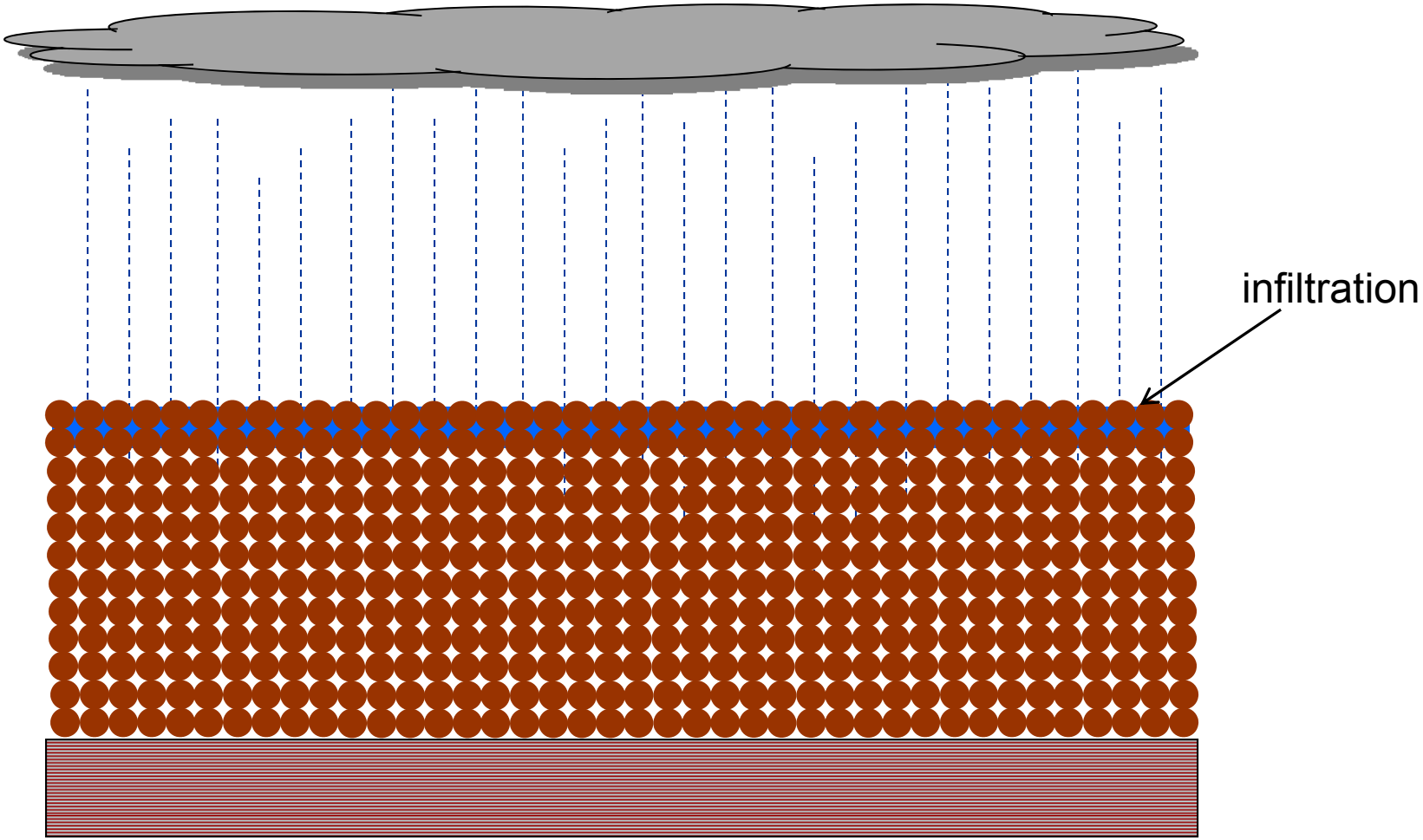
Lecture 8: Soils and Percolation

Key Questions

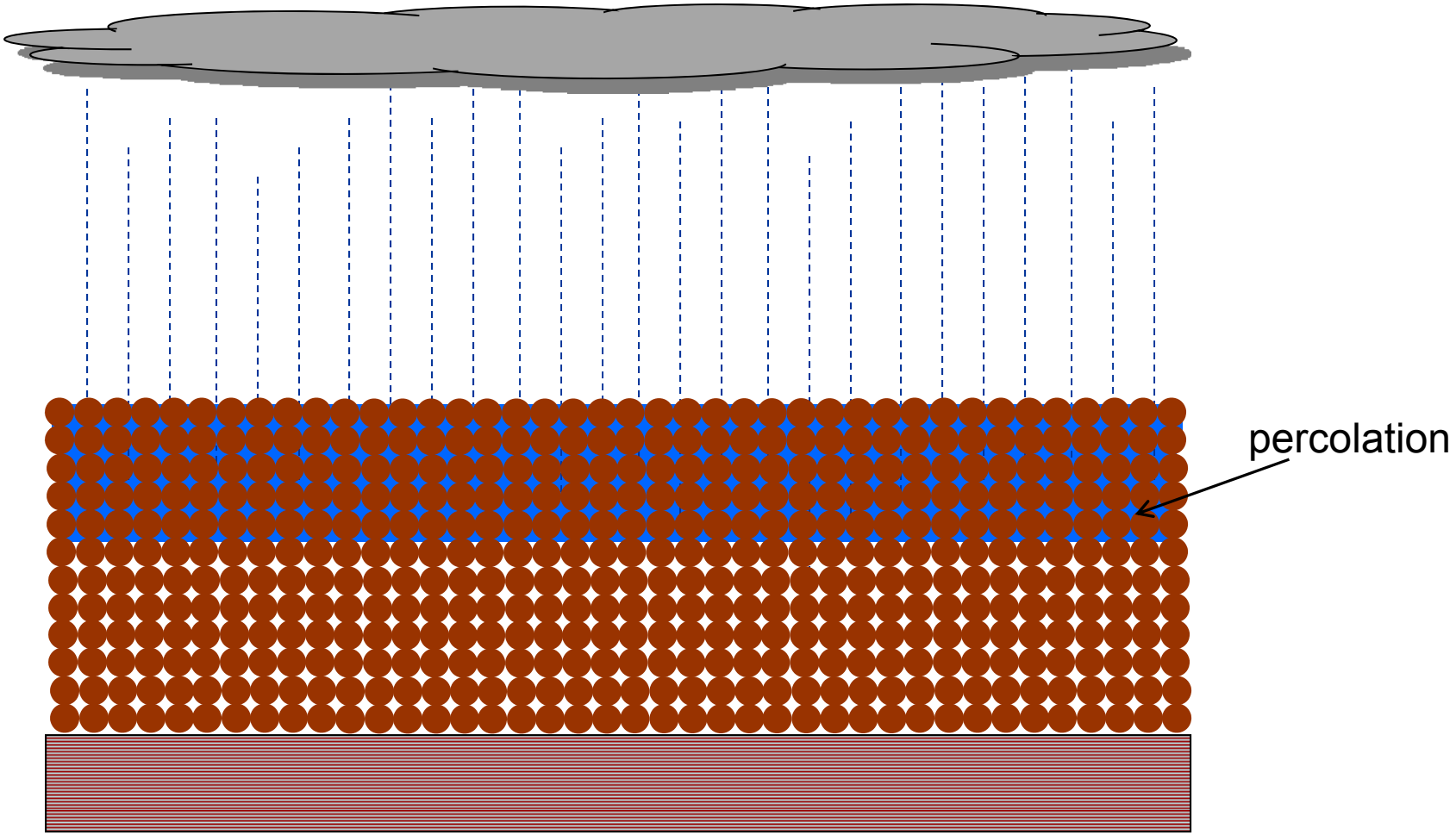
1. How does grain size control percolation?
2. What is hydraulic conductivity?
3. How do soils affect runoff?
4. How does rain on snow affect runoff?

New Western logo

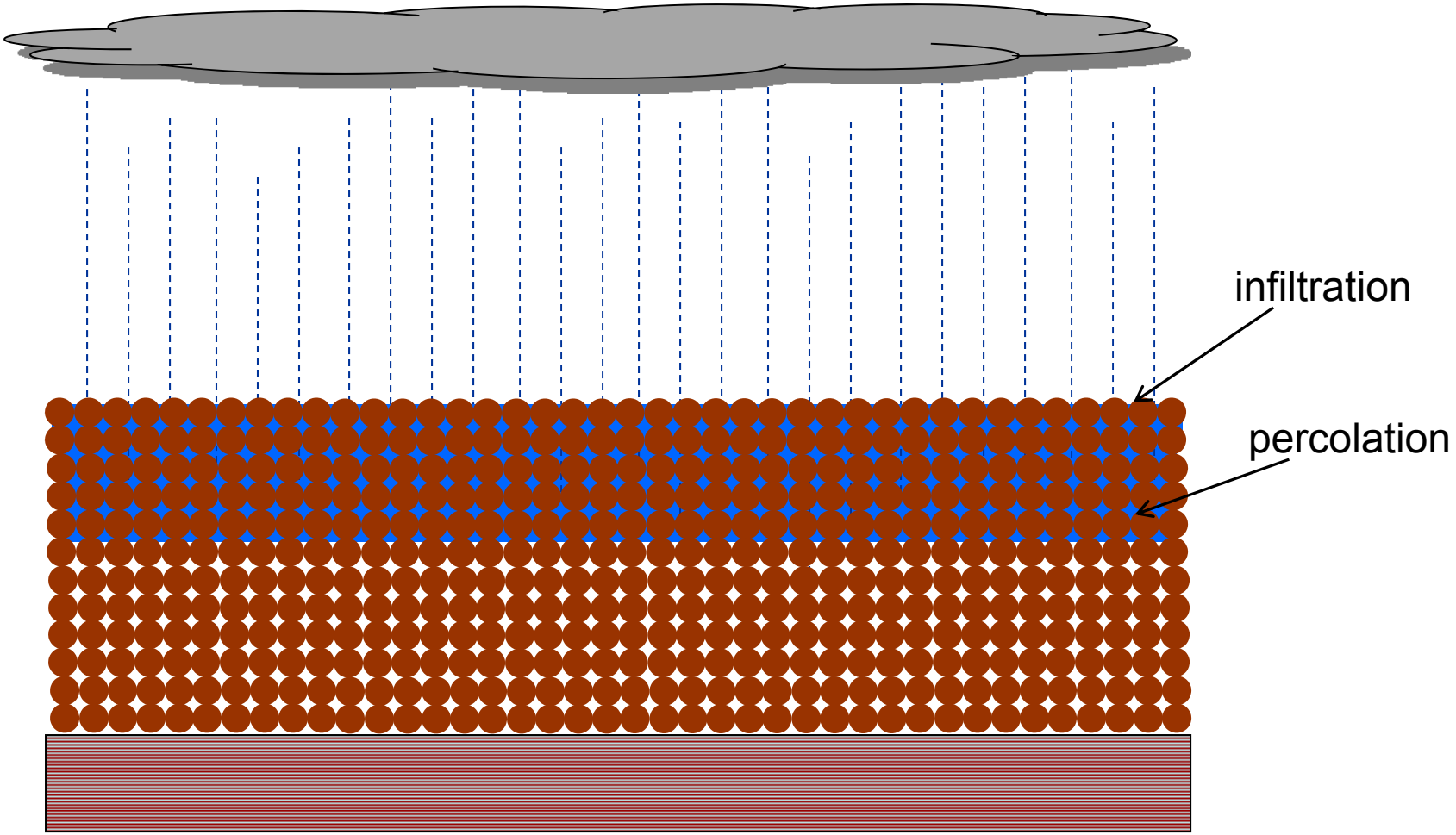
Infiltration is the movement of water INTO the soil surface



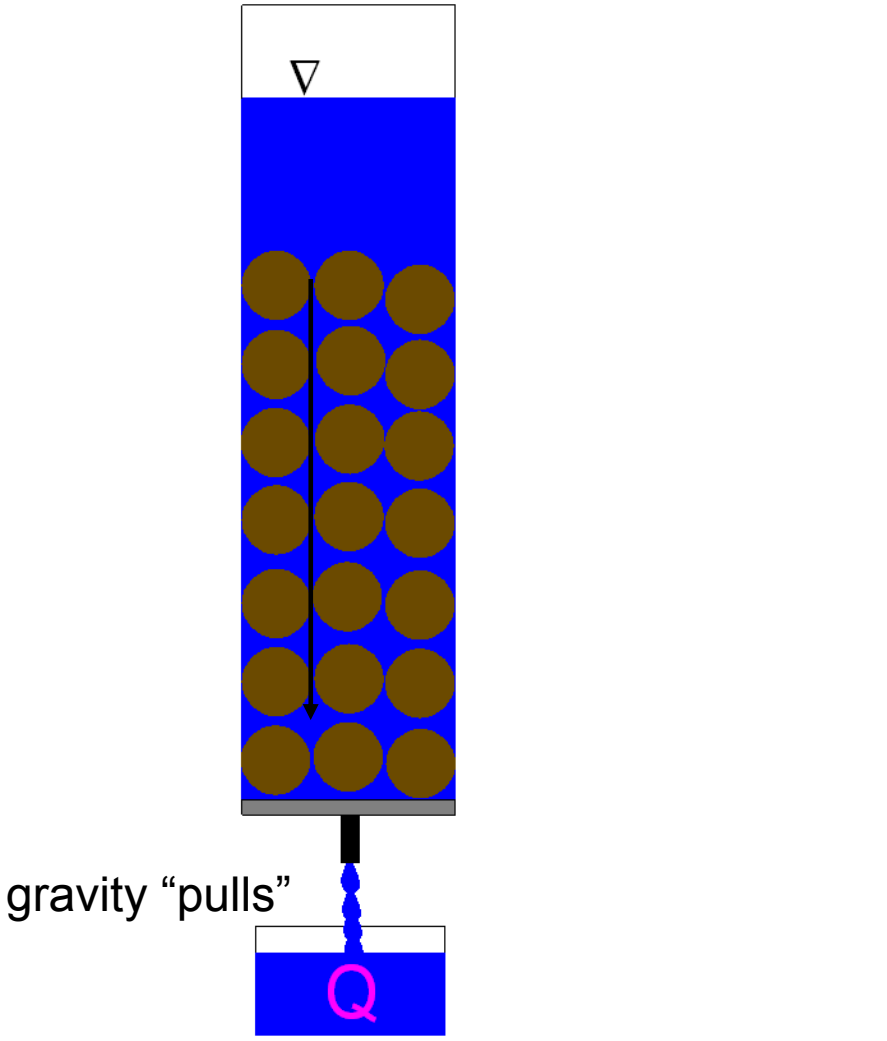
Percolation is the movement of water WITHIN the soil matrix.



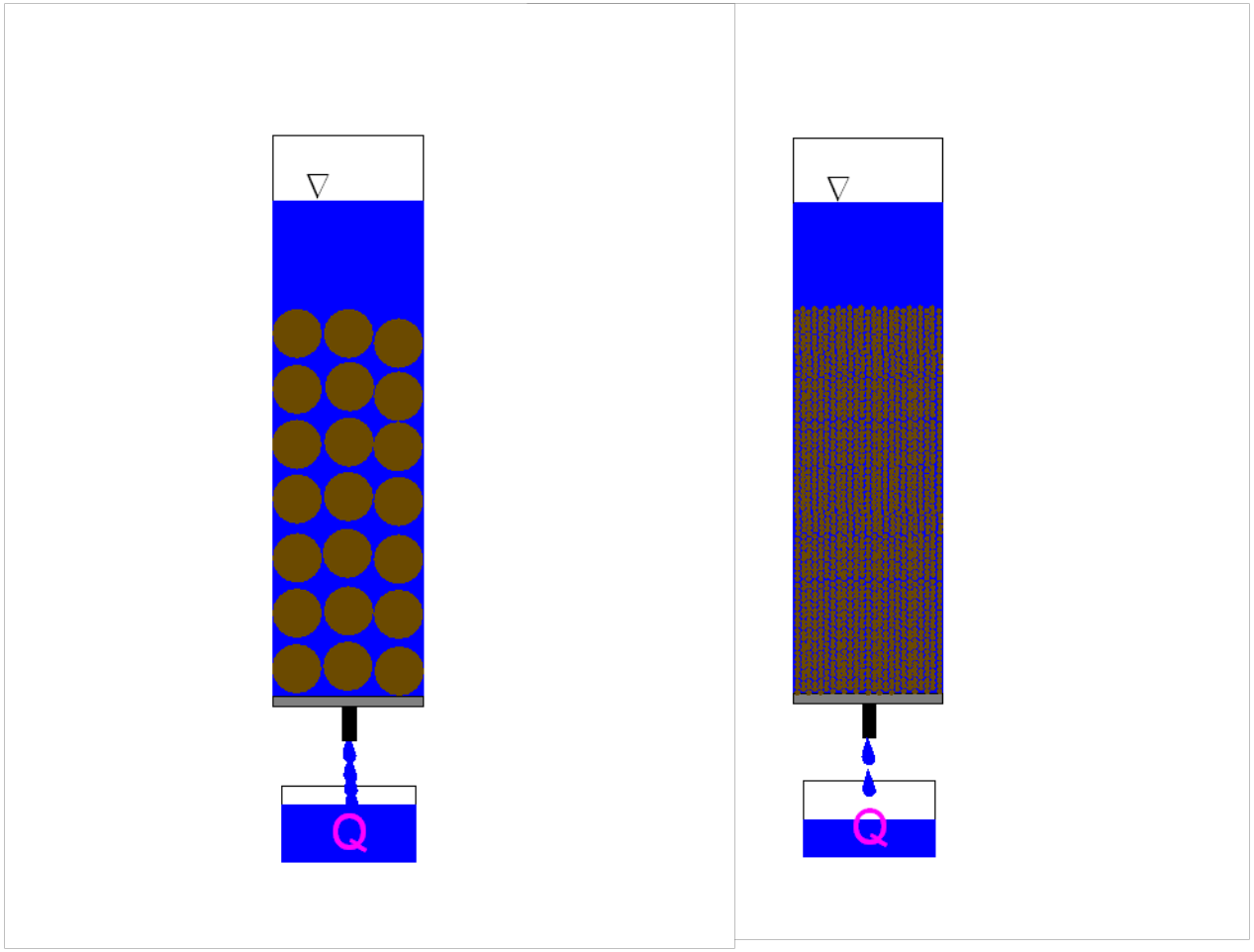
Percolation rate controls the infiltration rate



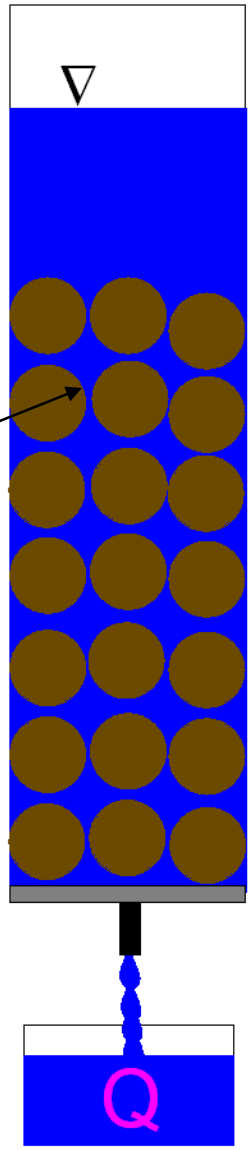
Percolation in soils is primarily due to gravity pulling the water vertically downward



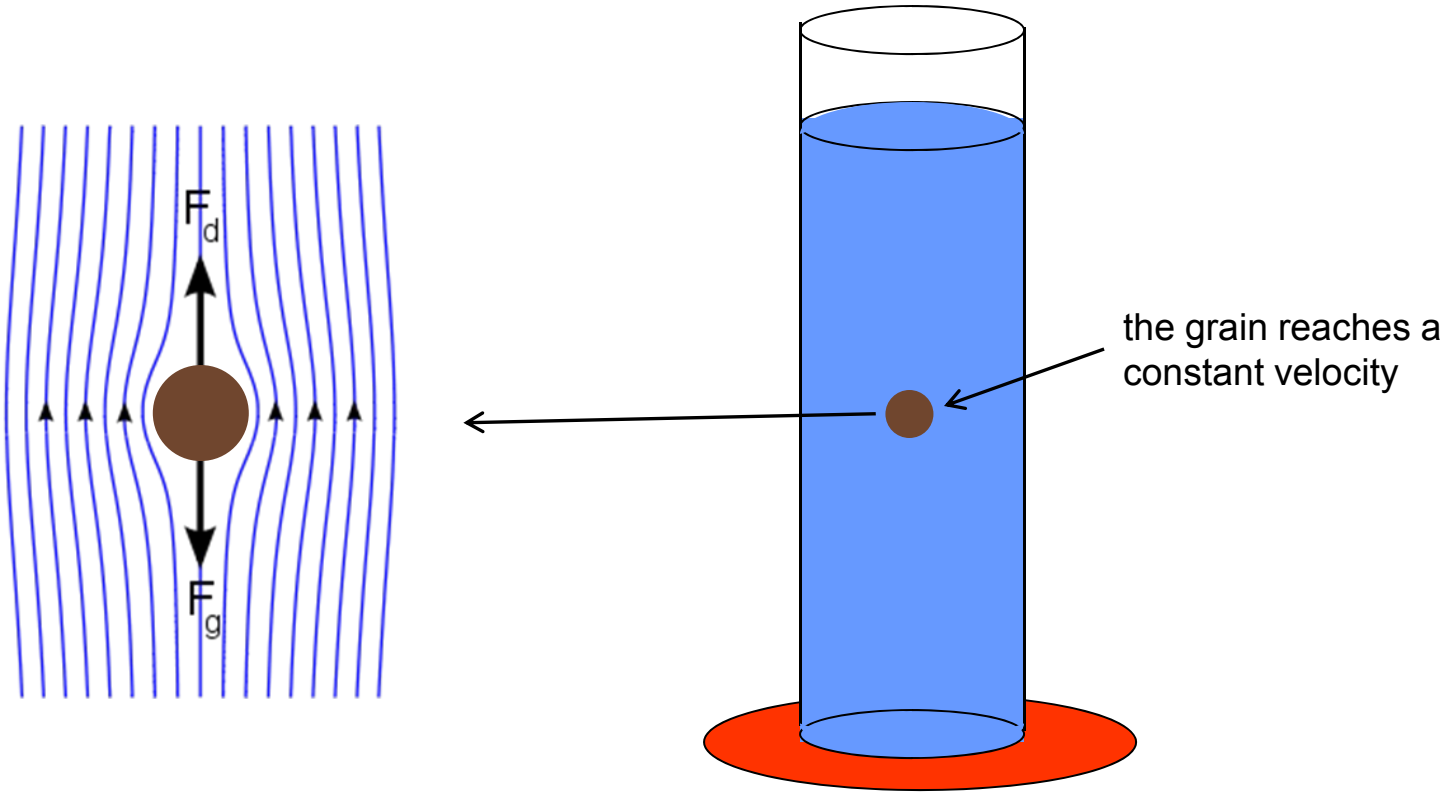
The rate of percolation is controlled by grain size



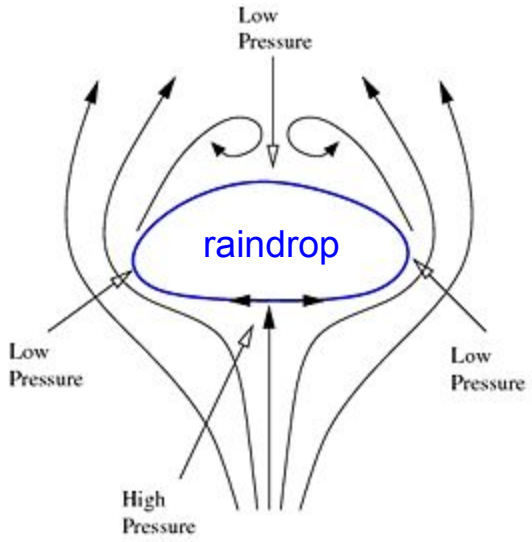
friction along the grain surfaces will resist water flow



The drag force (F_d) acting on a grain falling through liquid is initiated by the frictional interaction between the fluid and the grain.

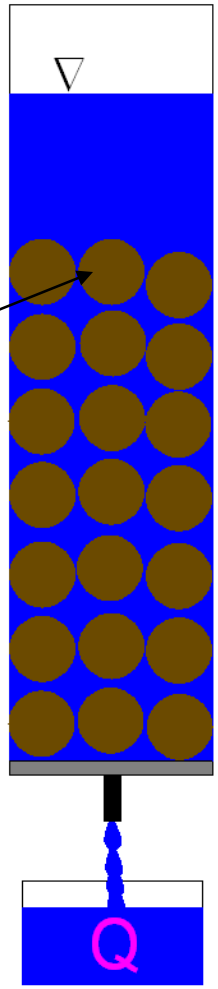


The drag force acting on a falling raindrop tends to flatten it into a disc shape

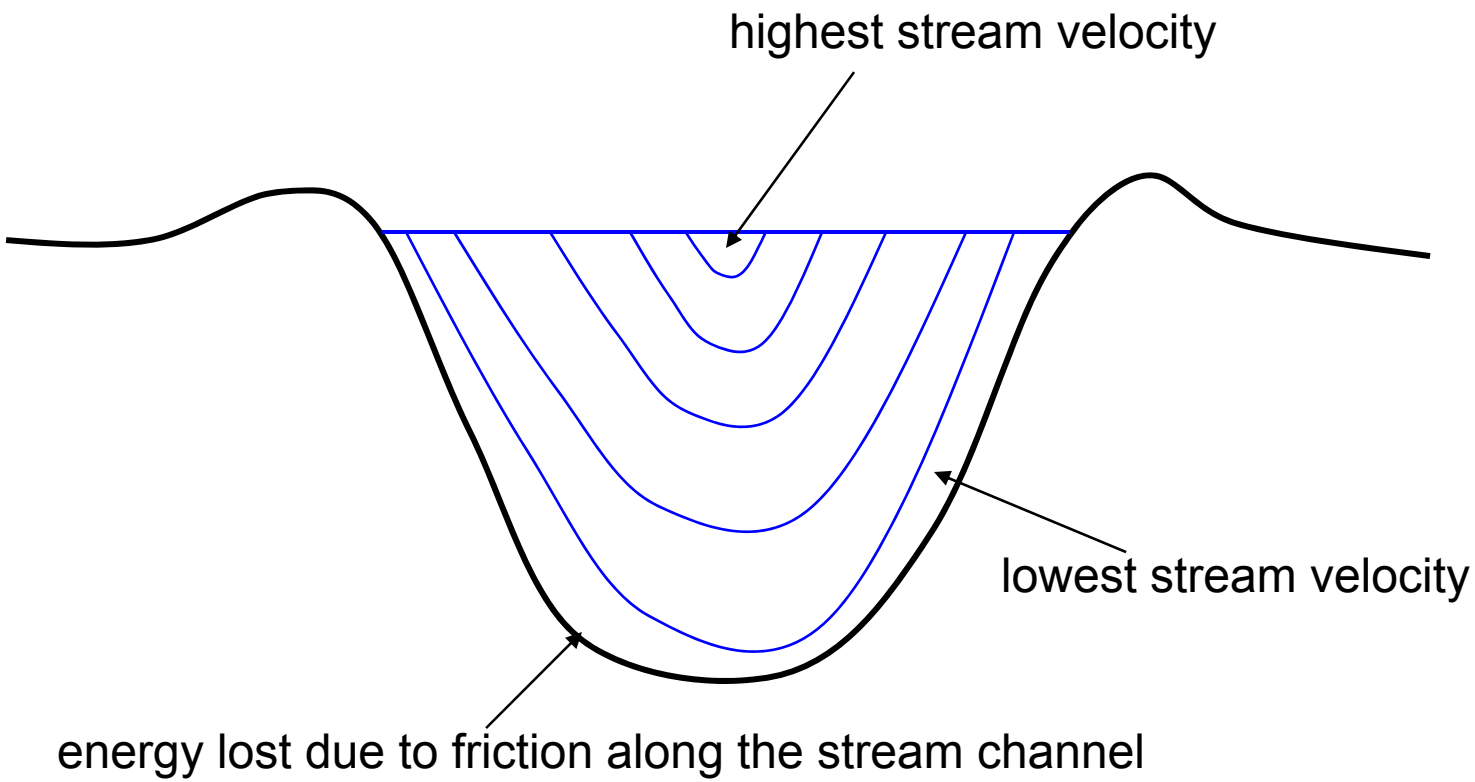


During percolation, the grains are fixed, but water is flowing past them, which produces the same drag force.

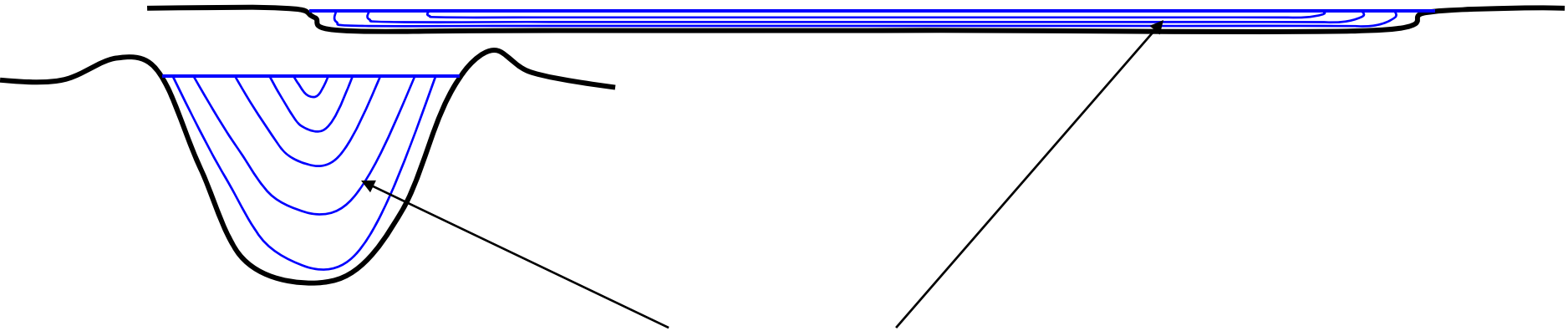
friction along the grain surfaces will resist water flow



Stream-Flow Analogy



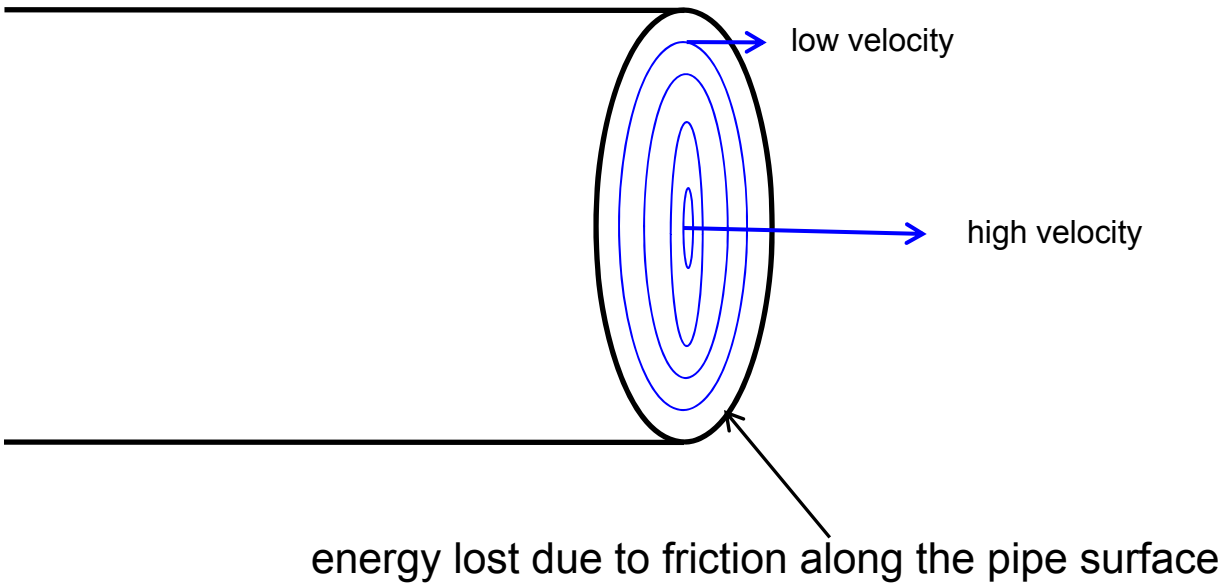
Stream-Flow Analogy

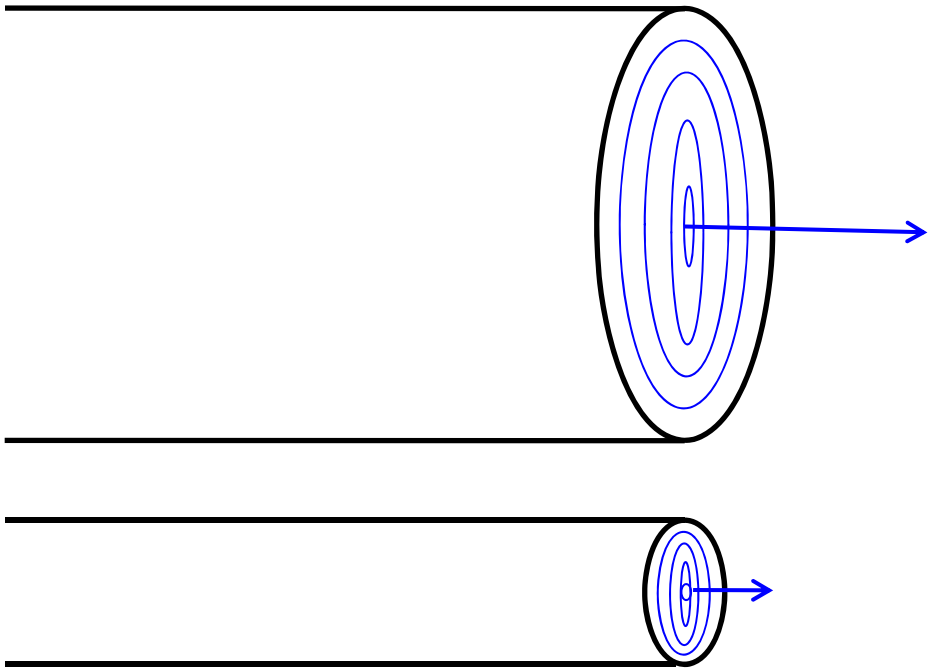


Equivalent stream-channel volumes.

Which one has the lower velocity? Why?

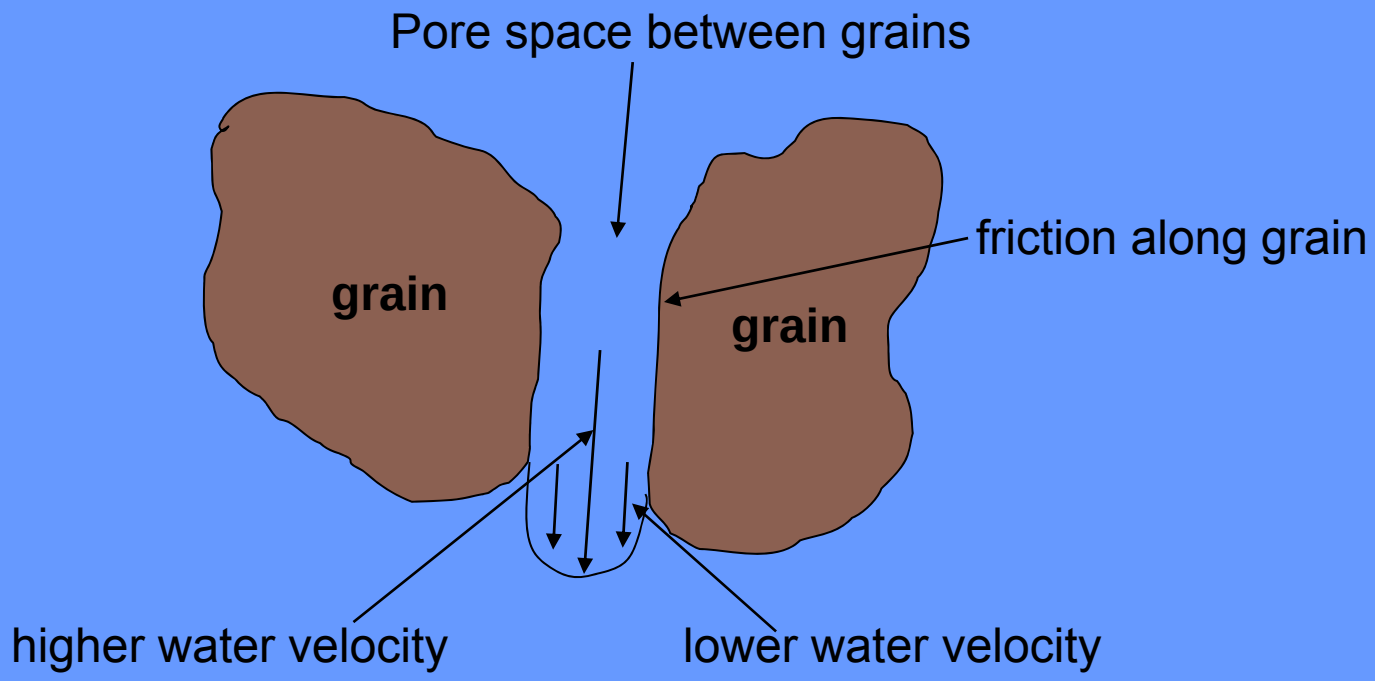
Pipe Flow


low velocity
high velocity
energy lost due to friction along the pipe surface



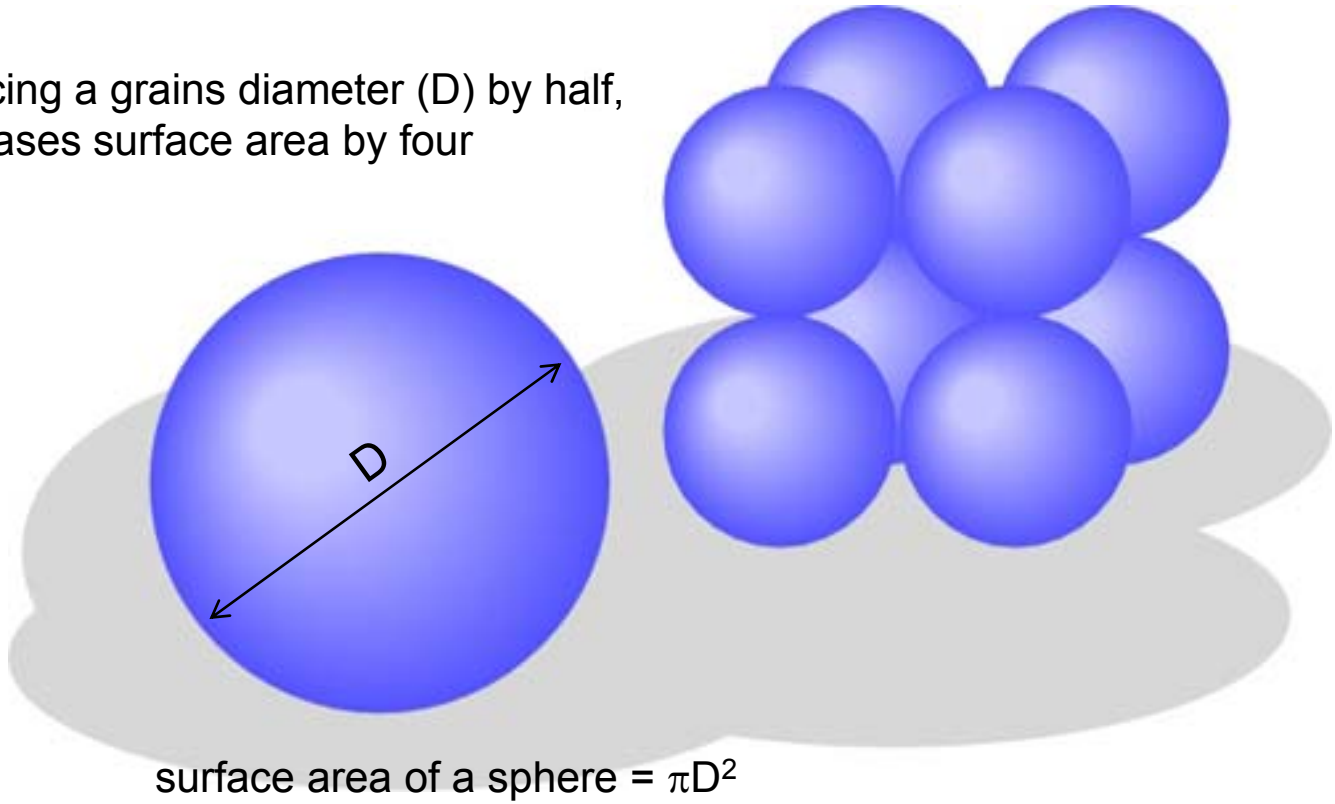
Which one has the higher friction loss? Why?

Water Flow in Porous Media



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

Assuming spherical sediments, the surface area per a 1 cm^3 volume of spheres is given as

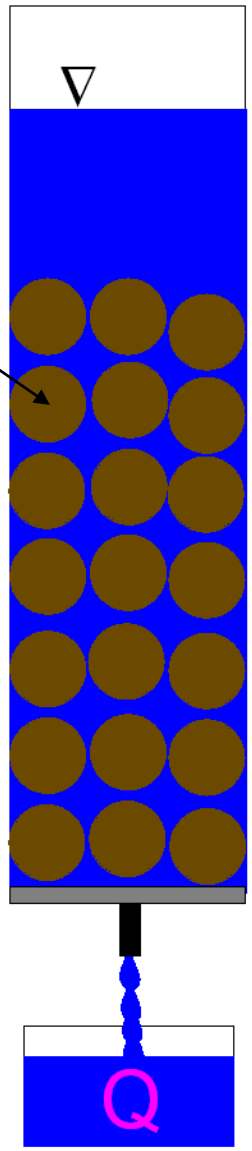
$$SA_v = 6/D$$

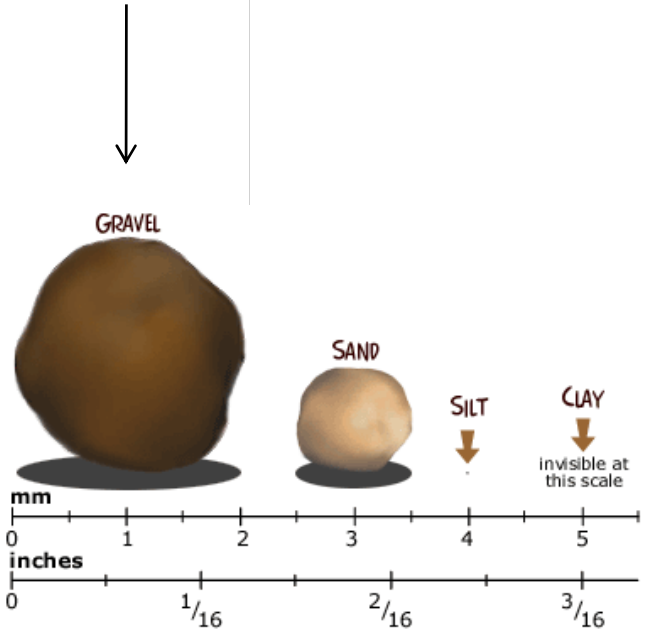
where D = grain diameter

1 cm^3

gravel having grain diameters of 4.0 mm

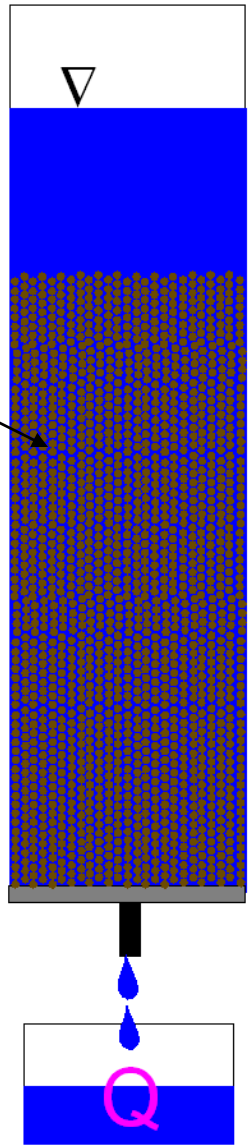
SA_v = 15 cm^2 per cm^3

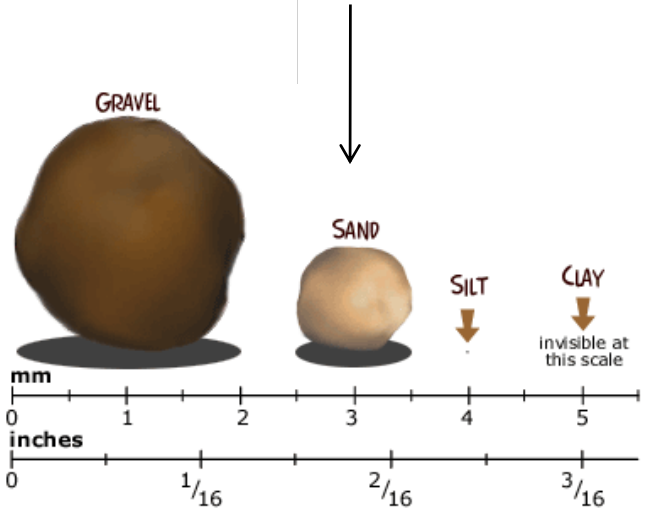




sand having grain diameters of 0.4 mm

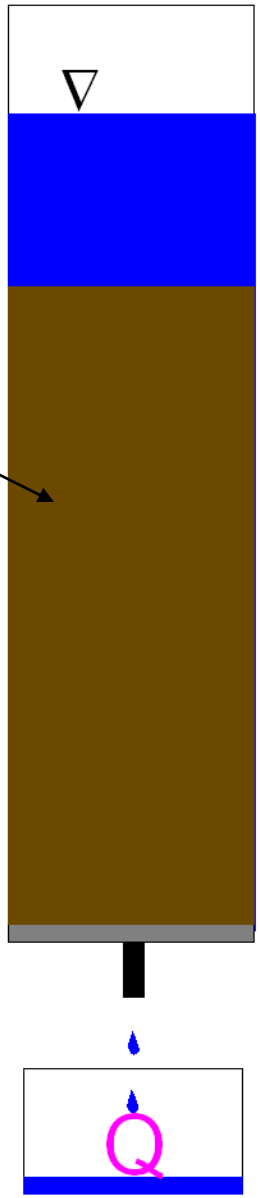
SA_v = 150 cm^2 per cm^3

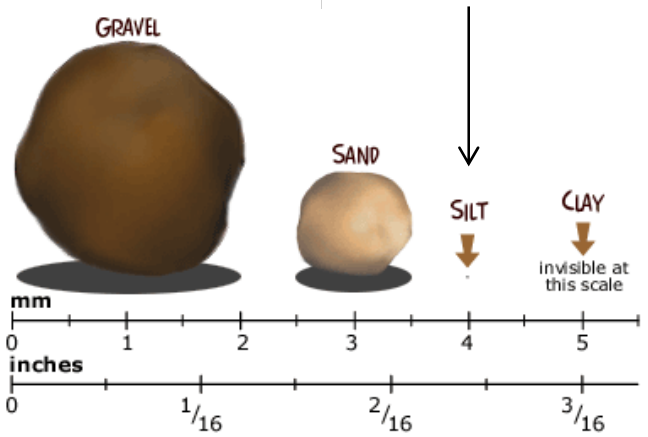




silt having grain diameters of 0.04 mm

SA_v = 1500 cm^2 per cm^3



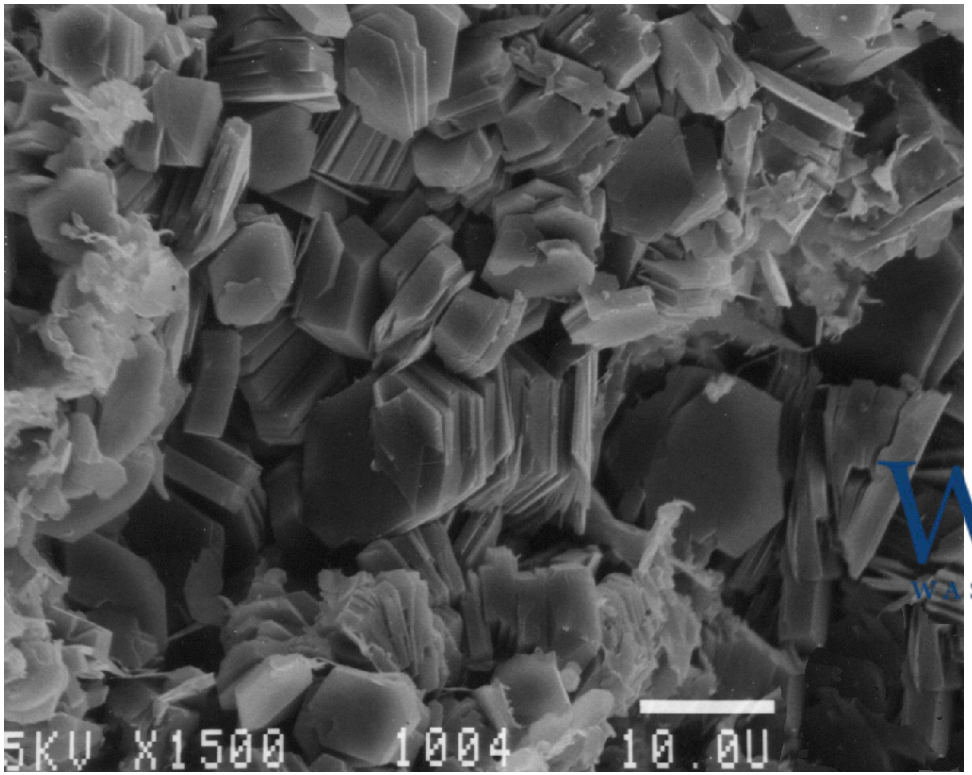


1 gram of smectite clay has 8,000,000 cm^2 of surface area

or

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

scanning electron microscope image of clay



diameter ≈ 0.00000002 cm

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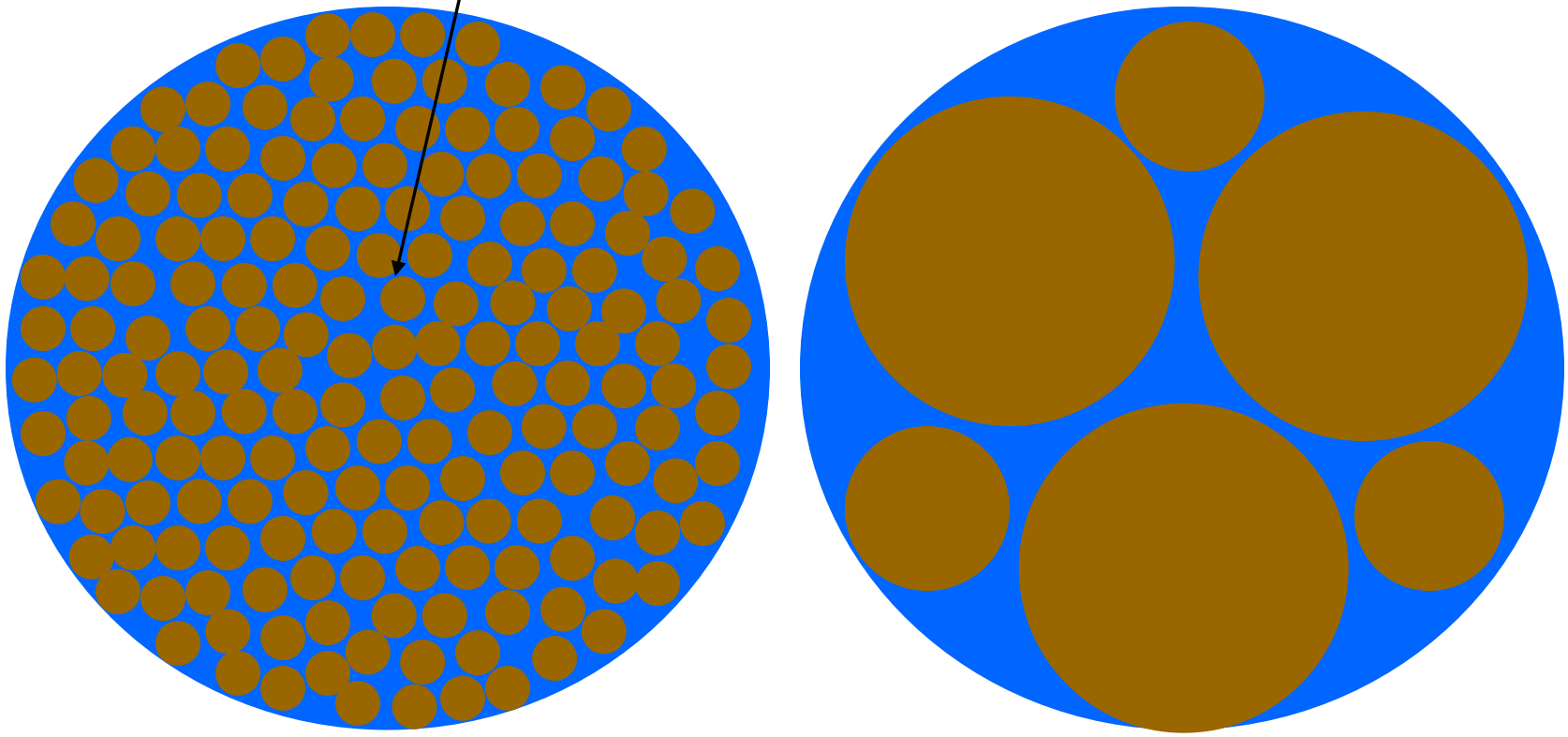
The hydraulic conductivity (K) is a measure of the sediments ability to transmit fluid.

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)

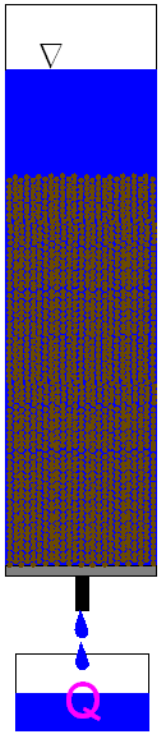
Smaller grains, means smaller pores, more frictional resistance, and lower hydraulic conductivity



lower hydraulic conductivity means lower percolation rate

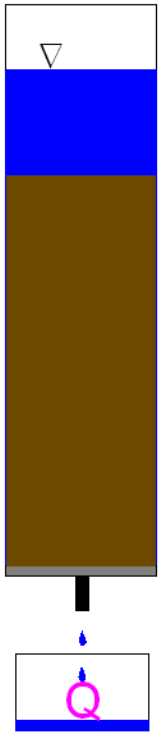
Sand

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

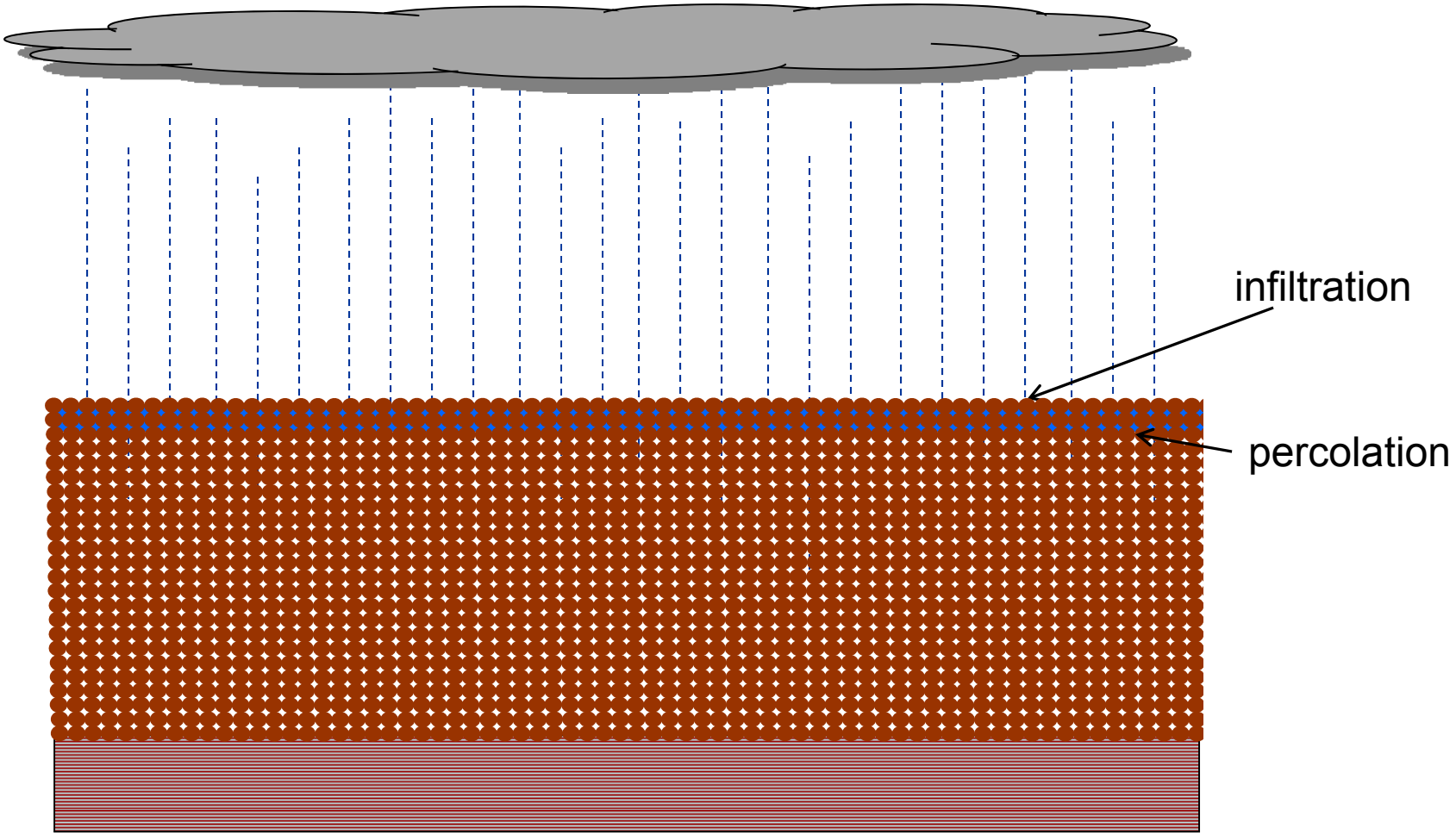


Silt

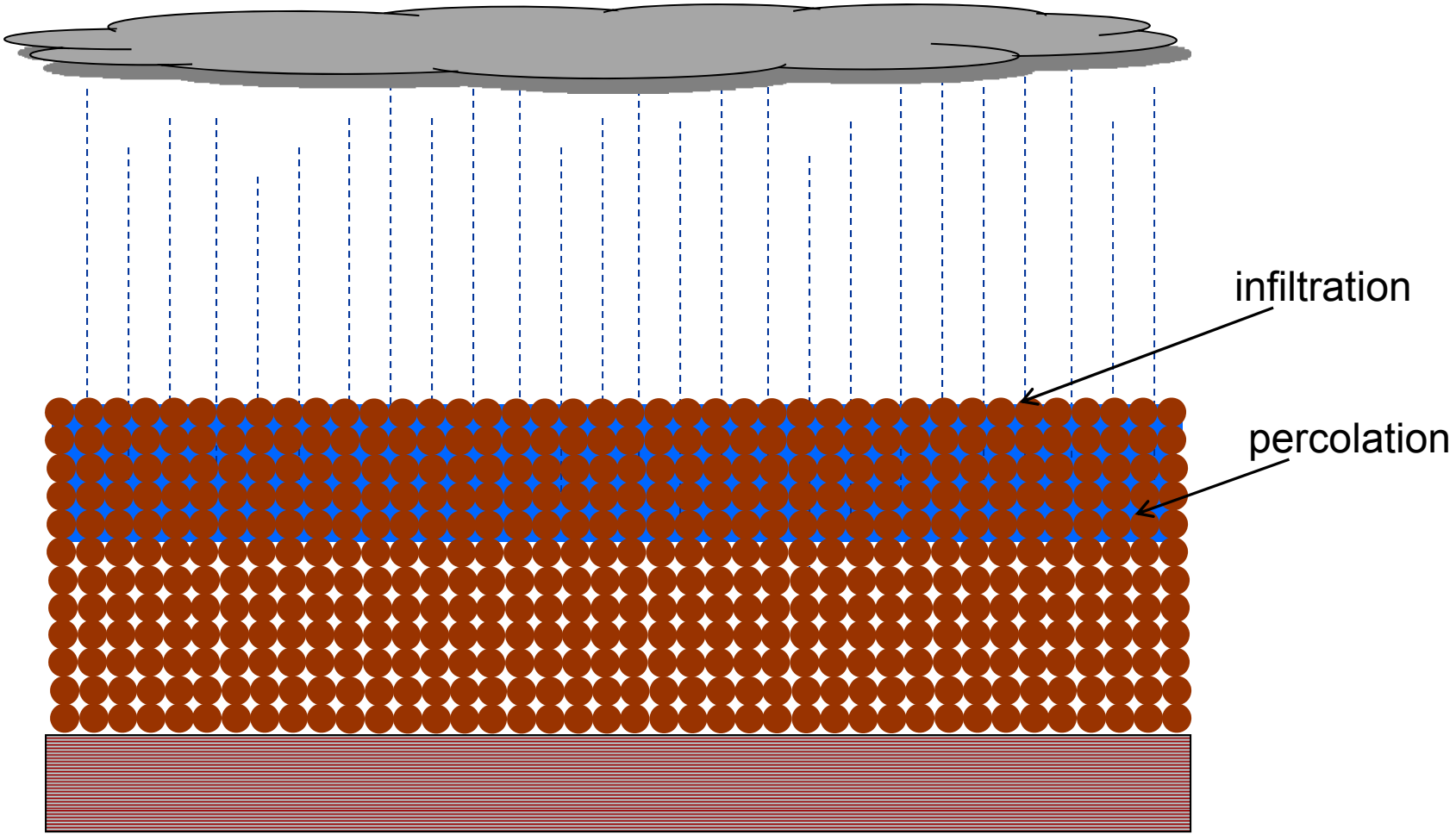
$K \approx 1 \times 10^{-6}$ cm/s



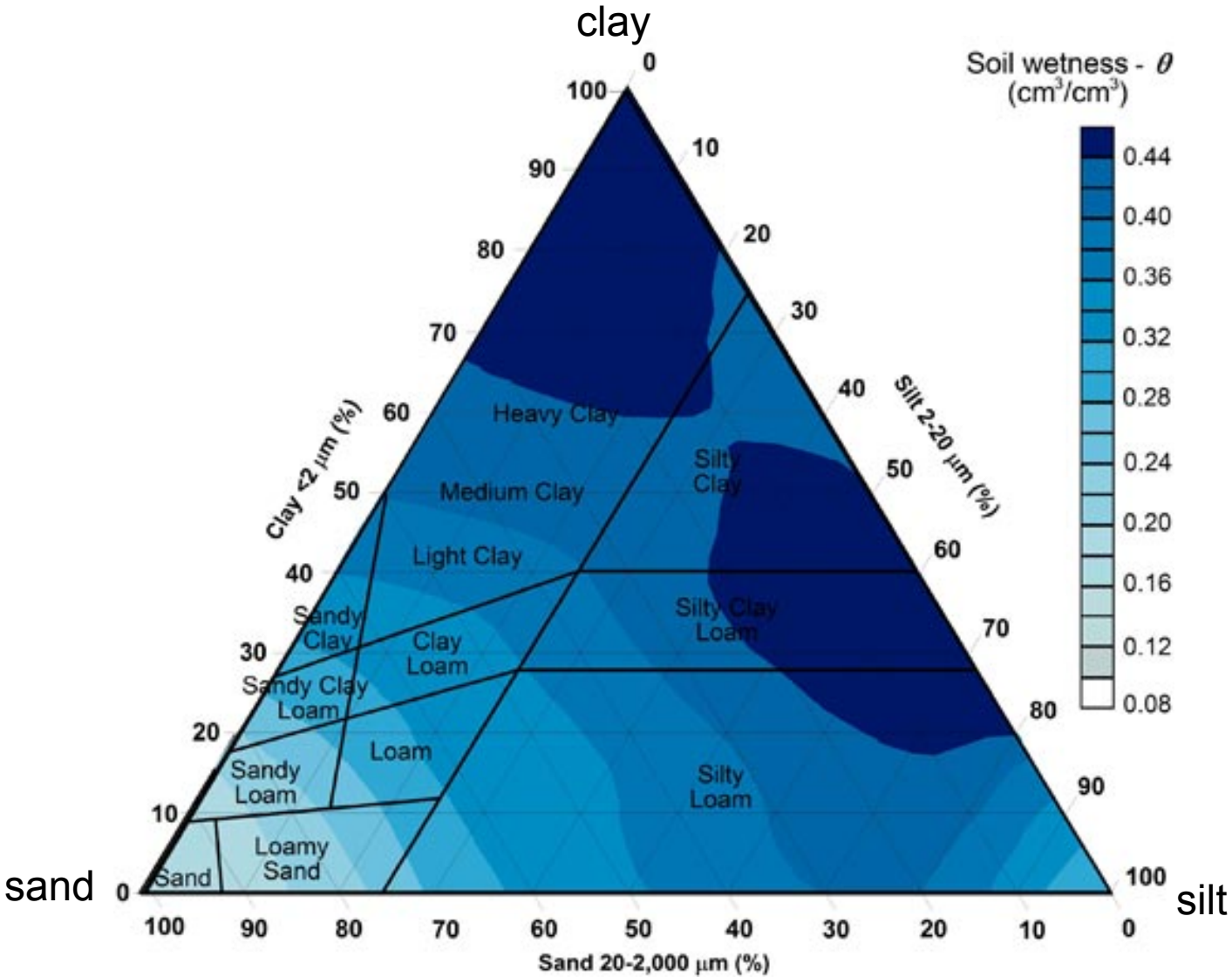
low hydraulic conductivity means low infiltration rate

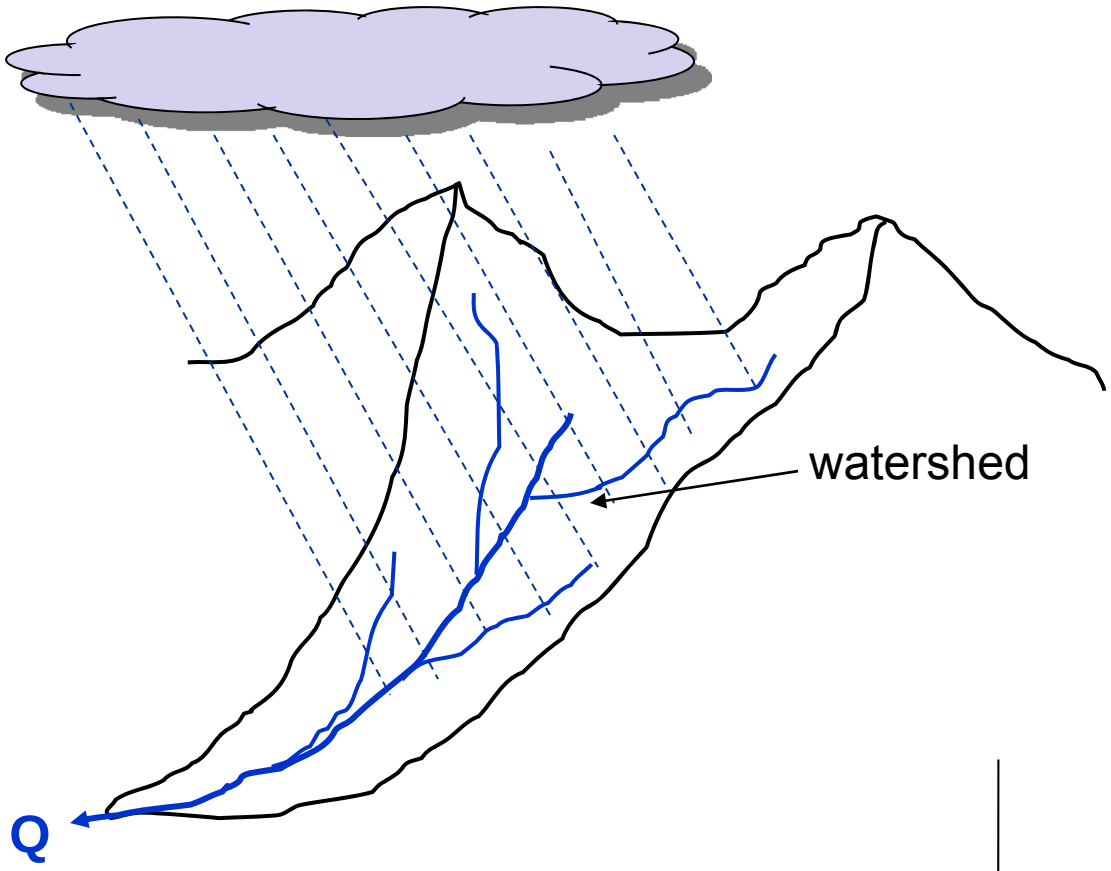


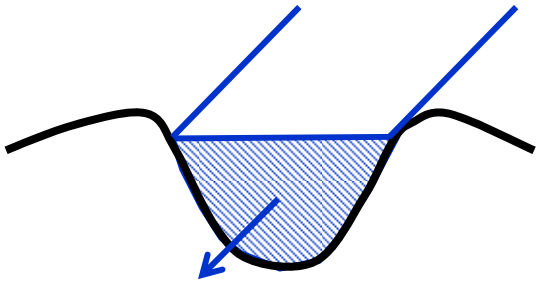
high hydraulic conductivity means high infiltration rate



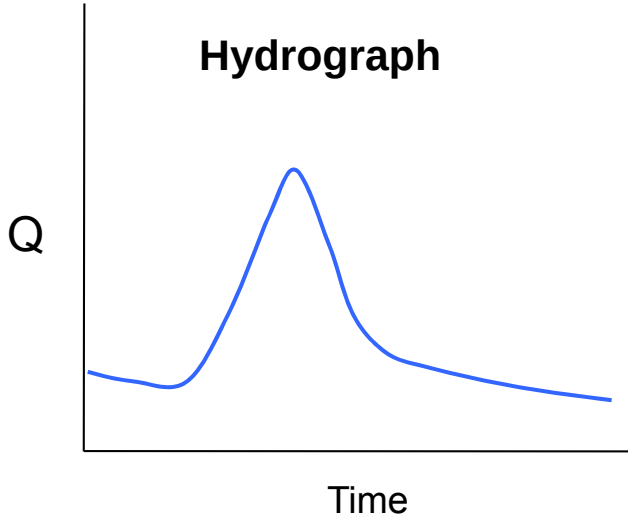
Soils with smaller clasts also have greater water holding capacity (stronger capillary forces)

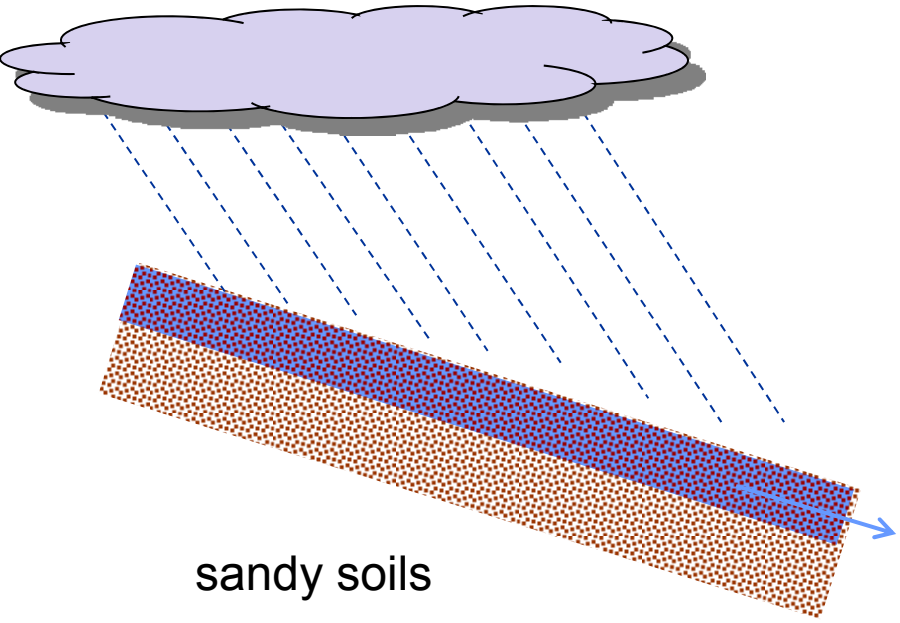


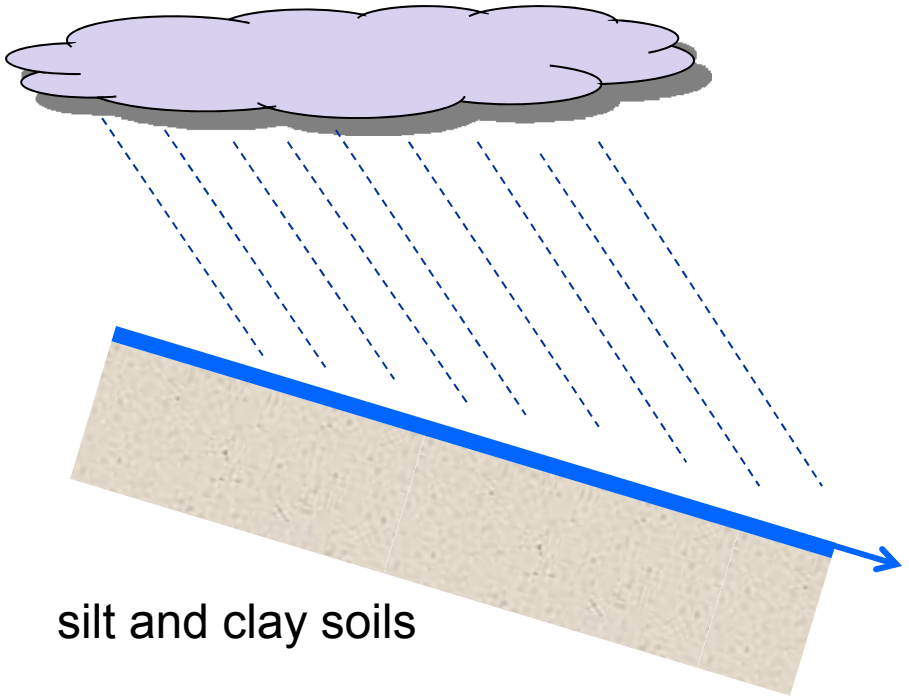


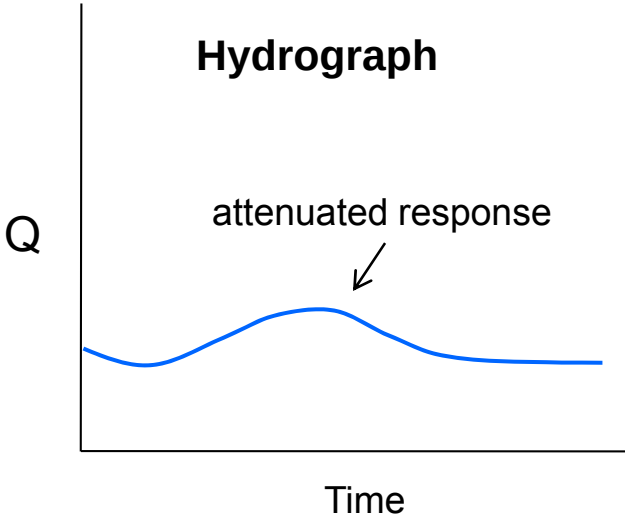


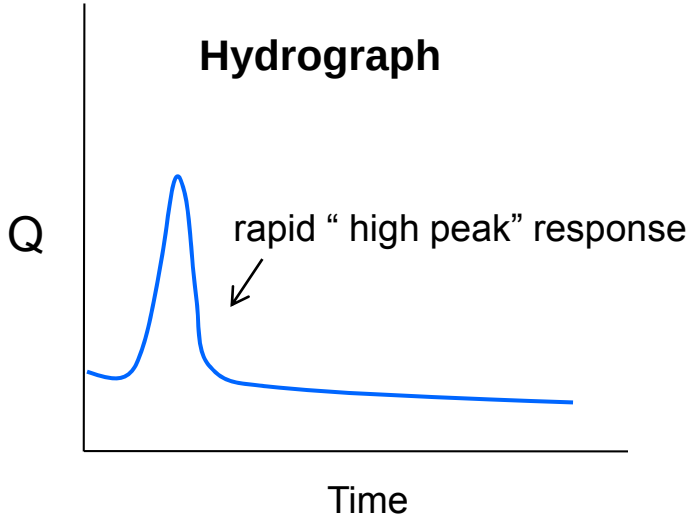
Q = stream discharge

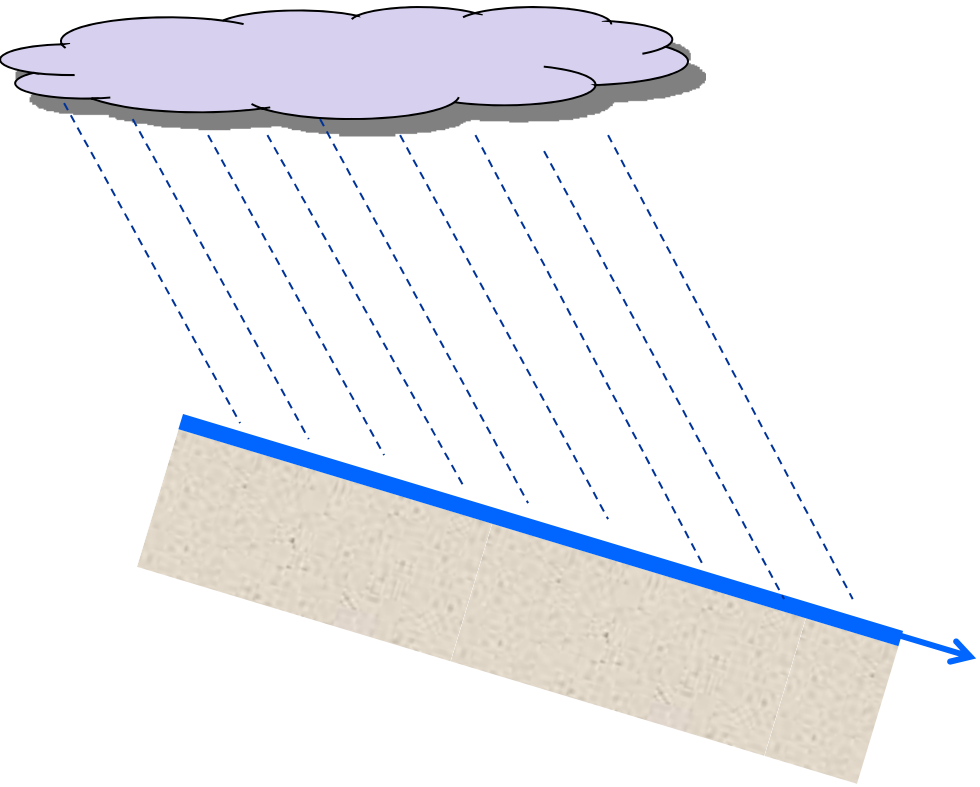


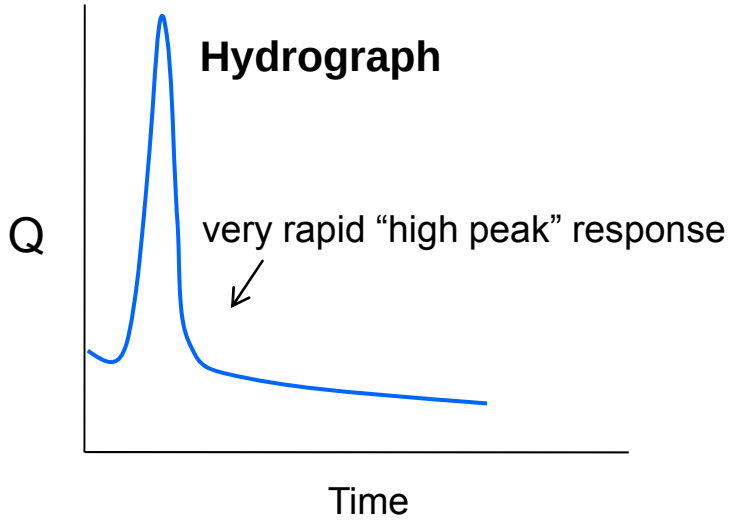

sandy soils


silt and clay soils


Hydrograph
Q
attenuated response
Time


Hydrograph
Q
rapid “ high peak” response
Time

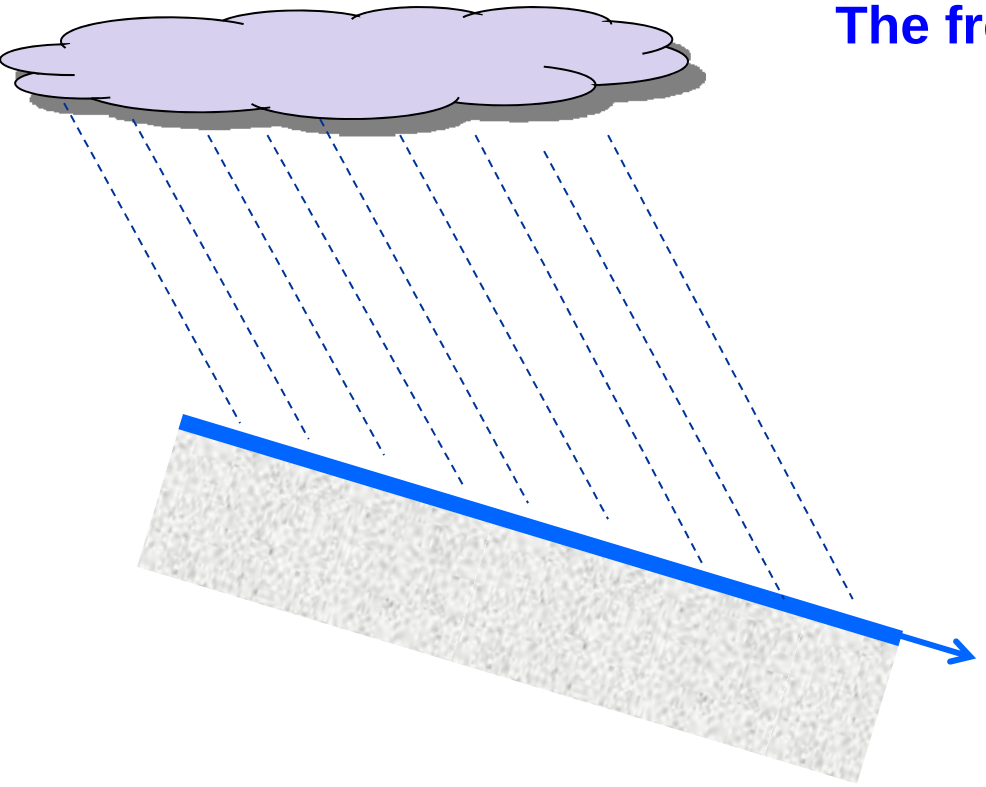


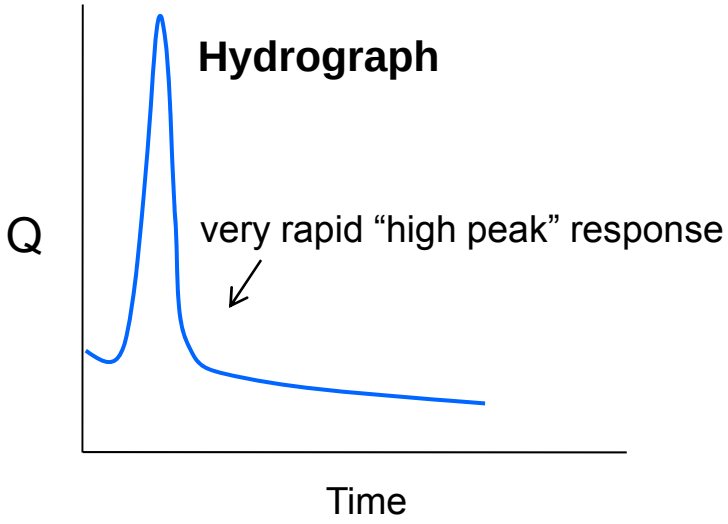


Impervious surfaces in urban settings don’t allow any infiltration, hence very rapid surface runoff

Water flows to both sides and across Squalicum Parkway near the intersection with Roeder Avenue on Wednesday, January 7, 2009

The frost line is 4 to 6 feet in Minnesota





Frozen soils don’t allow any infiltration, hence very rapid surface runoff

The Fargo Flood Homepage (Red River of the North) - Windows Internet Explorer

http://www.ndsu.nodak.edu/fargoflood/

File Edit View Favorites Tools Help

flood red river

The Fargo Flood Homepage (Red River of the North)

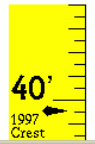
NDSU NORTH DAKOTA STATE UNIVERSITY - FARGO, N D

NDSU HOME PAGE | GEOSCIENCES HOME PAGE | GEOLOGY IN NORTH DAKOTA | FARGO GEOLOGY

THE "FARGO FLOOD" HOMEPAGE

Red River of the North flood at Fargo, April, 1897.

NOTE: The Fargo Flood Homepage provides access to scientific (i.e. geologic and hydrologic) and historic information on flooding in the Fargo region. For public service announcements regarding current flooding, visitors should instead start at the Fargo city flood site or the In-Forum web site.

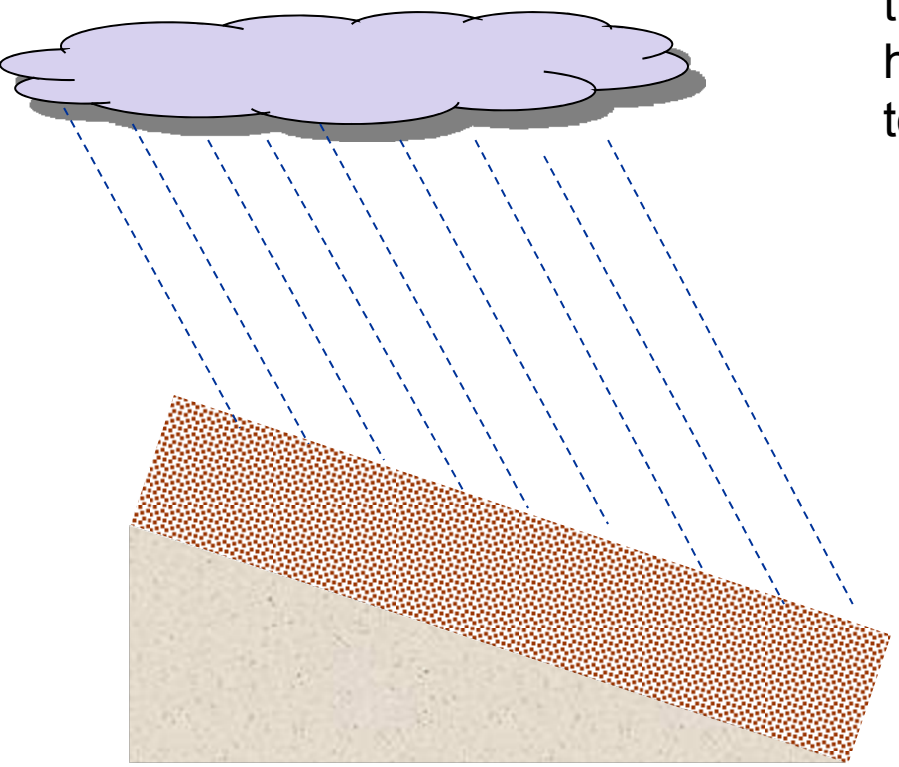


- **Flood Information for Fargo** - The geology of Red River flooding, current water levels of the Red River and its tributaries, plus a photographic archive of past Red River floods.

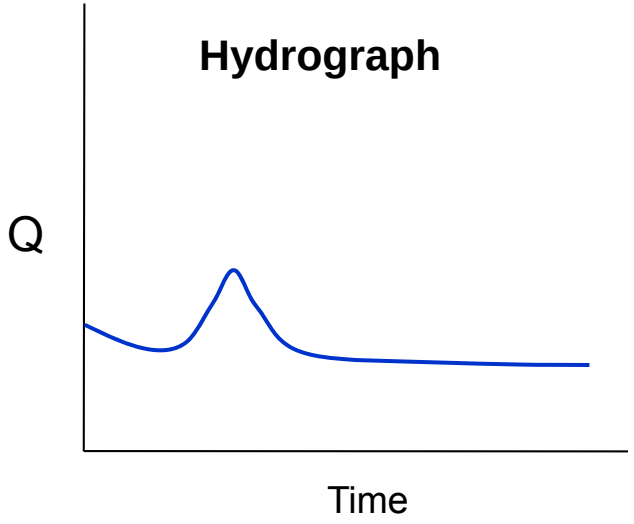
- **Fargo Geology** - Information on the geology of Fargo and the Red River Valley, including comprehensive maps presenting land stability conditions along the Red River

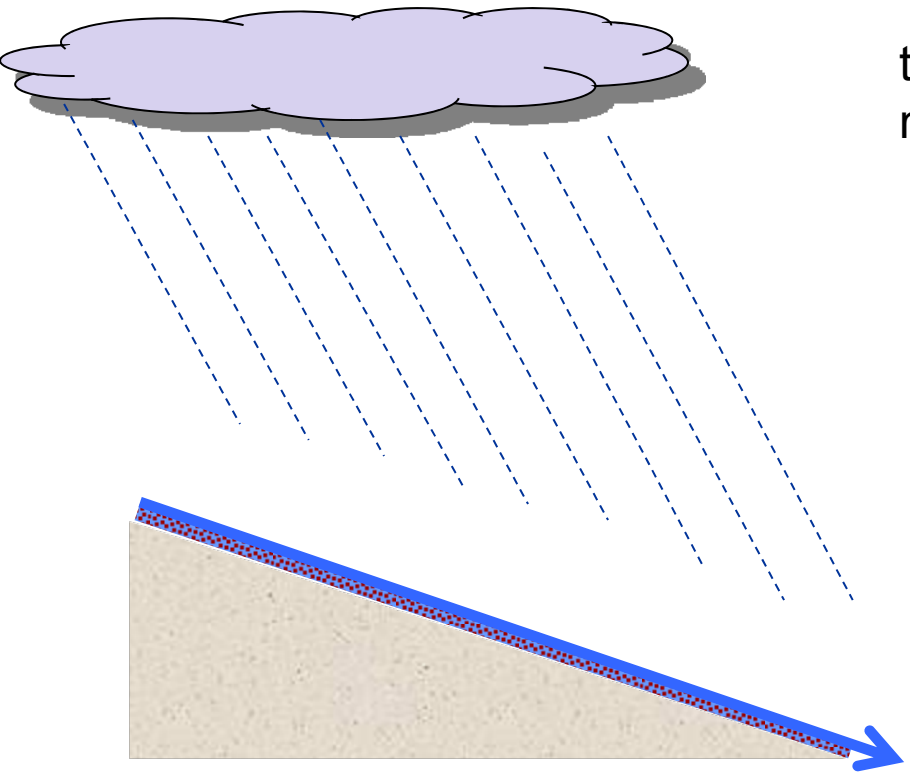
Internet 100%

Fargo North Dakota: March 13, 2010

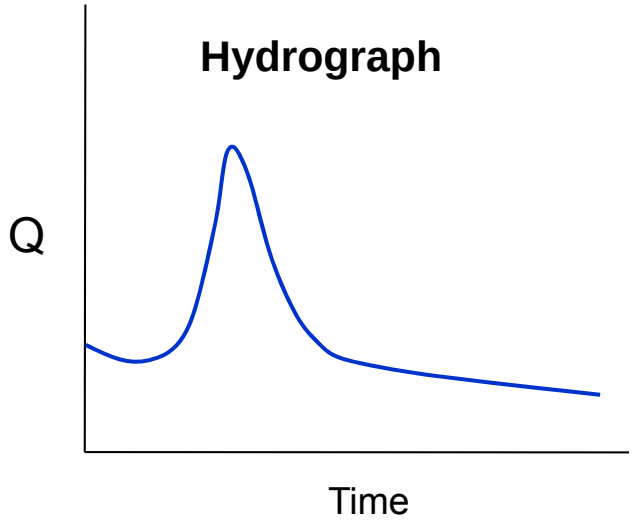


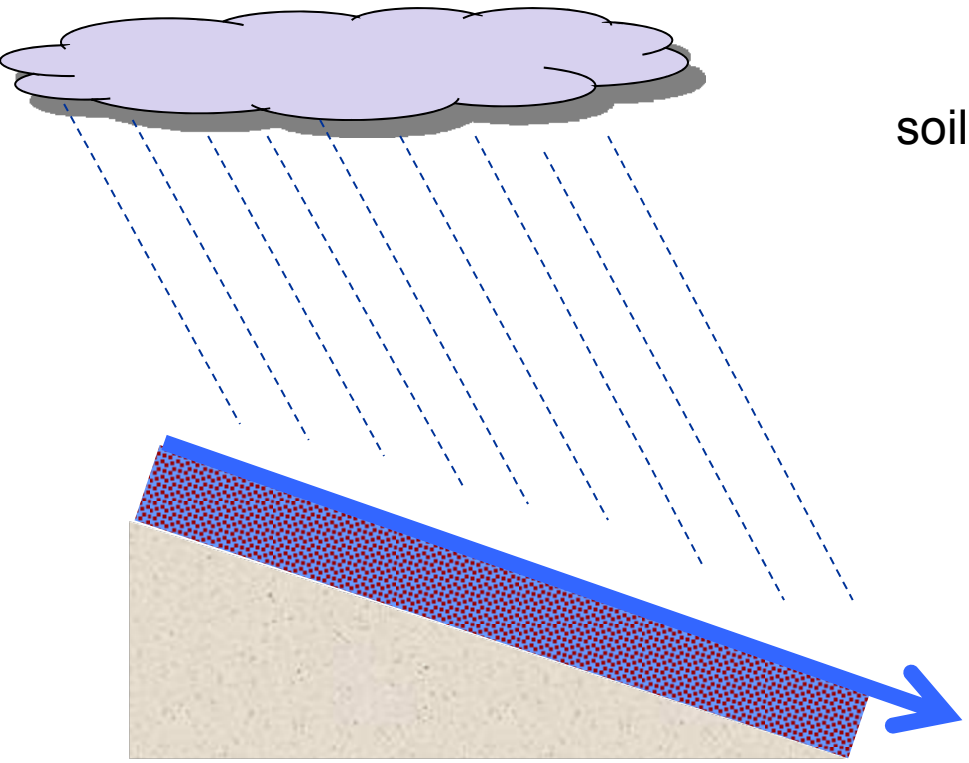
thick, dry soils can store a lot of rain, hence produce less runoff (if they are dry to begin with)



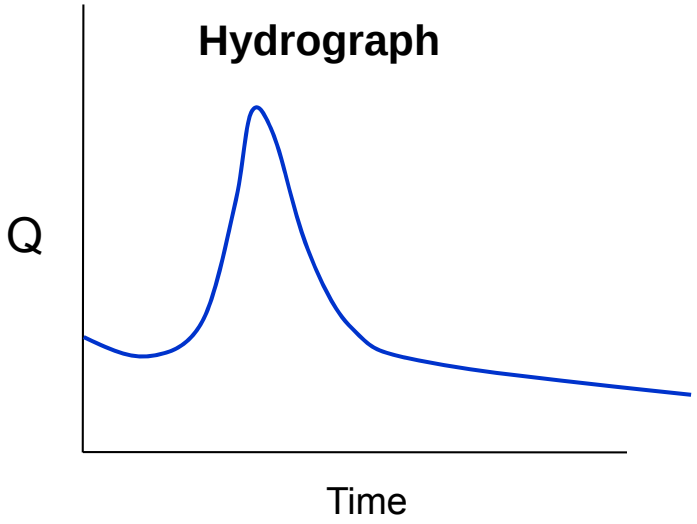


thin soils saturate quicker, hence produce more runoff

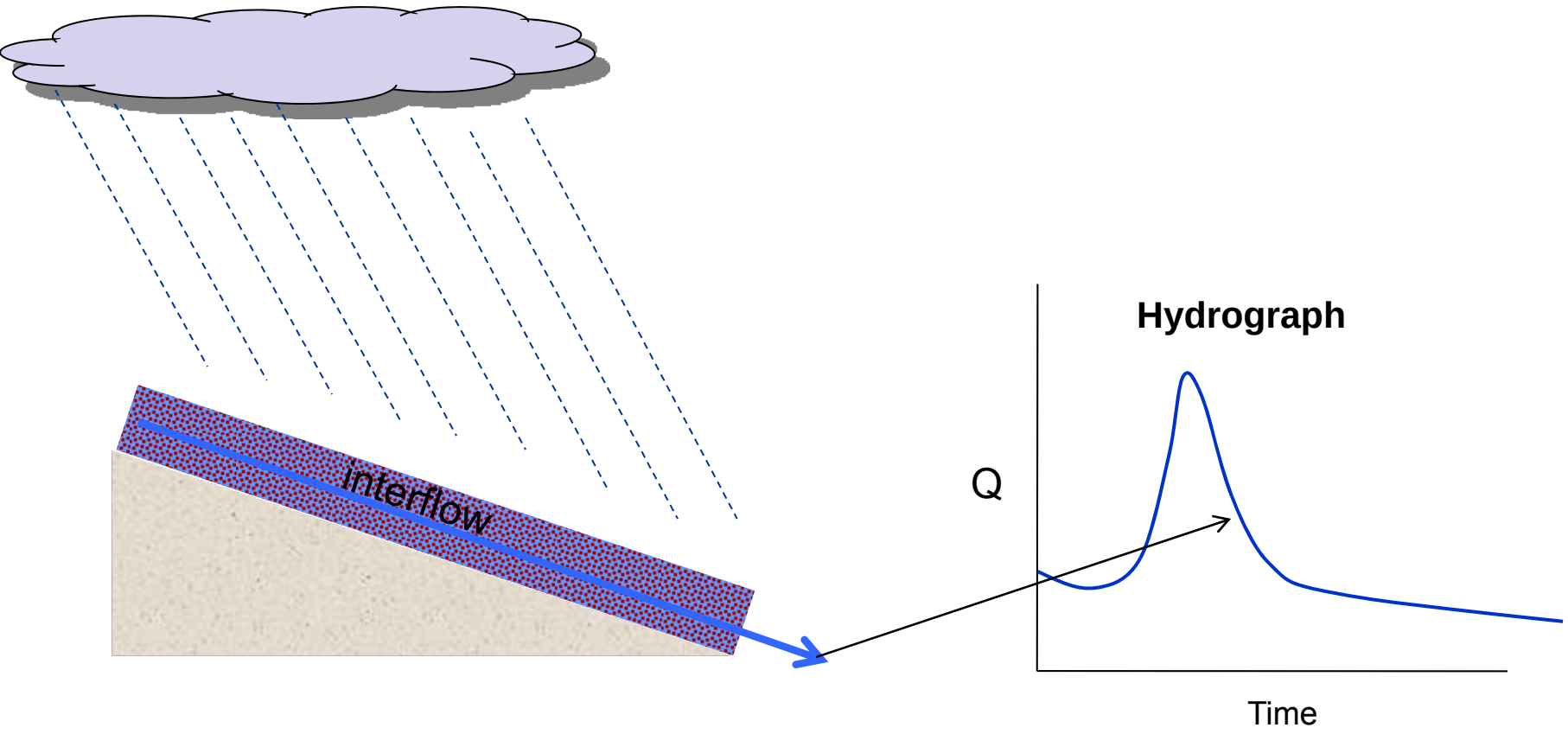


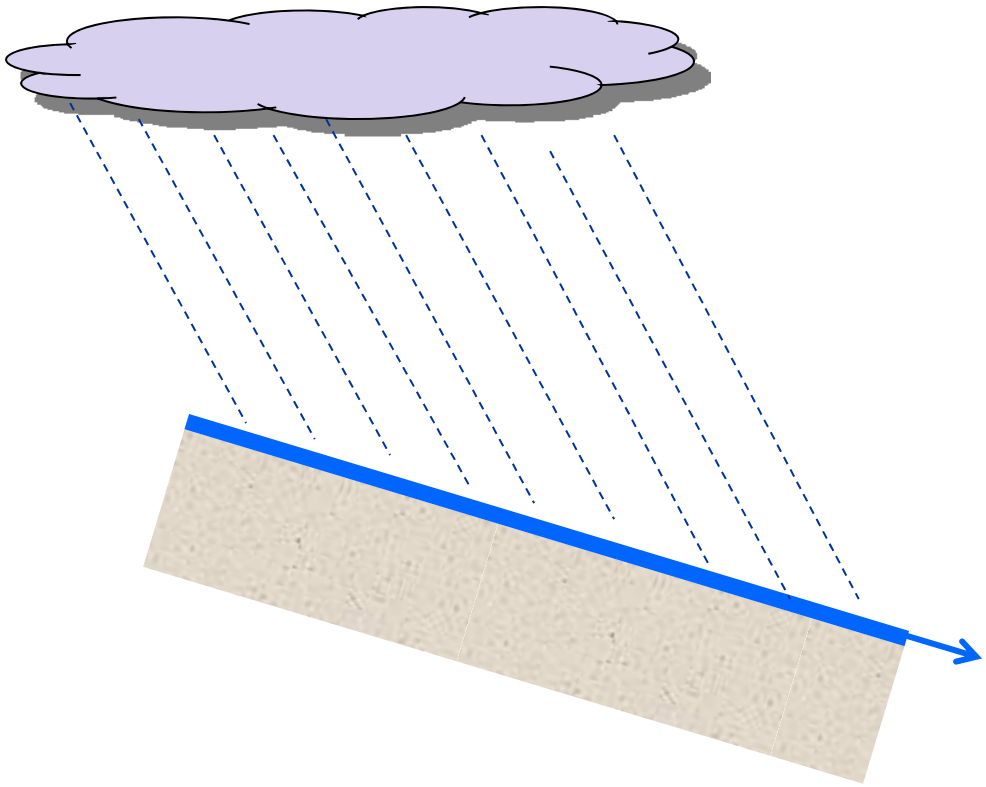


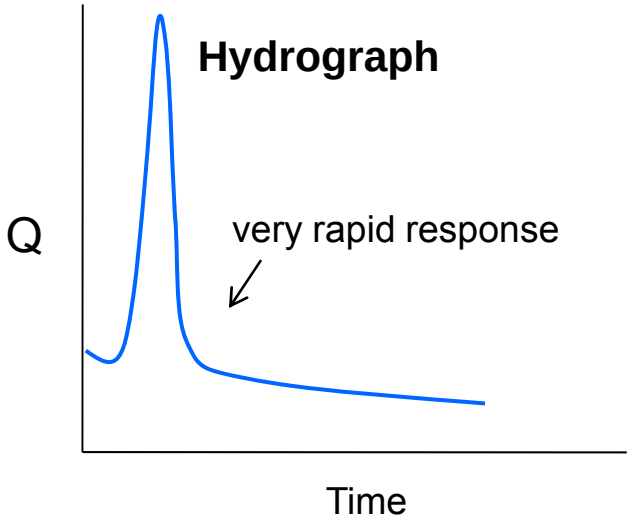
soils near saturation produce more runoff



water can flow through the soils toward a stream







bedrock surfaces in mountain settings have low infiltration rates, hence very rapid surface runoff

Flood Statistics

- Up to 15 inches of rain fell with an average of 10 inches over 60 square miles.
- Peak flow on Rapid Creek 50,600 cubic feet per second...more than 10 times greater than the previous flood of record.
- During the flood, water rose as fast as 3.5 feet in 15 minutes.
- 238 people killed.
- 3,000 people injured.
- 1,335 homes destroyed.
- 5,000 automobiles destroyed.
- $160 million in total damages (1972 dollars, $644 million in 2002 dollars).
- 15 of the 23 bridges over Rapid Creek were destroyed.

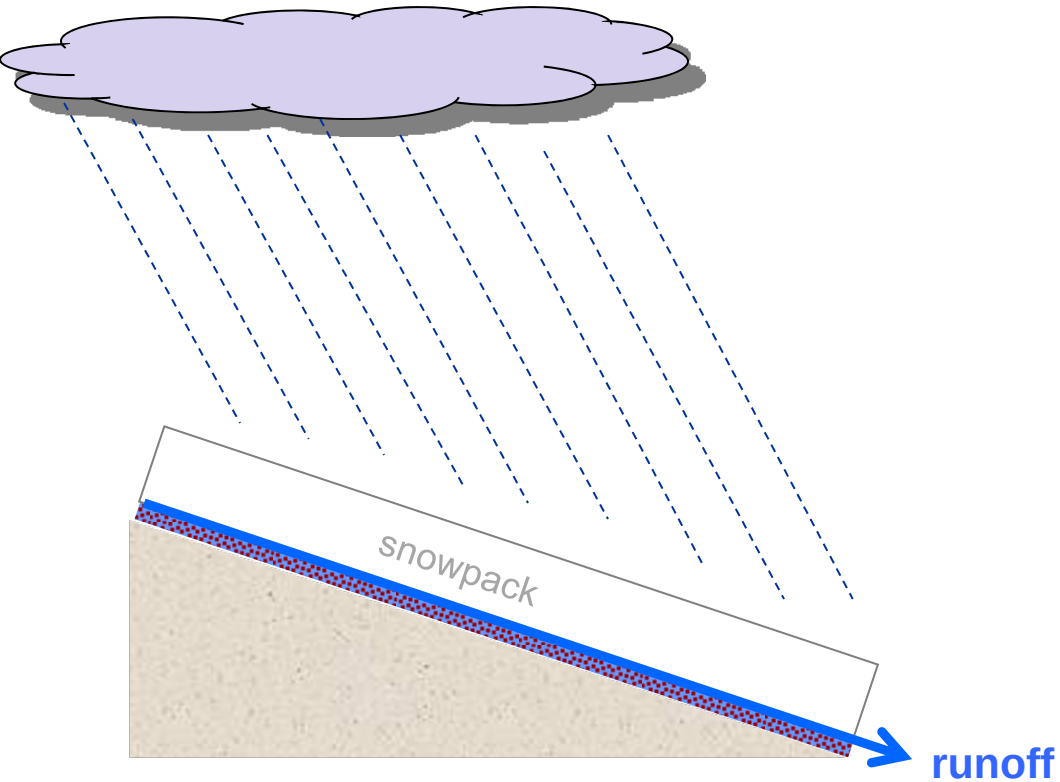
Rapid City South Dakota, 1972

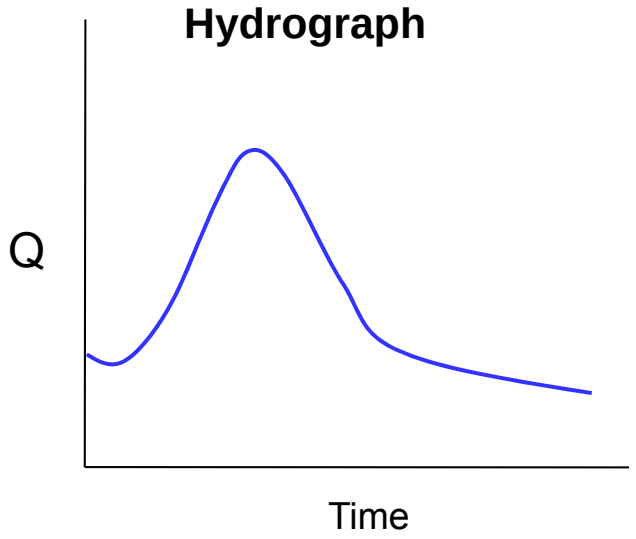
Flash Flood

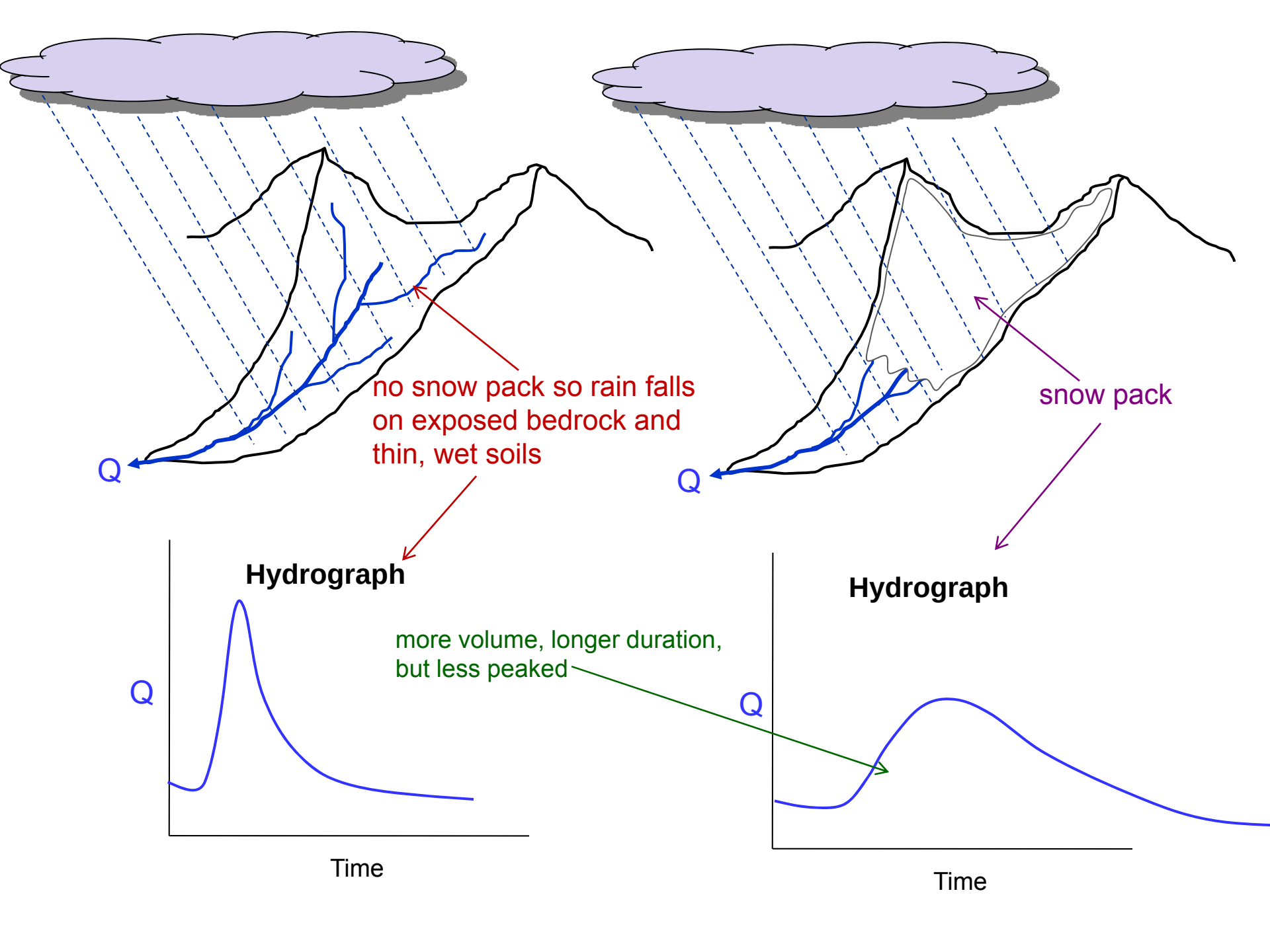
http://sd.water.usgs.gov/projects/1972flood/photos.html

Rain on Snow

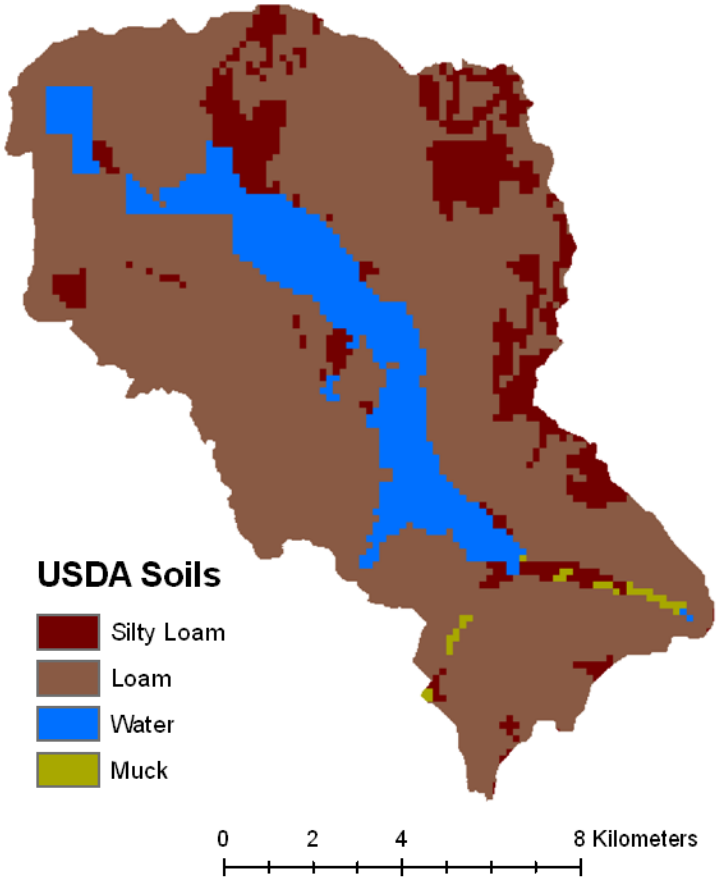
Early winter snow packs are relatively warm. Warm rains release heat into the snowapck causing some snow to melt, which will produce more runoff.



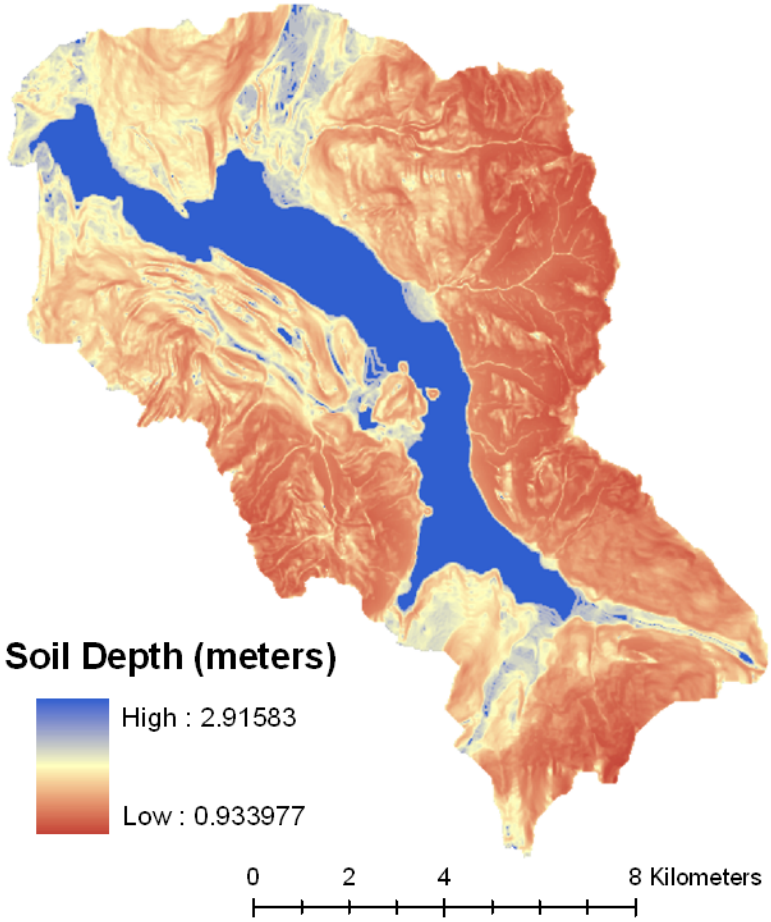



Q
no snow pack so rain falls
on exposed bedrock and
thin, wet soils
Q
snow pack
Hydrograph
Q
Time
more volume, longer duration,
but less peaked
Hydrograph
Q
Time

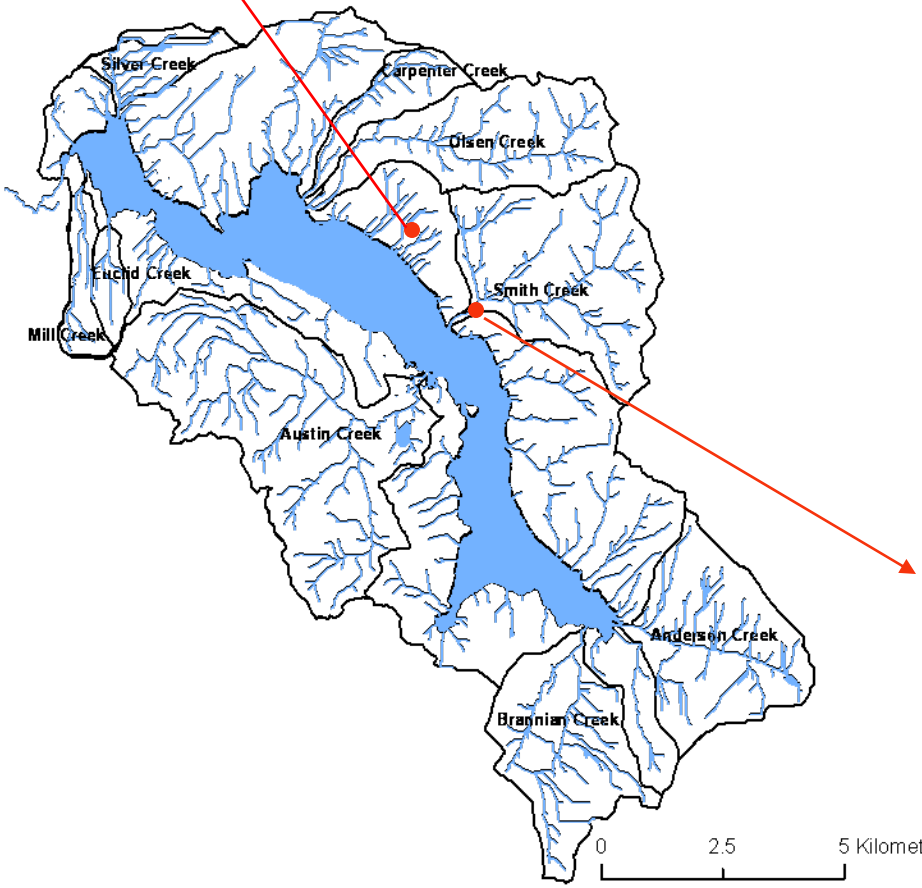
Soil Coverage (USDA)



Soil Depth (estimated)

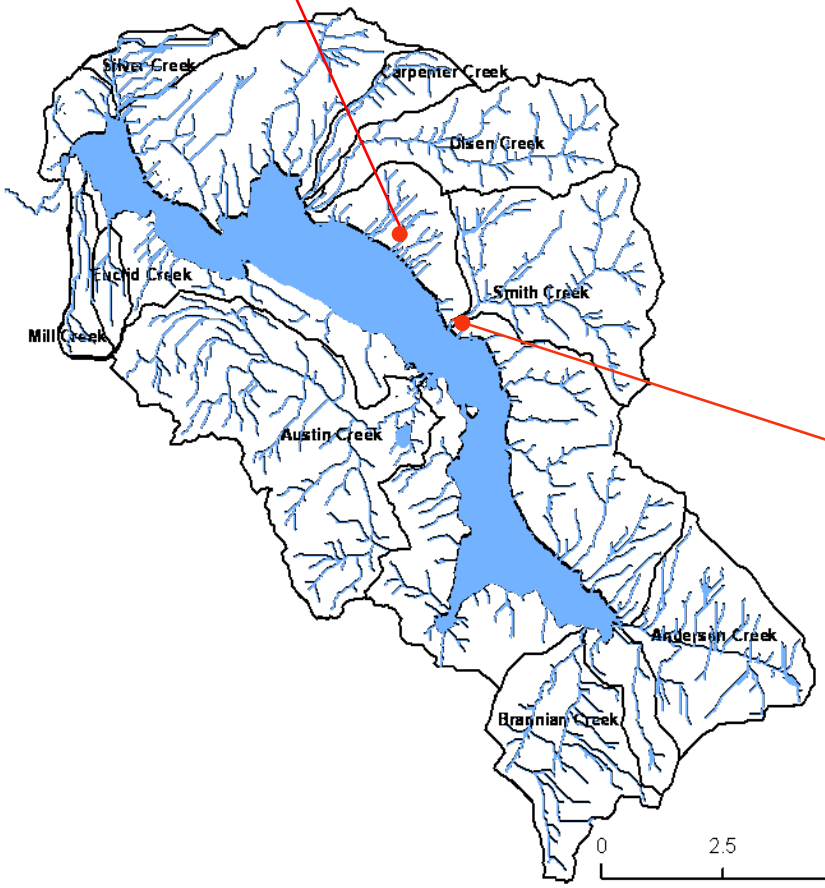


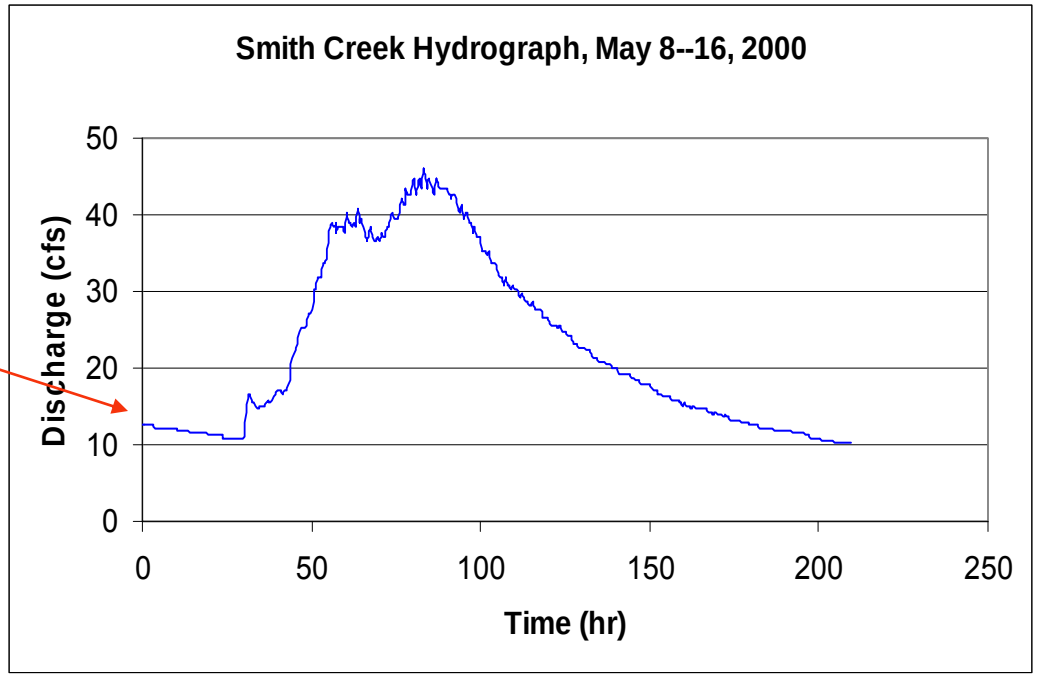
North Shore MET Station



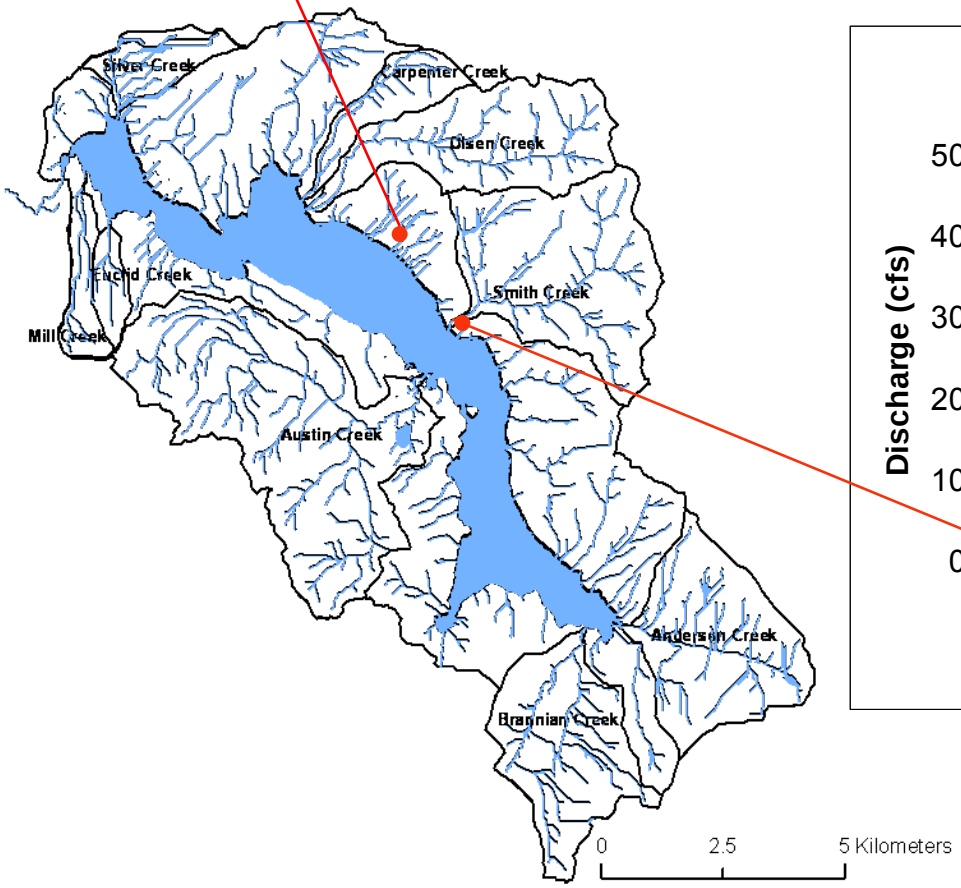
Smith Creek Stream Gauge

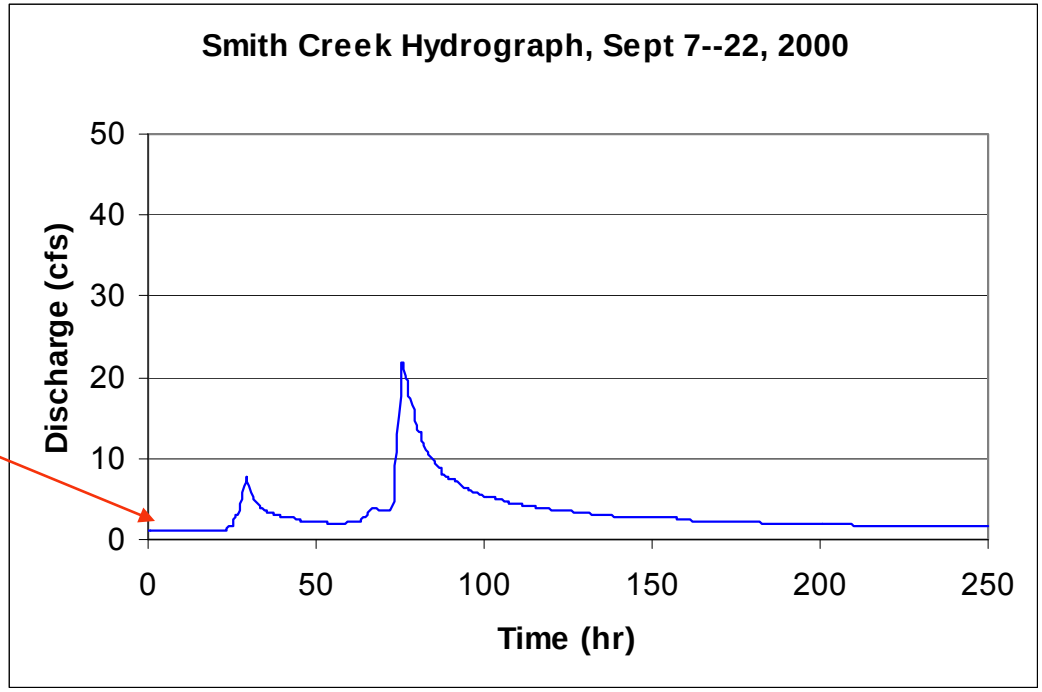
1.2 inches of rain in 24 hours





1.2 inches of rain in 24 hours





Smith Creek Stream Gauge

1.2 inches of rain
in 24 hours