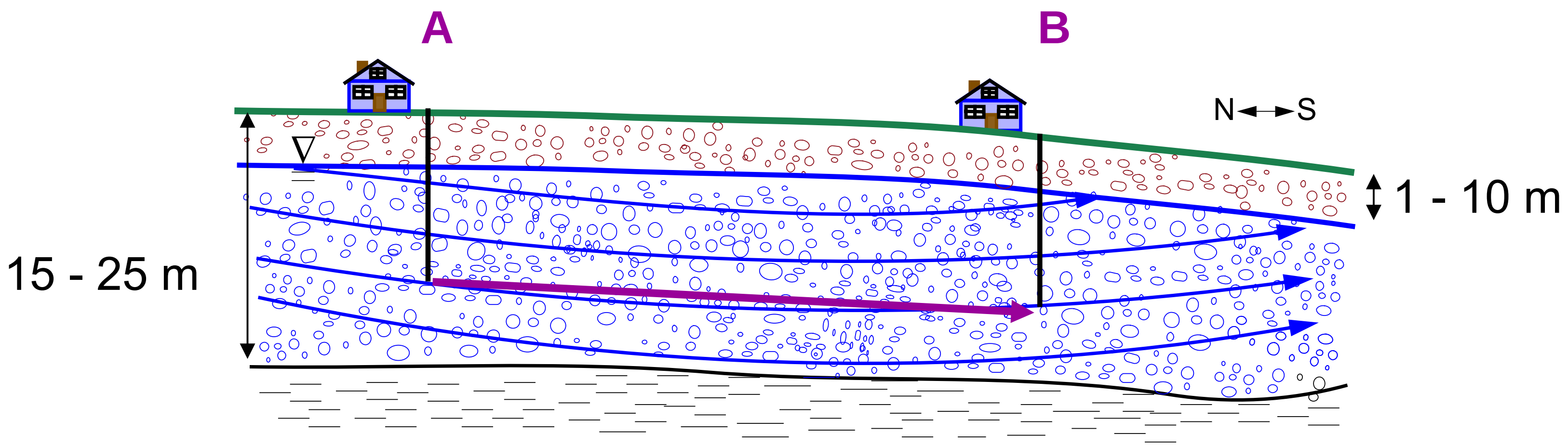
$$\text{velocity} = v = -545/0.30(-0.0055) = 10\ \text{ft/day}$$

which is very fast for groundwater

The average groundwater velocity is 10 ft/day

How long would it take water to travel from well A to well B

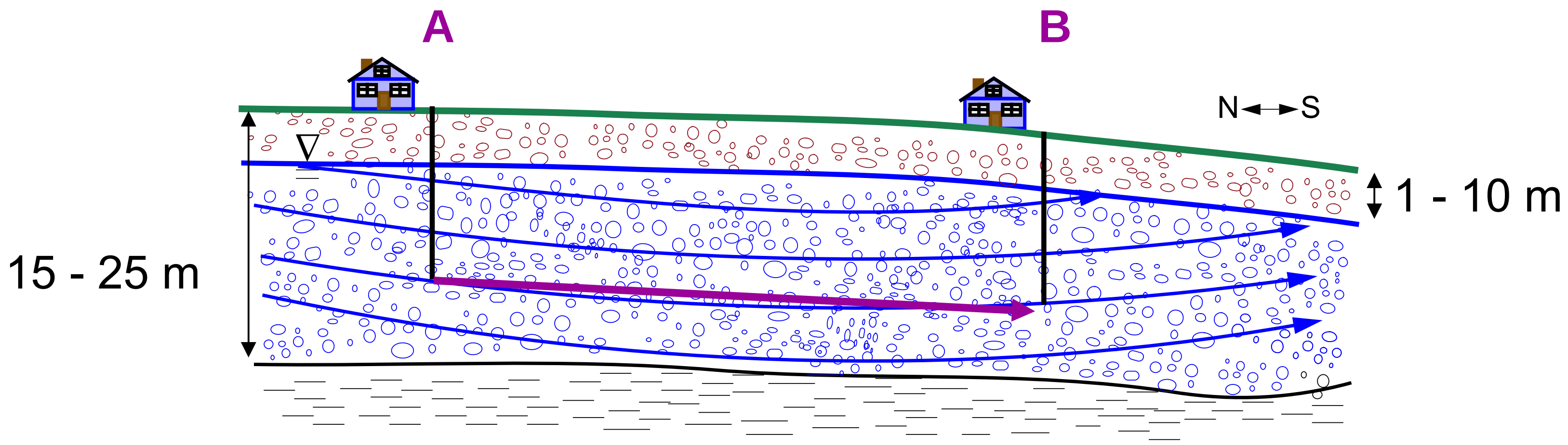
If the distance from A to B is 1000 ft



Time = distance ⁄ velocity

Time = 1000 ft ⁄ 10 ft/day

Time = 100 days

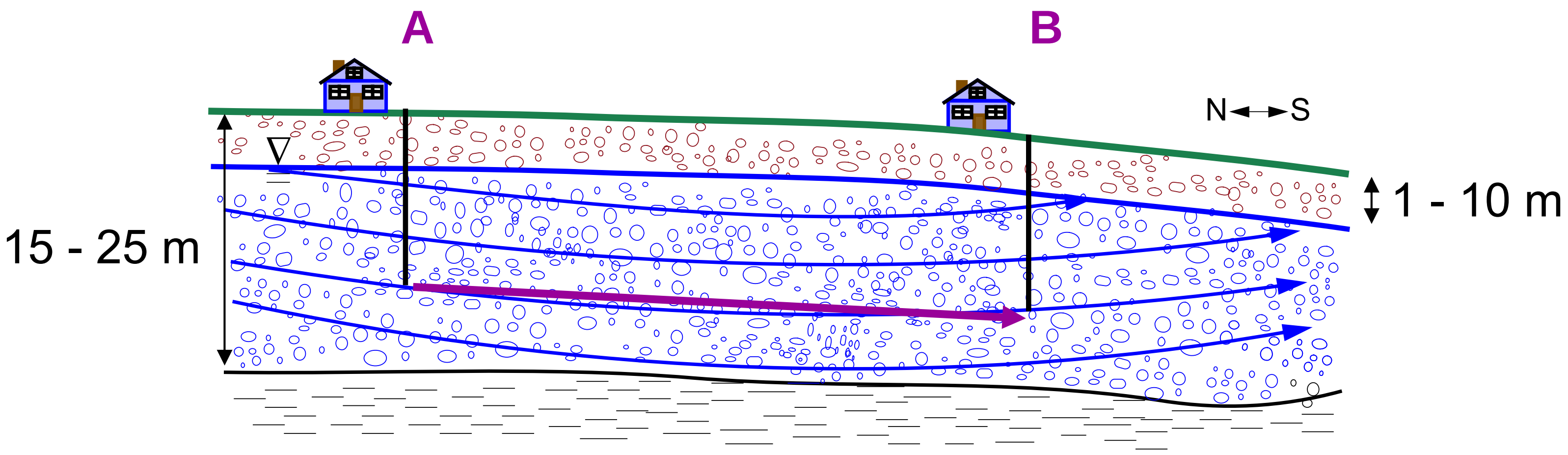


If the aquifer were a fine sand with a hydraulic conductivity of 5.45 ft/day……then the

Velocity = 0.10 ft/day

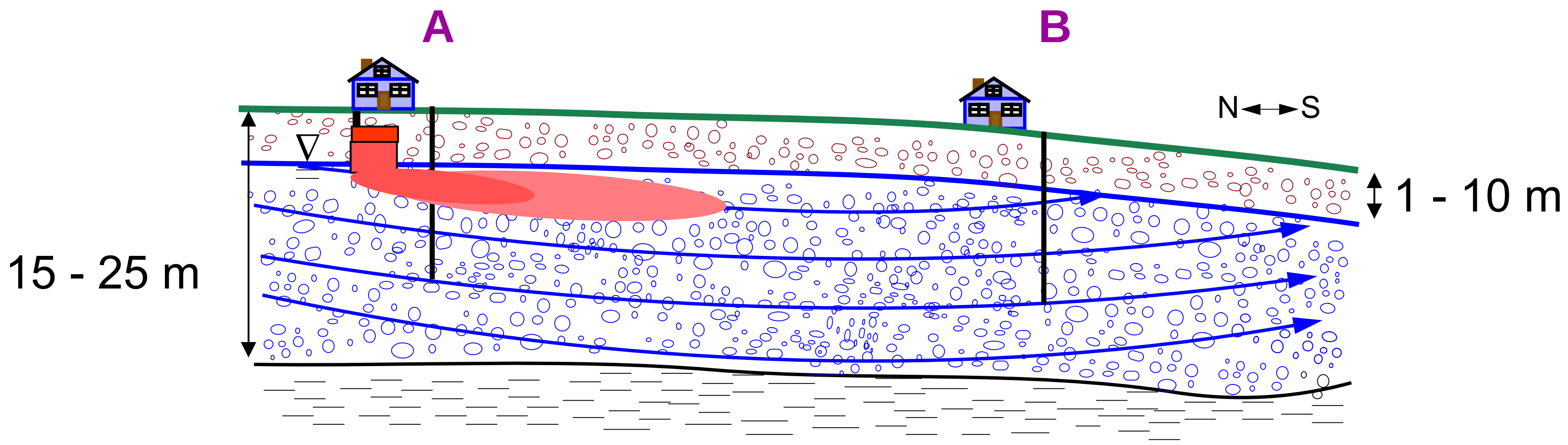
Time = 1000 ft ⁄ 0.10 ft/day

Time = 10,000 days or 27 years!!

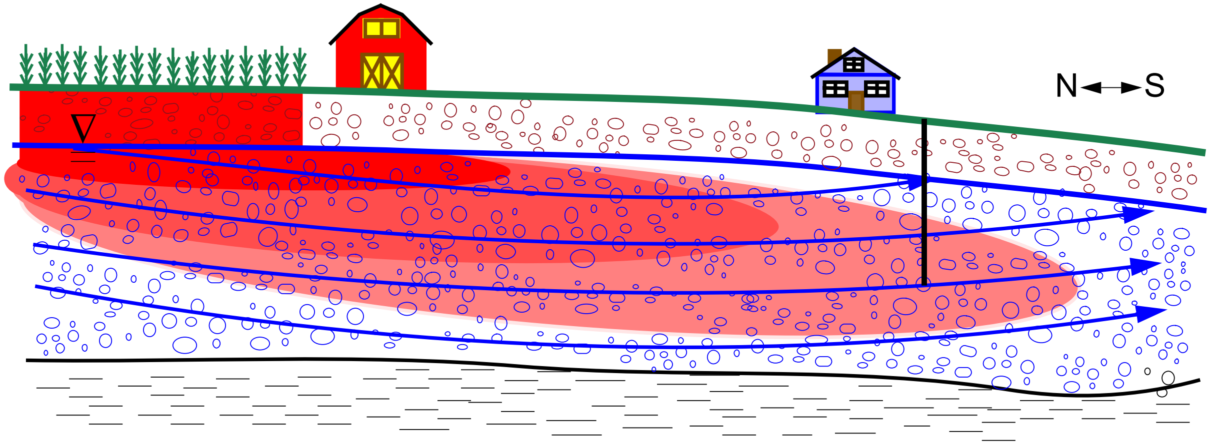


Why is this important?

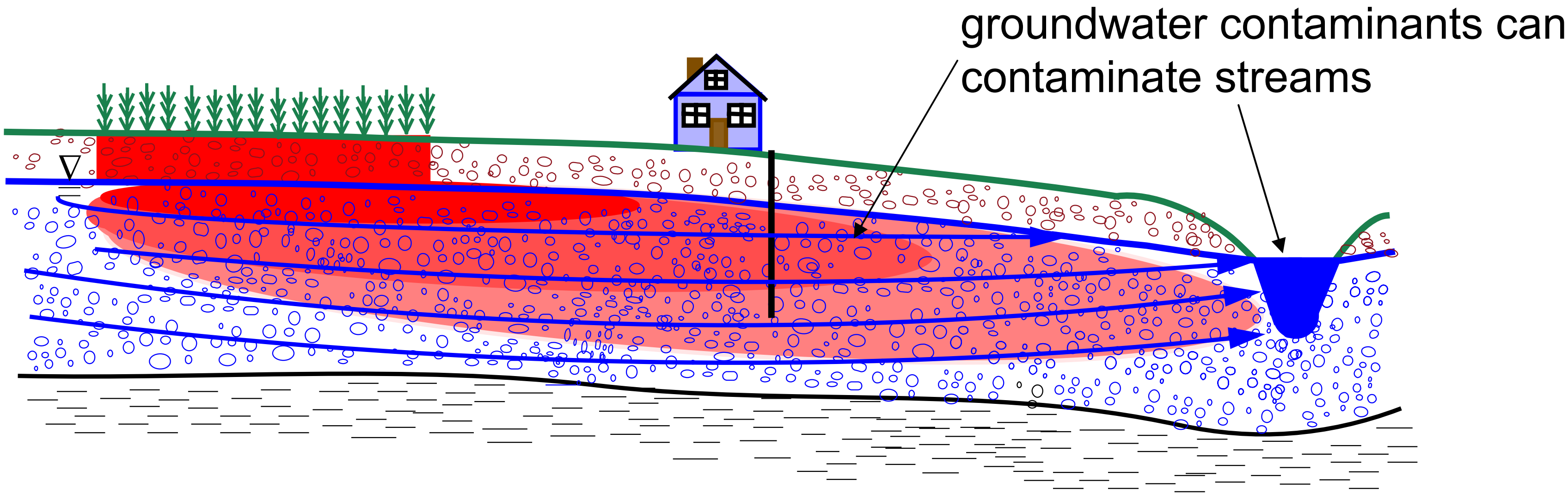
Transport of Septic System Discharge



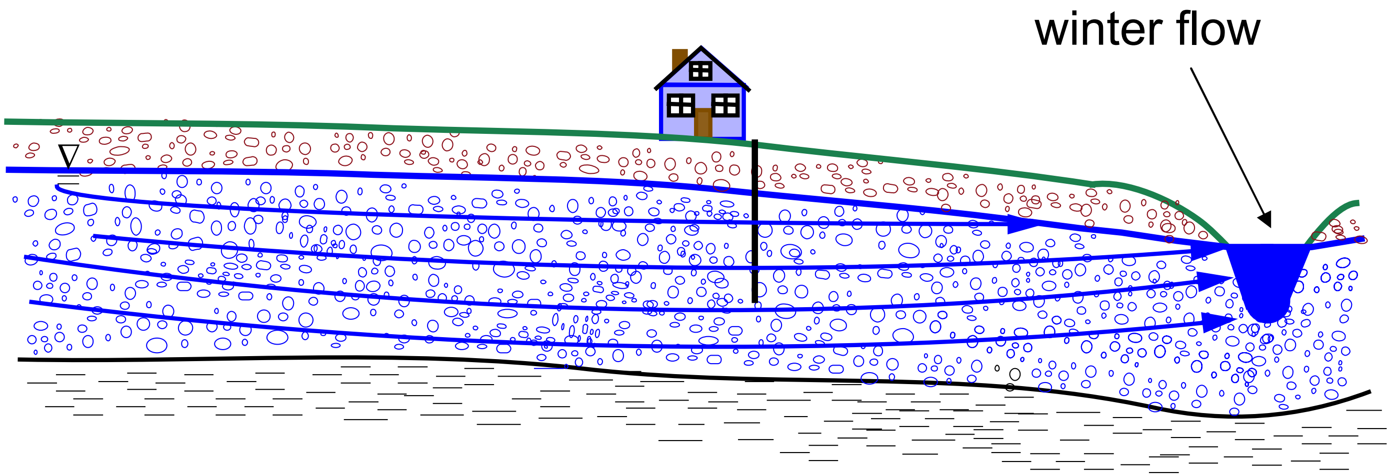
Contaminant transport in an aquifer



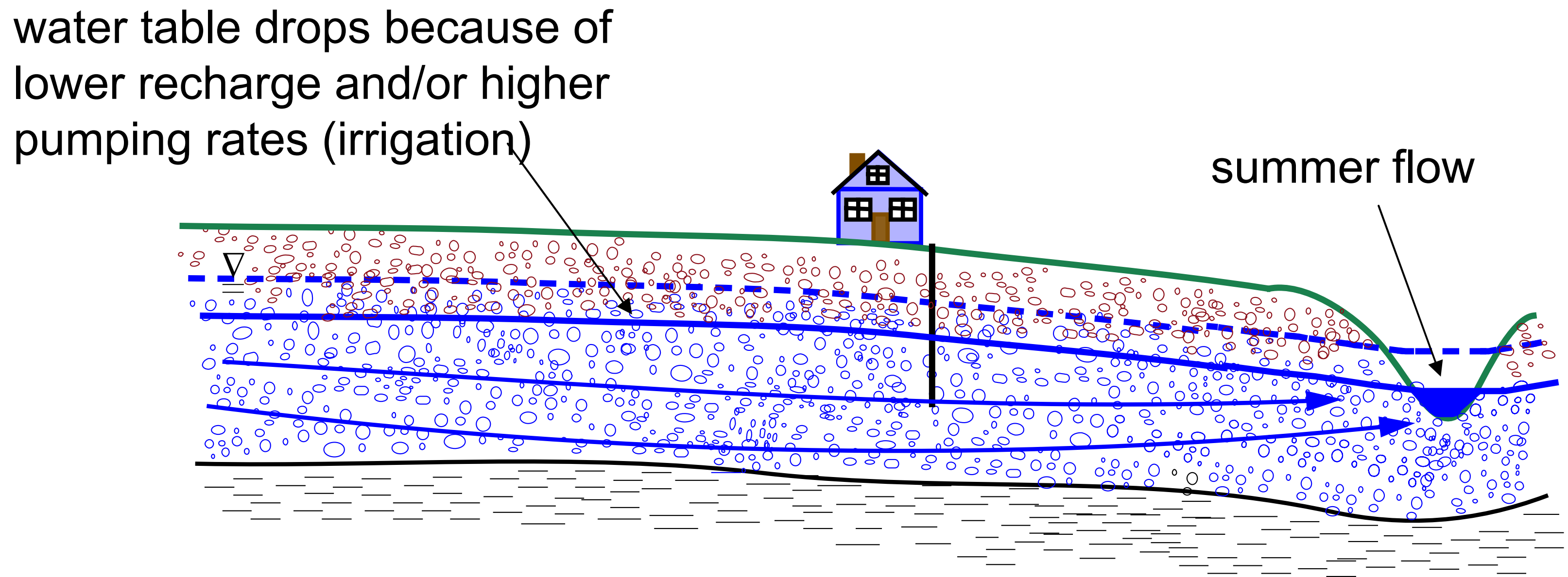
Groundwater surface water interactions

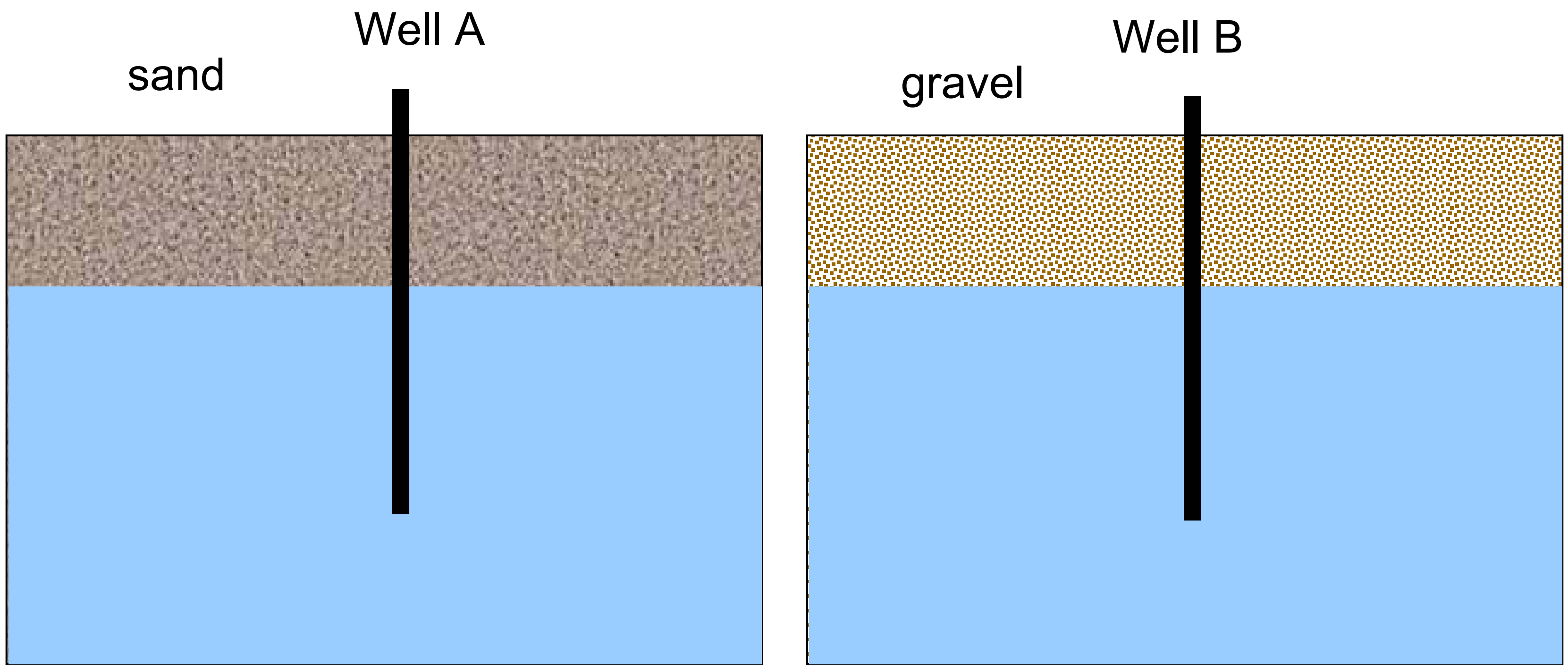


Groundwater surface water interactions

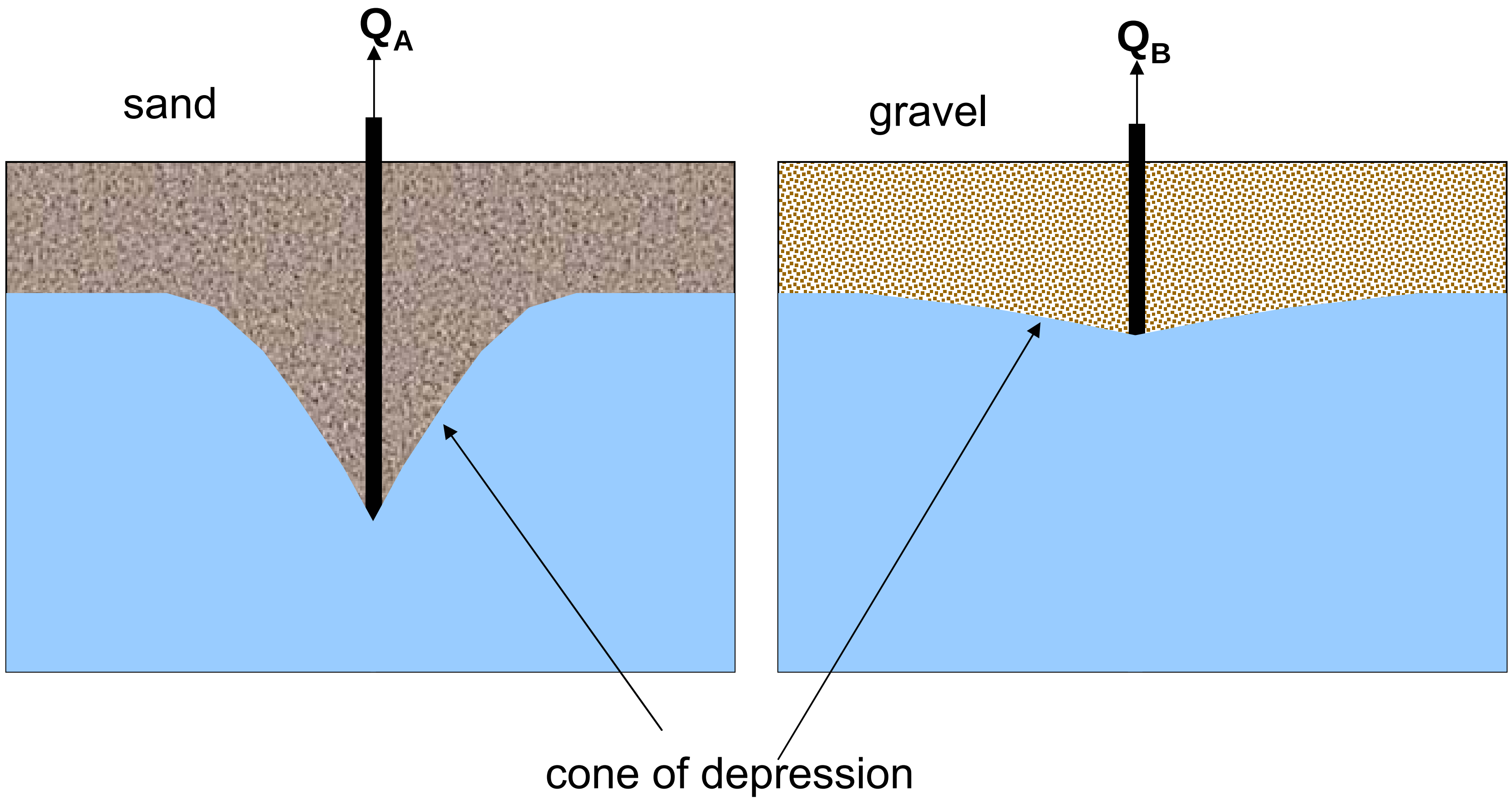


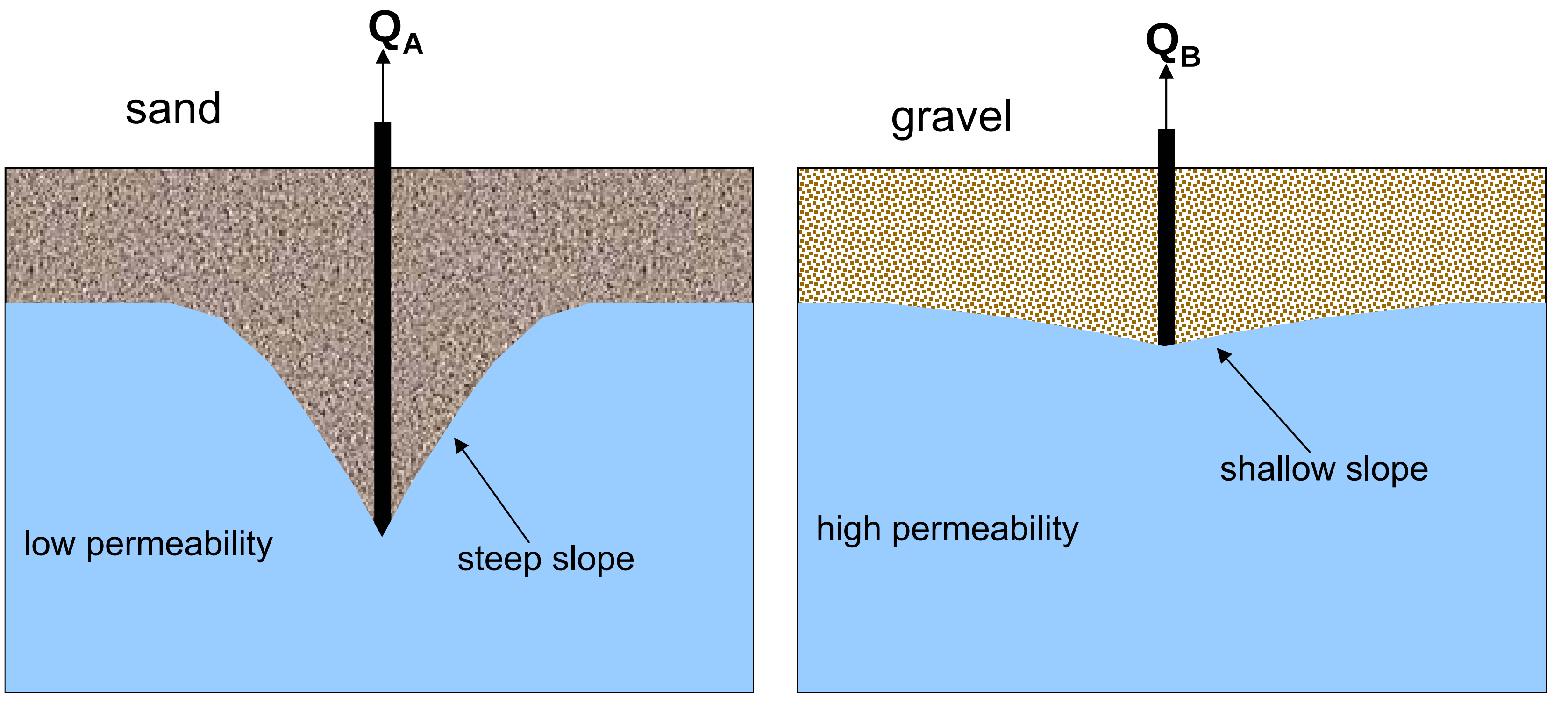
Groundwater surface water interactions



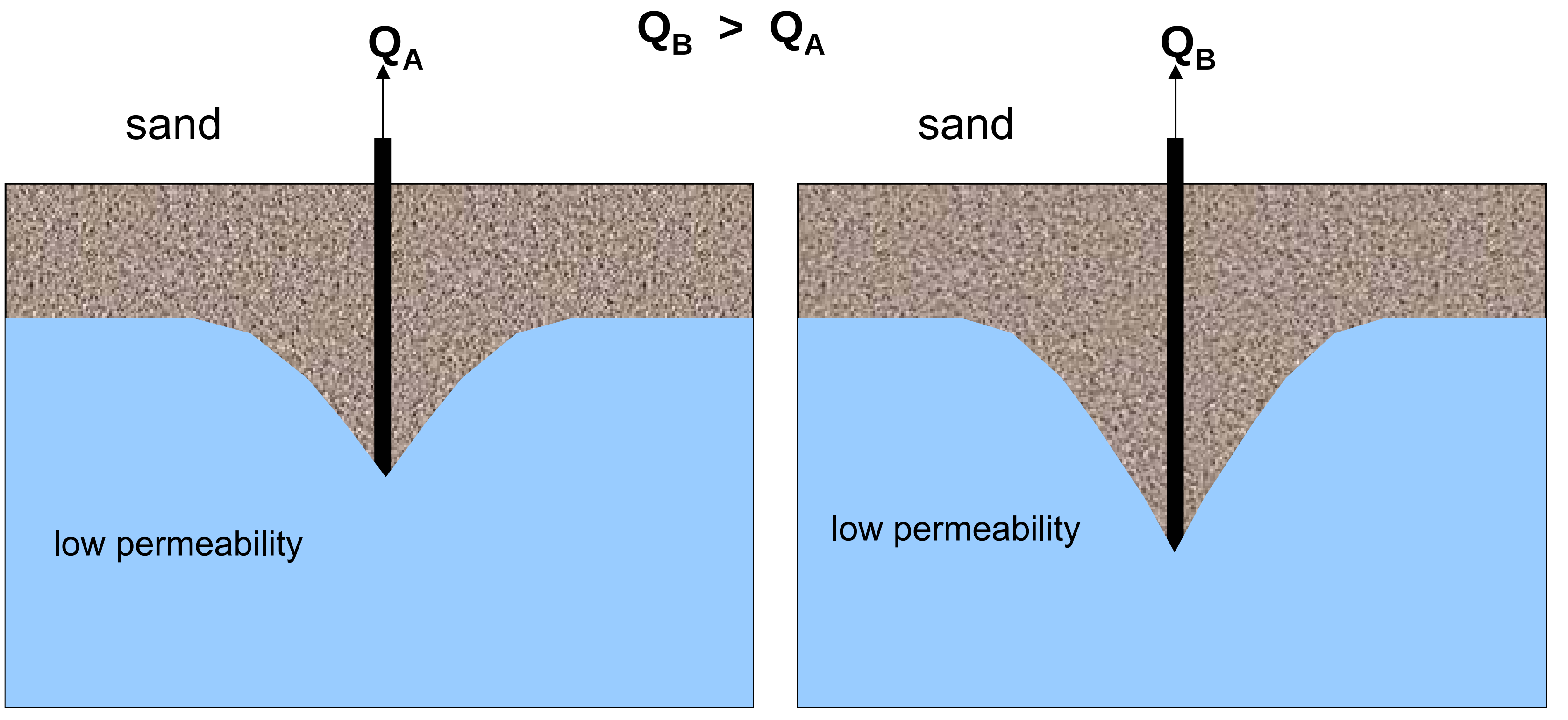

Well A
sand
Well B
gravel

$Q_A = Q_B$ = pumping rate

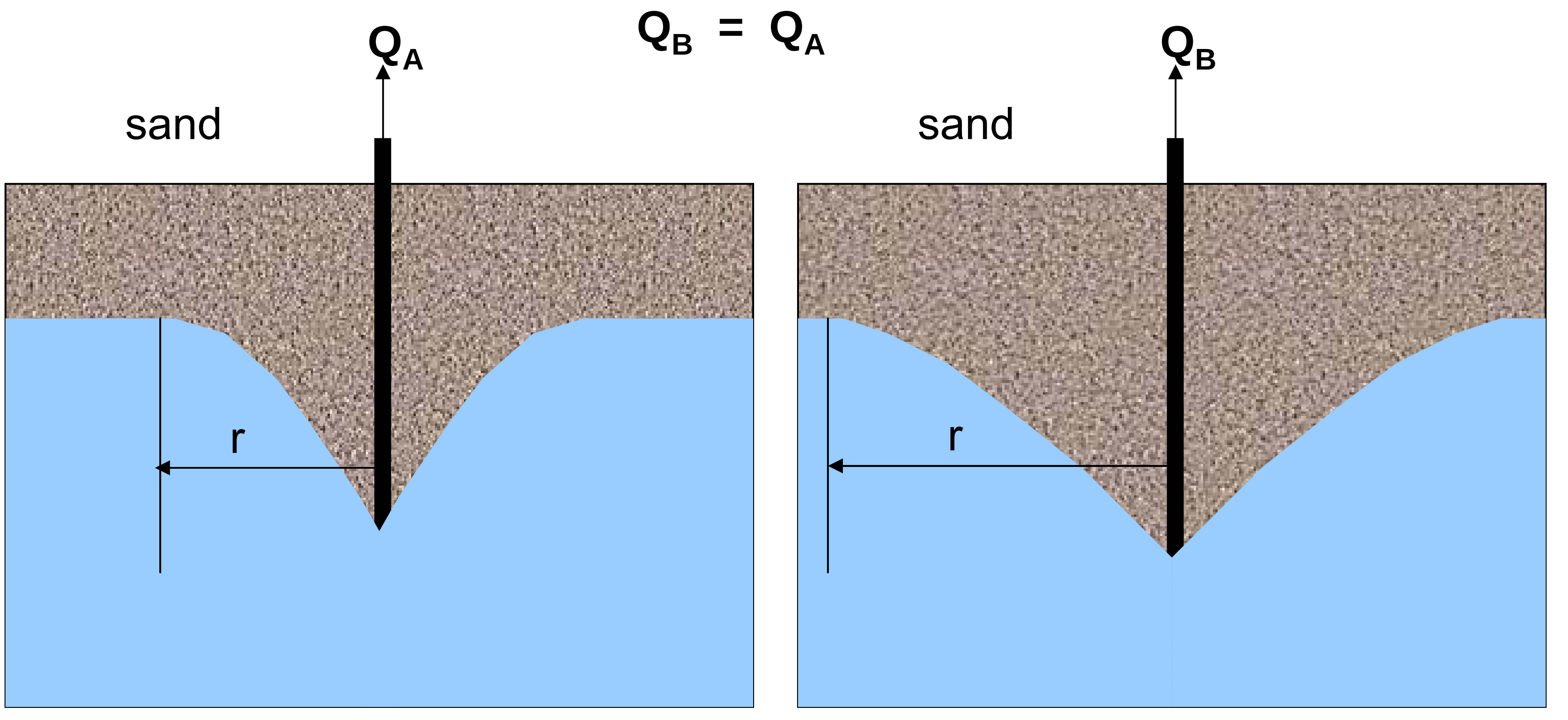




The slope of the cone of depression is determined by the permeability



The depth of the cone of depression is determined by the pumping rate



The <u>radius</u> of the cone of depression is determined by the pumping duration

Groundwater surface water interactions