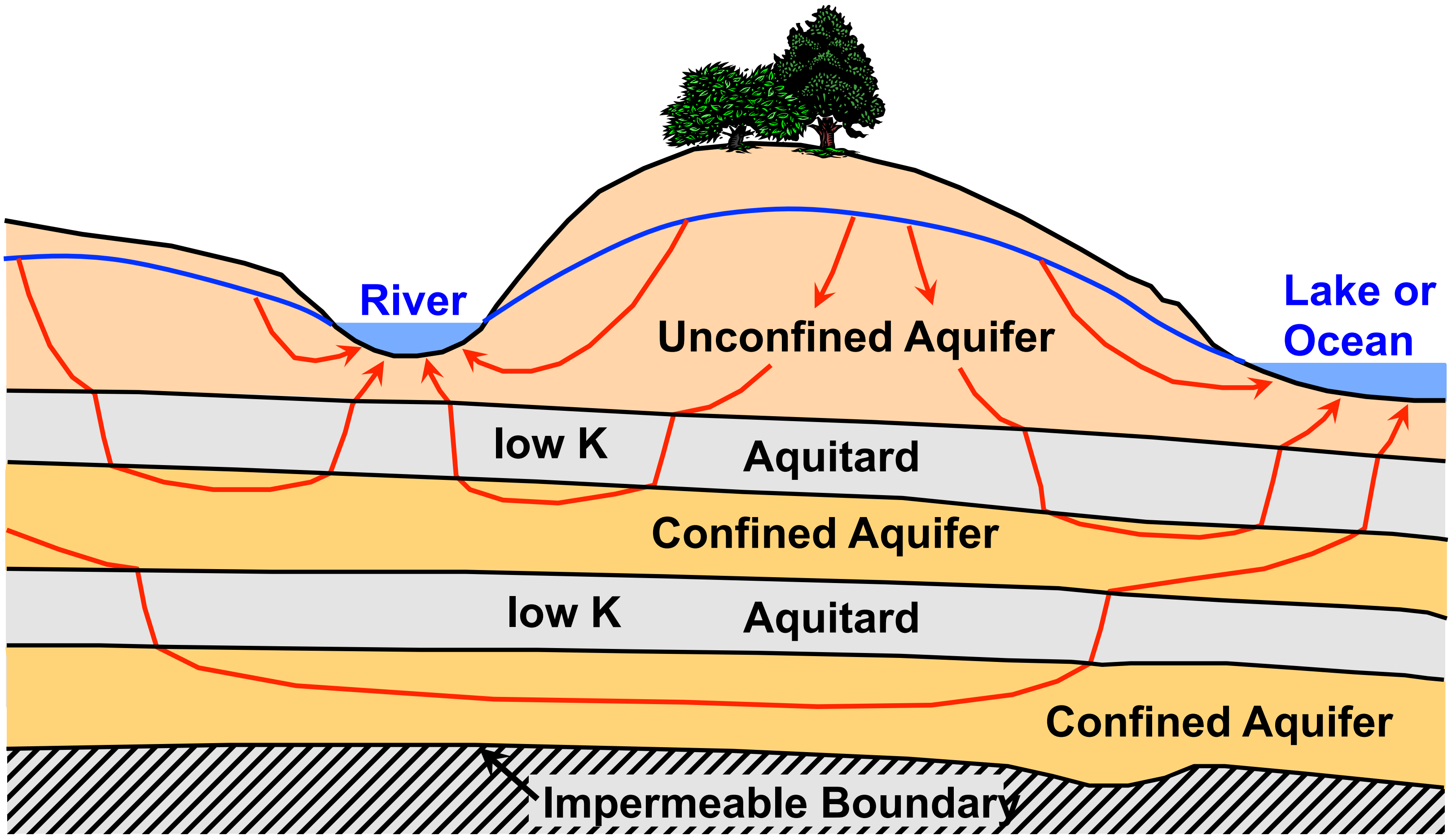
Hydrogeologic Properties and Mechanisms of Groundwater Flow

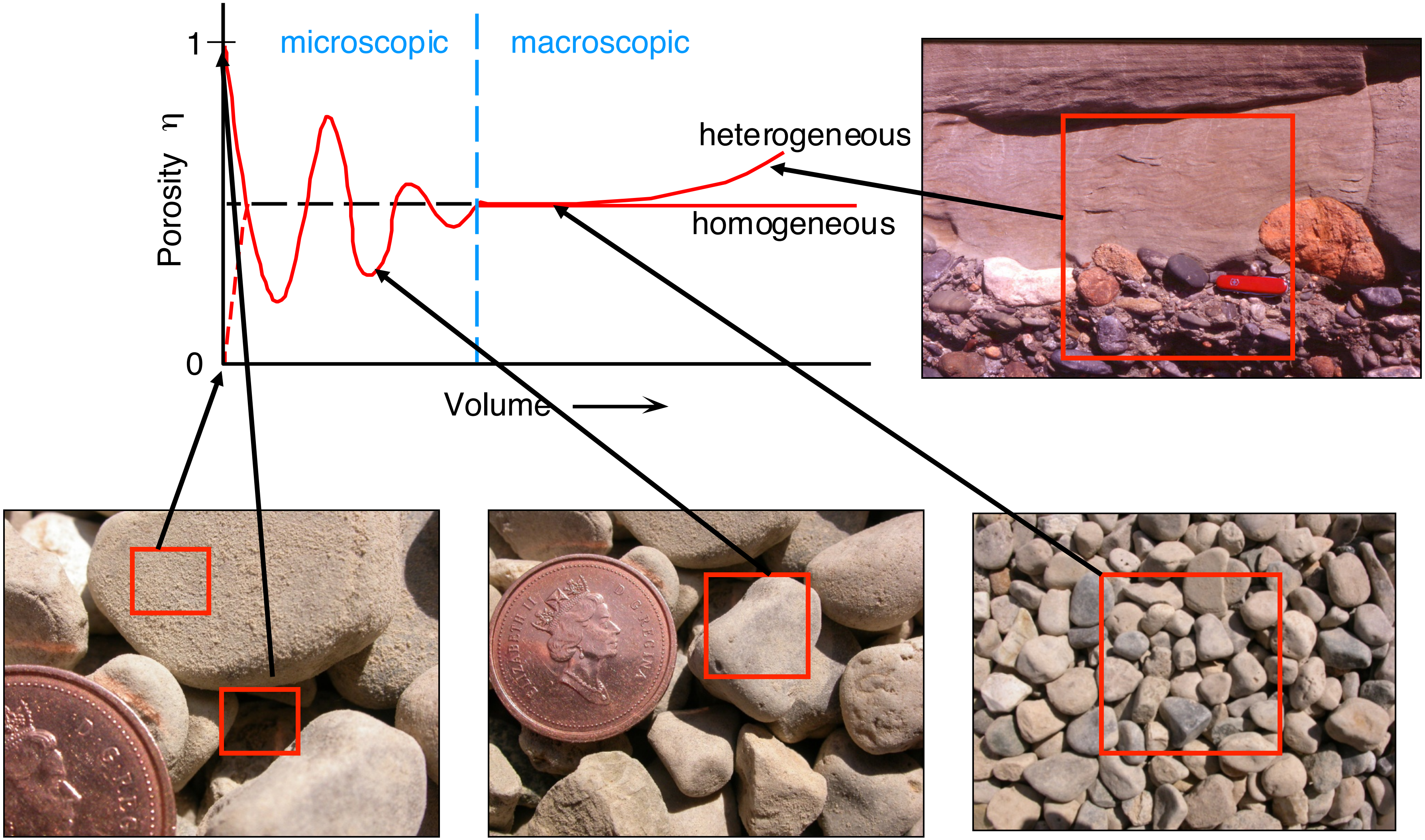


Hydrogeologic Properties and Concepts (Part 1)

- porosity and void ratio
- fluid potential, hydraulic head and potentiometric surfaces
- equipotential lines and hydraulic gradients
- groundwater flow

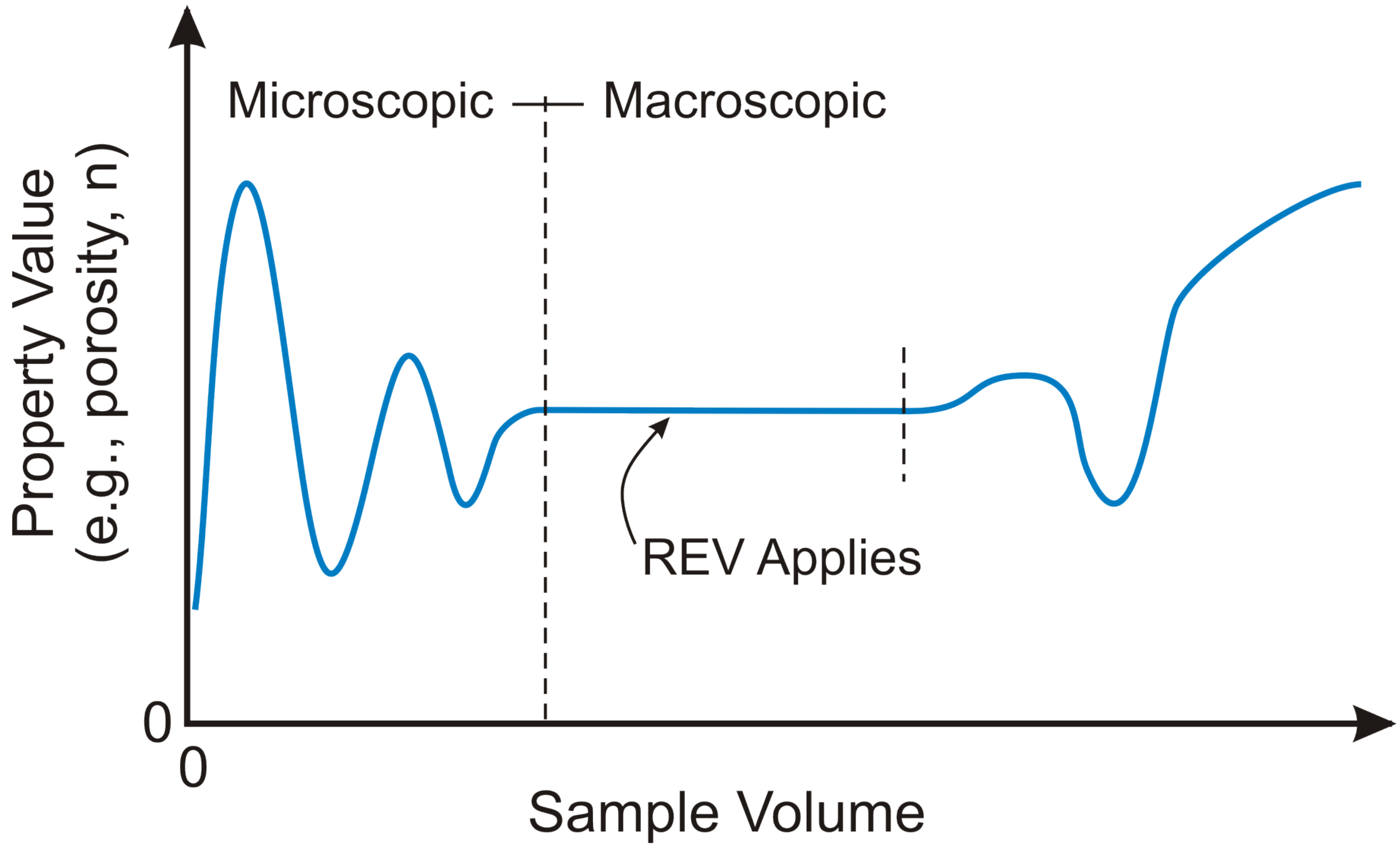
Recommended Readings: Schwartz and Zhang Chapter 3

Representative Elemental Volume (REV)



B. Conant

Property values change depending on the scale of measurement. This is a critical concept that allows us to describe and quantify field-scale observations.



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Grain Sizes

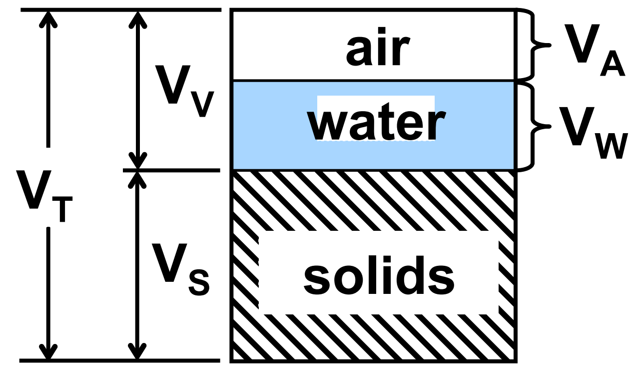
Photos by B. Conant

Porous media has three phases.

Let M = mass (kg)

V = volume (m^3)

$$M_{total} = M_{solid} + M_{water}$$
$$V_{total} = V_{solid} + V_{water} + V_{air}$$



$$\text{Porosity, n} = \frac{\text{Volume of Voids}}{\text{Total Volume}} = \frac{V_V}{V_T}$$

$$\text{Void Ratio, e} = \frac{\text{Volume of Voids}}{\text{Volume of Solids}} = \frac{V_V}{V_S}$$

What are the units of porosity?

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For partially saturated materials we characterize the "wetness" of the sediments.

$$\text{Volumetric Water Content, } \theta = \frac{V_W}{V_T}$$

$$\text{Water Saturation, } S_W = \frac{V_W}{V_V} = \frac{\theta}{n}$$

We can also characterize the density of the sediments.

$$\text{Dry Bulk Density} = \rho_B = \frac{M_S}{V_T}$$

units???

$$\text{Solid Particle Density} = \rho_S = \frac{M_S}{V_S}$$

For most geological materials,

ρ_S **= 2500-3000 kg/m^3 (or 2.5-3.0 g/cm^3)**

Since ρ_S is relatively constant for most materials, we can estimate n given ρ_B (or vice versa). You should be able to derive this n- ρ_S - ρ_B relationship.

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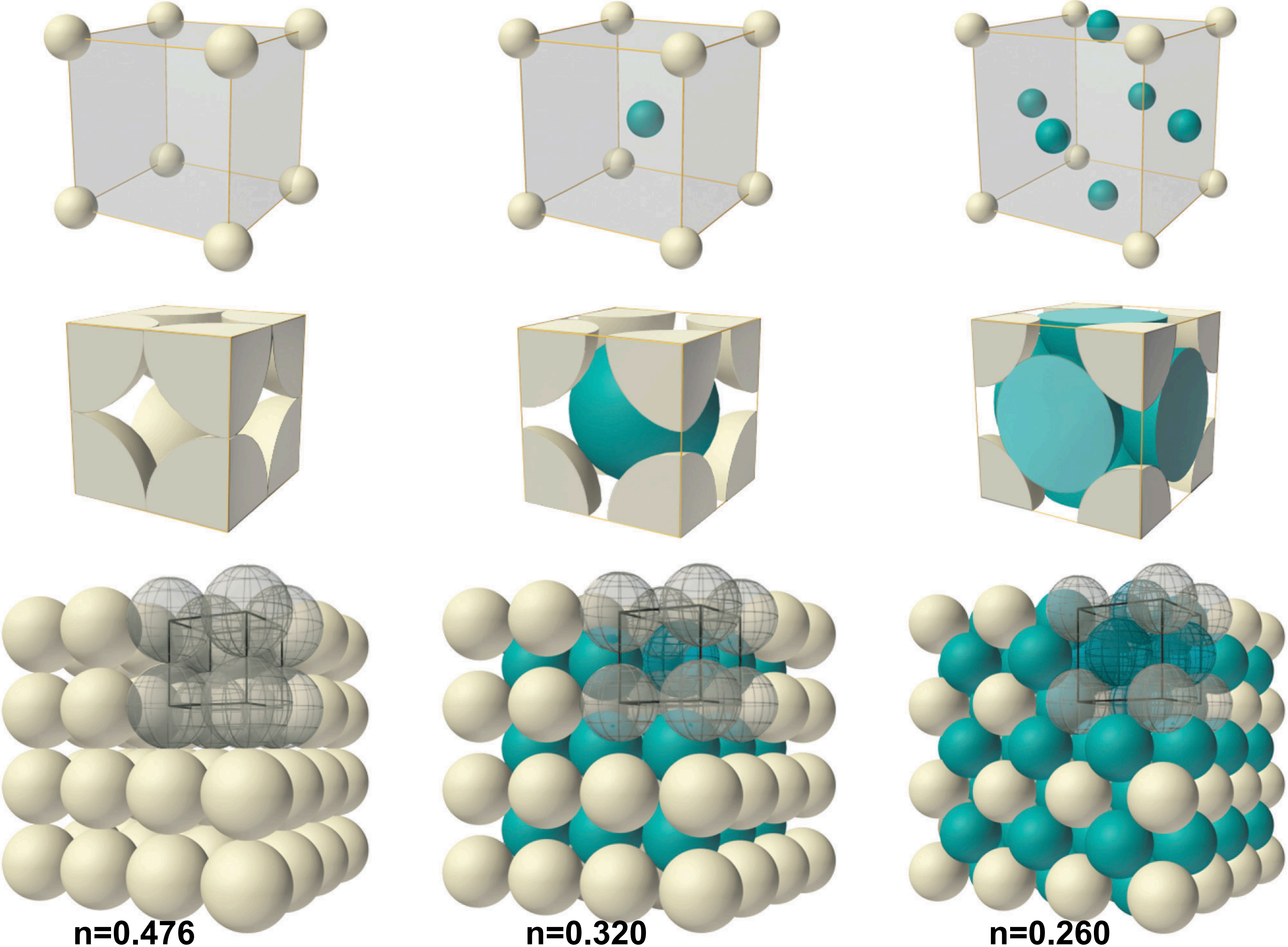
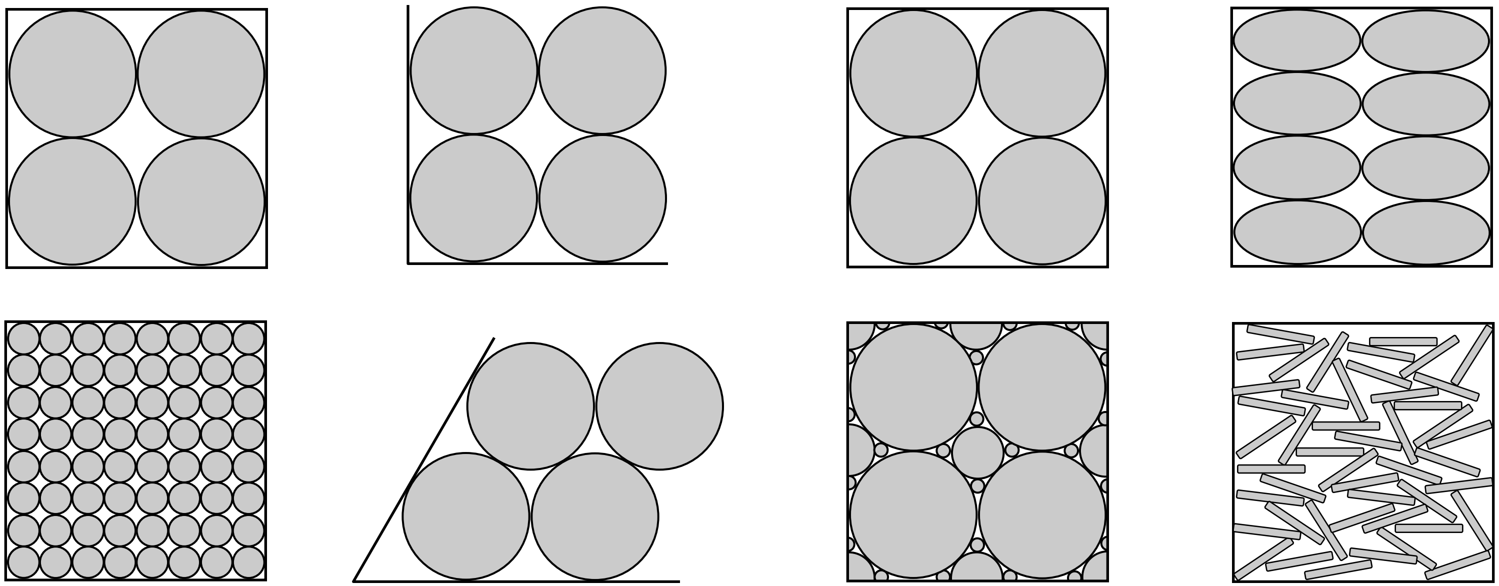


(a) Simple cubic (b) Body-centered cubic (c) Face-centered cubic

What controls the porosity of unconsolidated sediments?

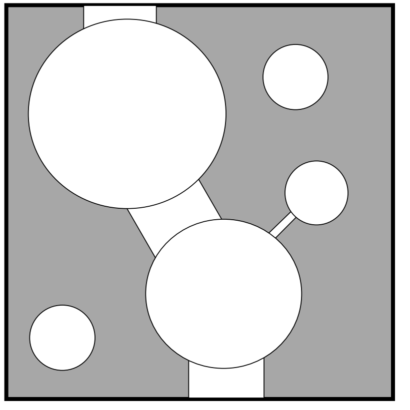


Factors:

- **packing**
- **grain size distribution or sorting**
- **grain shape (angularity/roundness)**
- **grain orientation (arrangement of particles)**

Effective Porosity

Disconnected pores (e.g., consolidated rocks) will not contribute to flow or storage of groundwater. The interconnected pores that control groundwater flow are termed effective porosity, n_e.



Even small connected pore "throats" may not effectively transmit water. If the pore throat has a very small diameter, large molecules may not pass through the pore throat, and the "dead-end" pore may not be accessible to some dissolved species.

For clay-rich sediments, n_e may be significantly smaller than the total porosity (n).

Range of typical porosity values.

Material	**n (%)**	**n_e (%)**
Sand and gravel	25-45	25-45
Silt and clay	30-60	<1-60
Till	20-40	1-40
Sandstone	5-30	0.5-10
Siltstone	20-40	0.5-15
Limestone	0-20	0.1-5
Crystalline rocks (granite)	0-10	0-0.05

Fluid Potential & Hydraulic Head

- The **fluid potential** is a measure of mechanical energy at a given point *P*

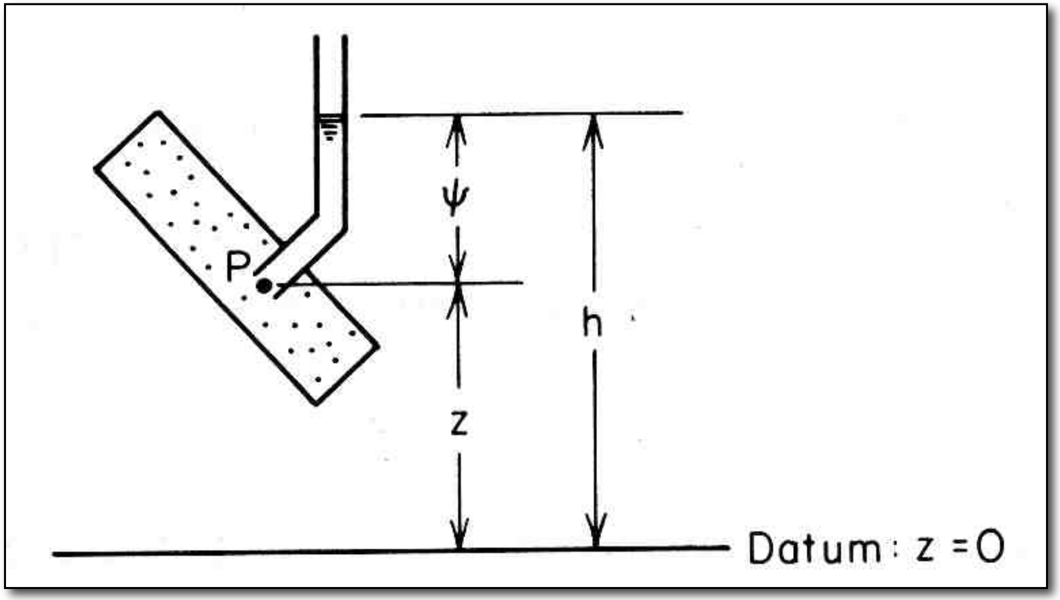


Figure 2.4: Freeze and Cherry (1979)

- Flow occurs from areas of high potential to areas of low potential
- The potential gradient or **hydraulic gradient** is the driving force for flow

Review of Energy Principles

Potential measures the capacity of a unit mass of fluid to do work. Work is done when a force is applied to a fluid to move it a certain distance.

Potential comes in many forms:

1. **Gravitational**
2. **Pressure**
3. **Kinetic**
4. **Thermal**
5. **Electrical**
6. **Osmotic**
7. **Others…**

$$\mathrm{h} = \text{hydraulic head} = z + \frac{P}{\rho g} + \frac{v^2}{2g}$$ **Bernoulli's Equation**

Groundwater velocities are very small, and hence the kinetic term is almost always negligible. This gives the standard equation for hydraulic head,

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

where we define $\psi = P/\rho g$

Hydraulic head = Elevation + Pressure head

h = z + ψ

Hydraulic Head (h)

- A measurable physical quantity involving:

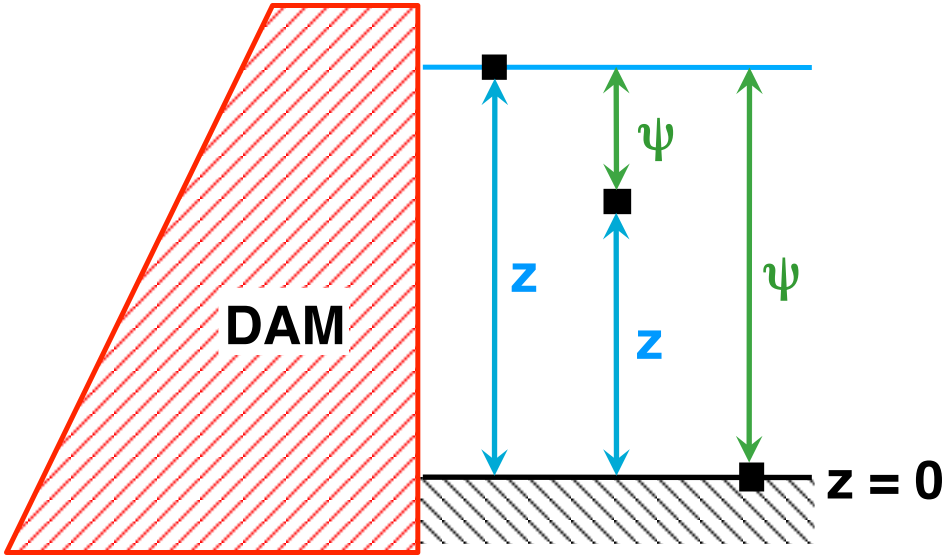
  1) Elevation – z

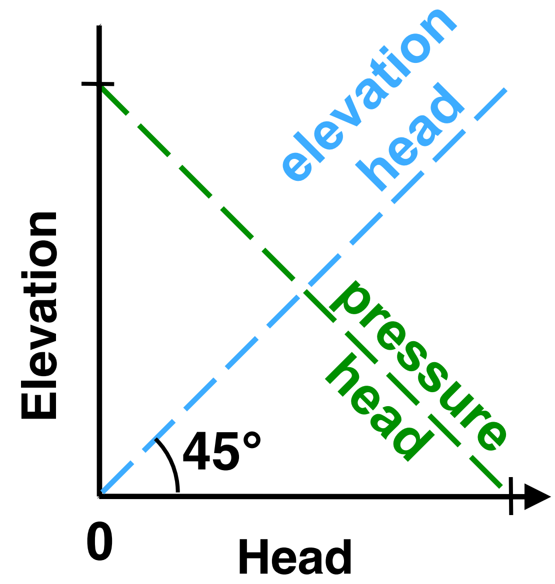
  2) Fluid Pressure – P or Ψ

$$\boxed{h = z + \Psi}$$

Graphical representation of heads for the case of a static water column in a reservoir.

$$h = z + \psi$$





What is the total hydraulic head in the system?

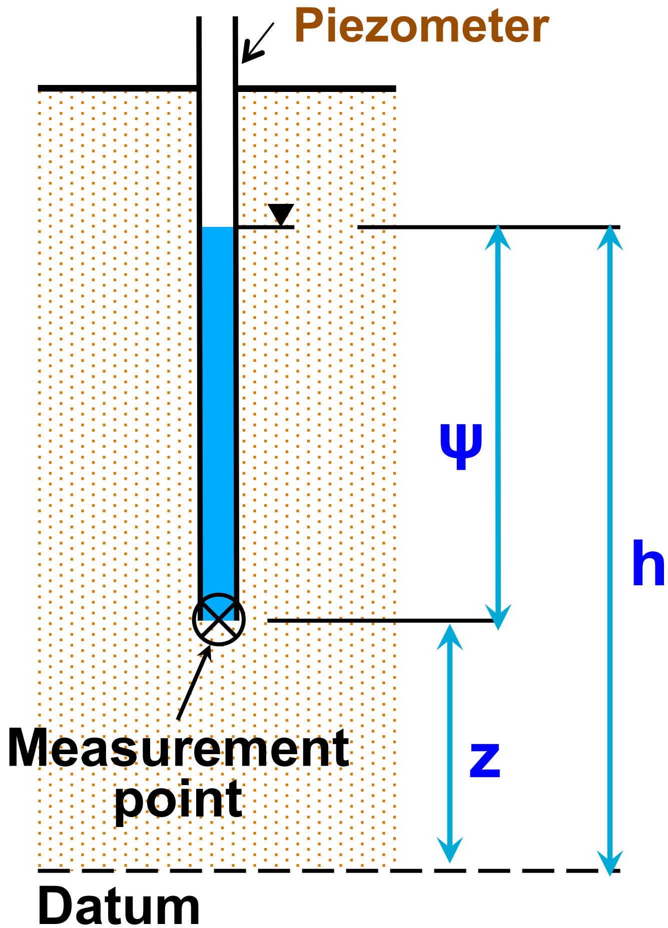
What does this all mean in practical terms?

Consider the water level measured in a well or piezometer.

h = hydraulic head at a point is the elevation of the top of the static water column above the point (relative to the datum)

z = elevation of the point above the selected datum

ψ = height of the water column above the point



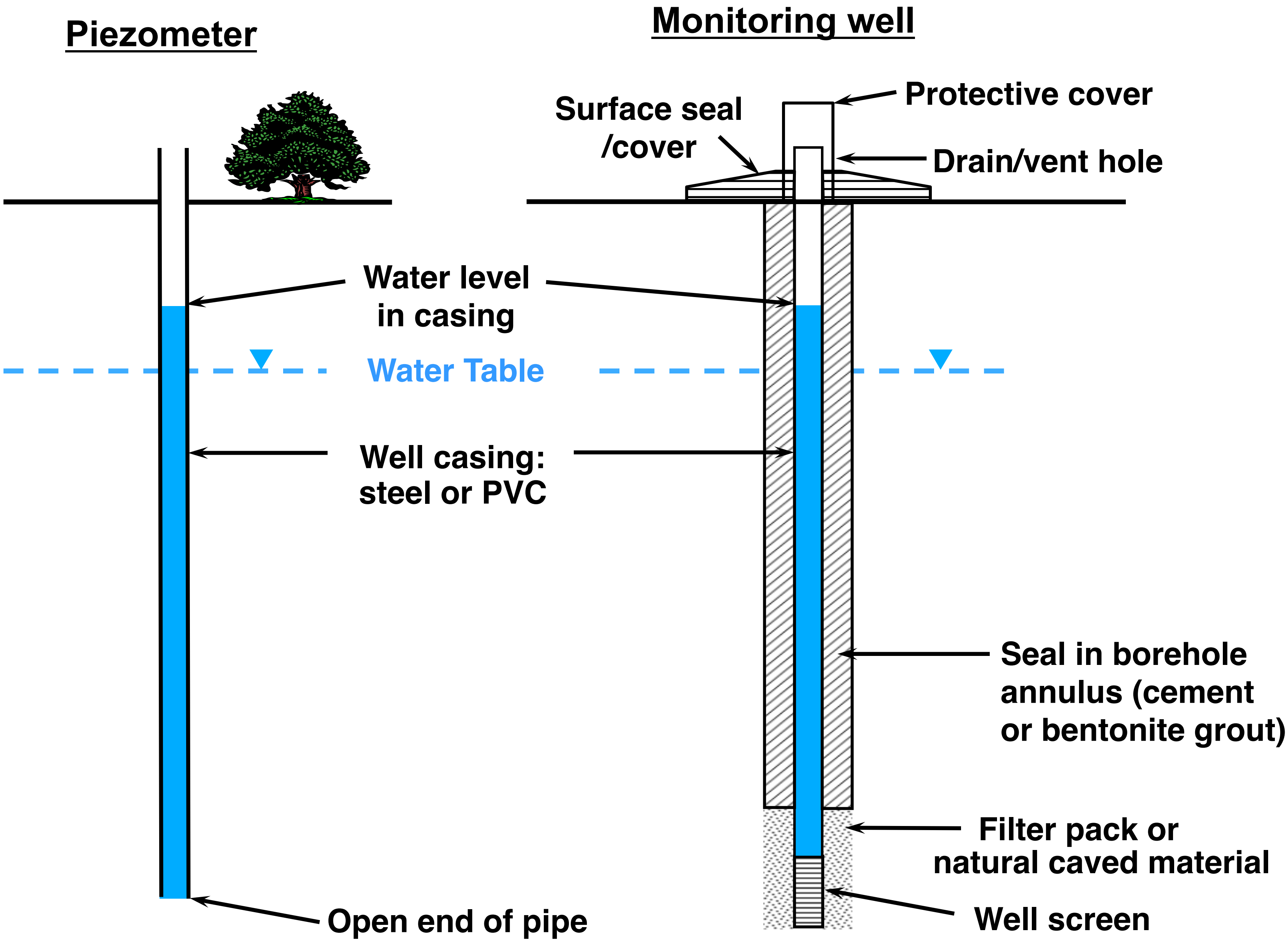
Piezometer - ***any device used to measure hydraulic (or piezometric) head at a point in a groundwater system***

Types of piezometers:

- ***open standpipes***
- ***any type of well***
- ***drivepoints***
- ***pressure transducer (vibrating wire)***

A well is the most common type of piezometer. Typically consists of a pipe (or casing) terminating with an open interval or screen at the measurement point. The water level inside the pipe is the hydraulic head for the open interval.

Why are they different?



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PVC pipe for well casing

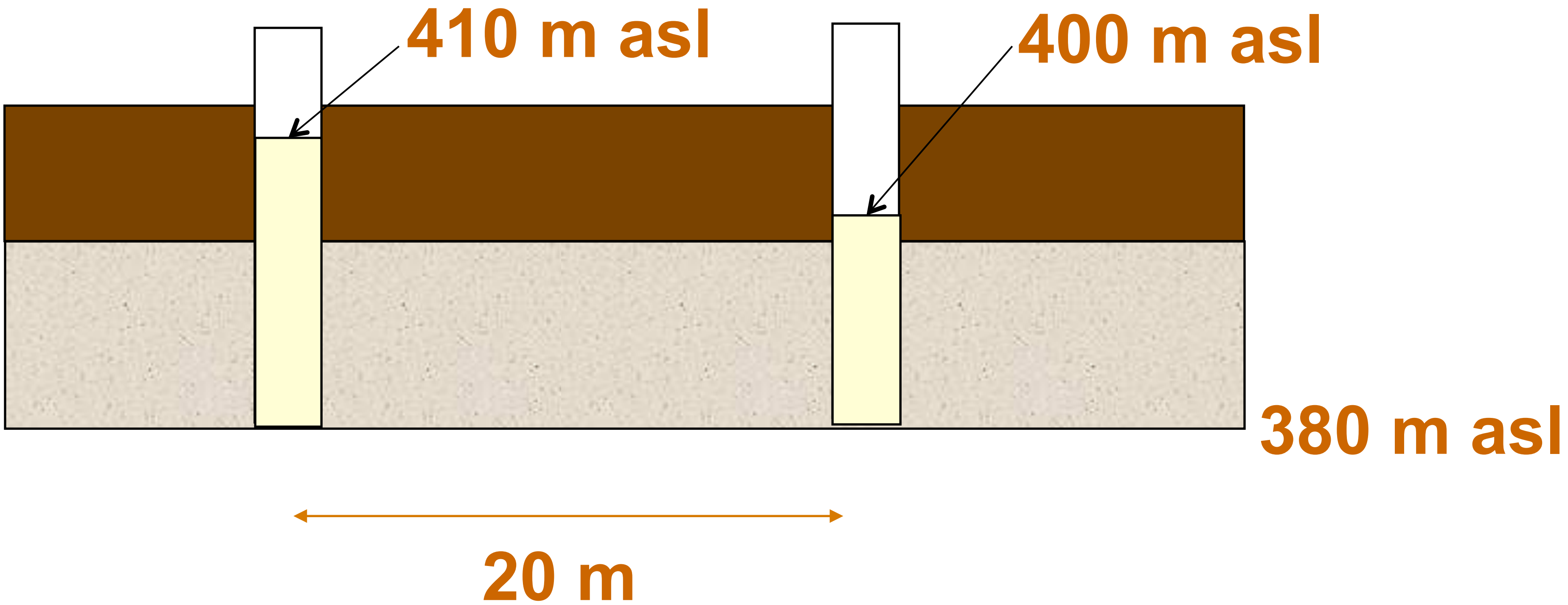
PVC casing installed in borehole

Evaluating Groundwater Flow on a Regional Basis

- To determine the rate and direction of groundwater flow regionally, piezometers can be installed at various locations in the aquifer so that hydraulic head gradients can be measured.

Hydraulic Head Gradient

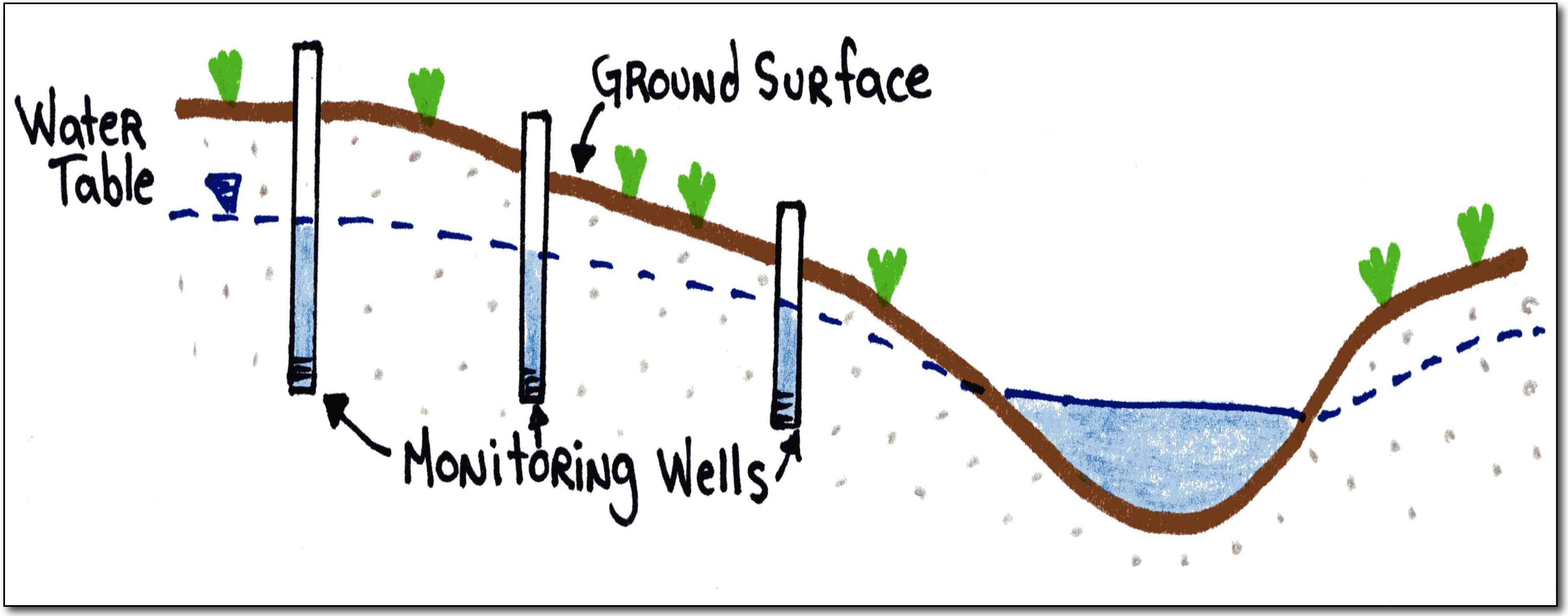
- *change in hydraulic head over distance*



How do we calculate this?

Lateral or Horizontal Flow

a) Cross-Section

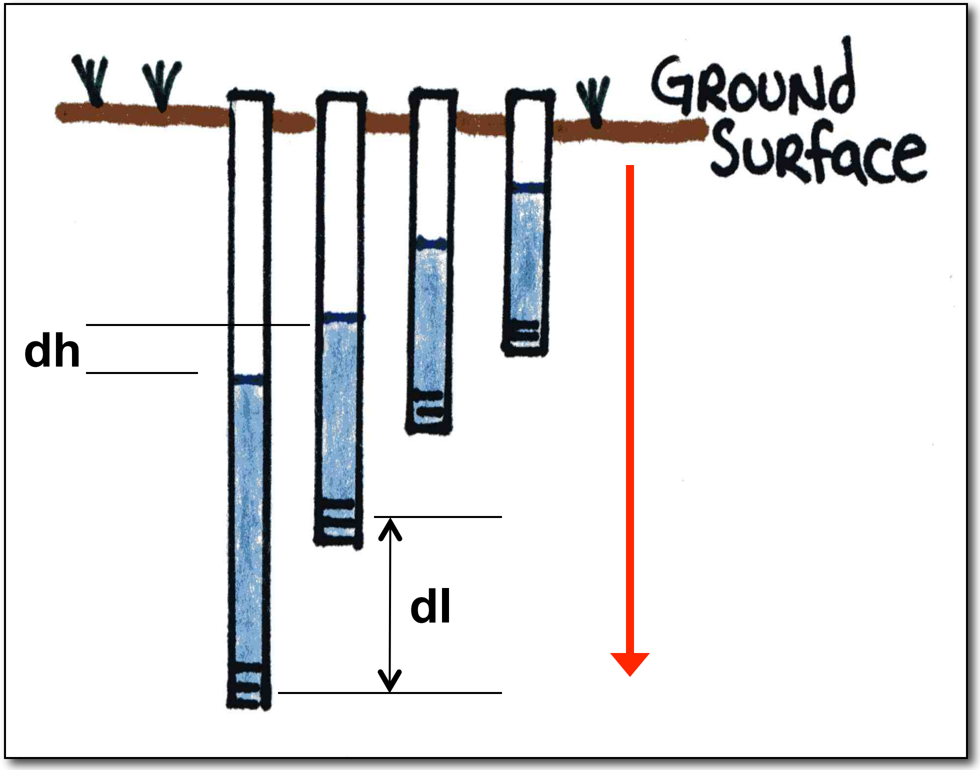


- **Piezometers installed along a cross-section in a study area can be used to determine the direction of groundwater flow**

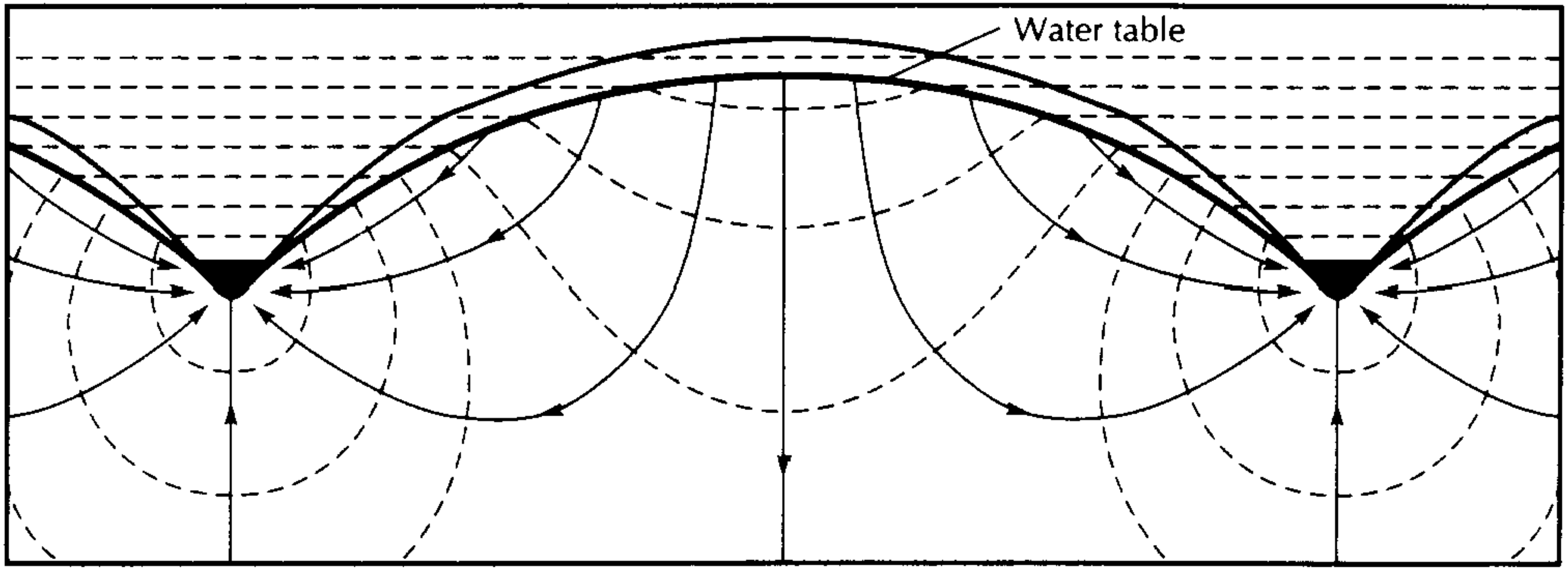
Piezometer nest - several piezometers at the same location but with their open ends at different elevations (depths) in the subsurface.

Vertical Flow

- Piezometers can be installed at various levels at a single location to measure the vertical hydraulic gradient



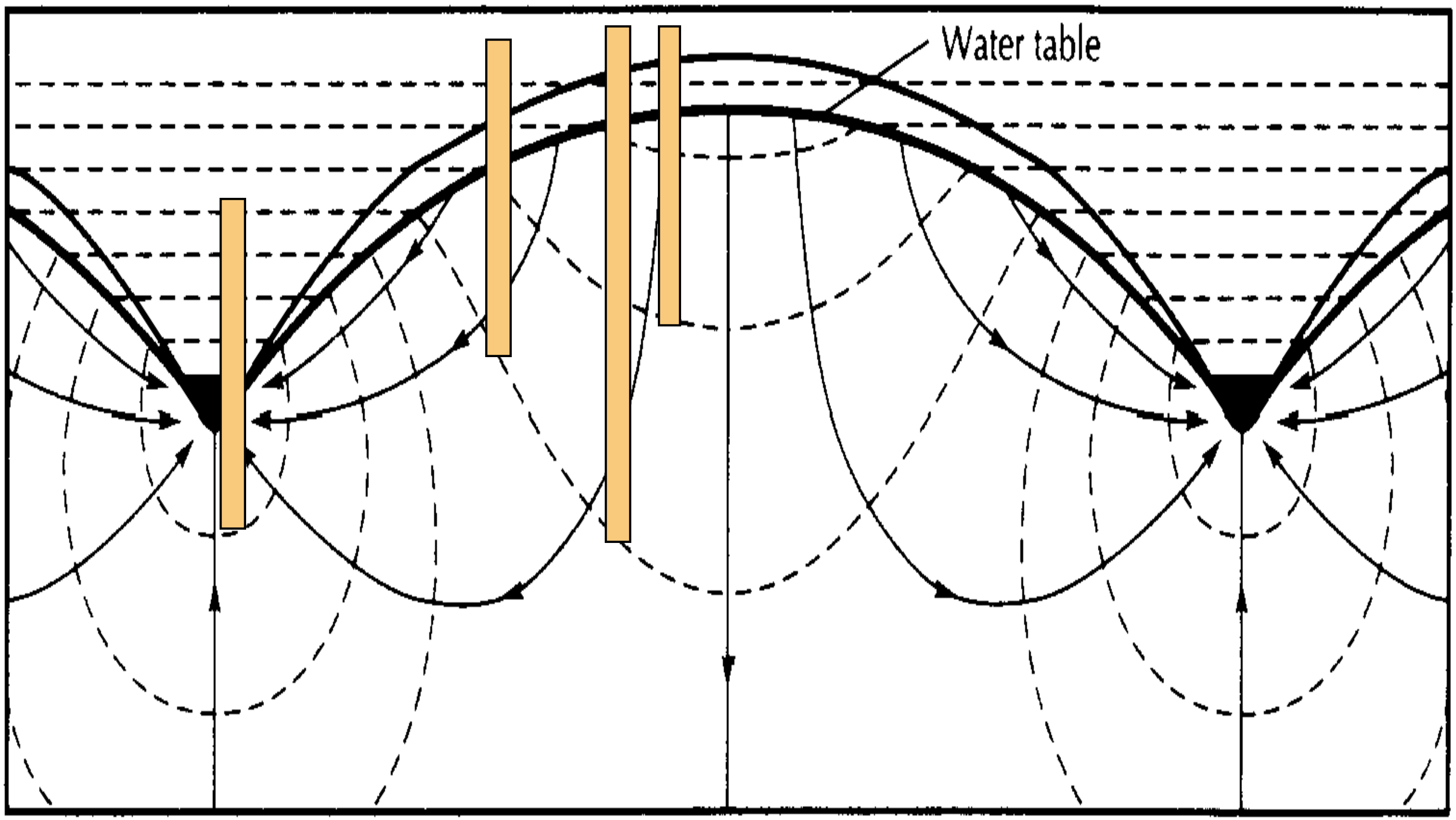
Effect of Topography on Groundwater Flow



Equipotential Lines (Total Head)

Flow Lines

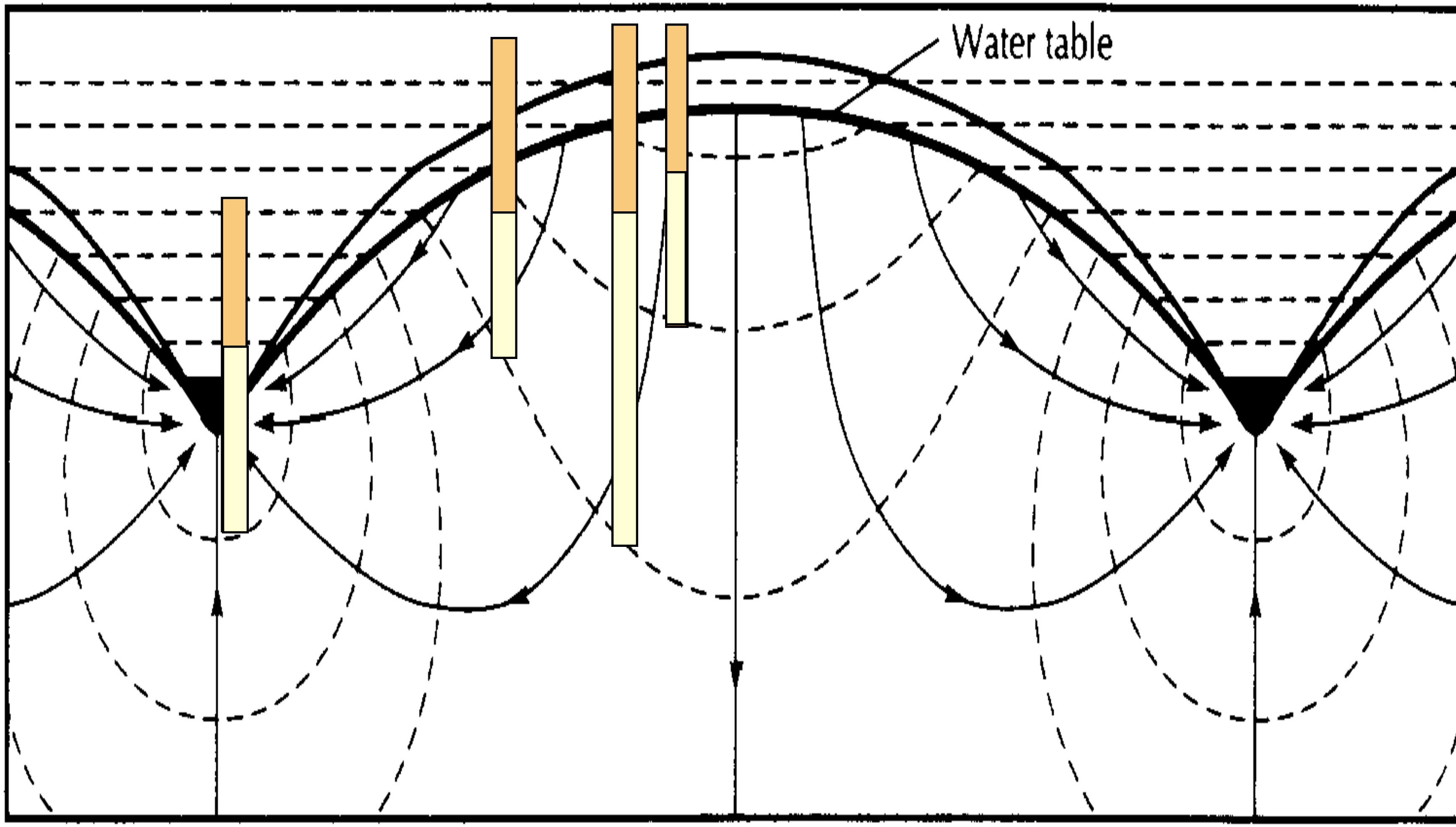
Water Levels in Piezometers?



Fetter, 2001.

G. Parkin

Water Levels in Piezometers?



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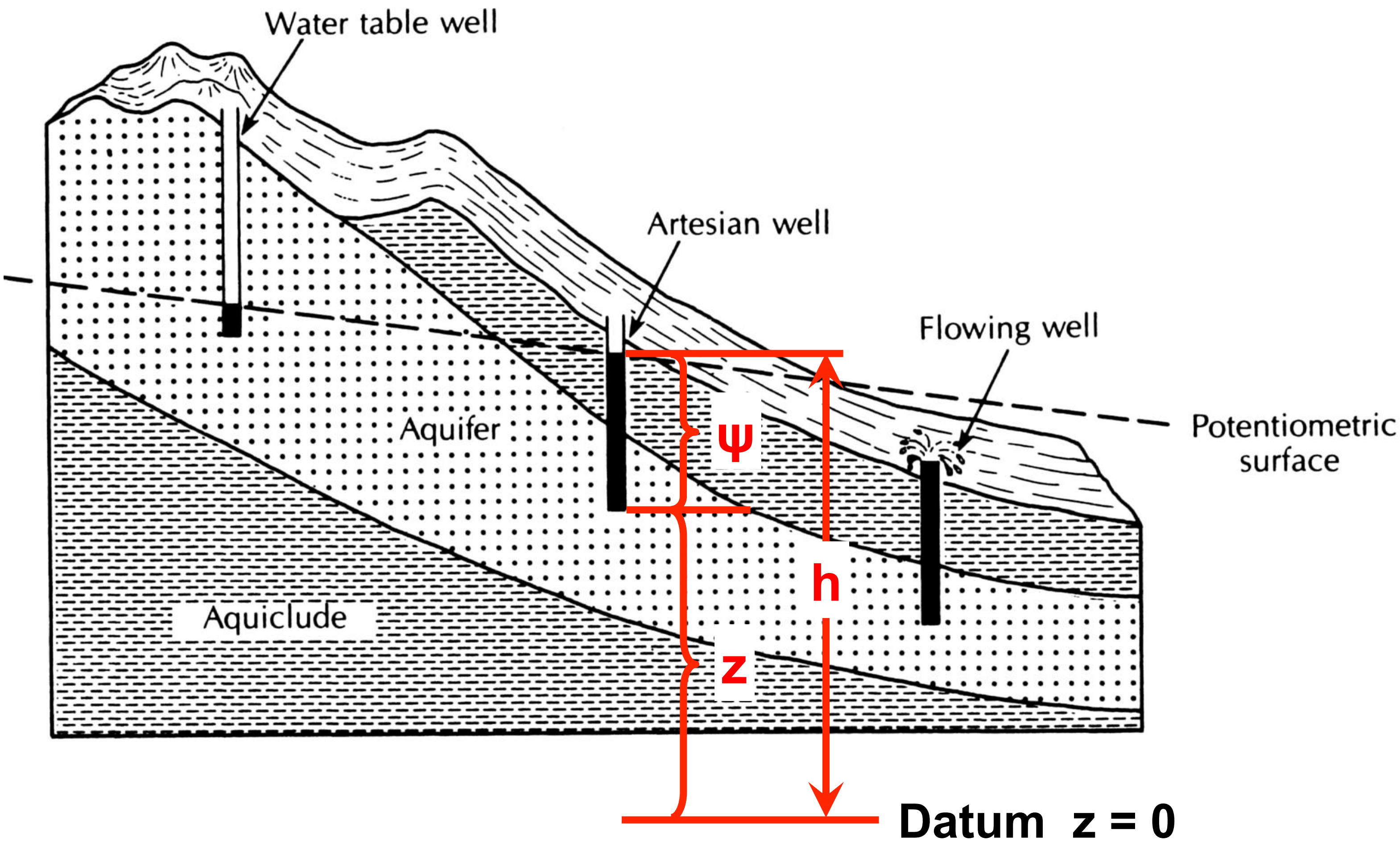
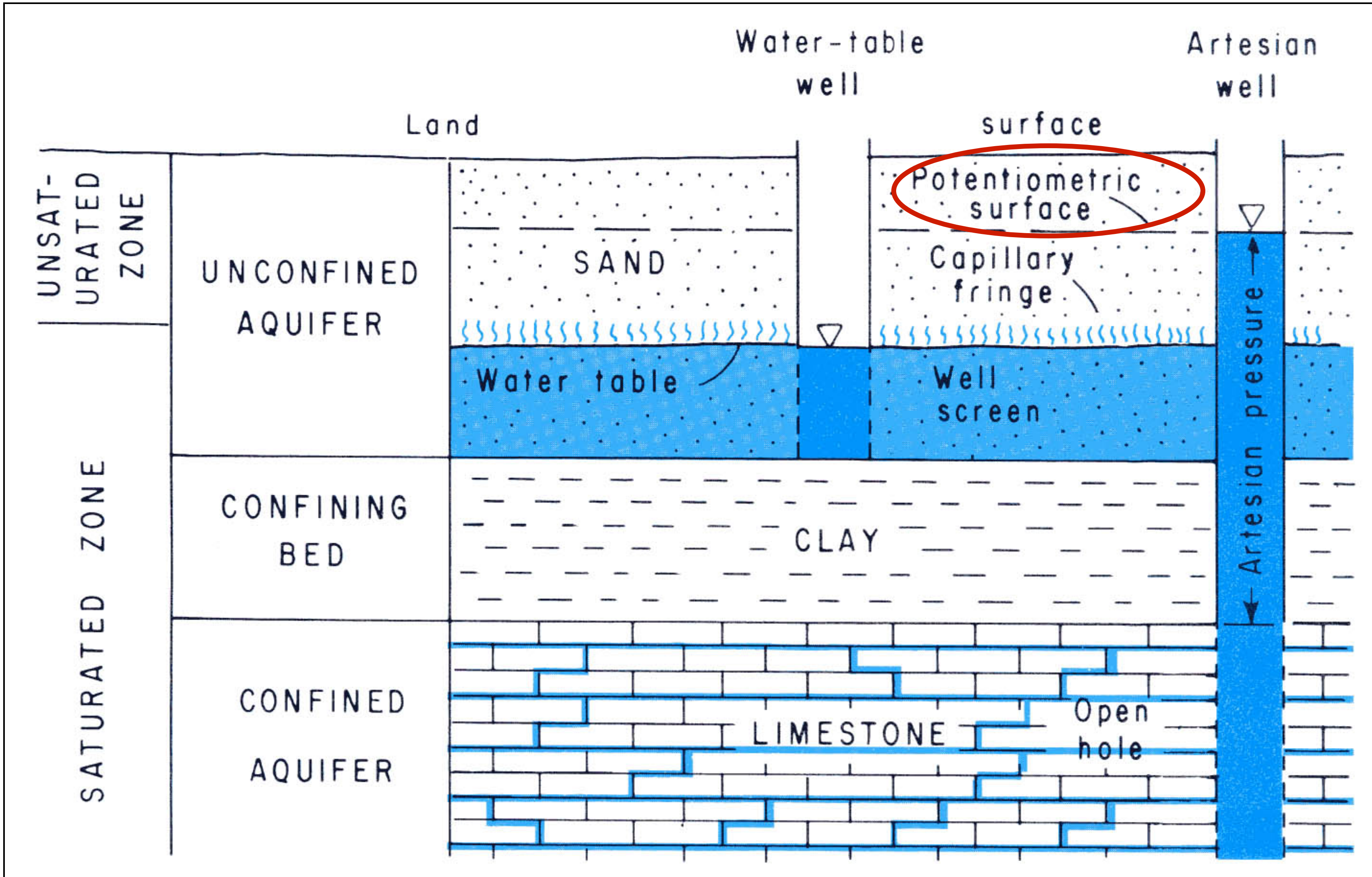


Wells measuring hydraulic head in a confined aquifer.
(Fetter, 2001)

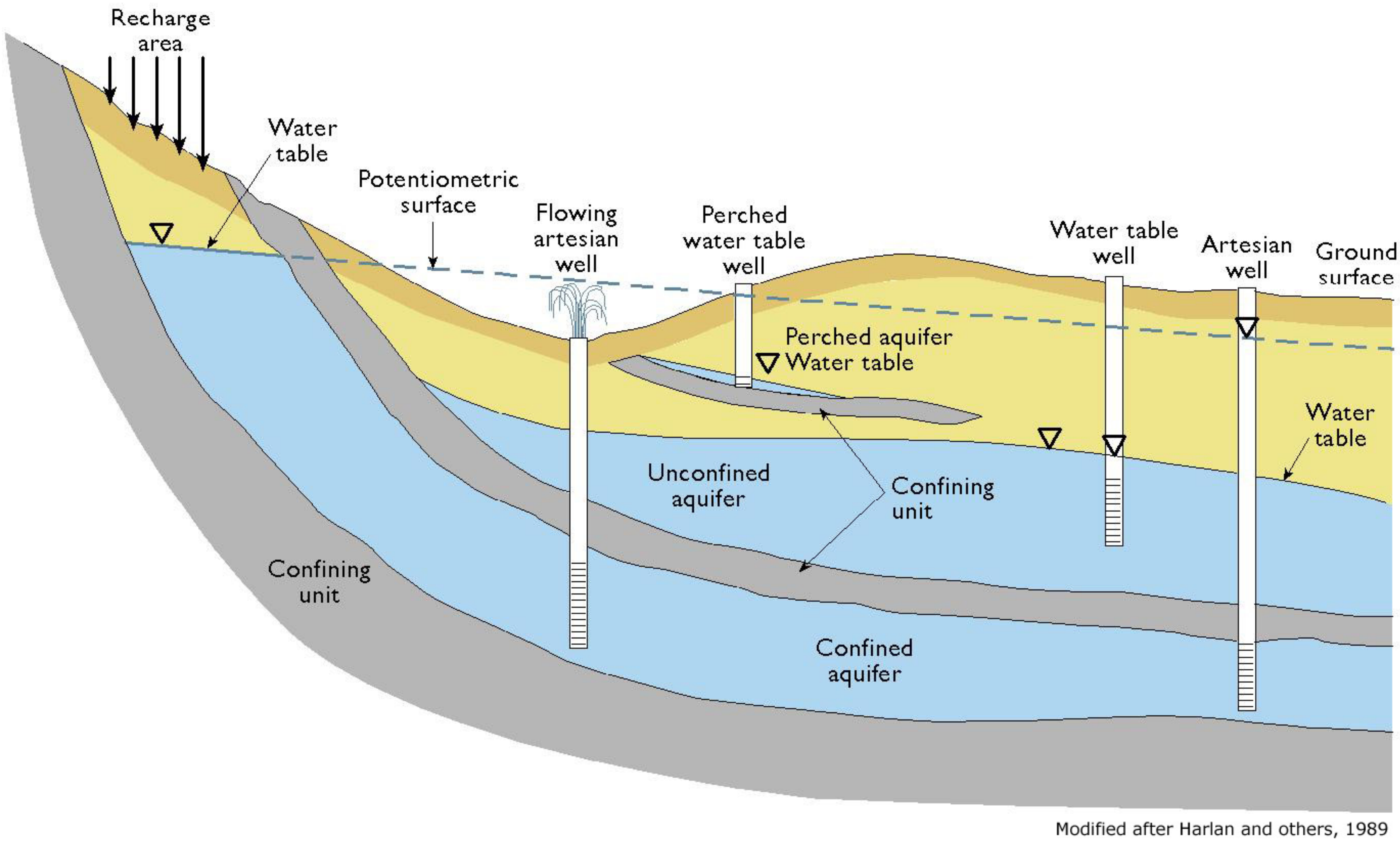
Water Table vs. Potentiometric Surface



Which direction is groundwater flow?

USGS Water Supply Paper 2220 (1987)

Schematic of different aquifer types



(http://geosurvey.state.co.us/wateratlas/images/fig2_3hi.jpg)

Note from the previous figure that water levels (and thus hydraulic head) can rise above the surface of the ground.

This is termed a *flowing artesian condition*.

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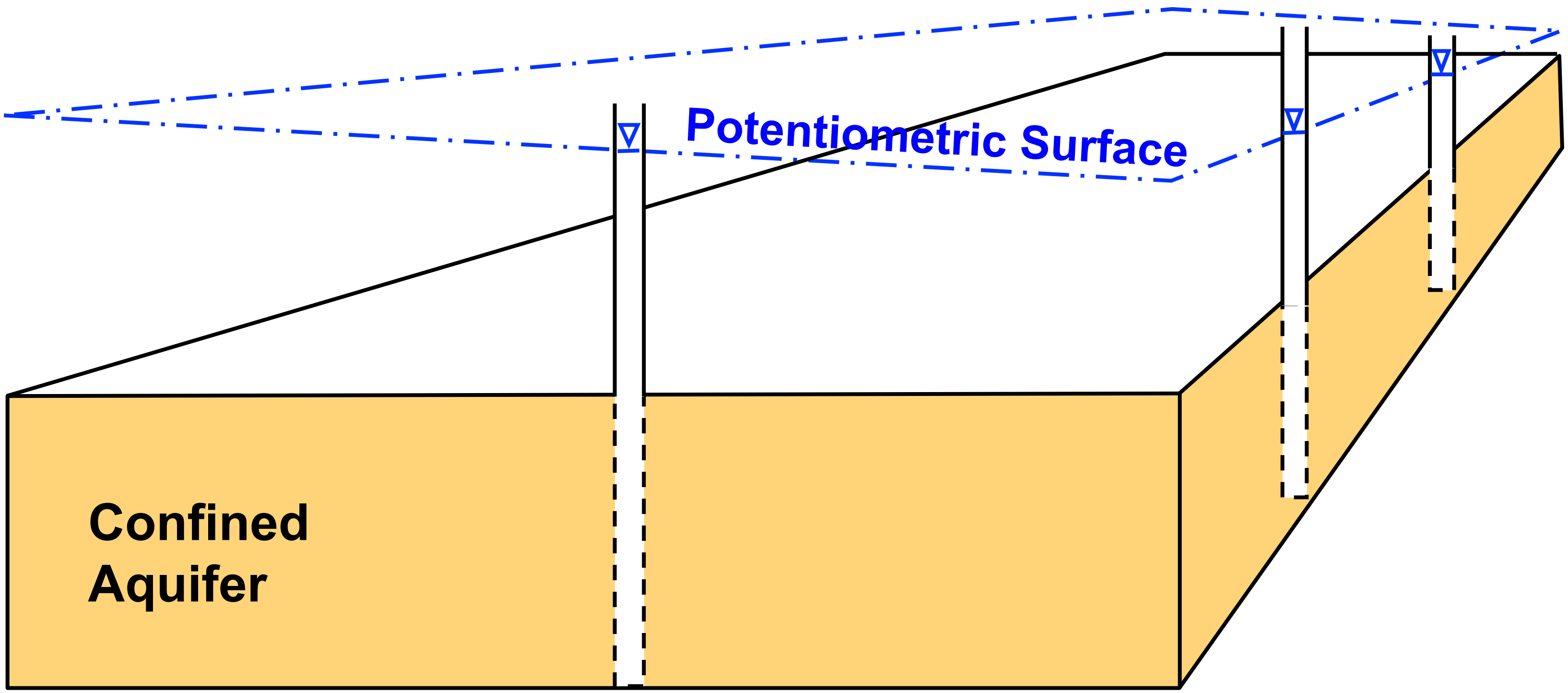
Remember that the water table and potentiometric surface are 3D surfaces. They are typically shown in cross-section or plan view.



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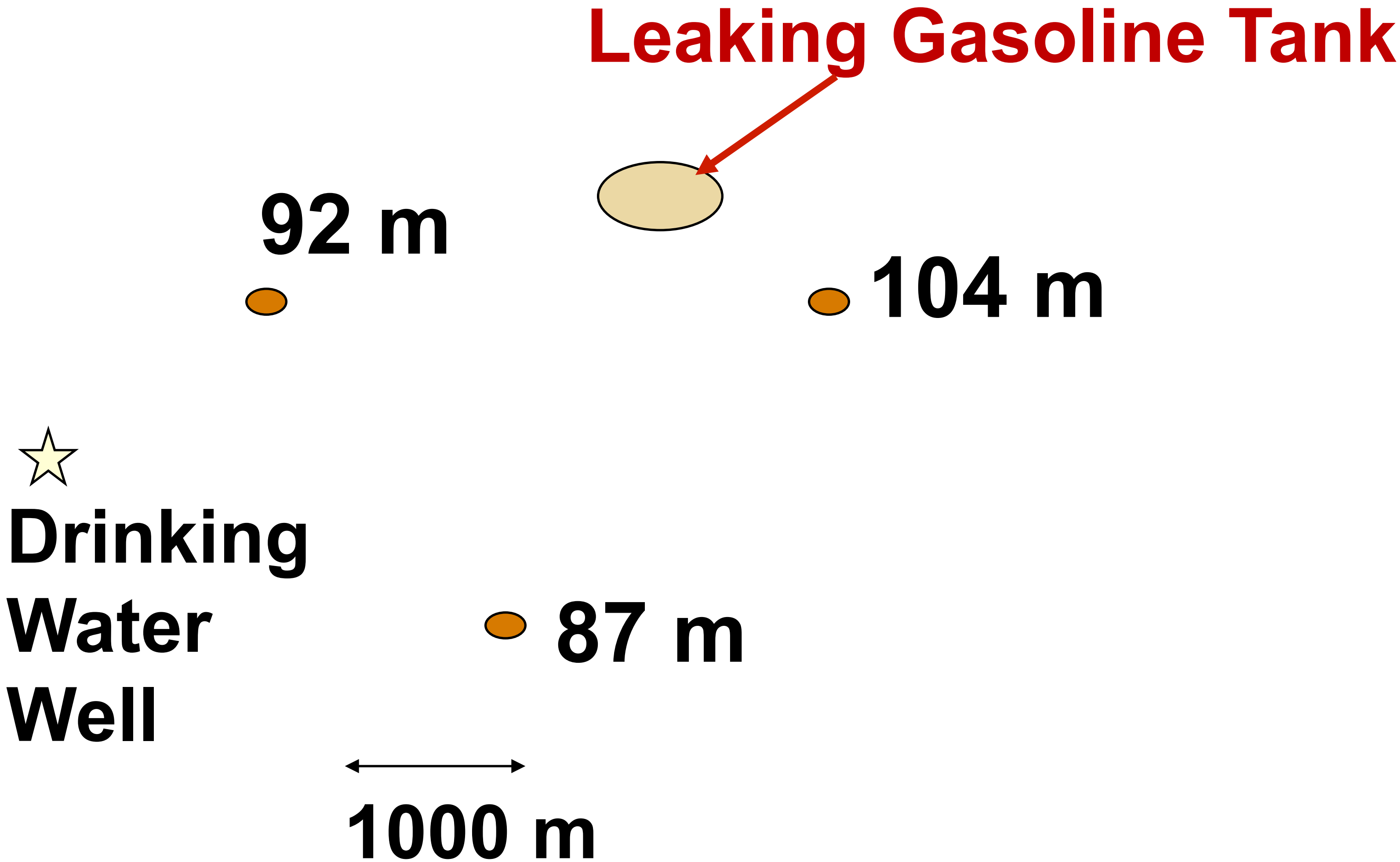
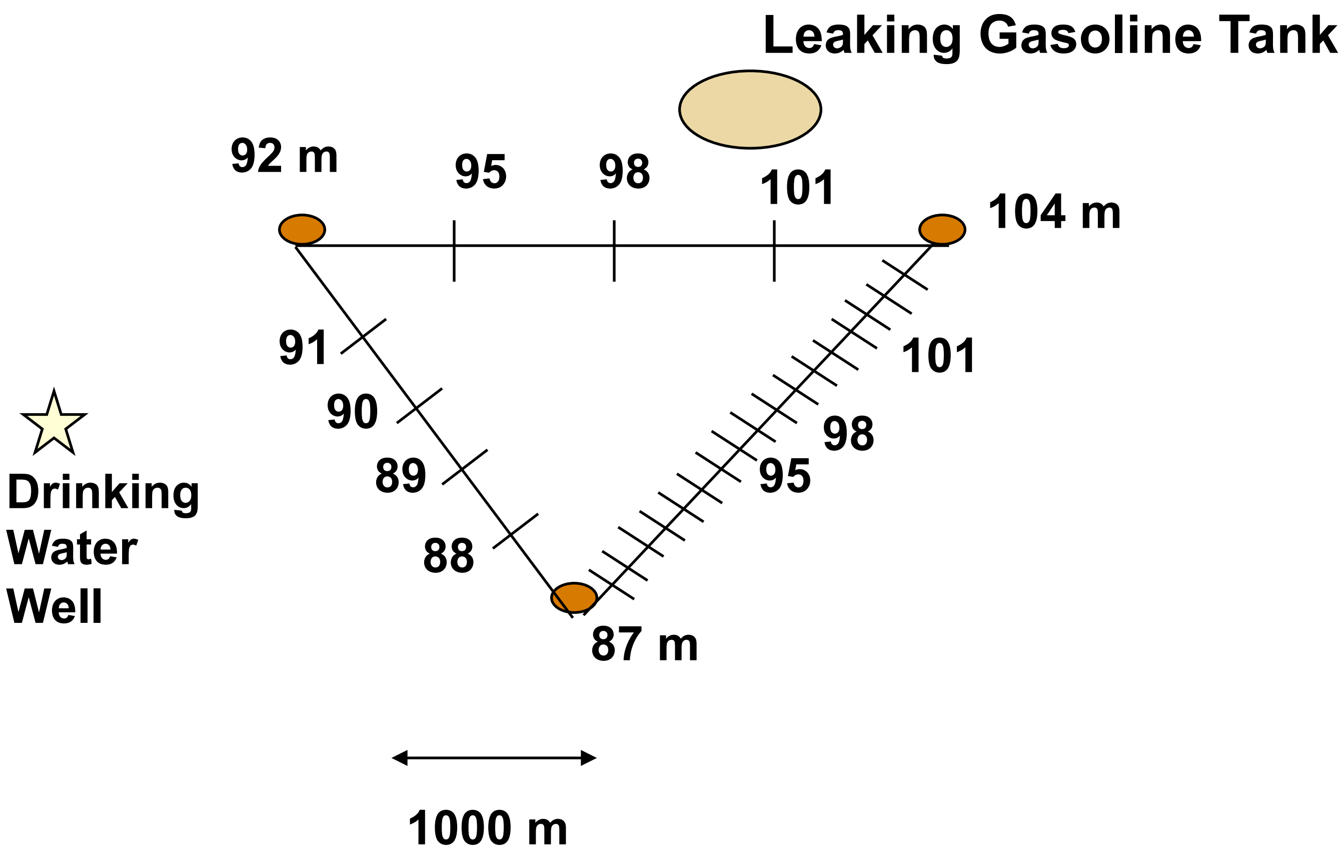
Would you drink the water?



Monitoring Wells with measured hydraulic head.

Classic *3-Point* Problem



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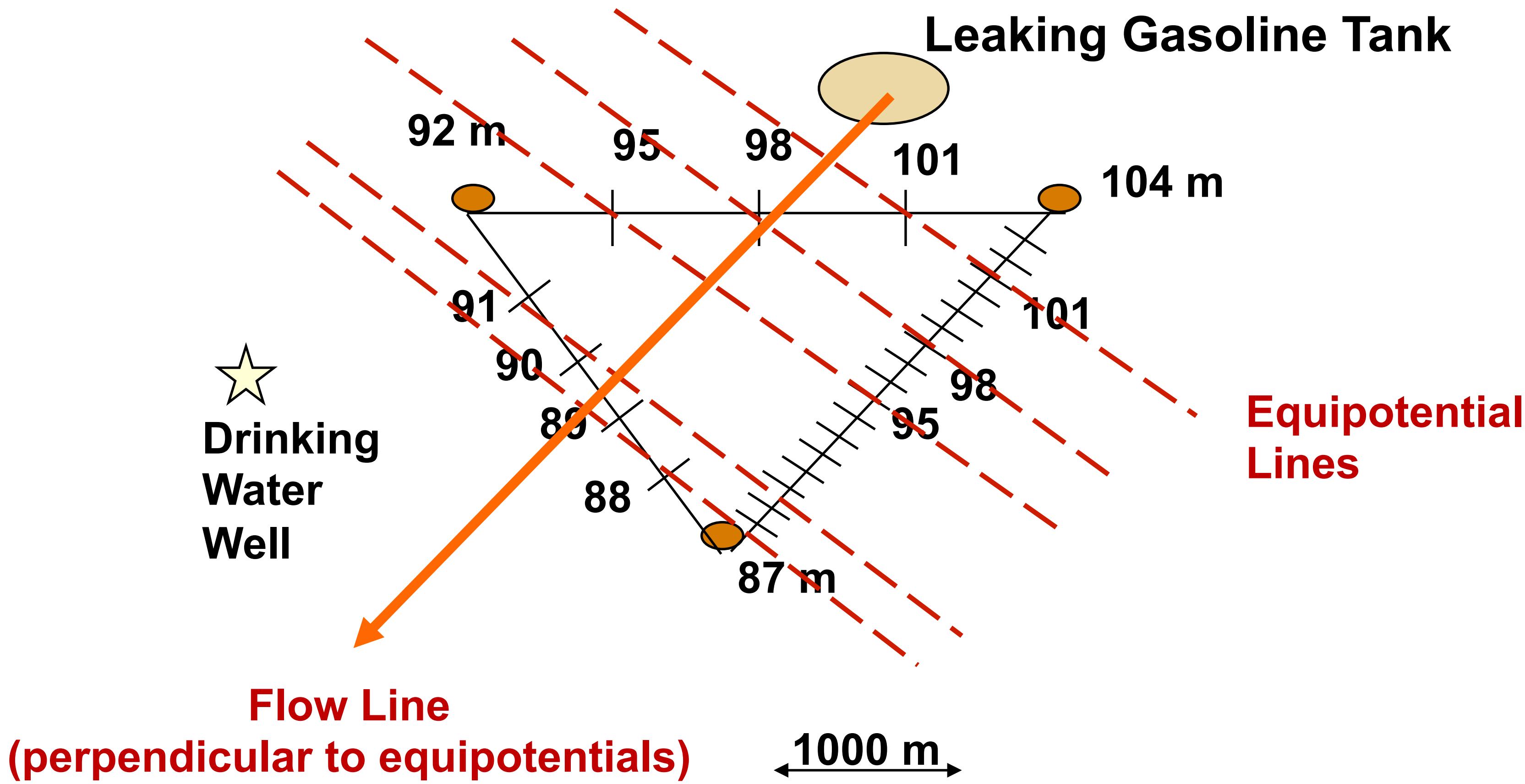

Monitoring Wells with measured hydraulic head.

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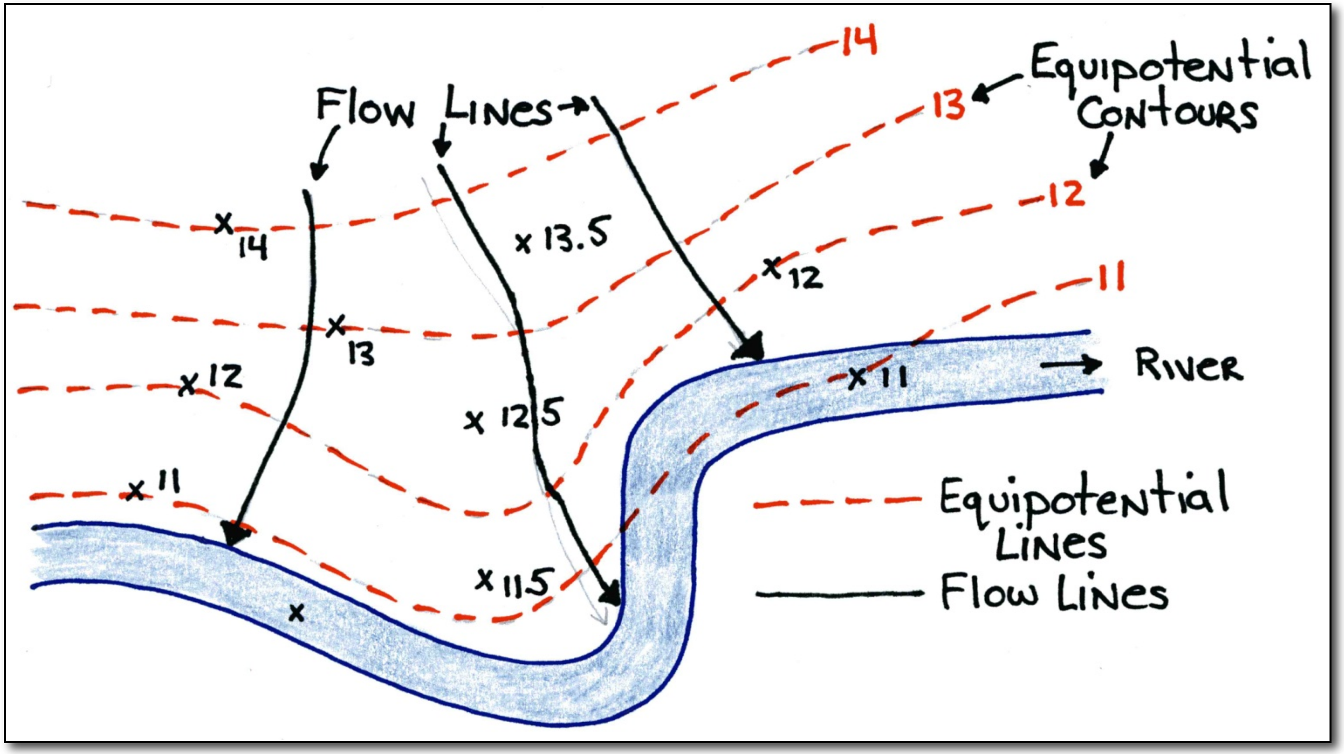
Lateral or Horizontal Flow con't

b) Plan View



- Piezometers installed laterally throughout the study area can be used to construct a contour plot of the water table or piezometric levels in a confined or semi-confined aquifer