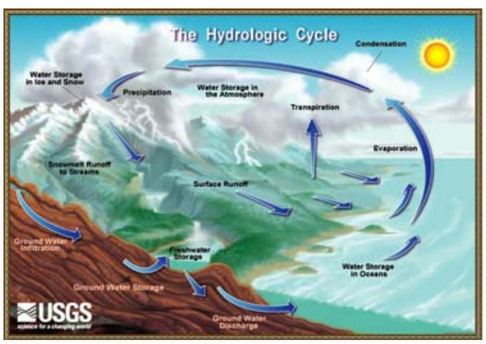
Source Water Protection – Introduction to Ground Water

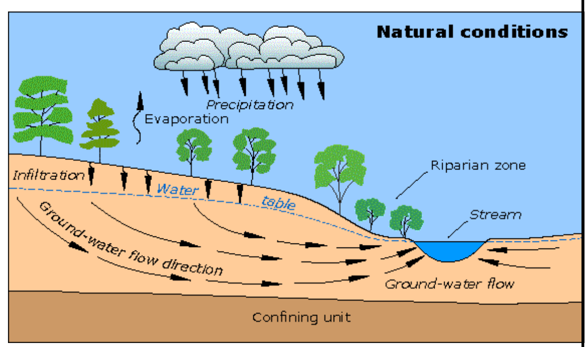
Prepared by The Cadmus Group, Inc.

Objectives of This Presentation

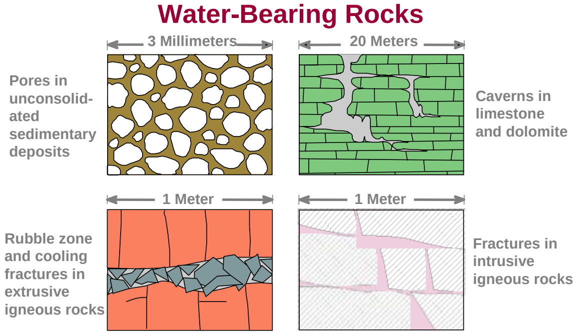
Gain a working knowledge of the basics of hydrogeology in order to

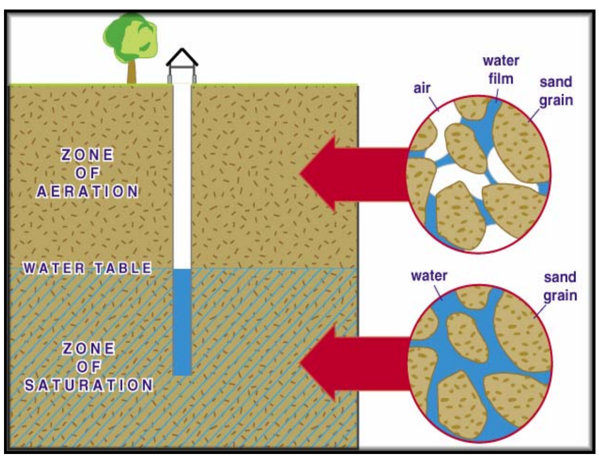
- **Better understand groundwater flow and threats from contamination**





Types of Openings In Selected Water-Bearing Rocks





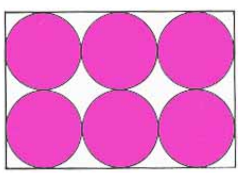
Pores and Saturation

- Pores are the spaces between sediment grains
  - These spaces can be filled with air (e.g., when sand is dry). They can be filled with water (e.g., in an aquifer). Or they can be filled with some air and some water.
  - When the pores in a sample of sediment are filled with water, the sample is FULLY SATURATED.

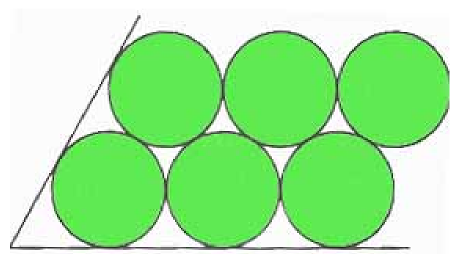
Pore Size

- Big grains tend to result in big pores
- Small grains tend to result in small pores
- Sorting: Are the grains all the same size?
  - **Poorly sorted (well-mixed) sediment has lots of different sizes of grains. The small grains fill in part of the spaces between the big grains.**

One grain on top of another: "Cubic Packing"

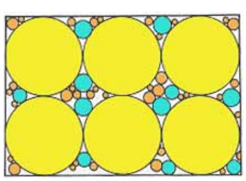


More tightly packed grains (lower porosity)



Small grains fill in the empty spaces between large grains.

(This sample is poorly sorted.)



Grain Size

Name	Size Range (mm)
gravel	> 2.0
very coarse sand	1.0-1.999
coarse sand	0.500-0.999
medium sand	0.250-0.499
fine sand	0.100-0.249
very fine sand	0.050-0.099
silt	0.002-0.049
clay	< 0.002

(Loxnachar et al, 19)

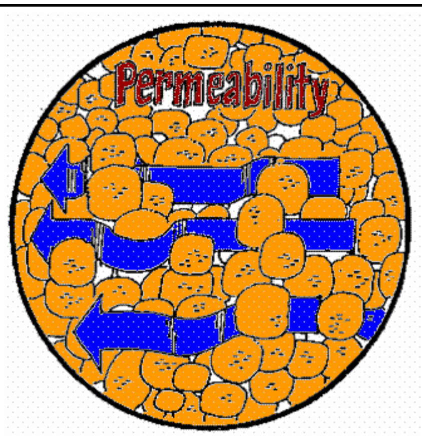
Porosity

- The % of pores in a given volume of aquifer
  - Sometimes few of the pores are connected.
  - Sometimes there's a lot of FRICTION as the water tries to get out of the skinny part of the pore
  - So high porosity does NOT automatically mean high permeability.
- Definition of porosity: [volume of pores / volume of your sample] x 100
  - ($[V_V/V_T]$ x 100)

Porosity Ranges for Sediments

Material	Porosity (%)
well-sorted sand or gravel	**25-50**
sand and gravel, mixed	**20-35**
glacial till	**10-20**
silt	**35-50**
clay	**33-60**

(Based on Meinzer (1923a); Davis (1969); Cohen (1965); and MacCary and Lambert (1962) as quoted by C.W. Fetter [2])



Permeability depends on pore size

- **Permeability - the ability to transmit water or other fluid**
- **Friction slows water down as it moves against the sides of the pore (e.g., as it moves past individual grains of sand)**
- **When pores are big, less water has to touch the sides of the pore**
  - **So water moves faster through big pores**
  - **Does water move faster through gravel or through clay?**
  - **Which has a higher permeability, gravel or clay?**
- **What kind of permeability do you think sand has? High or low?**

Hydraulic Conductivity

- The permeability of sand is the same whether water or oil or any other fluid flows through it.
- Hydraulic conductivity is a concept similar to permeability, but its value will vary depending on the fluid flowing through the aquifer.
- We are only concerned about water here.
- So… we will talk about hydraulic conductivity from this point on.

Hydraulic Conductivity (K) for Sediments

Material	Hydraulic Conductivity	
	(cm/s)	(ft/day)
well-sorted gravel	**10^{-2} to 1**	**28.3 to 28300**
well-sorted sands, glacial outwash	**10^{-3} to 10^{-1}**	**2.83 to 283**
silty sands, fine sands	**10^{-5} to 10^{-3}**	**0.0283 to 2.83**
silt, sandy silts, clayey sands, till	**10^{-6} to 10^{-4}**	**0.00283 to 0.283**
clay	**10^{-9} to 10^{-6}**	**0.00000283 to 0.00283**

(C.W. Fetter [2])

Expressing Small Numbers

$$0.001 = \frac{1}{1{,}000} = \frac{1}{1\text{x}10^{3}} = 1\text{x}10^{-3}$$

$$0.000001 = \frac{1}{1{,}000{,}000} = \frac{1}{1\text{x}10^{6}} = 1\text{x}10^{-6}$$

What makes groundwater flow?

Answer:

Hydraulic head differences!

Question: What is hydraulic head?

Answer: A measure of the energy water has at a particular point in the aquifer.

So…. what gives water that energy???

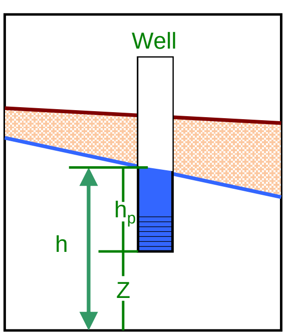
Most of the energy of groundwater at a particular location in an aquifer is derived from…

1. **Its ELEVATION.**

and…

2. **How much PRESSURE it is under.**

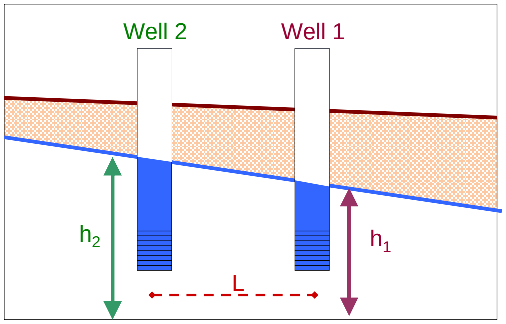
- Elevation and pressure head add up to total head.
- $\mathbf{h = z + h_p}$



Surface water generally flows downhill.

- **Groundwater flows from areas of HIGH head to areas of LOW head.**
- **This is analogous to surface water (e.g., rivers), which flows from areas of HIGH elevation to areas of LOW elevation.**

Horizontal Hydraulic Gradient

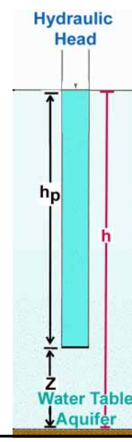


Confining Layers

- Aquitard = confining layer; a geologic unit that does not transmit very much water
- Confining layers are part of what keeps water in certain aquifers under a lot of pressure.
- Confining layers also protect some aquifers from being easily contaminated.

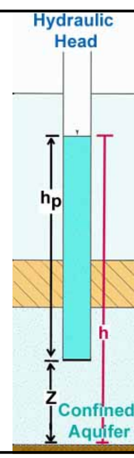
Unconfined Aquifers

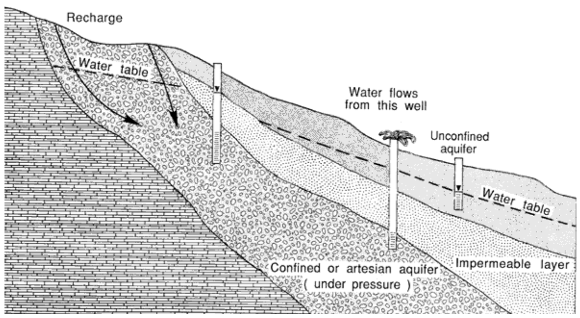
- Also called Water Table Aquifers
- Unconfined aquifers don't have any confining layer (e.g., clay or silt) on top.
- Wells that are open or "screened" in unconfined aquifers will have water levels that rise to the level of the water table.



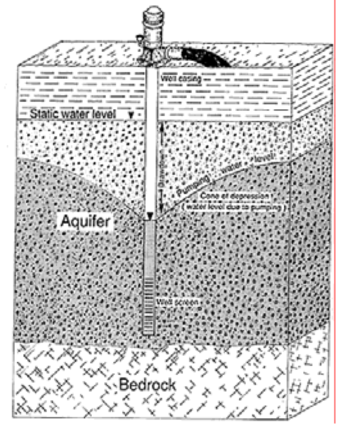
Confined Aquifers

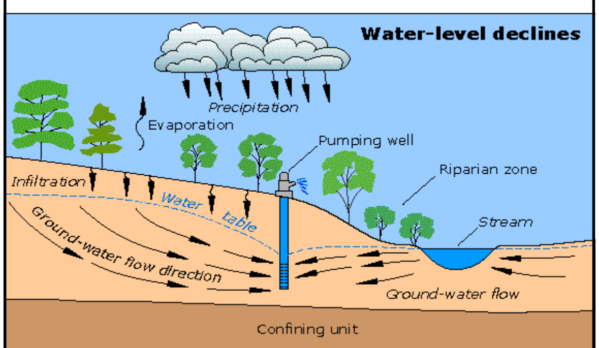
- Confined aquifers have a confining layer above them.
- The water in confined aquifers are under pressure (like the gases in a bottle of soda!)
- When you "screen" a well in a confined aquifer (after drilling through the confining layer), water will rise ABOVE the top of the aquifer



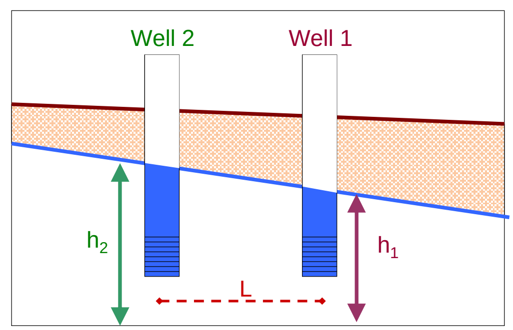


http://www.ianr.unl.edu/pubs/Water/g1128.htm#OCCOGRNDW





Horizontal Hydraulic Gradient



Hydraulic Gradient

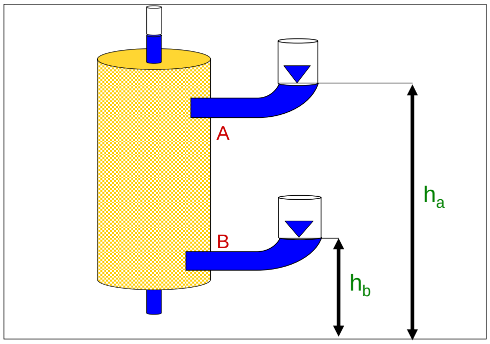
$= (h_2 – h_1) / L$

How much water? How fast does it flow? Darcy's Law

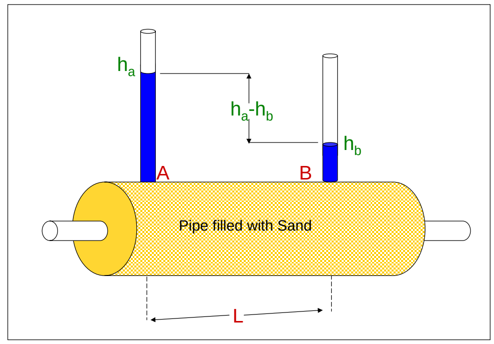
$Q = - K A \Delta h/L$

- Q = volumetric flux
- K = hydraulic conductivity
- A = cross-sectional area of flow
- Δ h = head difference from one location to another ($h_2 – h_1$)
- L = distance from one location to another
- Δ h/L = hydraulic gradient

Darcy's Experiment



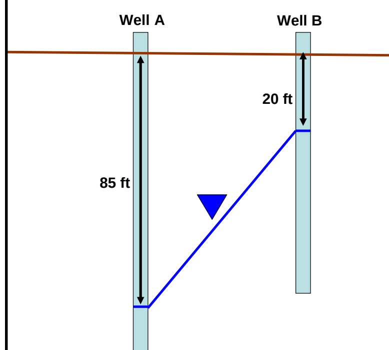
Darcy's Experiment



The Difference Between Water Elevation in a Well and "Depth to Water"

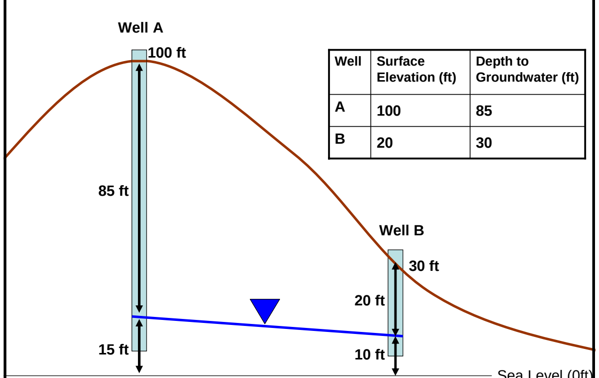
- If a site's land surface is FLAT, it's easy to interpret depth to water measurements and determine which well has the highest head. (Then flow directions can be determined.)
- If wells are located in a hilly area, it's important to know the land surface elevation at each well.

When the land surface is flat…



Well	Depth to Groundwater (ft)
A	85
B	20

When the land surface is not flat…



Well	Surface Elevation (ft)	Depth to Groundwater (ft)
A	100	85
B	20	30

In the field…

- Pump tests, conducted in the field, involve measuring Q and water levels in wells.
- After interpreting pump test results, we can calculate 2 aquifer parameters:
  1. T = Transmissivity
  2. S = Storativity

Transmissivity

- Transmissivity = K x b

  K = hydraulic conductivity

  b = saturated thickness of the aquifer

  For a confined aquifer, b = the thickness of the entire aquifer.

  For an unconfined aquifer, b = the thickness from the bottom of the aquifer unit, up to the water table, which may vary from day to day.

Storativity

- Storativity (S) has to do with how much water you get out of a well when you lower the head (i.e. the water level) in an aquifer.
- S is bigger for unconfined aquifers than for confined aquifers

Aquifer Type:	Unconfined Aquifer	Confined Aquifer
Typical range of S:	0.1 – 0.3	10^{-5} – 10^{-3}

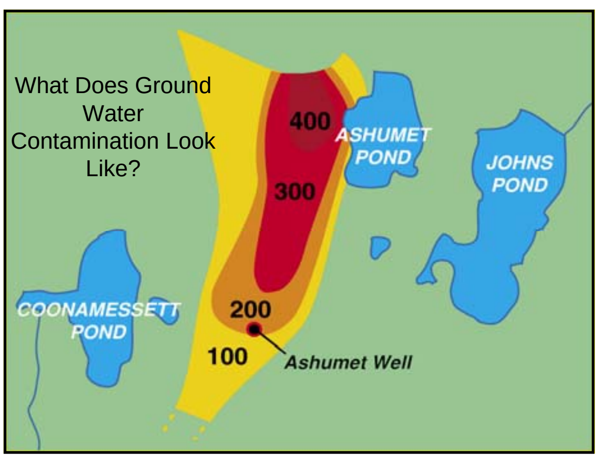
Who cares? What's so important about storativity?

1. Since S is one of the results of a pump test analysis, looking at S data is a quick and easy way of telling if an aquifer is confined or unconfined.
2. A high S means you won't have to use a lot of pump power to get water out of an aquifer.

So which kind of aquifer is "better" – confined or unconfined?

Unconfined aquifers do have high S's, which make them sound preferable.

But… confined aquifers are more protected from contamination. Their water quality tends to be better.



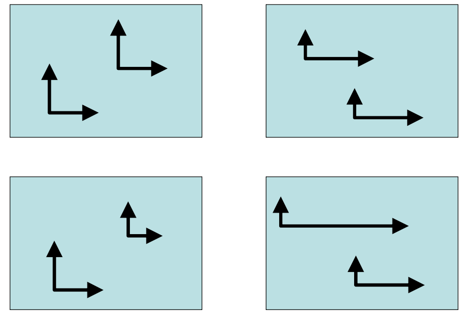
A few more terms…

- Recharge = the way in which water enters an aquifer (e.g., precipitation and infiltration; injection through wells; infiltration from streams)
- Boundaries = the edges, top, and bottom of an aquifer (e.g., rivers, solid rock/ impermeable boundaries)

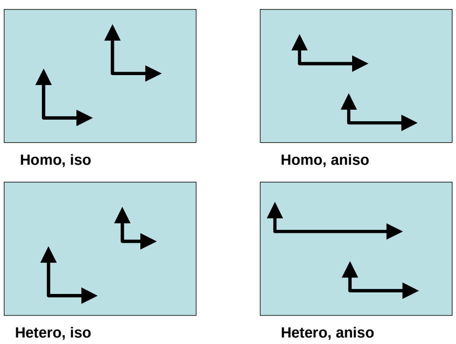
Variations in Space

- **The natural world is very complex**
  - **Not every point in an aquifer has the same K**
- **We can describe that complexity in two ways**
- **Heterogeneity = Variations in space (comparing one location to another)**
- **Anisotropy = Variations with directions (standing at one location, water will flow faster in one direction in comparison to another direction)**
  - **For example, this may be caused by small layers of clay that make it difficult for water to flow up or down, but allow horizontal flow**

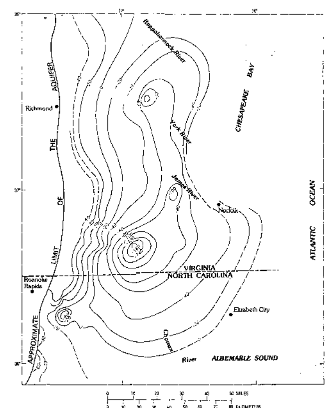
Heterogeneity and Anisotropy



Heterogeneity and Anisotropy



Water Level Contours



What about fractured rock aquifers???

- Very complex systems
  - standard ground water flow equations may not be applicable
  - difficult to predict flow direction and velocities
- Most of the flow is through the fractures
  - pores may be present
  - pores may not be well-connected
- Very rapid flow is possible

So what is the hydraulic conductivity (K) of fractured rock aquifers??

- Varies widely
- For example, at one site in New England groundwater flows through fractured rock at 9-16 ft/day (comparable to a well-sorted gravel or sand aquifer)
- Velocities can be even faster
- Implication: Fractures can provide a means for dangerous pathogens and other contaminants to quickly enter drinking water supplies.