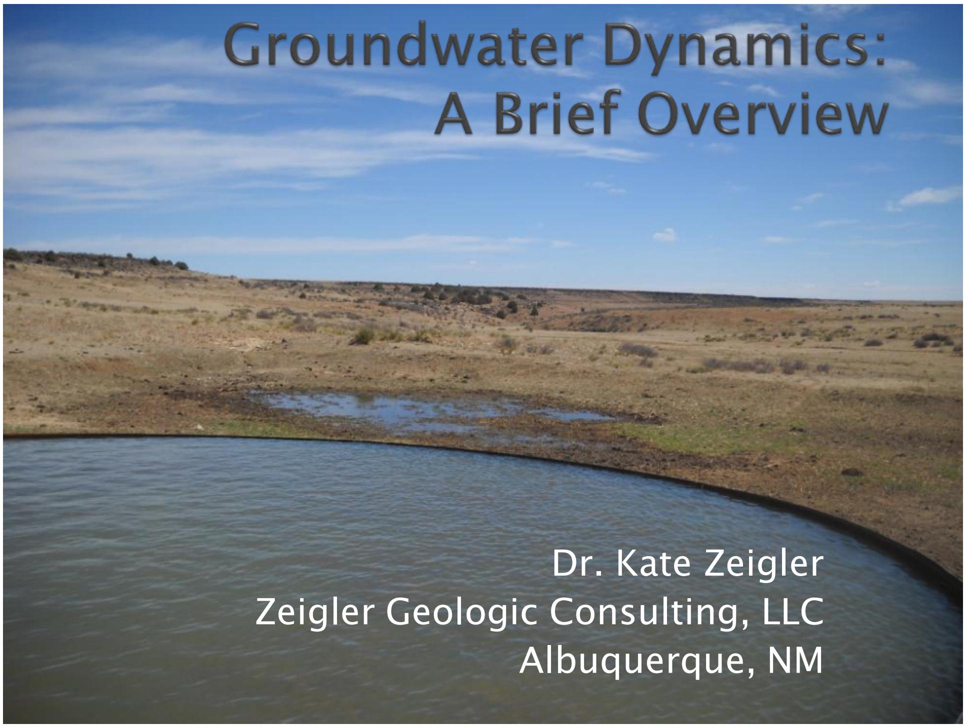
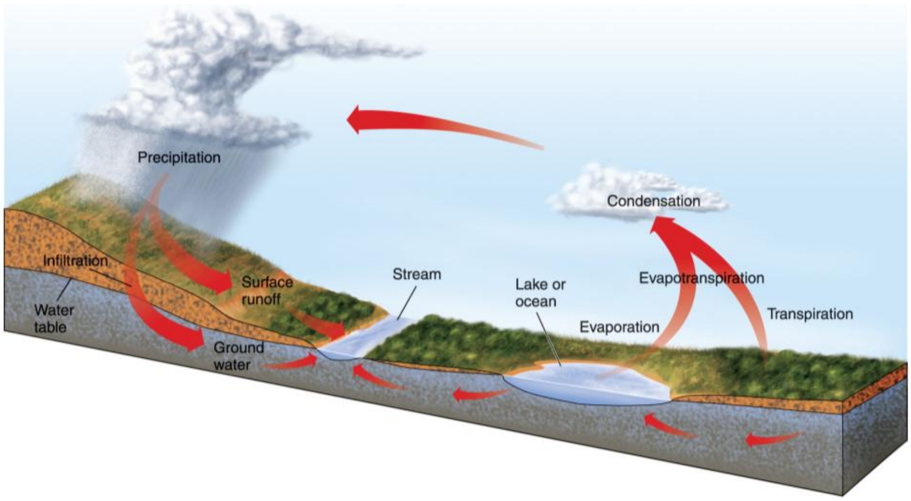


The Hydrologic Cycle

- Water moves through the Earth system along pathways in the hydrologic cycle.
- Evapotranspiration moves water into the atmosphere; precipitation brings it back to Earth.
- Once on the ground, it may flow across the surface as runoff (into stream channels) or infiltrate down into the subsurface and become part of the ground water.

The Hydrologic Cycle



Climate

- Short term versus long term:
  - Long scale changes such as glacial v. interglacial
  - Short scale changes such as El Nino
- How are these each contributing to moisture in the region?
  - How to determine timing of water entering the soil or groundwater?

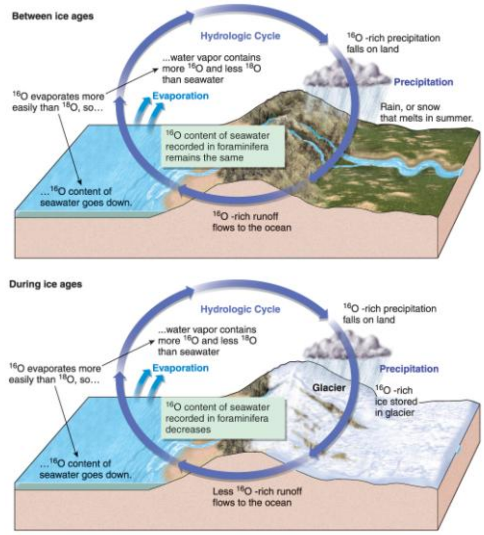
Ice Age Timing

The oxygen isotope ratios of forams (shelled microorganisms) are used to date glacial events.

The hydrologic cycle removes more O_{16} than O_{18} during ice ages, so the oceans become isotopically "light" during glacial events.

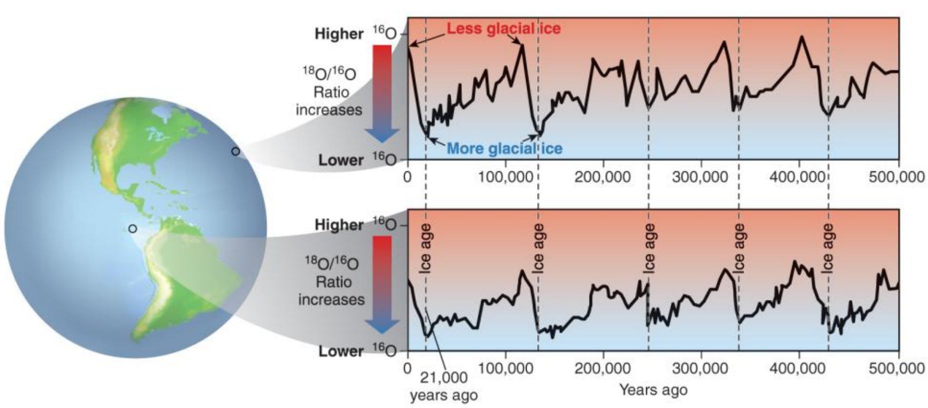
The O_{16}/O_{18} isotopic signature is recorded in the shells of carbonate-bearing organisms like forams. Foram fossils record what the oxygen isotope ratio was when they lived.

Calcite shells of tiny foraminifera record oxygen-isotope content of seawater



Ice Age Timing

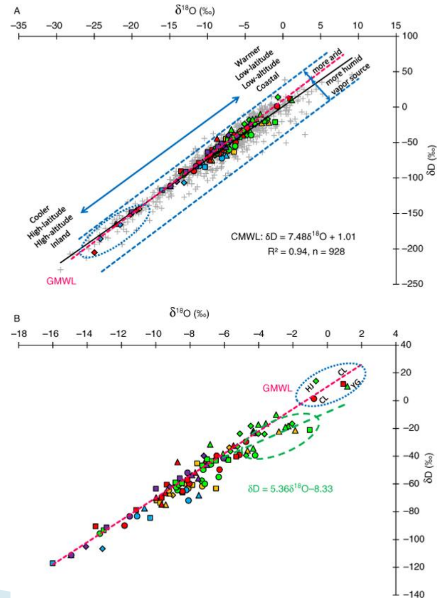
Oxygen isotope data shows a literal parade of ice ages across geologic time.



Isotopes and Precipitation

In colder waters, the concentration of ^{18}O decreases. So, relative to recent precipitation collected at weather stations, one can determine if groundwater is recharging via summer or winter precipitation.

Distance from a recharge source (e.g., Gulf of Mexico) will also lead to declines in the amount of ^{18}O in precipitation.

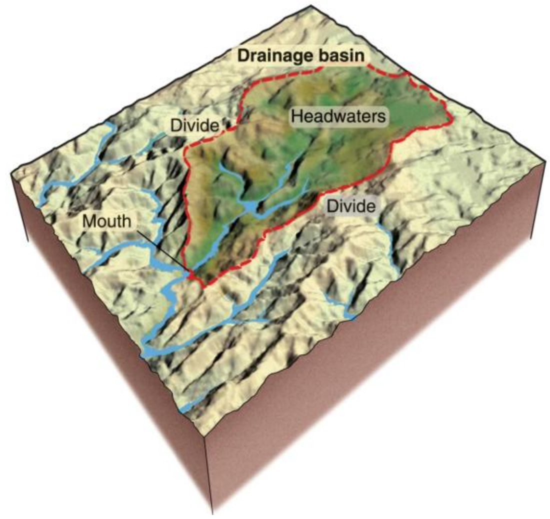


Surface Water and Soil Moisture

- Surface waters can include
  - Streams and rivers
  - Lakes and ponds
  - Can act as a source of recharge or discharge for groundwater
- Soil moisture
  - In the upper few inches of soil or weathered rock
  - Recharged via precipitation, discharged via evapotranspiration
  - Can reinforce existing climate patterns in a region

Drainage Basins

A drainage basin is the area that drains into a stream. Basins are separated by ridges called divides. Larger streams (like major rivers) contain the drainage basins of all the tributaries that feed into it.



Drainage Basins

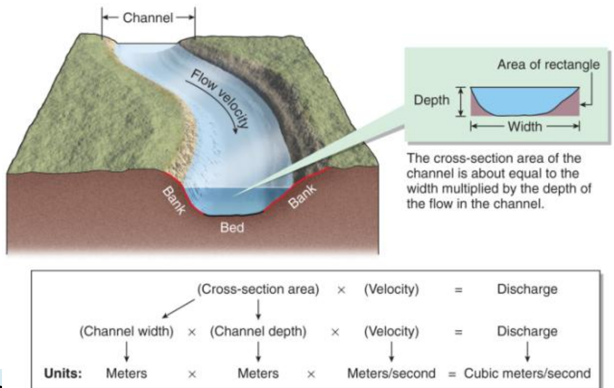
Major drainage basins of the North American continent.

The Great Basin, west of the continental divide, does not drain into a sea or ocean, but instead exits into lakes and playas.

Surface Waters: Discharge

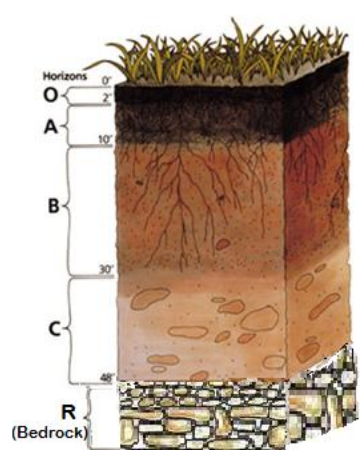
- Discharge is the amount of water that flows through a channel. Discharge is calculated by first finding the cross-sectional area of a stream and then multiplying this times the velocity. The result will always be in a measure of volume per unit time.

Geologist measuring water depth and flow velocity



Soils and Their Importance

- Soils are part of the interface between the atmosphere, surface waters and groundwater.
- Soil formation is controlled by
  - Presence/absence of living things
  - Climate
  - Topography
  - Parent material
  - Time



ROLES OF THE FIVE FACTORS OF SOIL FORMATION

- Living things: Plant roots physically break rocks into small pieces; lichen dissolves rock; burrowing animals mix the soil and help aeration
- Climate: heat and water accelerate chemical changes (so moist, temperate areas have different soils than arid, tropical, or polar areas).
- Topography: Loose soil stays in place in flat areas, allowing more thorough physical and chemical alteration of its grains. On steep slopes, the soil moves downhill before complete alteration can occur.
- Parent material: Chemical changes during soil formation depend on what minerals and rocks are present. *Example*: Calcium-rich soils generally form from calcium-rich rocks (like limestone) but not from calcium-poor rocks like granite.
- Time: When bedrock is exposed at the surface, chemical, biologic, and physical processes combine to produce a thin soil layer. Over time, the processes extend vertically downward, developing soil horizons whose position and thickness change over time.

Soil Interactions

- Atmosphere:
  - Dew begins chemical alteration
  - Rain erodes loose soil (stops alteration)
  - Temperature controls rate, extent of alteration
- Hydrosphere:
  - Water entering the ground dissolves, redistributes elements
  - Evaporation dries the soil, changes texture
- Biosphere:
  - Plants add, remove chemicals
  - Roots anchor the soil and contribute to chemical reactions
  - Roots and animals mix the soil
- Geosphere
  - Rock and sediment are the parent materials for soil
  - Geologic processes both expose and bury rock, sediments and soils

Soil Moisture

- At its most basic:
  - n*Z (ds/dt) = I–E–L

  - n = porosity
  - Z = depth of soil
  - s(t) = saturation level
  - I = infiltration of rain
  - E = evapotranspiration rate
  - L = leakage and/or deep infiltration rate

  - → soil moisture is controlled by infiltration less the evapotranspirated and "leaked" moisture, and is dependent on porosity and the thickness of the soil profile.

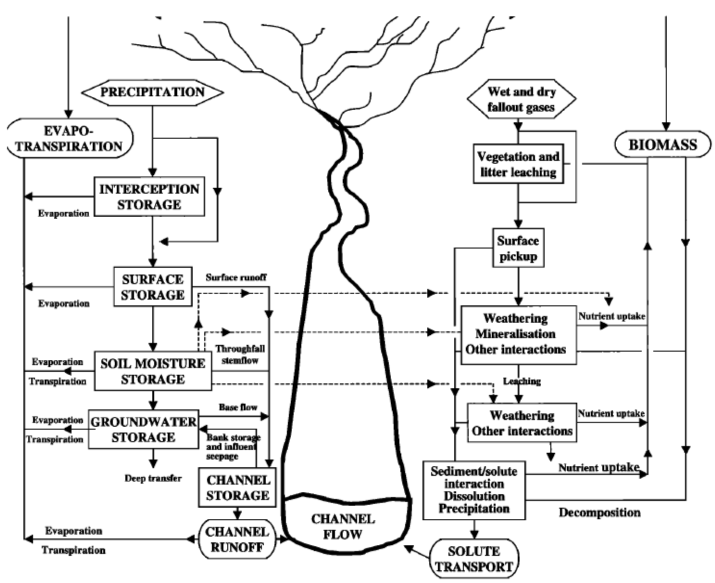
Soil Moisture and Climate

- Variability in soil texture (% sand, silt and/or clay) is closely related to soil moisture:
  - Sands: rain infiltrates quickly, but that moisture is not easily retained
    - Efficient delivery to plants
  - Clays: rain infiltrates slowly, can store larger volumes of moisture
    - Provided precipitation is sufficient – short, intense events = runoff
- In arid and semiarid areas, gravelly soils often develop a clay-rich horizon
  - Depth to and thickness of strongly influence the ability of the overall soil to absorb and store moisture.

Soil Moisture and Climate – A Hypothesis

- Appears to be a strong feedback mechanism for local climate dynamics
  - Rather than precipitation driving the cycle, soil moisture may be more in charge
  - Lack of soil moisture reinforces drought conditions whereas abundant soil moisture reinforces wet conditions

The Sum of a Drainage Basin



Groundwater: Where Is It Found?

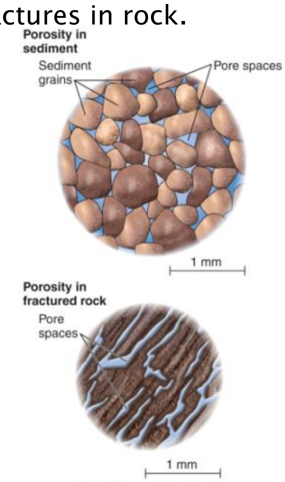
- Fractures, joints, and other open spaces below the surface are collectively known as pores.
- Porosity is the percentage of the total volume of the soil or rock that consists of pores.
- Ground water is water that soaks into soil and rock at the surface, percolates through fractures, pores, and other open spaces, and resides for some period in these subterranean zones.

Porosity and Permeability

The porosity of Earth materials varies according to the type of pore space and material. Generally, pores are small (a few mm or less) and found in between unconsolidated grains, and as fractures in rock.

TABLE 17.1 Example Porosity Ranges for Different Earth Materials

Material	Typical Porosity Range
Unconsolidated sediment	
Well-sorted sand and gravel	25–50%
Mixed sand and gravel	20–35%
Silt and clay	30–60%
Rock	
Shale	0–10%
Sandstone	3–30%
Limestone and dolostone	1–30%
Plutonic and metamorphic rocks	0–5%
Volcanic rocks	1–50%

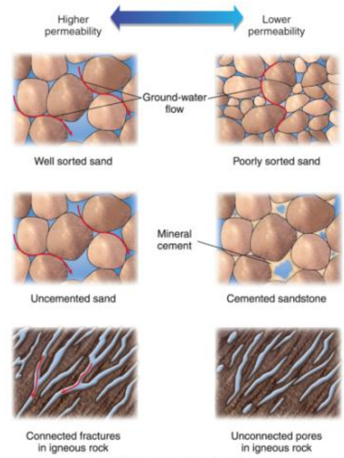


Porosity and Permeability

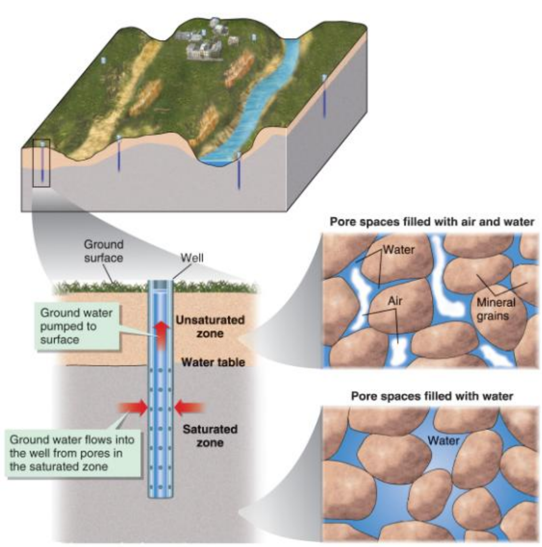
Water flows through pores. Its ability to do so is a measure of the permeability of the substance.

Permeability is literally the ability for water to flow through a porous material.

For geologic materials, what matters is the connectedness of the pores, and to an extent their diameter or size.



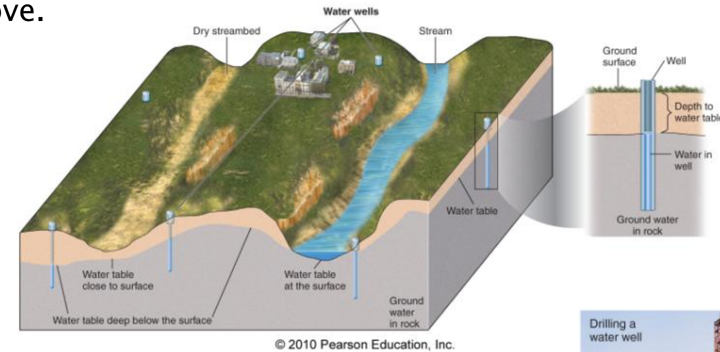
The Water Table

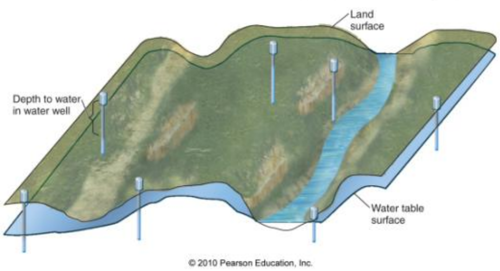


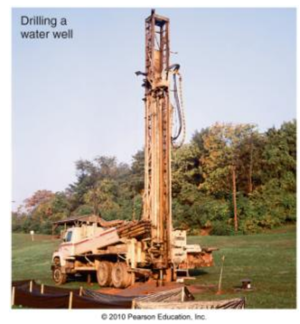
The water table: The water table separates the **saturated zone**, or the region underground where all pores are completely filled with water, from the **unsaturated zone**, above which contains at least some air in the pores.

It is the unsaturated zone from which most plants draw water. Soil feels moist because a thin film of water adheres to the surfaces of small particles due to minute electrical charges.

The water table is the top surface of ground water. It has a surface that mimics the topography of the ground surface above.







Water Table Variations

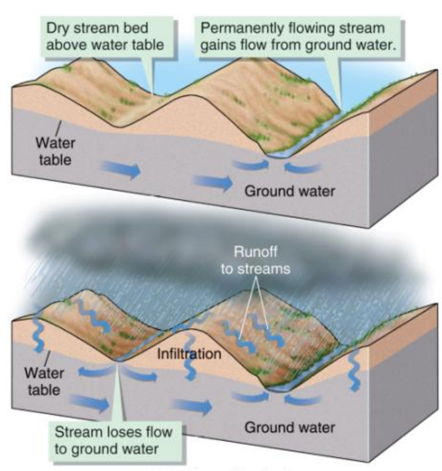
Changes in water table level over time

Discharge: water that leaves

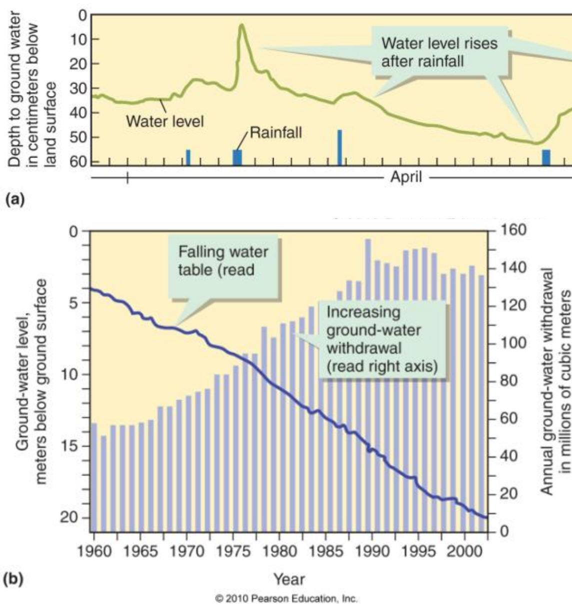
Recharge: water added to the ground water system

Streams may either gain (receive ground water) or lose (contribute to recharge)

This is why some streams flow year-round.



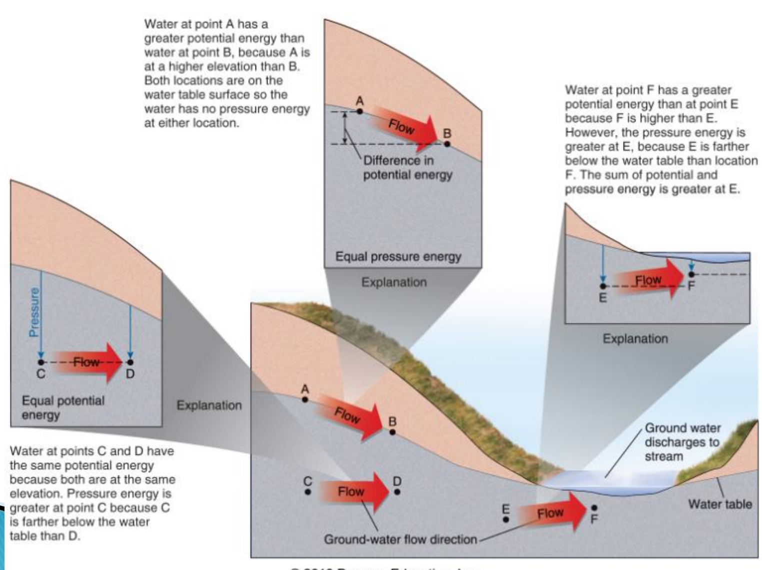
The Water-Table Level Changes Through Time



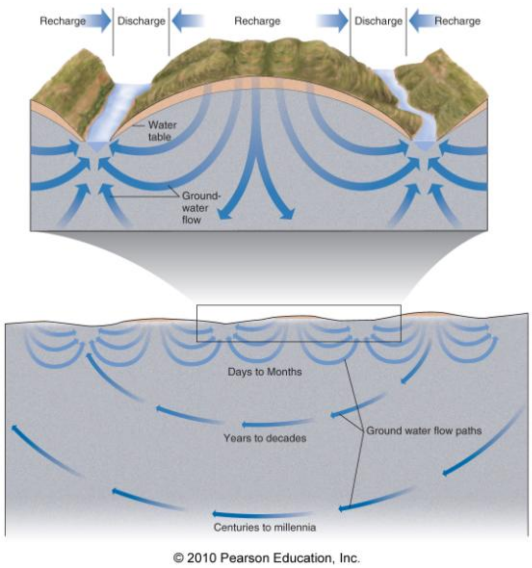
(A) Graph showing expected seasonal change in ground water level for a shallow well in NV.

(B) Shows ground water depletion and associated increased withdrawal over time in Albuquerque, NM.

Ground Water Flow



Groundwater Flow



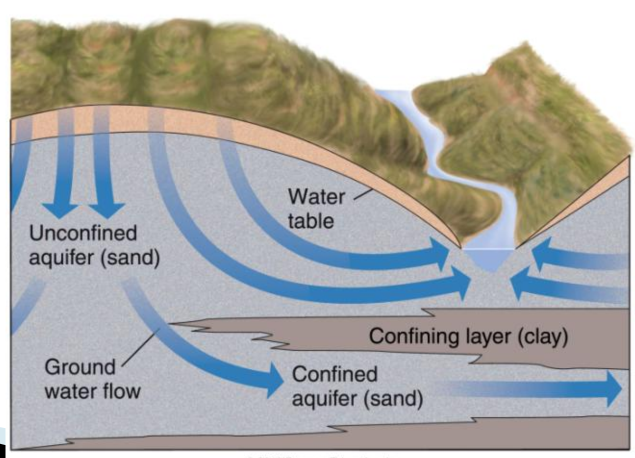
Where ground water flows

Towards the streams, pressure to push ground water in that direction is less than trying to push the water downward farther into the aquifer. So the ground water curves and comes back up towards the stream.

In ground water systems, deeper = slower.

Groundwater Flow

In areas with impermeable layers, ground water can be trapped between these confining layers. Thus, some areas have multiple aquifers that are effectively ***segregated*** from one another.

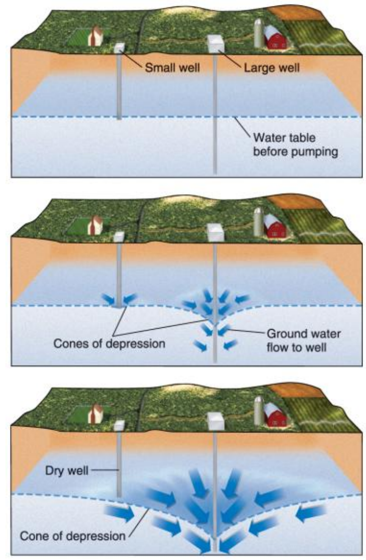


Groundwater Flow

Cones of depression form because a pumping well withdraws water faster than the recharge rate and the aquifer material offers some resistance to flow.

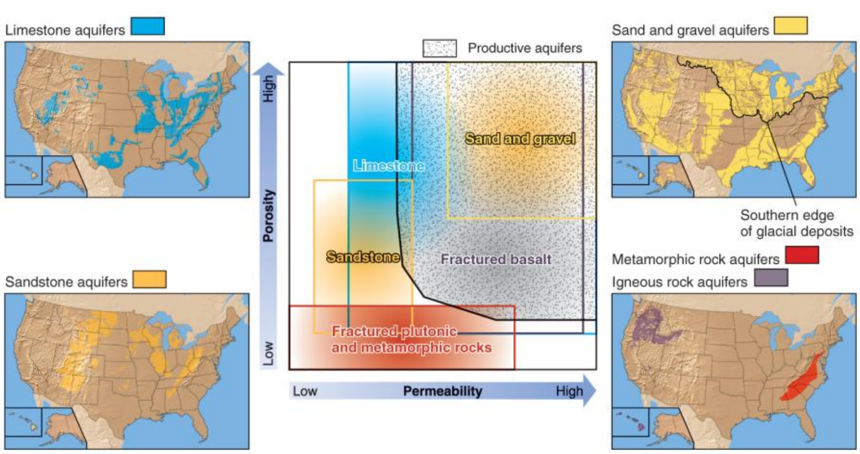
When the water flowing towards the well equals the withdrawal, the cone stabilizes.

As long as there is a pumping well, there will be a cone of depression.

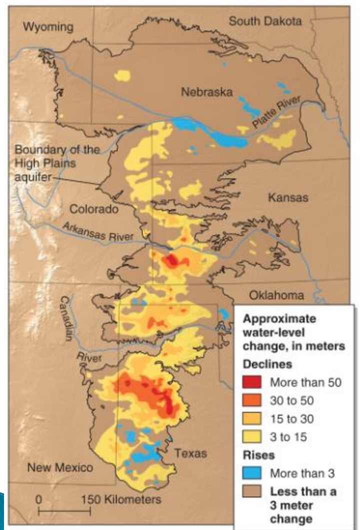


Aquifers

Aquifer: a body of ground water with sufficient porosity and permeability to provide ***useful*** quantities of water to wells or springs. The best aquifers have high porosity and permeability.

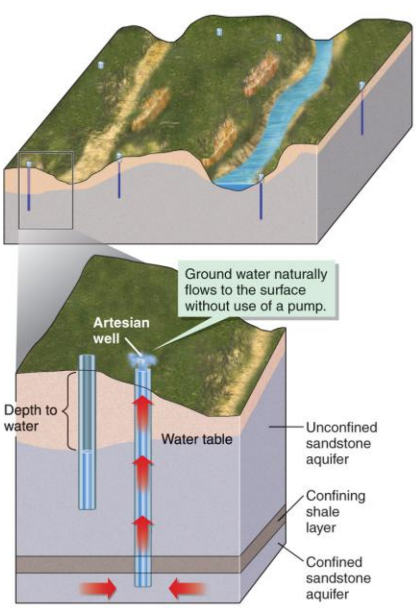


Aquifers



- The High Plains aquifer:
  - Both withdrawal and recharge streams used in an arid region of agriculture
  - Water level has declined over most of the aquifer
  - Feeds approximately 170,000 wells in the Texas/New Mexico end alone

Aquifer Types: Confined

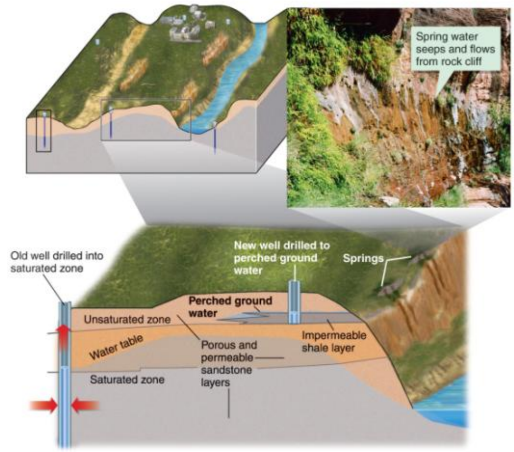


- **Confined** aquifers are under pressure.
- Water in wells drilled into confined aquifers generally rises.
- How much it rises depends on the pressure, and thus the energy difference.
- This is a function of the elevation of the recharge zone relative to the well, and the distance between them.

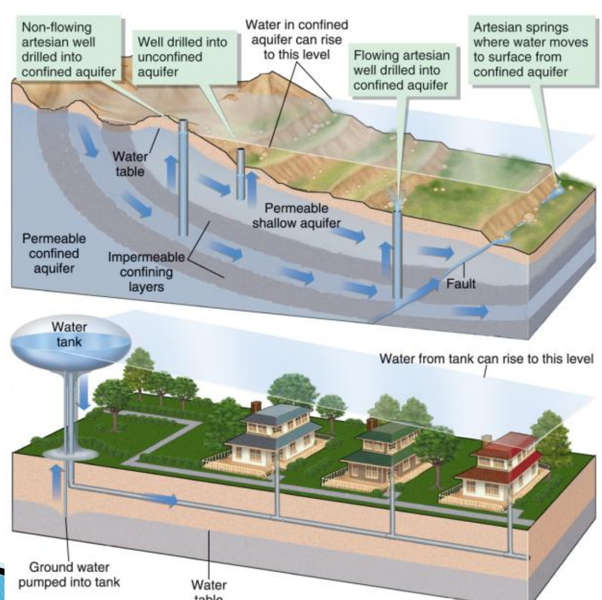
Aquifer Types: Perched

Perched ground water

Earth's crust is not the same everywhere. There are areas where impermeable layers overlain by porous layers trap pockets of water near the surface, or even at high elevation. These bodies of ground water are called perched ground water.

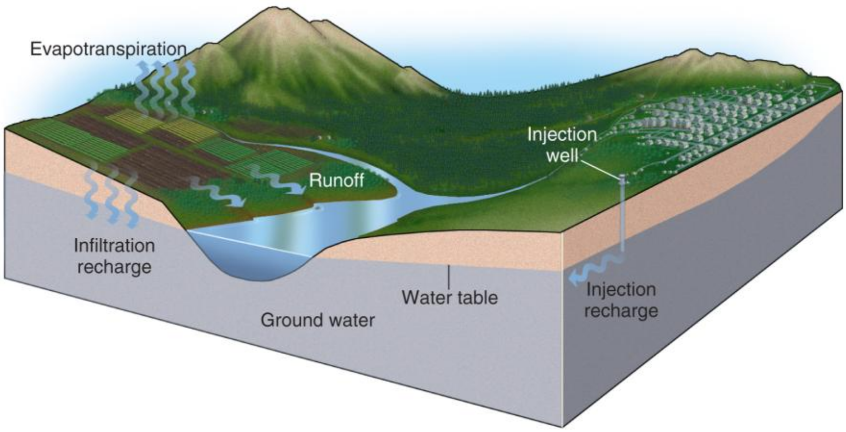


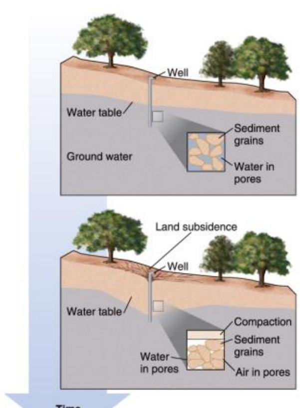
Aquifer Types: Artesian



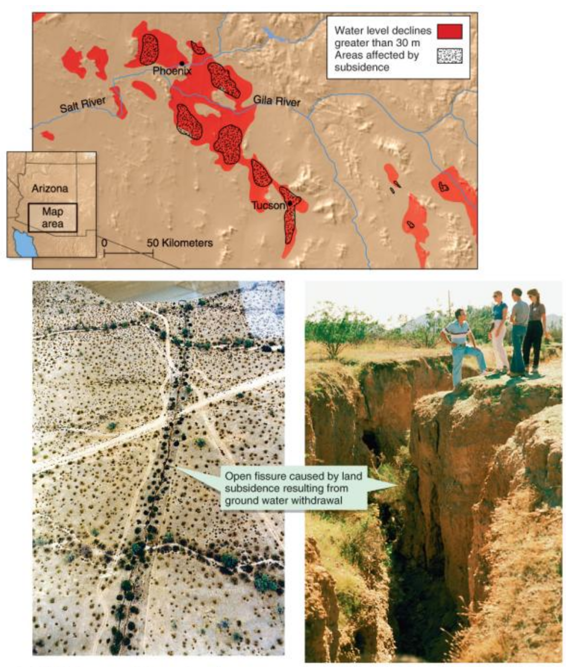
Artificial Recharge

Artificial recharge: the practice of using injection wells or infiltration ponds to assist ground water recharge.





Subsidence caused by ground water withdrawal. Compaction of pore space translates to surface elevation decrease and open fissure formation.



The Catch …

- Moisture partitioning:
  - How much goes into the soil?
    - Evapotranspiration of soil moisture
  - How much goes from the soil into aquifer units?
    - Data from Union County suggests: not much
- Data collection
  - Therefore: partition our data
    - Soil-atmosphere "box"
    - Deeper aquifer "box"

Data Sets

- A list of useful data sets for groundwater studies
  - Static water levels (biannual)
  - Water chemistry
  - ^{14}C and/or tritium age data
  - Subsurface geologic data
    - From petroleum and water wells
  - Surface geologic data
    - Detailed geologic maps