CALIFORNIA STATE UNIVERSITY
FULLERTON

Hydrogeology 101

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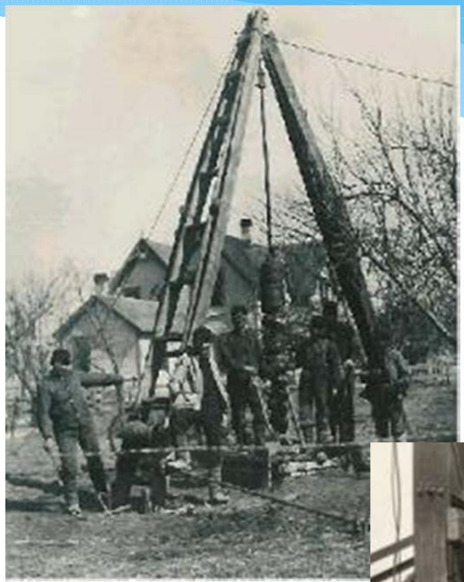
Hydrogeology 101

The objective is to obtain a better understanding of the principles of groundwater, hydrologic cycle and water budgets. The lecture will also cover various types of aquifers and general groundwater quality.

Objective

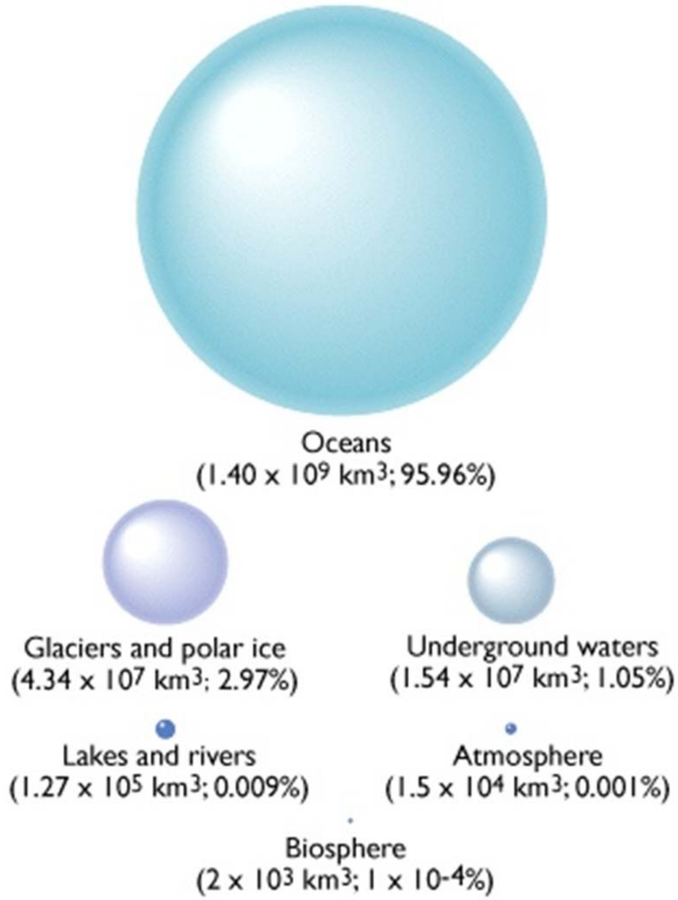
- To understand
  - Basic definitions
  - Hydrologic Cycle
  - Groundwater
  - Aquifers
  - How water flows
  - Water Budgets
  - Wells
  - Water Quality
  - Contamination
  - Investigation Tools

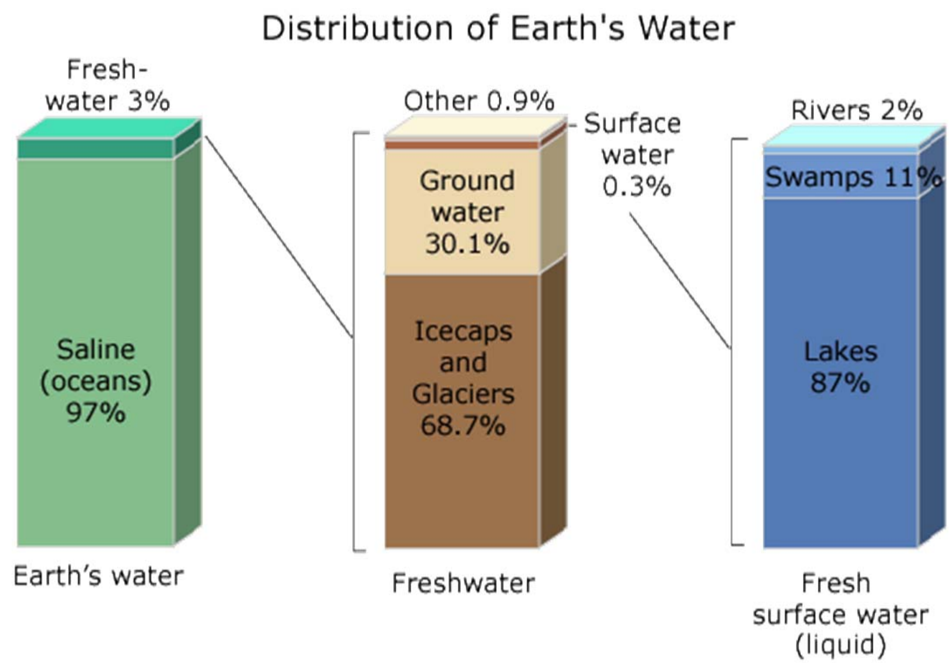


Definitions

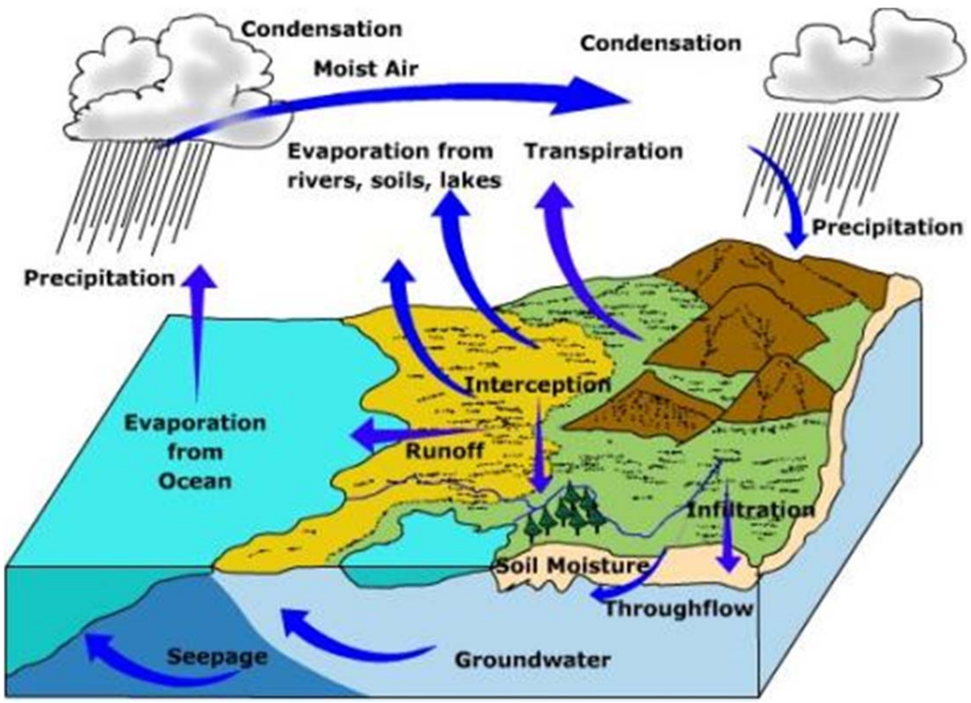
- Water on Earth
- Hydrologic Cycle
- Meteorology
  - weather
- Hydrology
  - Surface water
- Hydrogeology
  - Groundwater
- Unsaturated Zone
  - Vadose Zone
- Aquifers
  - Water Table
  - Unconfined
  - Confined
- Darcy's Law
- Safe Yield
- Water Chemistry

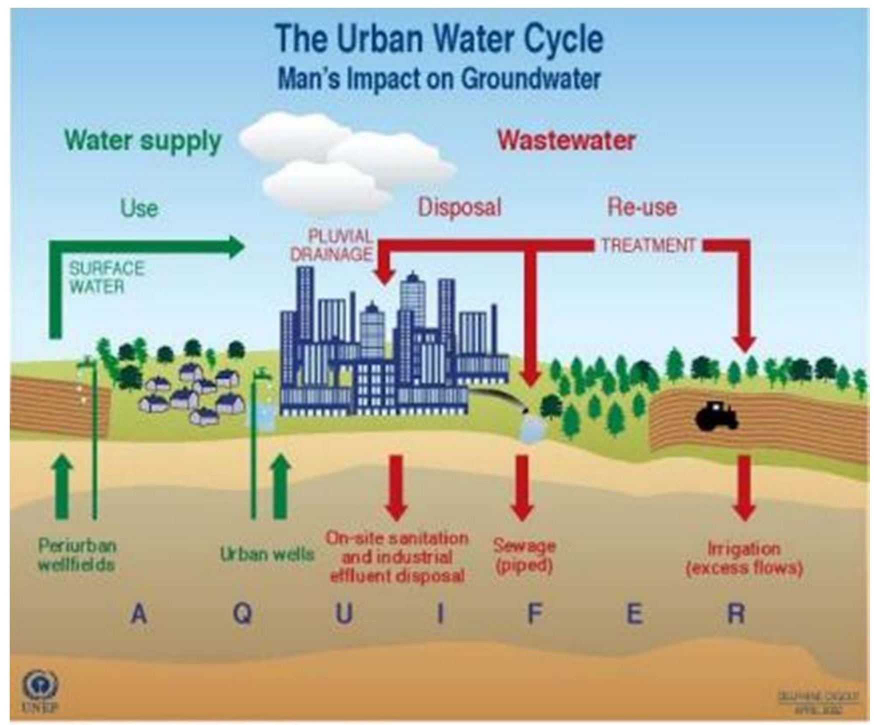
Distribution of H_2O on Earth



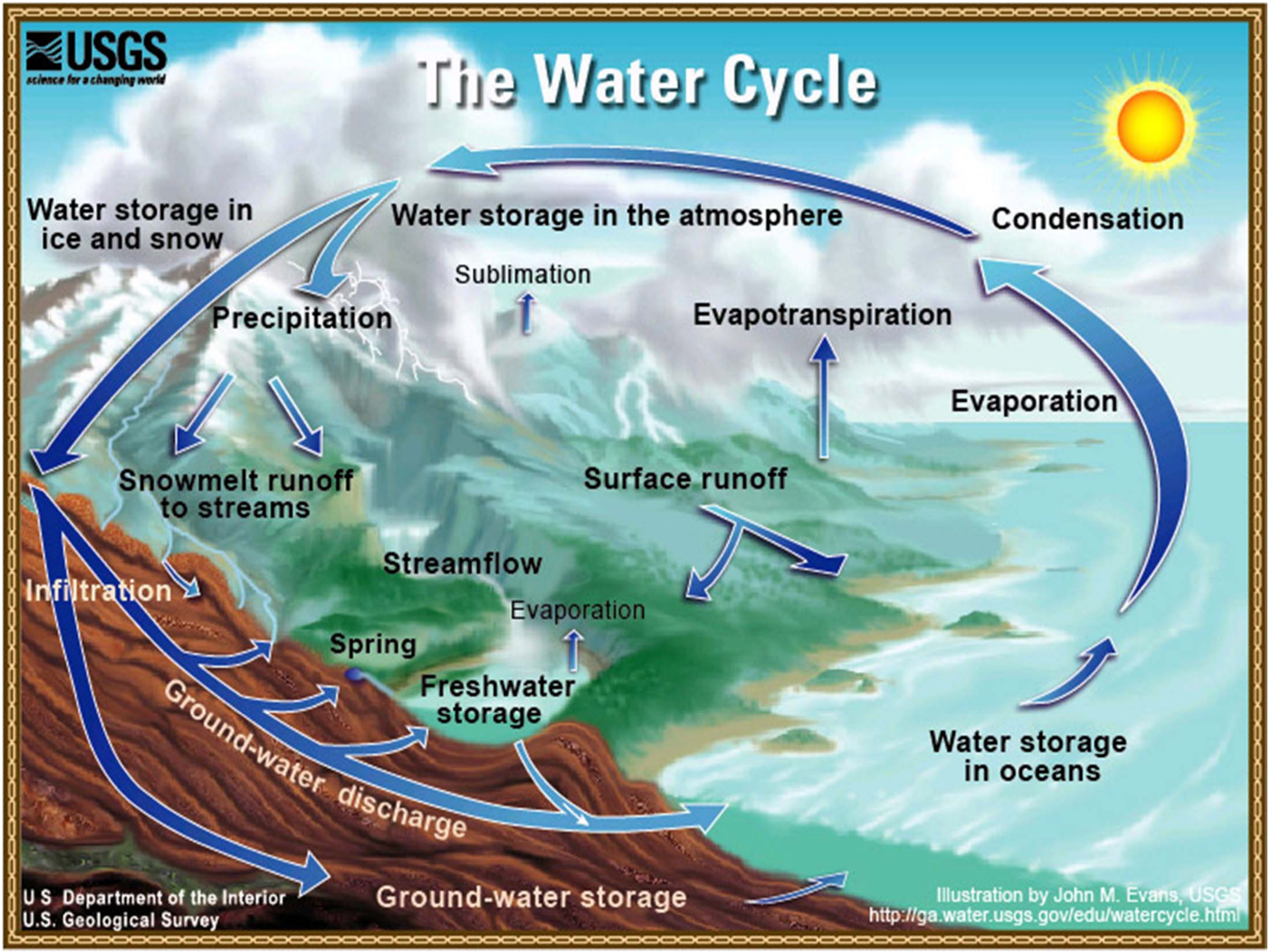


Hydrologic Cycle



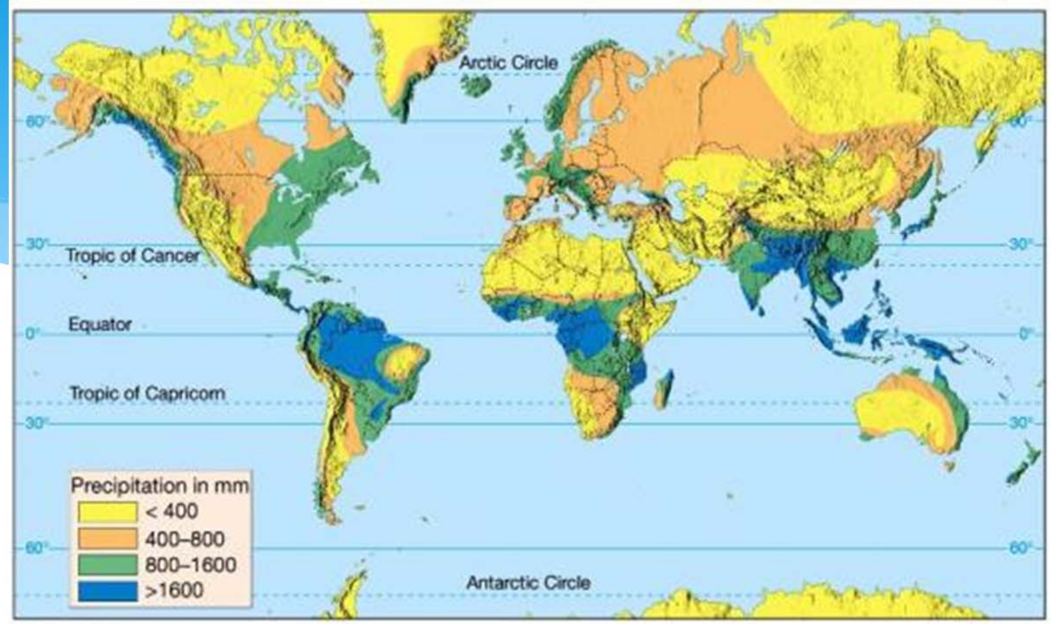


Source: Brian Morris, British Geological Survey, 2001.

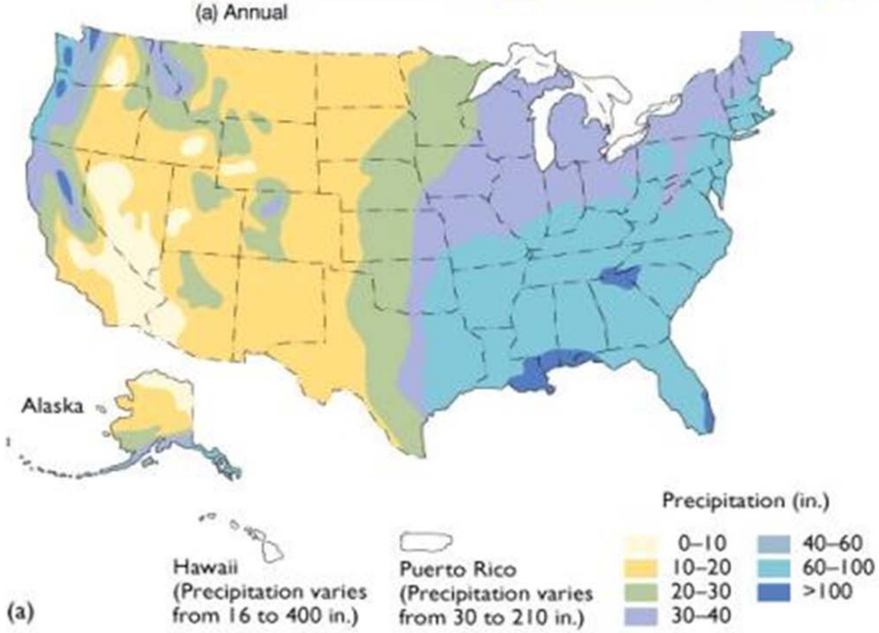

USGS
science for a changing world
The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Snowmelt runoff to streams
Surface runoff
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
U S Department of the Interior
U.S. Geological Survey
Illustration by John M. Evans, USGS
http://ga.water.usgs.gov/edu/watercycle.html

Meteorology

- Climate
- Precipitation
  - Rain
  - Snow
- Temperature
- Other factors
  - Location
  - Altitude

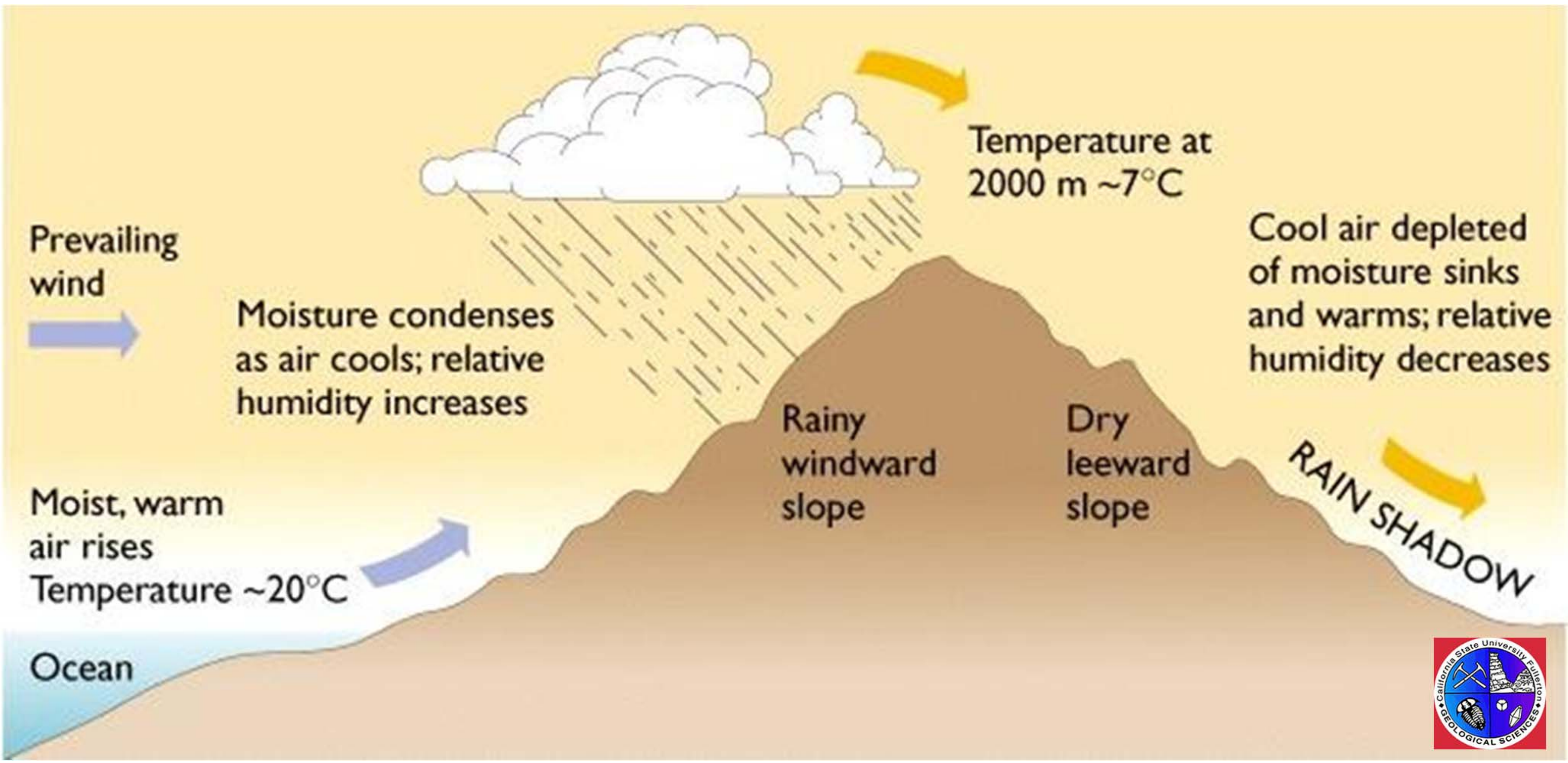


(a) Annual



(a)

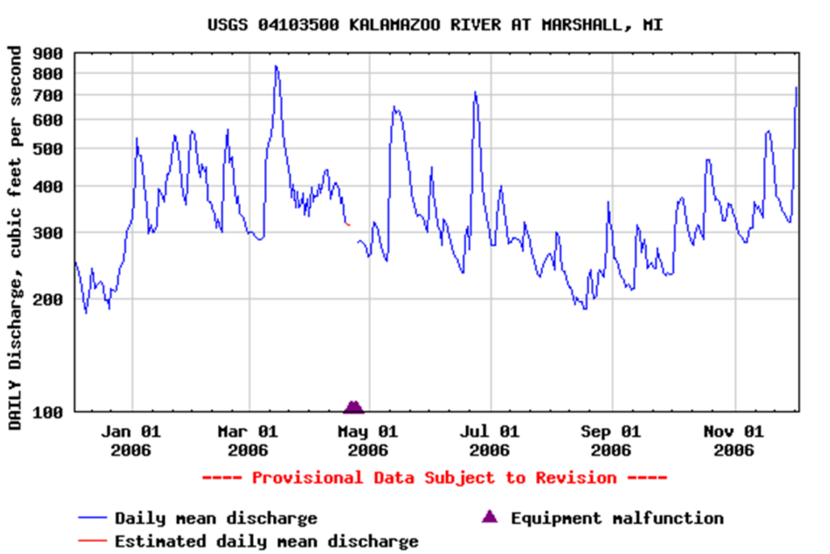
Rain Shadow Deserts

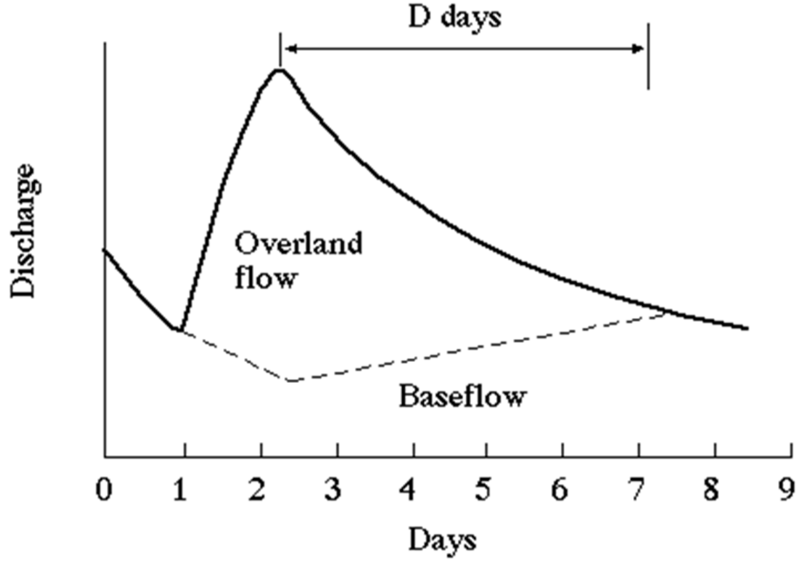


Surface Water

- Ocean, Lake, Pond
- River, Stream
- Spring, Wetland

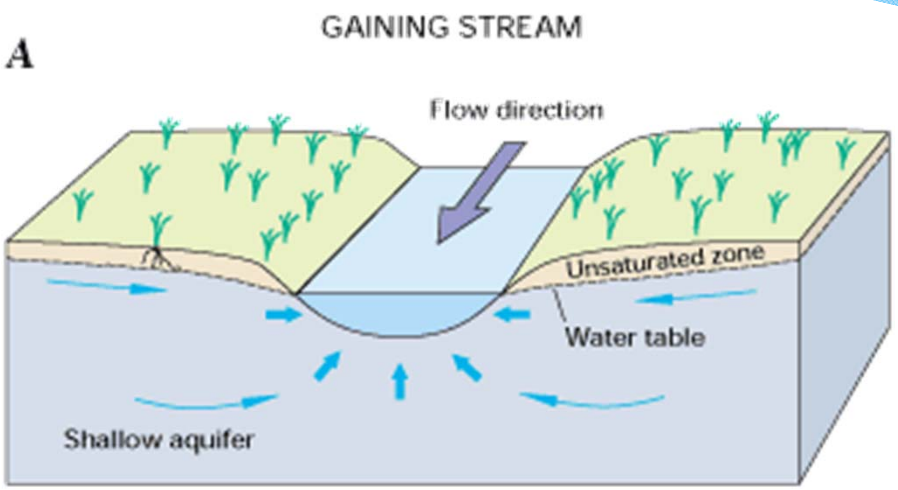
Surface Water Flow

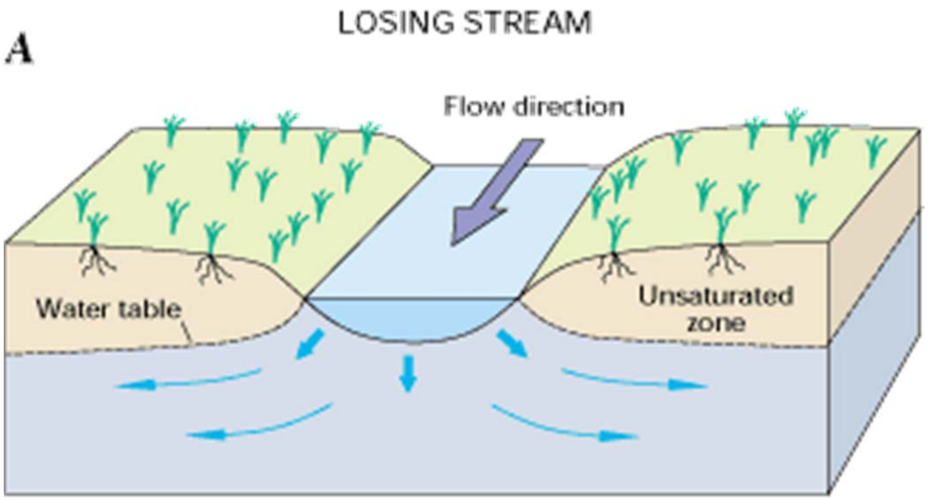




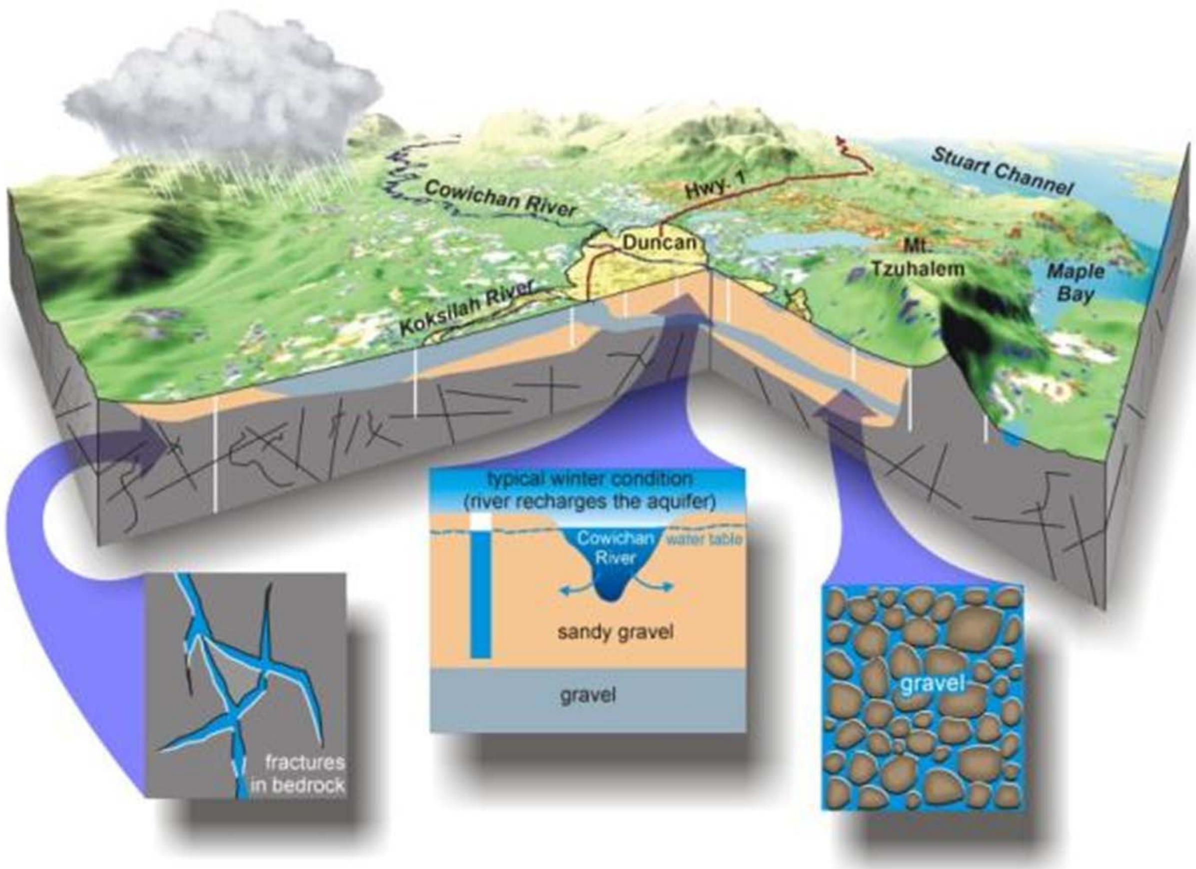
- Discharge
- Baseflow
- Flood Stage
- Gaining Stream
- Losing Stream

Gaining - Losing





Groundwater

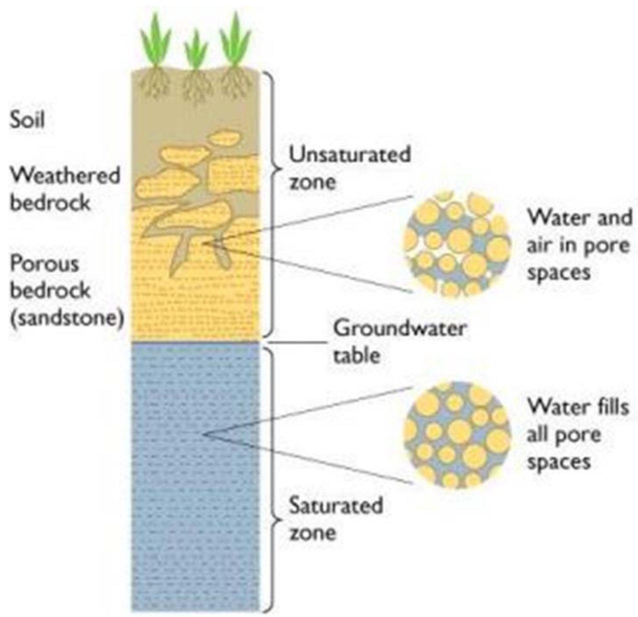


Groundwater

* Water contained in spaces within soil and bedrock
* Less than 1% of all H_2O on Earth
* 40 times more abundant than water found in lakes and streams

Groundwater terms

* *zone of aeration*: portion of soil and rock near the surface in which open spaces are filled primarily with air (a.k.a vadose zone, unsaturated zone)
* *saturated zone*: zone in which pore spaces are filled with water
* *water table*: boundary between zone of aeration and saturated zone



More groundwater terms

* *aquifer*: body of rock that is sufficiently water permeable to yield economically significant quantities to wells and springs

  Unconfined vs Confined

* *aquitard*: body of rock that retards but does not prevent flow of water to or from an adjacent aquifer
* *aquiclude*: body of relatively impermeable rock that is capable of absorbing water slowly but does not transmit it rapidly enough to supply a well or spring

Impacts of Faults on Groundwater Flow

* Conduits of Flow
* Barriers to Groundwater Flow

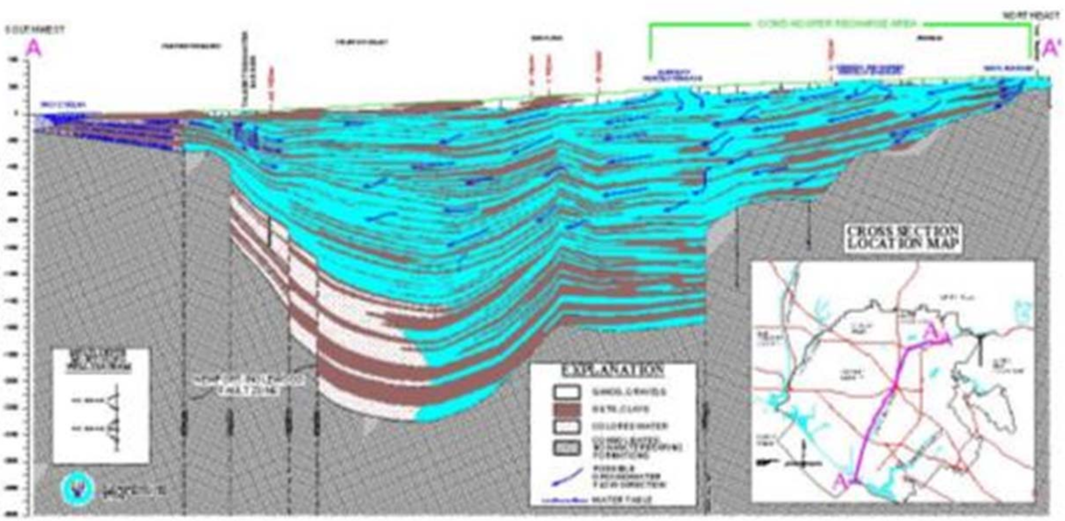
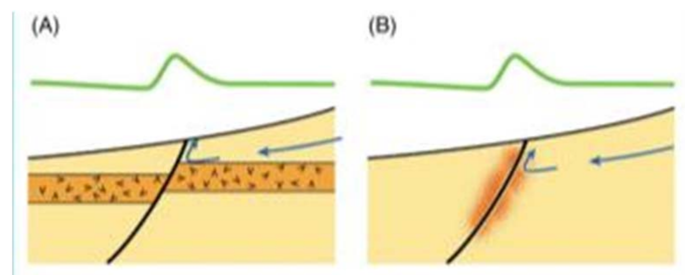
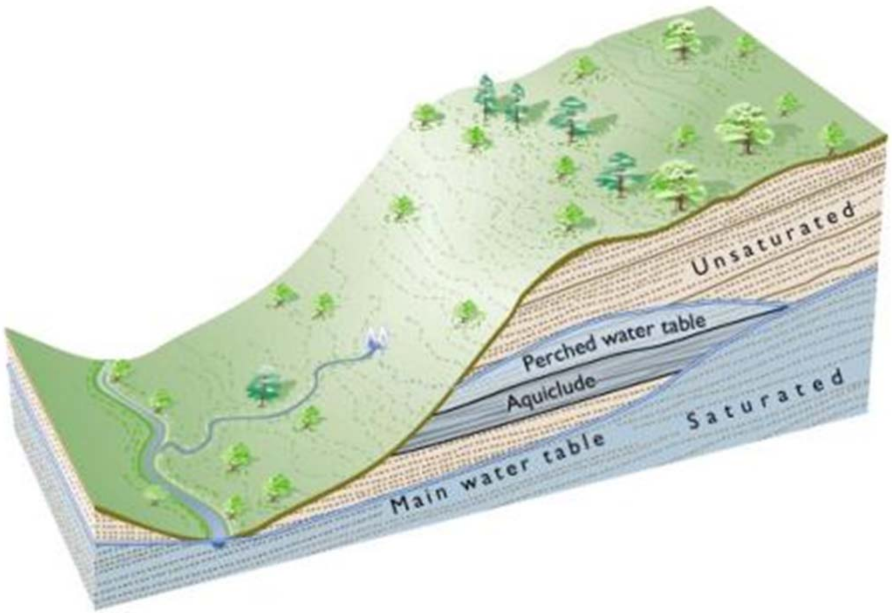


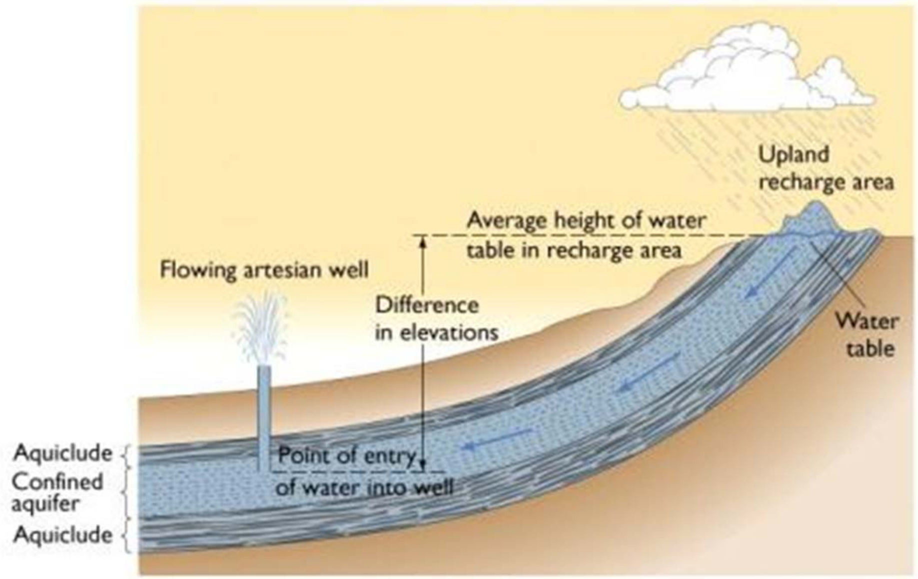
FIGURE 3-2. GEOLOGIC CROSS SECTION THROUGH ORANGE COUNTY GROUNDWATER BASIN ALONG SANTA ANA RIVER



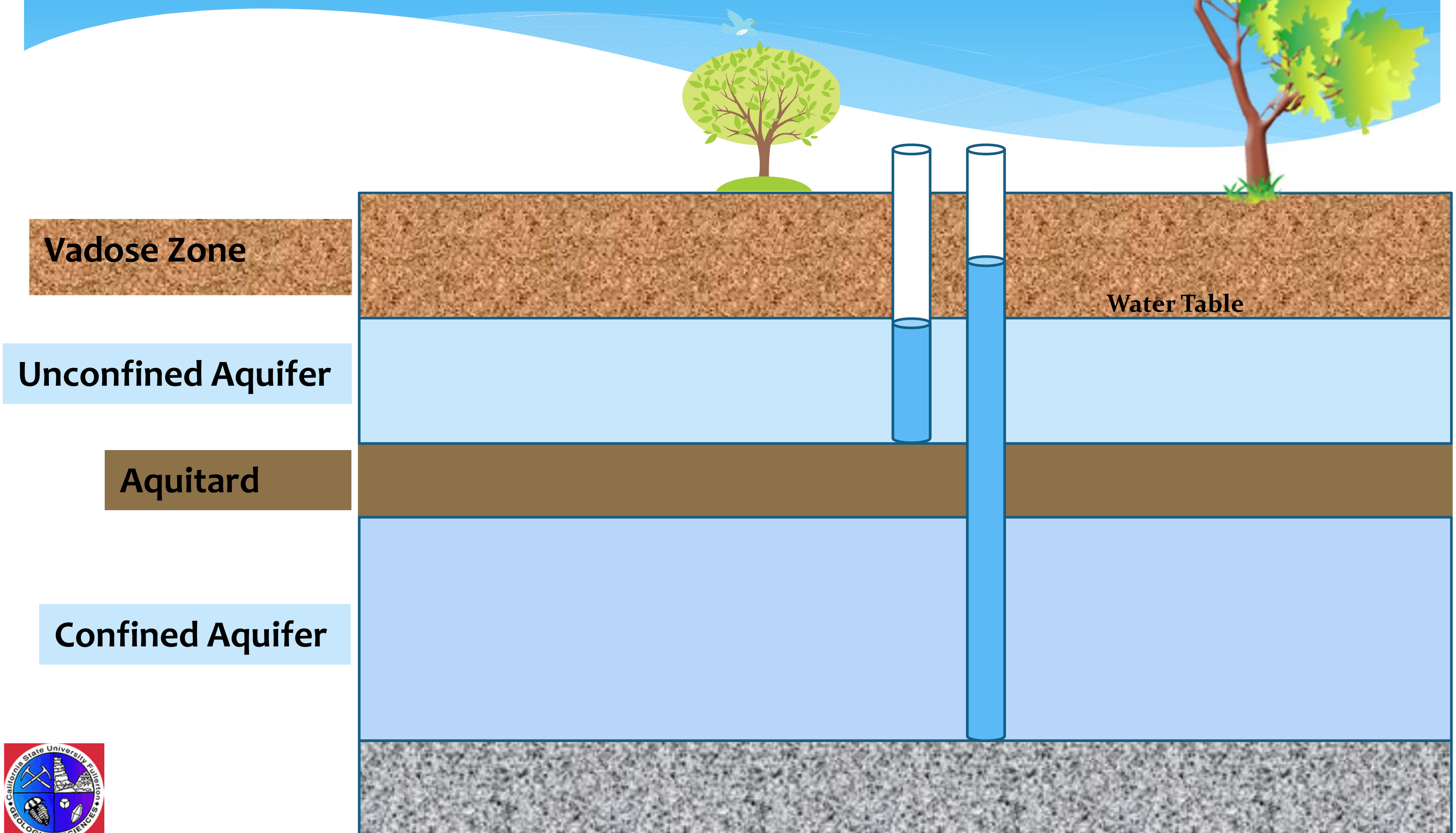
Perched Water Table



Confined Aquifer

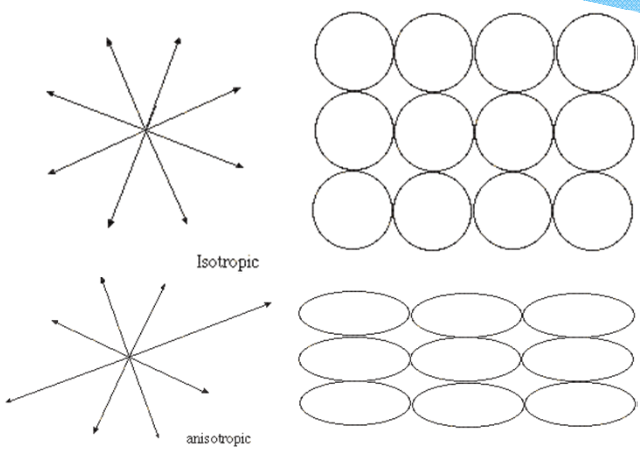


Aquifers

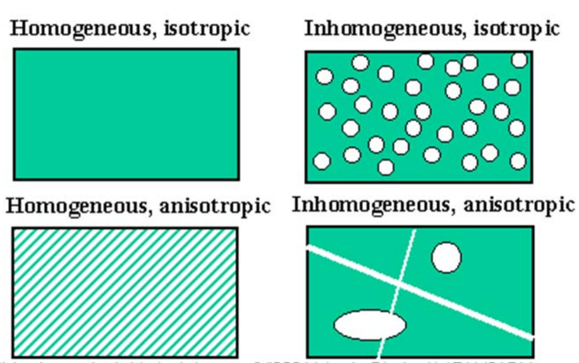


Vadose Zone
Unconfined Aquifer
Aquitard
Confined Aquifer
Water Table

Isotropy/Anisotropy
Homogeneous/Heterogeneous



Homogeneity vs Isotropy



http://physics.ucsd.edu/students/courses/fall2001/physics5/notes/ch17/sld015.htm

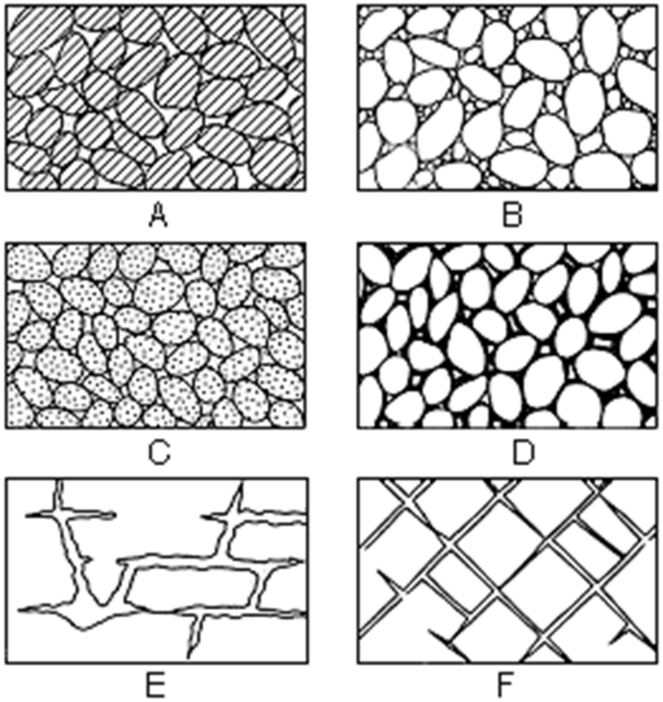
* **Isotropy** – The condition in which hydraulic properties of the aquifer are equal in all directions.
* **Anisotropy** – The condition under which one or more of the hydraulic properties of an aquifer vary according to the direction of flow.

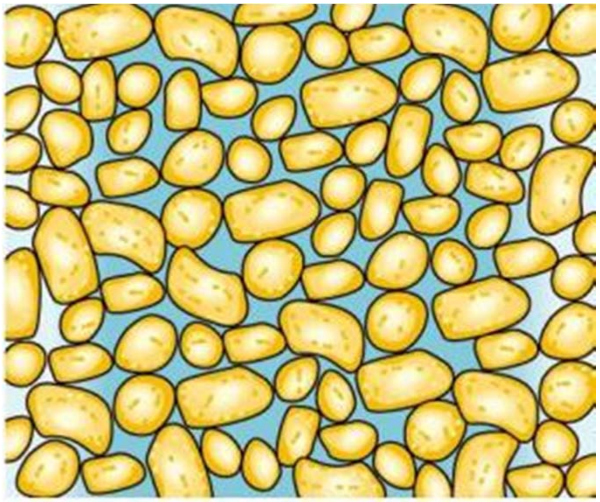
* **Homogeneous** – A geologic unit that has the same properties at all locations.
* **Heterogeneous** – Hydraulic properties vary spatially.

Soils and rocks are *not* completely solid

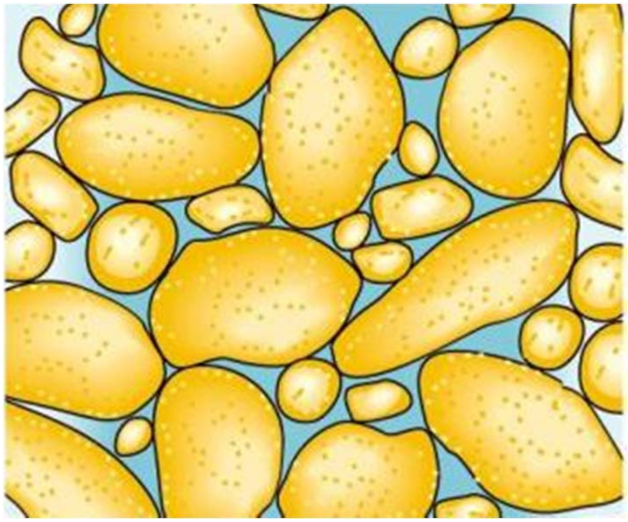
- *porosity*: portion of volume of a material that consists of open spaces
- *permeability*: measure of the speed at which fluid can travel through a porous medium

- Imagine two vertical pipes, one filled with gravel, one with sand. Out of which one will the water flow faster?



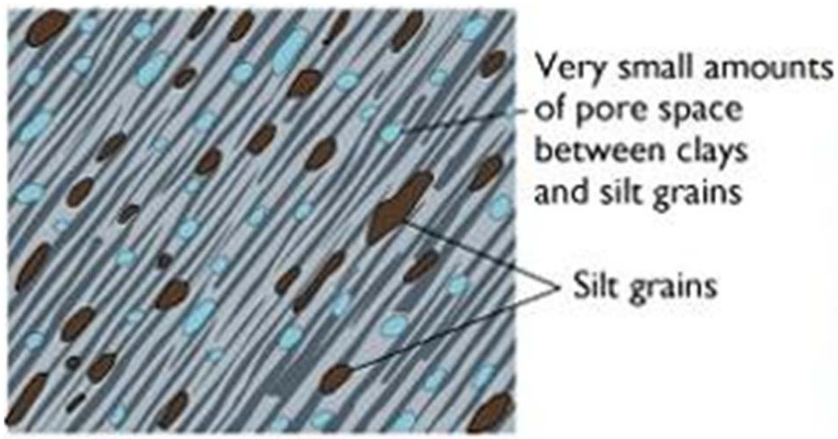


Well-sorted Sandstone

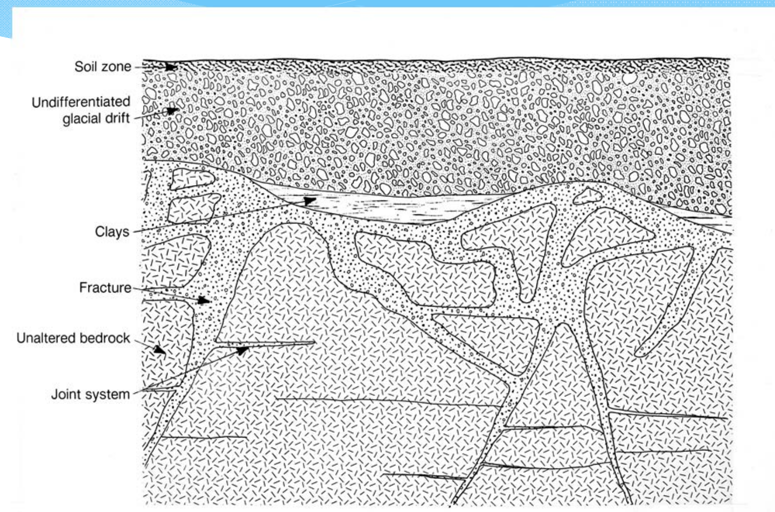


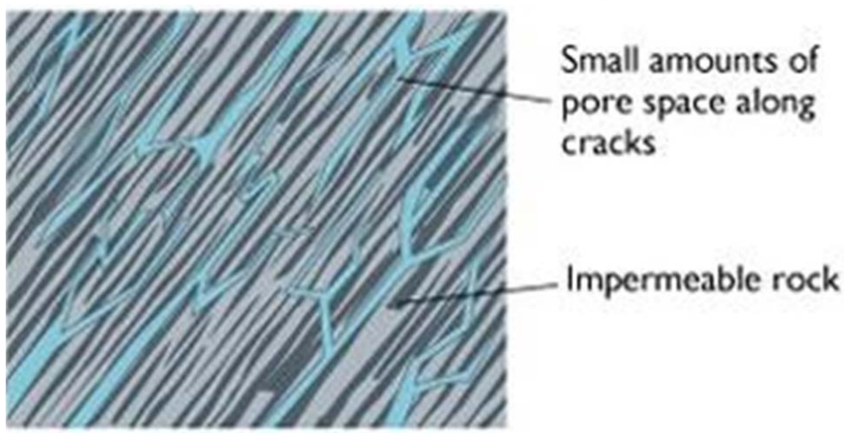
Poorly-sorted Sandstone

Fractured / Unfractured Shale



(e) Unfractured shale



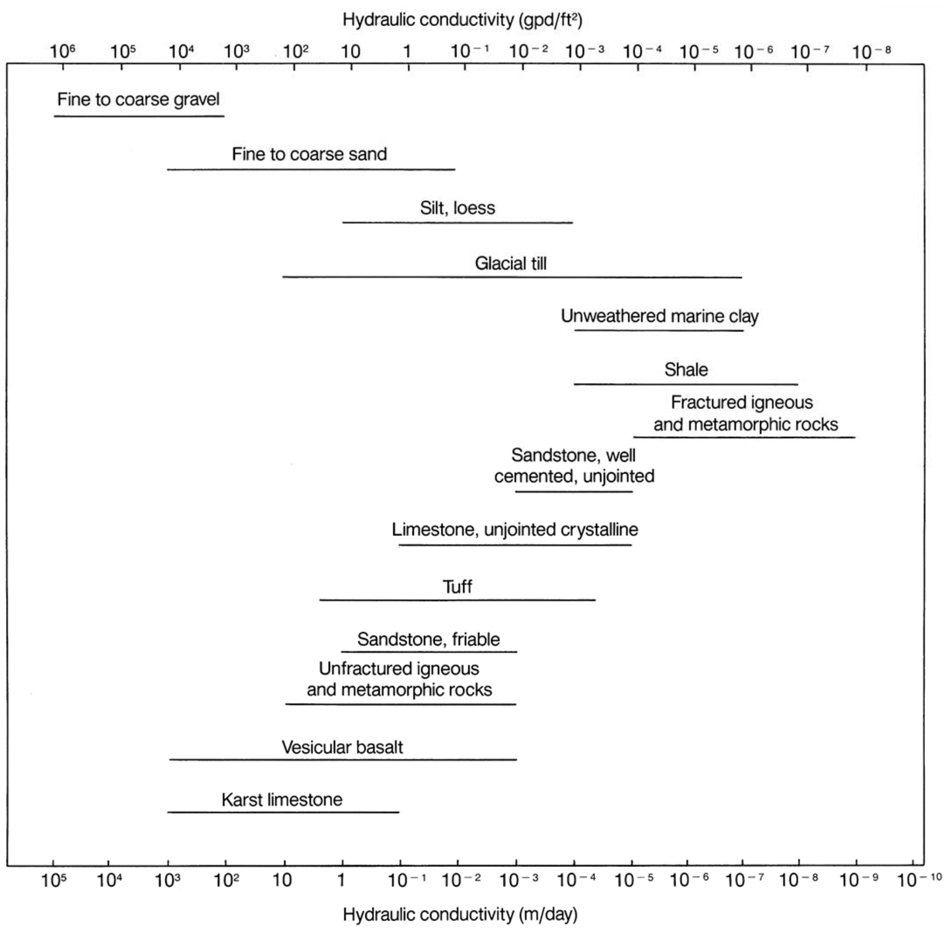


Porosity and Permeability

Primary and Secondary Porosity

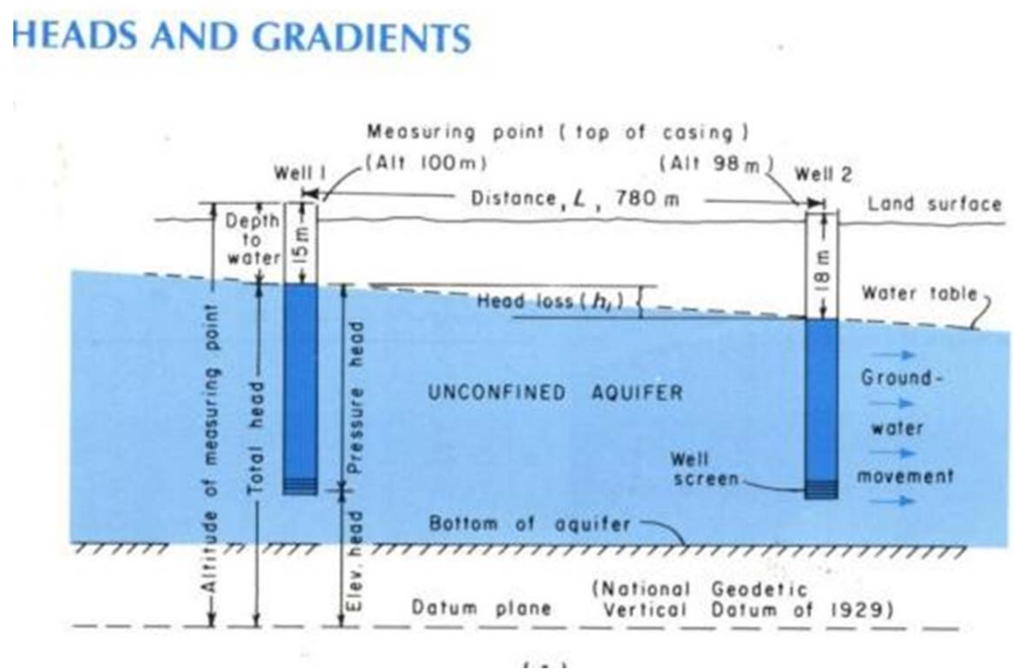
Rock Type	Porosity (Pore Space That May Hold Fluid)	Permeability (Ability to Allow Fluids to Pass Through)
Gravel	Very high	Very high
Coarse- to medium-grained sand	High	High
Fine-grained sand and silt	Moderate	Moderate to low
Sandstone, moderately cemented	Moderate to low	Low
Fractured shale or metamorphic rocks	Low	Very low
Unfractured shale	Very low	Very low

Hydraulic Conductivity
Transmissivity



Rates of groundwater movement

* Slow to very slow (depending on permeability)
* Generally within the range of 10 to 100 cm per day



Darcy's Law

$$Q = \frac{AK(h_1 - h_2)}{l}$$

Q = discharge (m^3/sec)

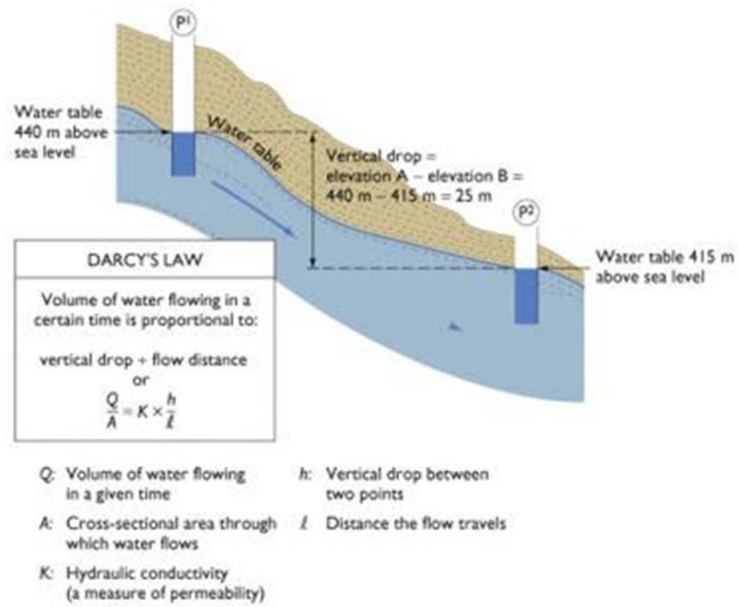
A = cross-sectional area (m^2)

K = coefficient of permeability (m/sec)

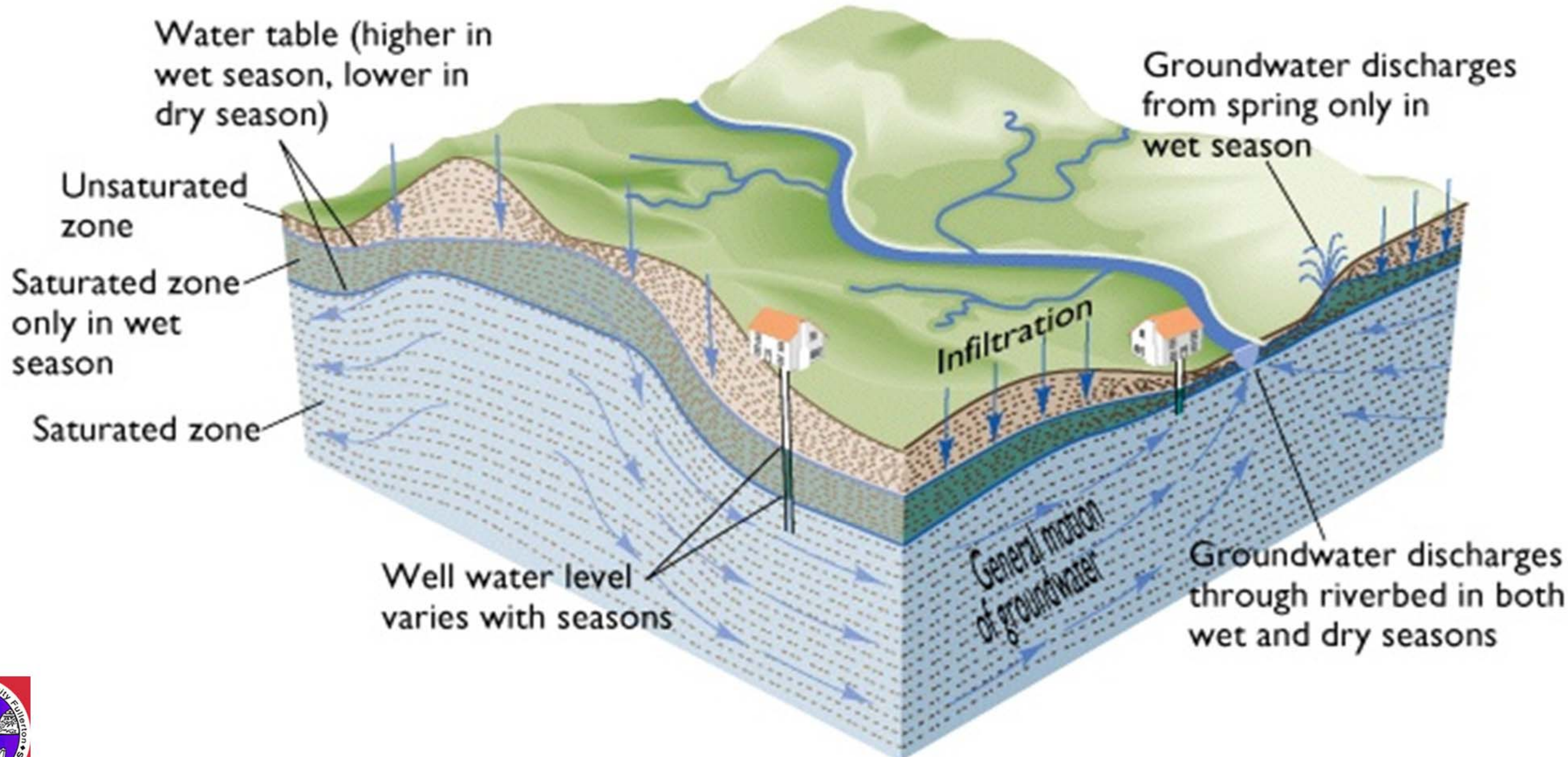
h_1 = beginning height (m)

h_2 = ending height (m)

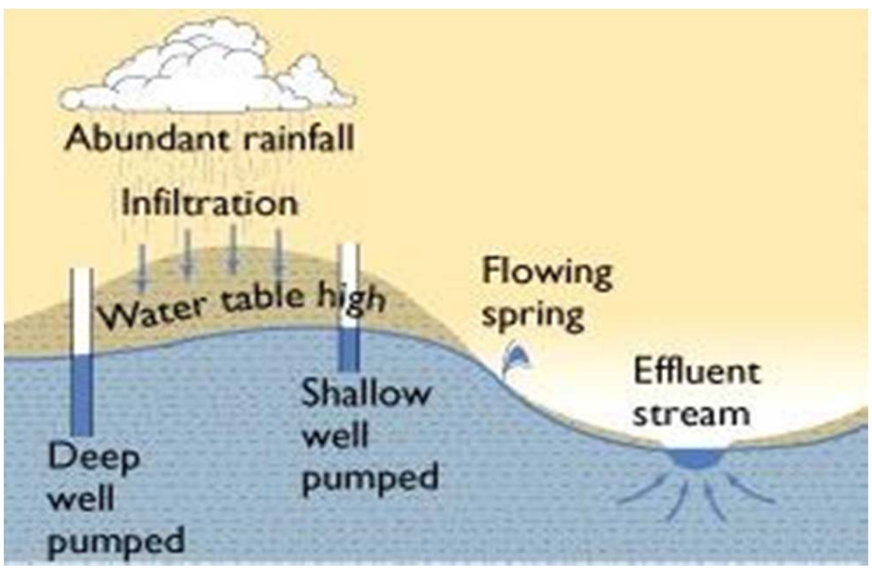
l = length of flow (m)



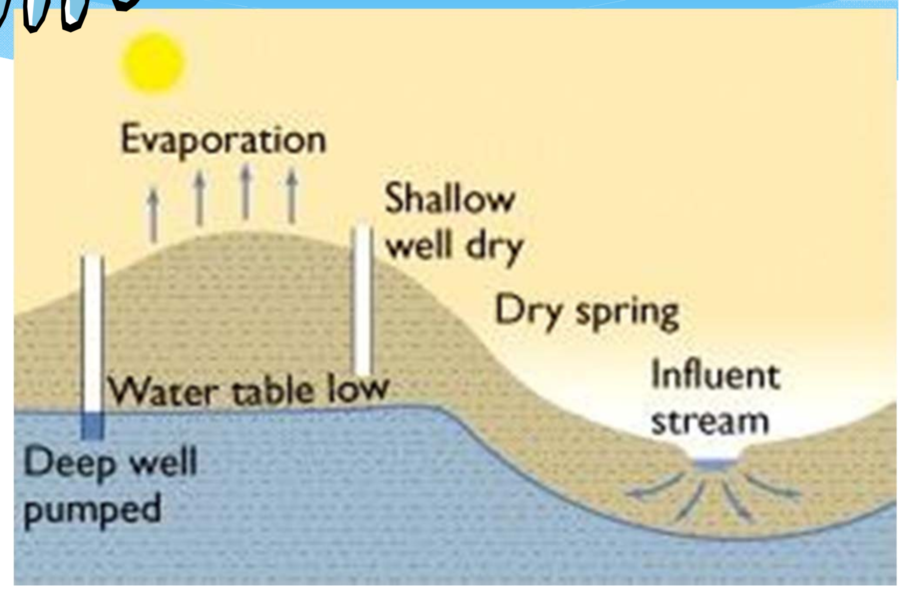
Groundwater Movement in Temperate Regions



Wet Period



Dry Period



Water Budgets

In = Out ± change in storage

- Simple in concept
- Data driven
- Difficult in practice

Assumptions – Water Budget

- How and where is the water coming from;
  - Recharge
  - Return flow
- How and where is the water going;
  - Pumping
  - Surface water
  - Evapotranspiration

Variables

* Inputs
  * Precipitation
  * Return flow
  * Overland Flow
    * Streams
    * Springs
  * Groundwater
* Outputs
  * Pumping
  * Evapotranspiration
  * Overland Flow
  * Groundwater

Example Water Budget

Inputs

Annual Average (acre-ft)	DWR [1967]	Goodrich [1978][2]	Brose [1987]
Surface Inflow	1,050[1]	1,050[1]	1,050[1]
Subsurface Inflow	-	-	-
Precipitation	694	-	700
Imported Water	-	-	-
Total	**1,744**	**1,050**	**1,750**

Outputs

Annual Average (acre-ft)	DWR [1967]	Goodrich [1978][1]	Brose [1987]	Stamos and Predmore [1995]
Surface Outflow	-	-	-	-
Subsurface Outflow	100	100	500	300 - 600
Consumptive Use	4,540	10,045	7,725	-
Total	**4,640**	**10,145**	**8,225**	-

Total

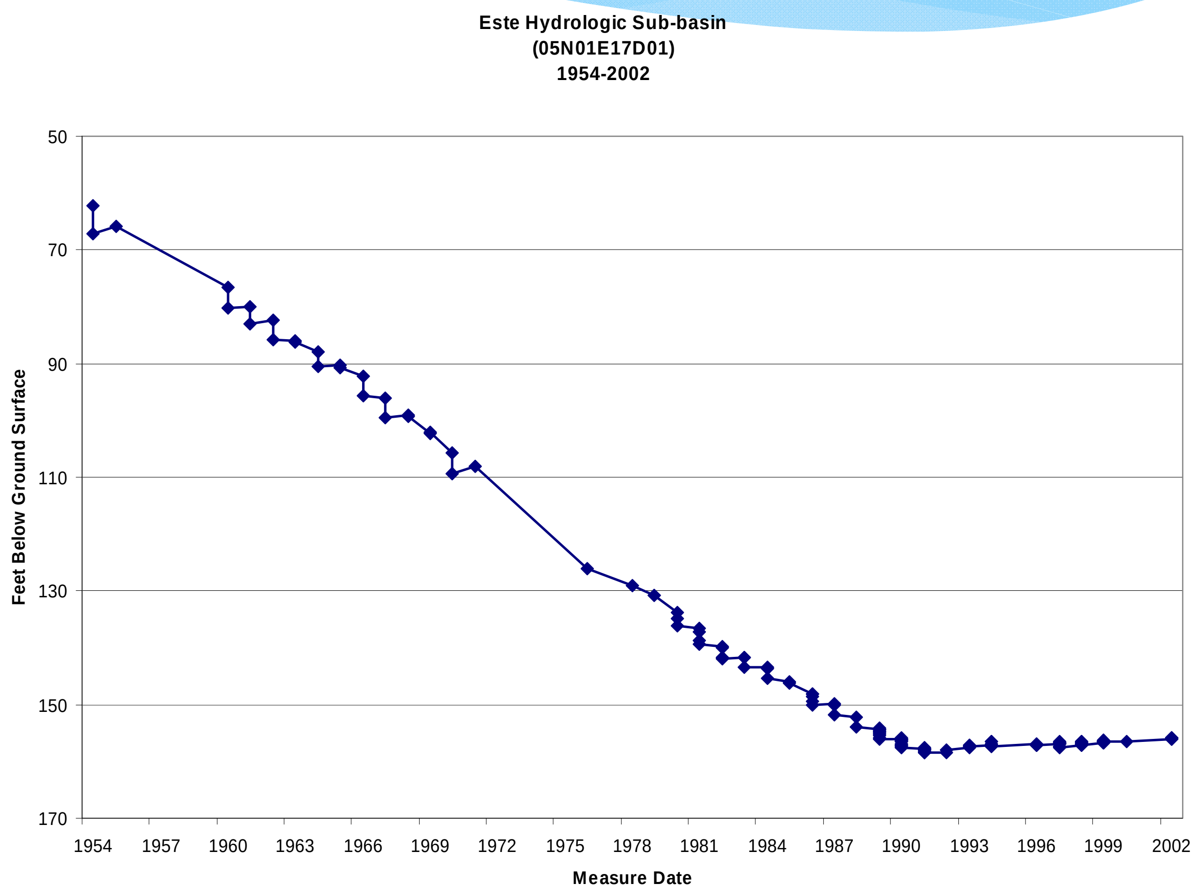
Annual Average (acre-ft)	DWR [1967]	Goodrich [1978][1]	Brose [1987]
Total Input	1,744	1,050	1,750
Total Output	4,640	10,145	7,725
Total Water Budget	**-2,896**	**-9,095**	**-6,475**

Safe Yield (sustainability)

* The amount of naturally occurring groundwater that can be economically and legally withdrawn from an aquifer on a sustained basis without impairing the native groundwater quality or creating an undesirable effect such as environmental damage. It cannot exceed the increase in recharge or leakage from adjacent strata plus the reduction in discharge, which is due to the decline in head caused by pumping.
  * C.W. Fetter, 1994.

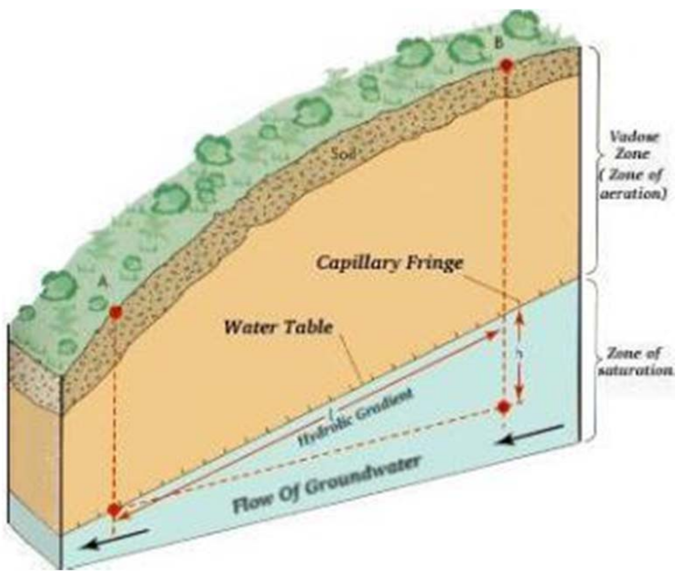
Groundwater Hydrographs

* Common
* Typically easy to interpret

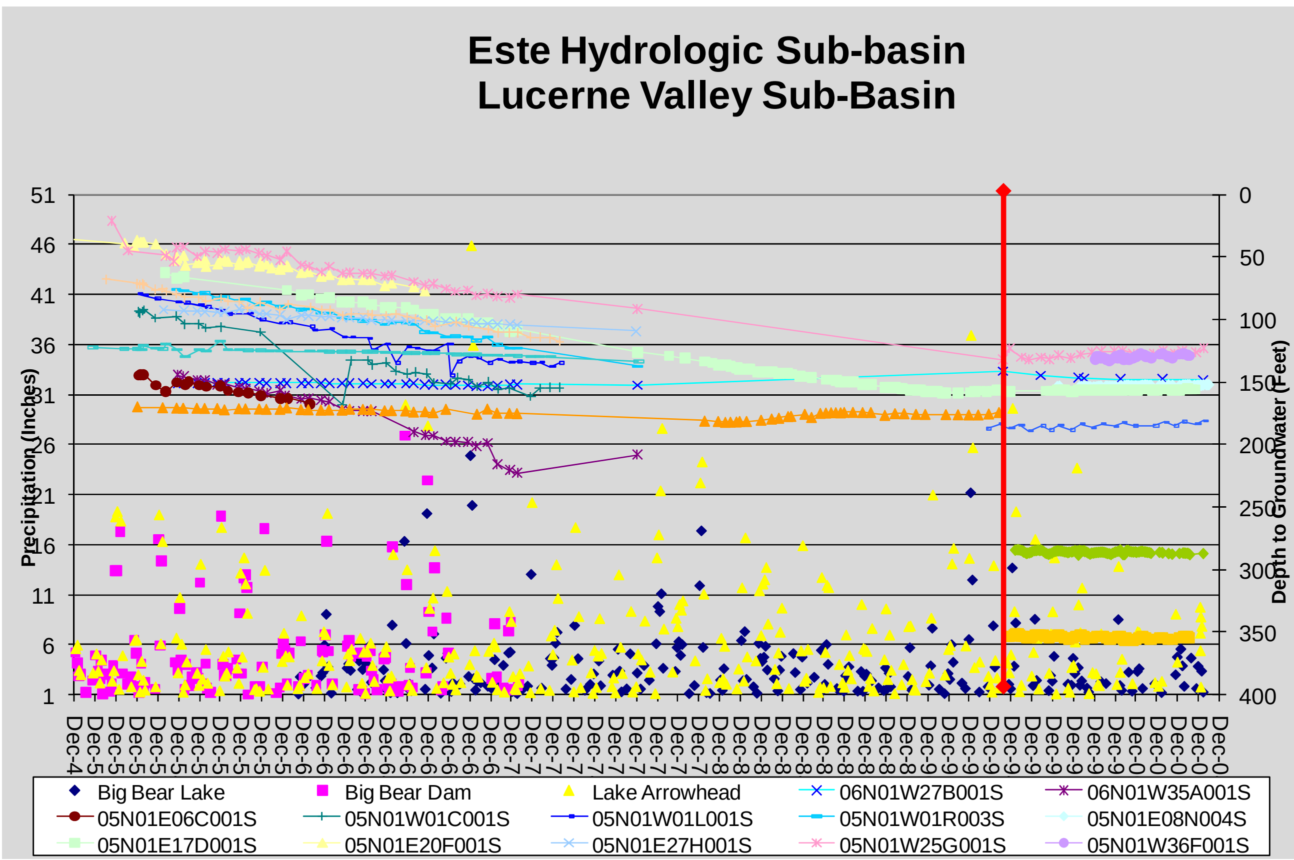


Assumptions - Hydrographs

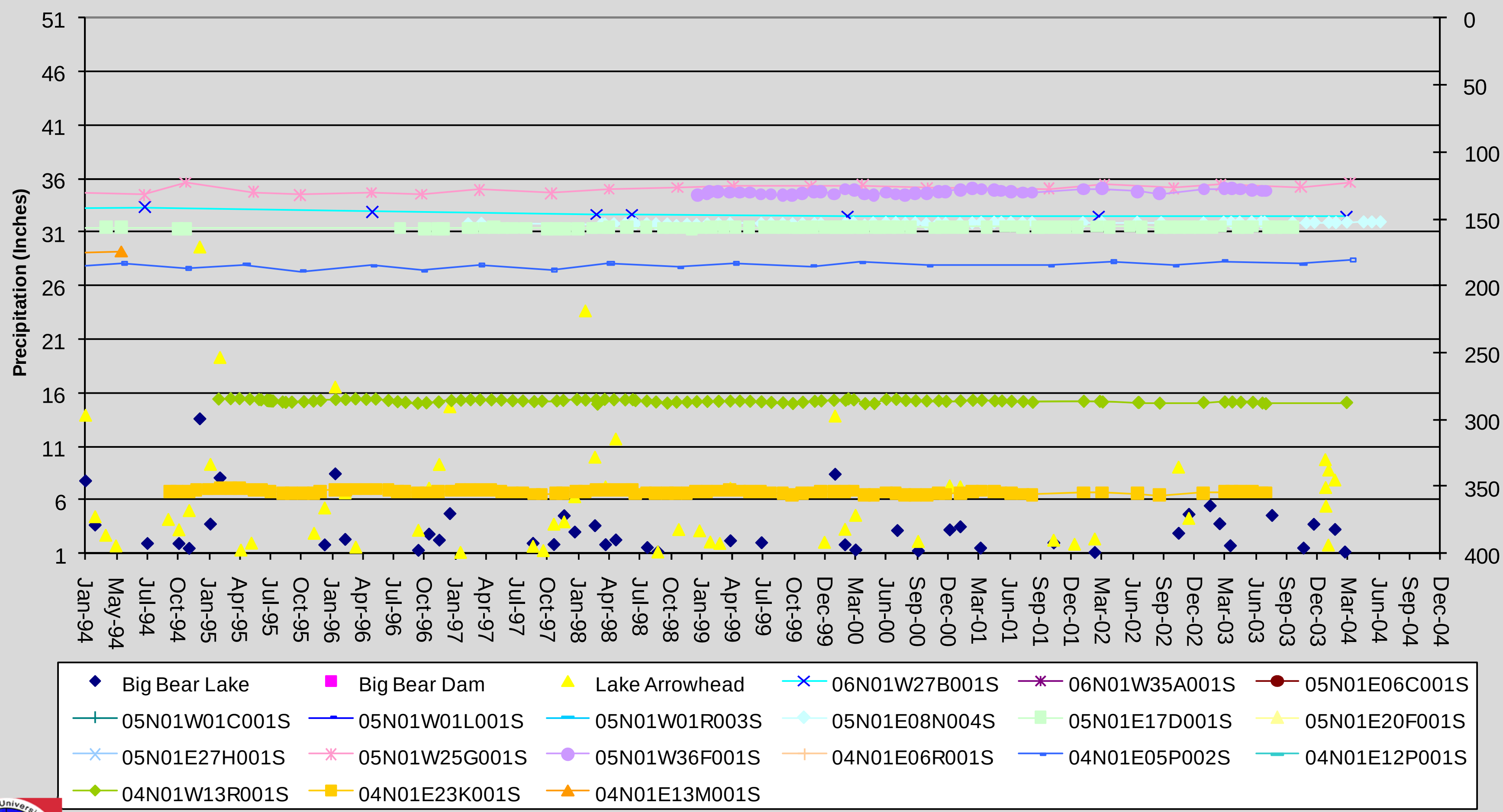
- Long-term monitoring
- Frequent monitoring
- Quality data you can trust



What do the hydrographs say?

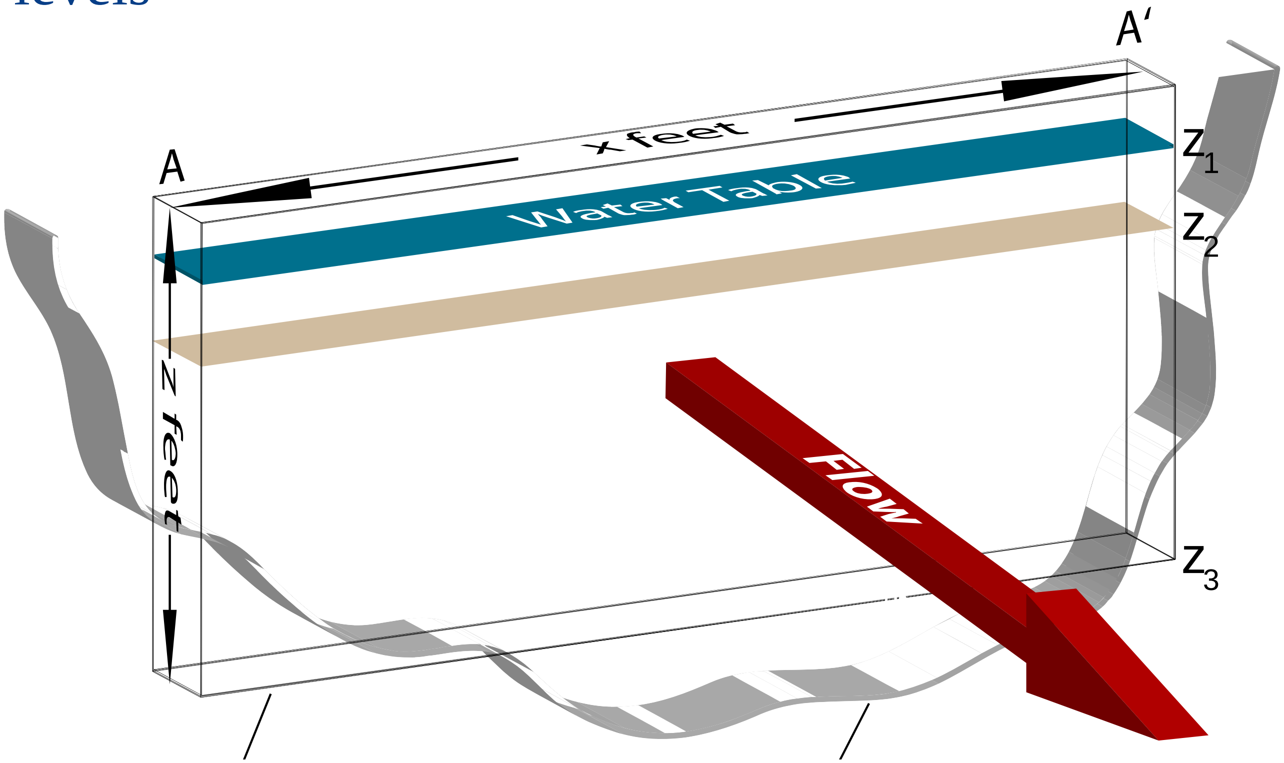


Este Hydrologic Sub-basin
Lucerne Valley Sub-Basin



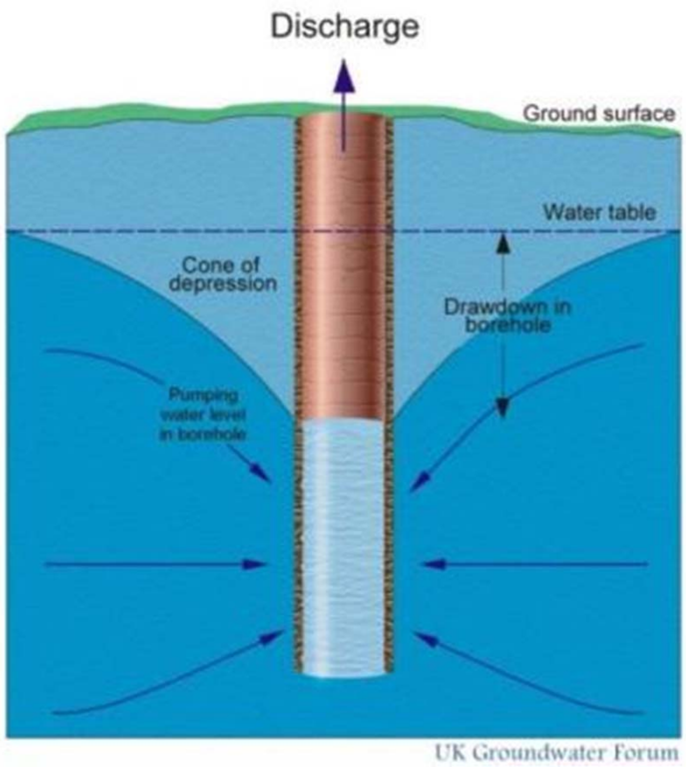
Analysis

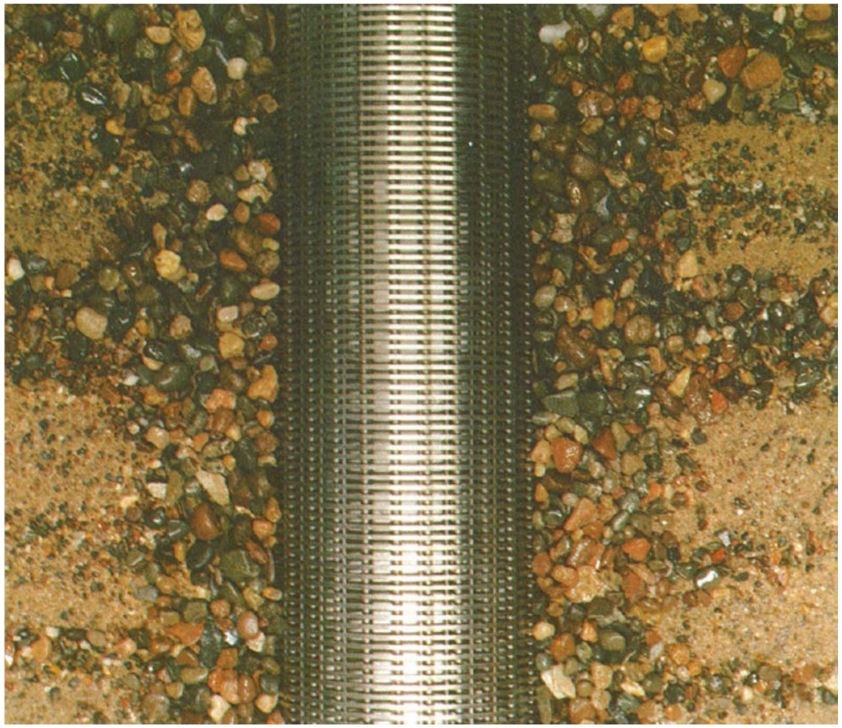
* Hydrographs – groundwater levels drive the analysis
  * Decline in water levels
  * Increased water levels
  * No change
* Balancing act



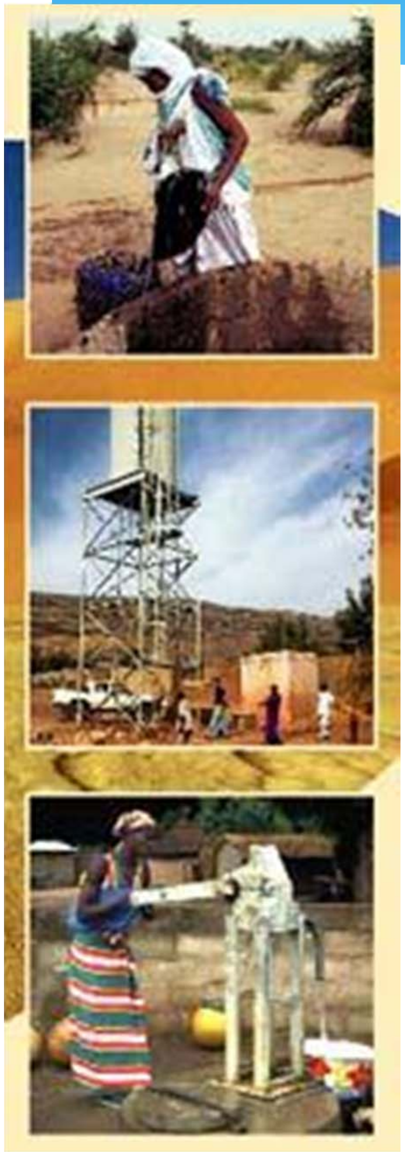
Groundwater and Wells

* Drawdown
* Cone of depression
* Capture zone



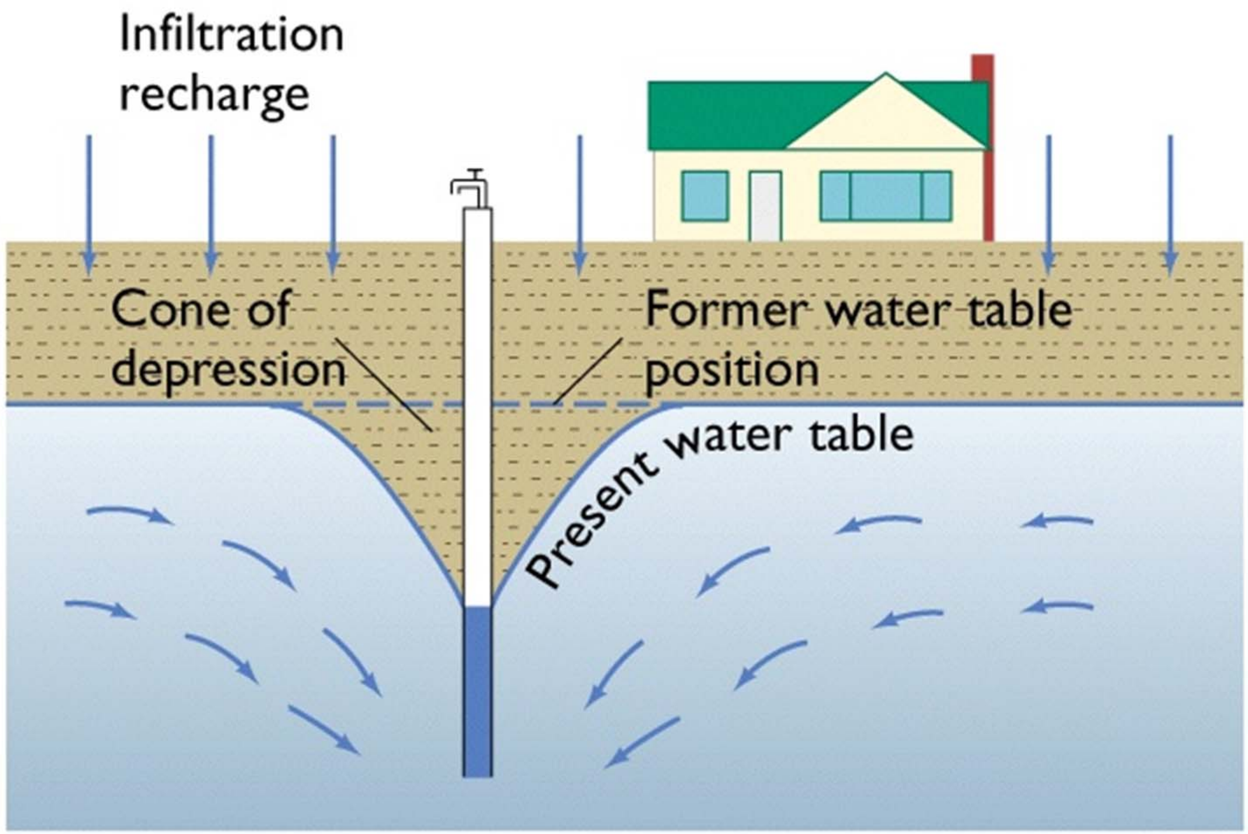


Groundwater Withdrawal

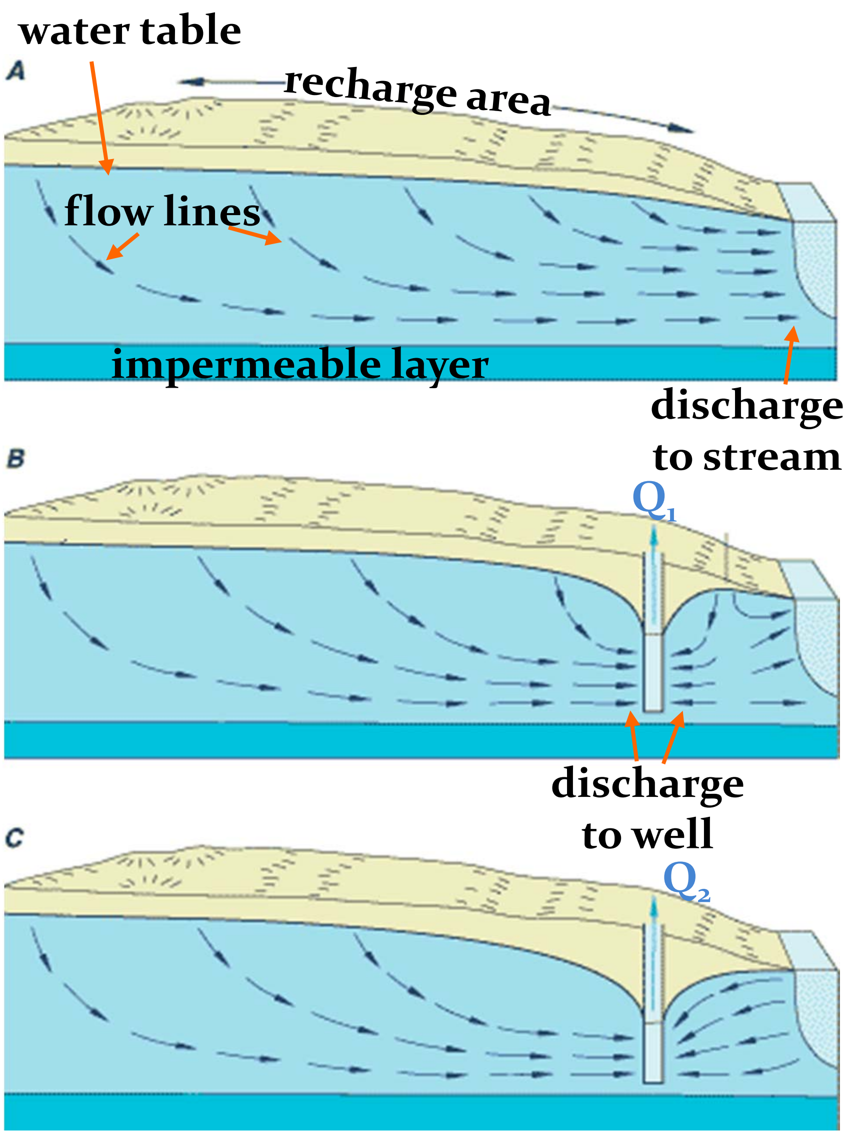


* Potable (municipal and private)
* Irrigation
* Industrial

Drawdown Due to Pumping



Water flowing underground



Water in aquifers is replenished primarily by infiltration of surface water (*groundwater recharge*).

Groundwater flows *from areas of high pressure (or hydraulic head) to areas of low pressure*. In unconfined aquifers, hydraulic head is given by the height of the water table above some reference level.

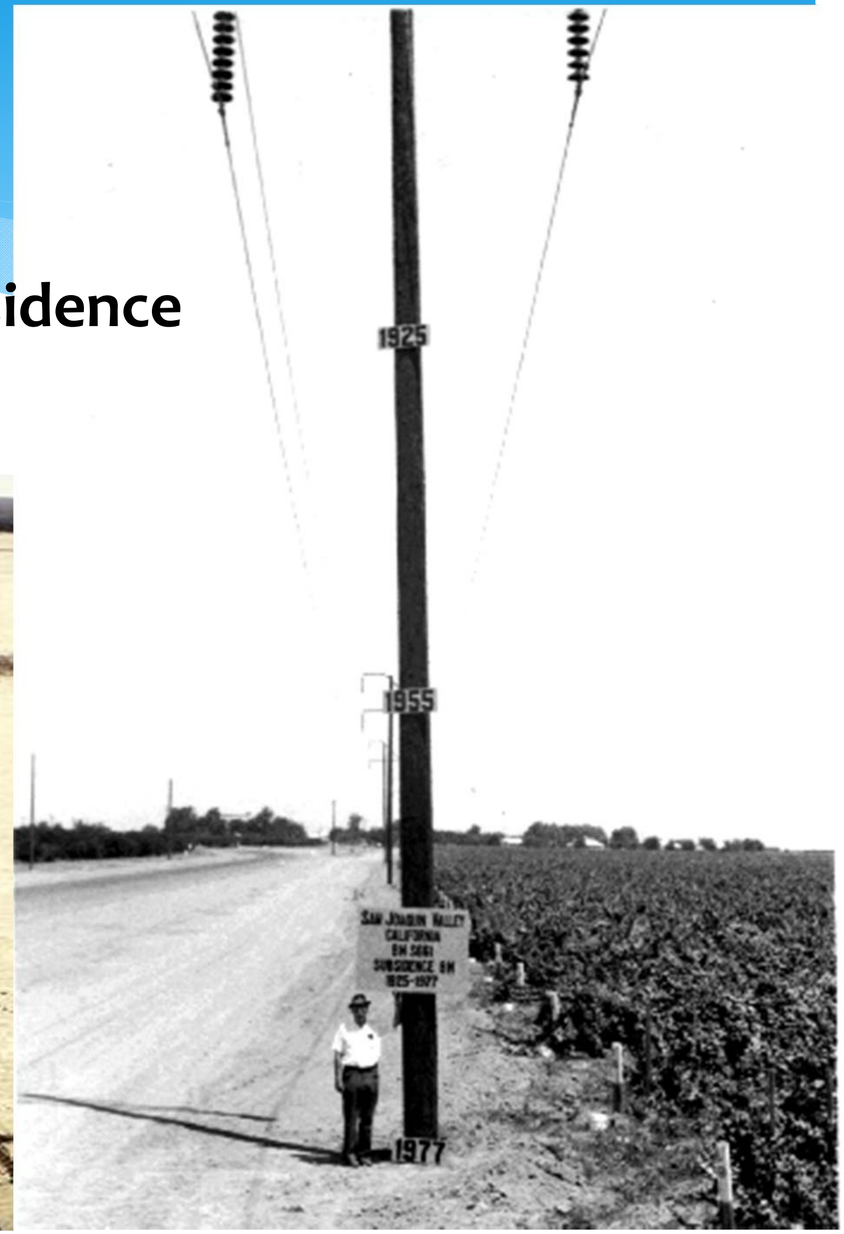
Left to itself, groundwater flow may intercept a surface water body, and flow into that body (*natural groundwater discharge, Q*).

Alternatively, it may be removed through wells for human consumption (*artificial groundwater discharge*).

Mans Interaction

* Groundwater Withdrawal
* Pollutants/Contamination

Fissures, Depressions and Land Subsidence Caused by Over Pumping



James W. Borchers/USGS

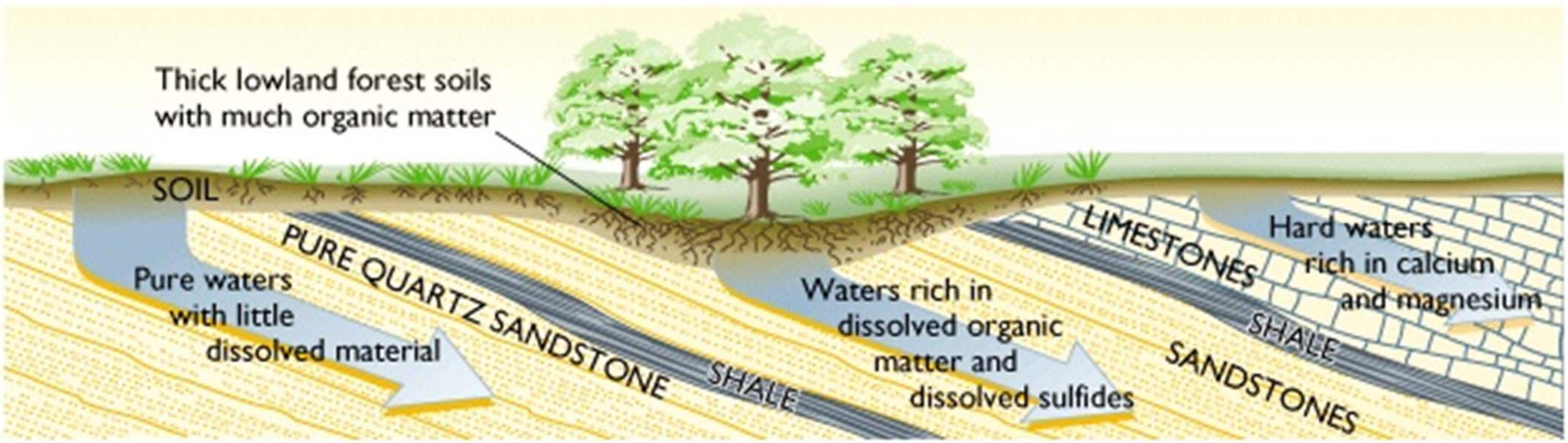
Water Quality

- **Water quality can be thought of as a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics. To determine water quality, scientist's first measure and analyze characteristics of the water such as temperature, dissolved mineral content, and number of bacteria. Selected characteristics are then compared to numeric standards and guidelines to decide if the water is suitable for a particular use.**

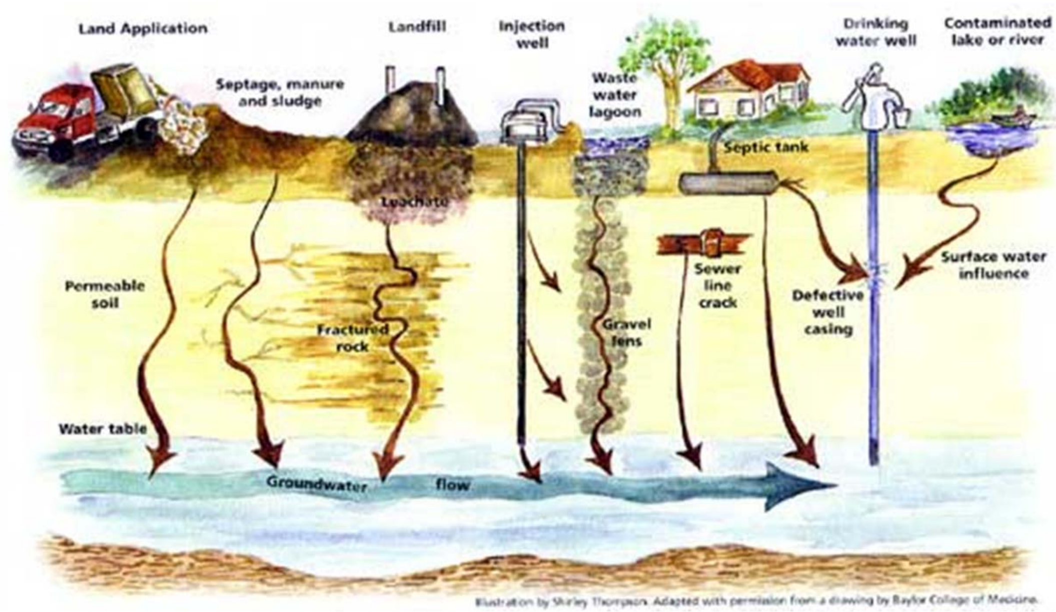
- **Some aspects of water quality can be determined right in the stream or at the well. These include temperature, acidity (pH), dissolved oxygen, and electrical conductance (an indirect indicator of dissolved minerals in the water). Analyses of individual chemicals generally are done at a laboratory.**

USGS, 2009

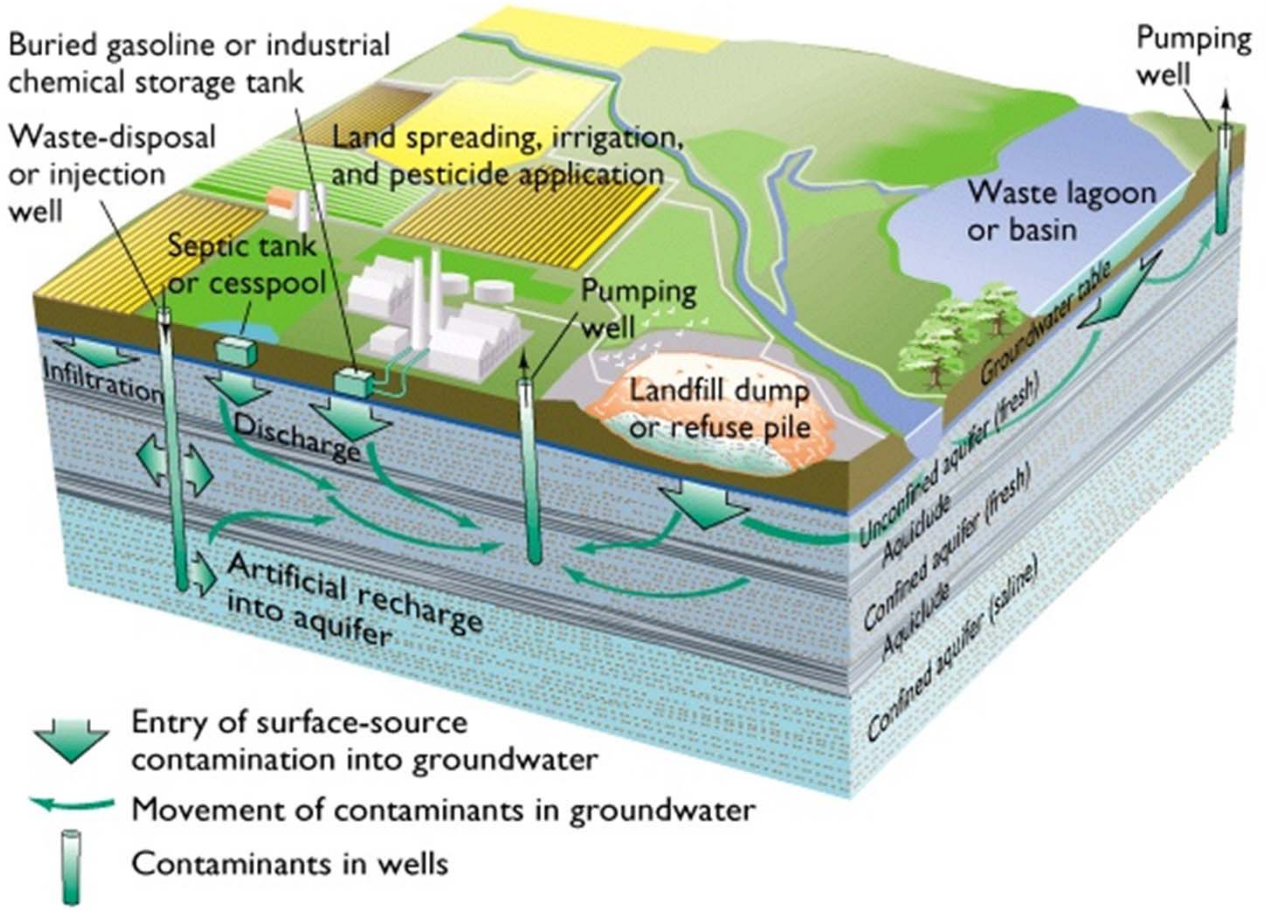
Water Quality and Groundwater Movement



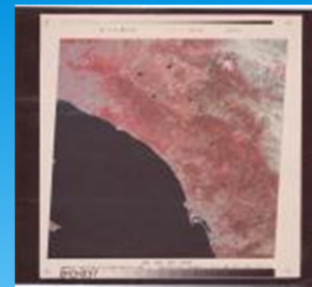
Sources of Contamination



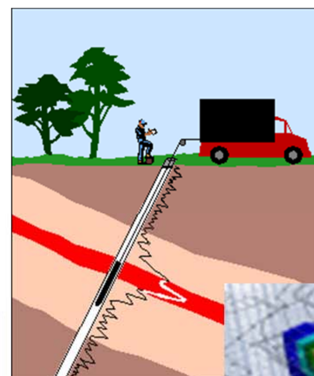
Groundwater Contamination



Investigation tools!



* Remote Sensing
* Geophysics
* Subsurface Investigations
  (monitoring wells, soil and rock borings, etc.)
* Aquifer Testing
* Water level monitoring
* Water Chemistry
* Computer Modeling



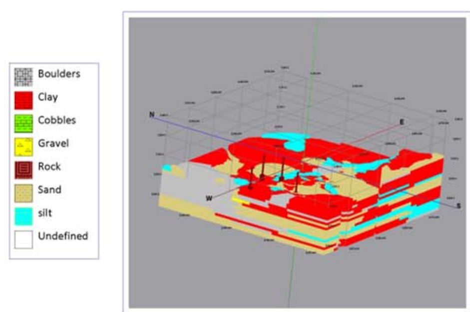
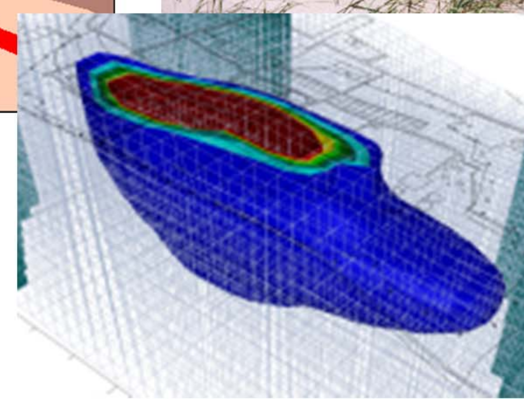
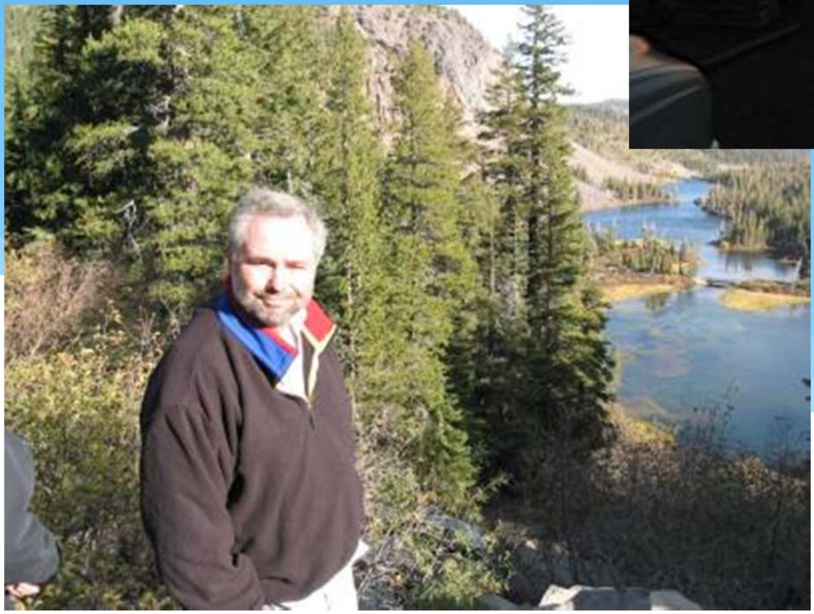


Figure 9: Lithology Model Showing All Units with Interpolated Outliers.
-X and Y Node Spacing=250 Feet
-Vertical Node Spacing=25 Feet



Conclusion

- Basic definitions
- Hydrologic Cycle
- Groundwater
- Aquifers
- How water flows
- Water Budgets
- Wells
- Water Quality
- Contamination



Questions?