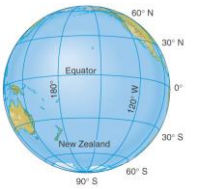
Water, Weather And Climate Systems

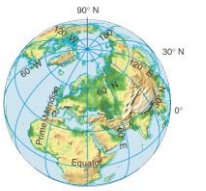
Water Resources

Water Hemisphere

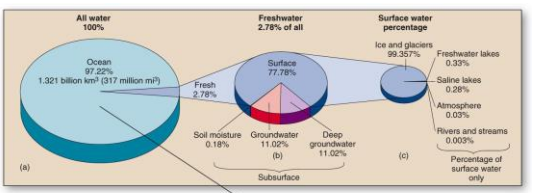


Approximately 71% Of Earth's Surface Area Is Covered By Water

Land Hemisphere



Ocean and Freshwater Distribution



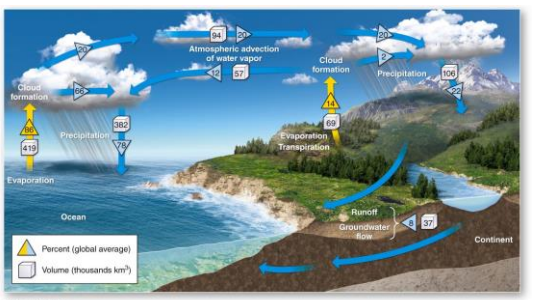
Ocean	Earth's Ocean Area (%)	*Area (km^2 [mi^2])	*Volume (km^3 [mi^3])	Mean Depth of Main Basin (m [ft])
Pacific	48	179,670 (69,370)	724,330 (173,700)	4280 (14,040)
Atlantic	28	106,450 (41,100)	355,280 (85,200)	3930 (12,890)
Indian	20	74,930 (28,930)	292,310 (70,100)	3960 (12,900)
Arctic	4	14,090 (5440)	17,100 (4100)	1205 (3950)

*Data in thousands (000): includes all marginal seas.

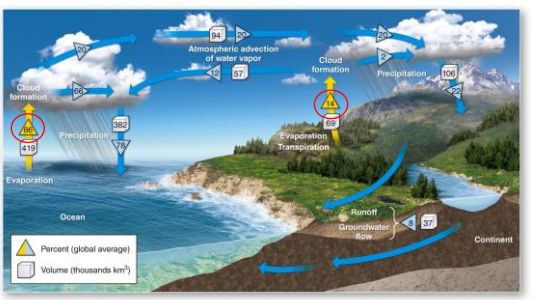
The Hydrologic Cycle

- The cyclical movement of water through the various reservoirs is represented by the hydrologic cycle
- Water is transferred from one reservoir to another through:
  - Evaporation
  - Precipitation
  - Ground infiltration
  - Surface runoff
  - Transpiration

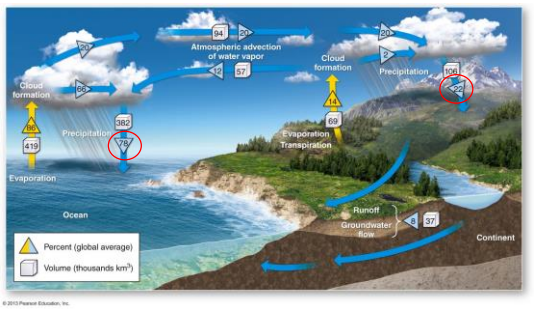
Hydrologic Cycle Model



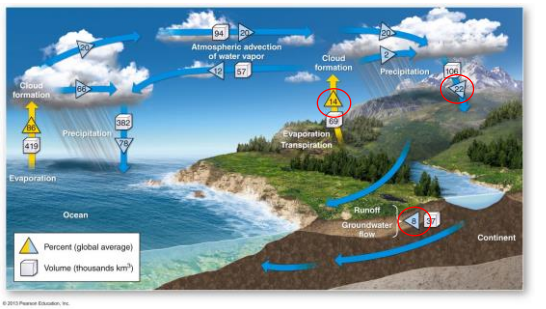
Evaporation: 86% from ocean + 14% from land = 100%



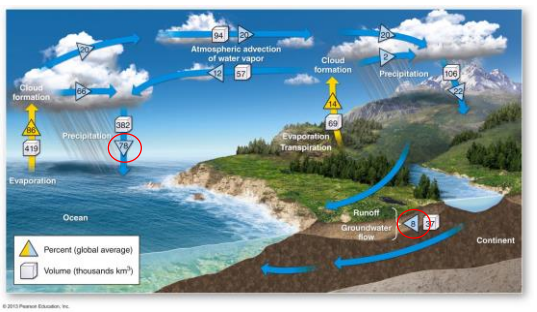
Precipitation: 78% over ocean + 22% over land = 100%



Land: 14% evapotranspiration + 8% runoff/groundwater = 22% total ppt



78% ppt over ocean + 8% runoff/groundwater = 86% returned to ocean



Earth's Water_HydroCycle

Surface Water On Land

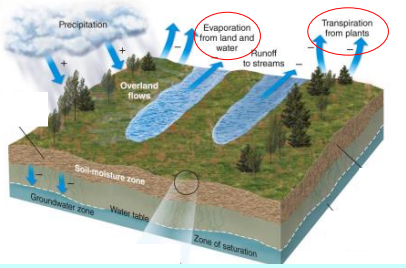
- **22% of all precipitation on Earth falls over land:**
  - **Over half is returned to the atmosphere via evapotranspiration**
  - **The remainder flows to the sea as runoff**

Precipitation in North America

Evapotranspiration

- **Evapotranspiration is the combination of evaporation and transpiration:**
  - **Evaporation: Net movement of water molecules away from a wet surface into air that is less saturated**
  - **Transpiration in plants: Outward movement of water through small openings (stomata) in the underside of leaves**

Over Half Of All Precipitation On Land Is Returned To The Atmosphere Via Evapotranspiration

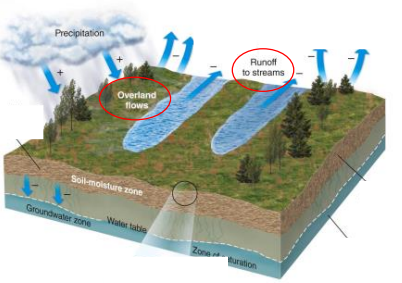


Evapotranspiration over land accounts for 14% of the entire hydrologic cycle

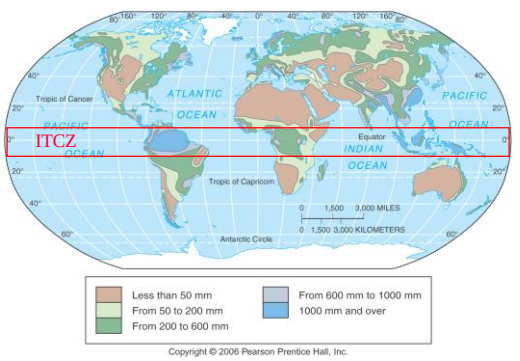
Runoff

- **Precipitation over land that is not returned to the atmosphere via evapotranspiration flows back to the sea as runoff**
- **Runoff accounts for 8% of the entire hydrologic cycle**
- **Runoff follows two basic pathways to the sea:**
  - **Overland flow (95%)**
  - **Subsurface flow as groundwater (5%)**

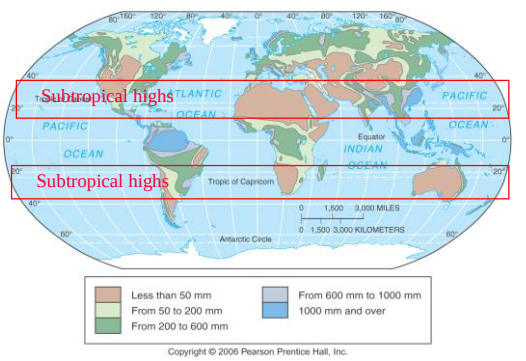
95% Of All Runoff Occurs As Overland Flow And Runoff To Streams



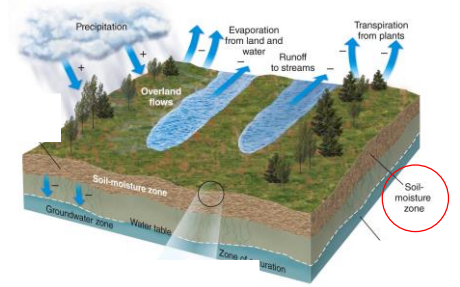
Annual River Runoff



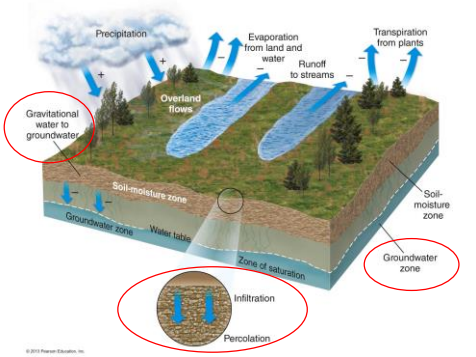
Annual River Runoff



5% Of All Runoff Percolates Through Underlying Soil And Bedrock To The Groundwater System



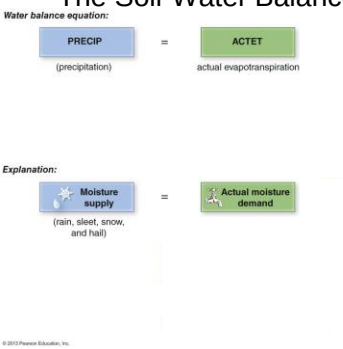
Groundwater System



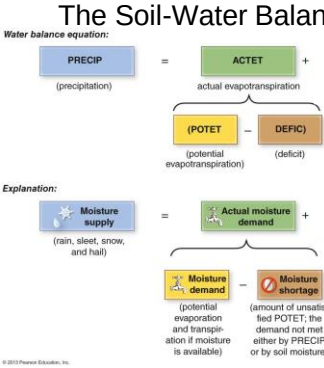
The Water-Balance Equation

- The water budget is a portrait of the hydrologic cycle at a specific site or area
- Input is precipitation:
  - Precipitation at a site is measured using rain gauge
- Precipitation input must be balanced by output
- Outputs Include:
  - Actual Evapotranspiration (ACET) is the net outward movement of water molecules away from land and plants
  - Potential Evapotranspiration (POTET) is the water that would evaporate and transpire under optimum moisture conditions (when enough moisture is available)

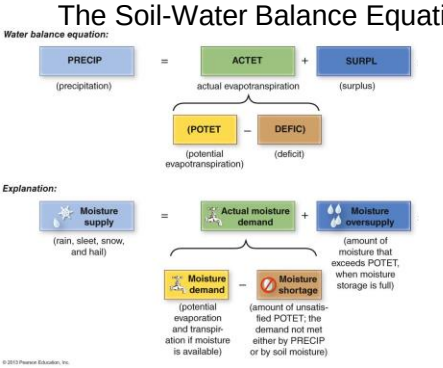
The Soil-Water Balance Equation



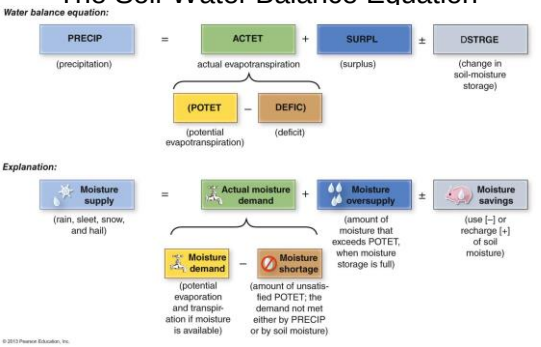
The Soil-Water Balance Equation



The Soil-Water Balance Equation



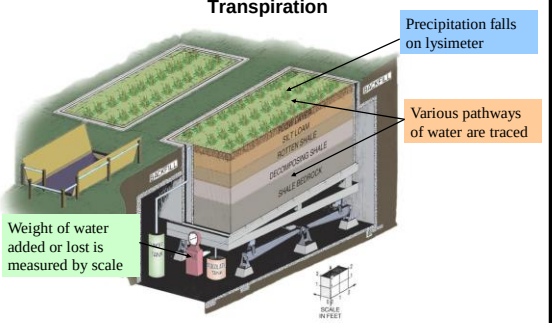
The Soil-Water Balance Equation



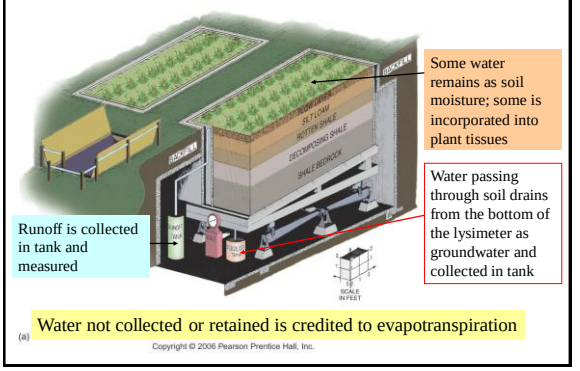
Determining POTET

- Potential evaporation is easily measured using an evaporation pan:
  - As evaporation occurs, water in measured amounts is replaced in the pan so that no shortage occurs
- POTET can also be measured with a lysimeter, which employs a buried tank opened at the surface
- A deficit occurs if there is not enough precipitation or moisture to meet demand
- A surplus occur when there is an oversupply of water

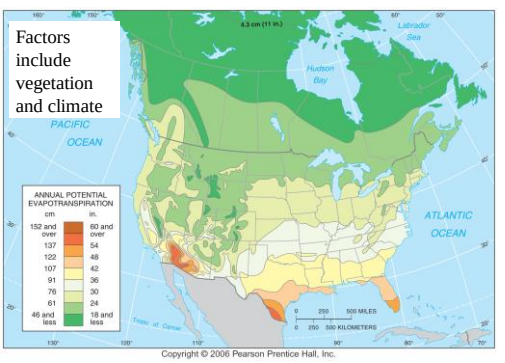
A Weighing Lysimeter For Measuring Evaporation And Transpiration



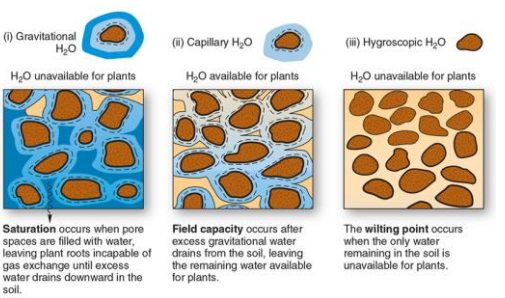
A Weighing Lysimeter For Measuring Evaporation And Transpiration



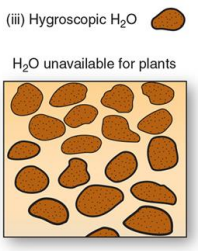
Potential Evapotranspiration (Water Demand)



Types of Soil Moisture

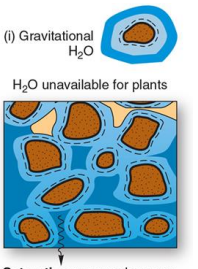


Hygroscopic water: thin molecular layer of water tightly bound to soil particles but not available for moisture demands



The **wilting point** occurs when the only water remaining in the soil is unavailable for plants.

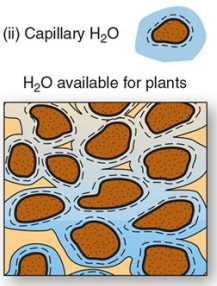
Gravitational water is excess water that percolates downward from the shallower capillary zone to the deeper groundwater zone



Saturation occurs when pore spaces are filled with water, leaving plant roots incapable of gas exchange until excess water drains downward in the soil.

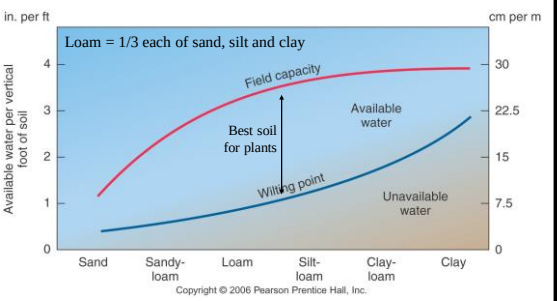
Capillary water is held in soil by surface tension and hydrogen bonding and is generally accessible to plant roots:

- Field capacity is the maximum amount of water that that can be retained in pore spaces for plants



Field capacity occurs after excess gravitational water drains from the soil, leaving the remaining water available for plants.

Soil-Moisture Availability



Sample Water Budget For Kingsport, Tennessee

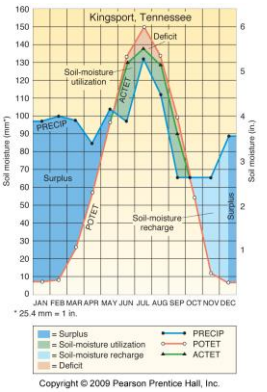
PRECIP: Moisture supply available

POTET: Amount of water that would evaporate and transpire under optimum moisture conditions

ACET: Actual evapotranspiration

If precipitation exceeds the amount of water required for POTET, water surplus occurs

If ACTET is less than POTET, then a water deficit will occur



Sample Water Budget For Kingsport, Tennessee

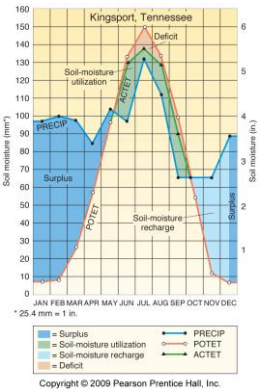
PRECIP: Moisture supply available

POTET: Amount of water that would evaporate and transpire under optimum moisture conditions

ACET: Actual evapotranspiration

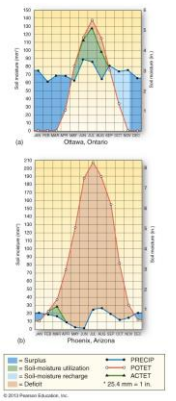
What accounts for the higher POTET and ACET in summer vs winter?

Higher temperatures and greater plant activity in the summer



Sample Water Budgets

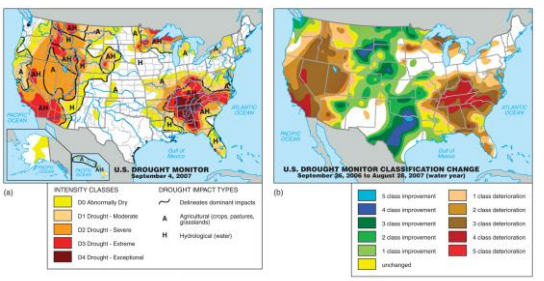
Which area is most likely to experience desert conditions?

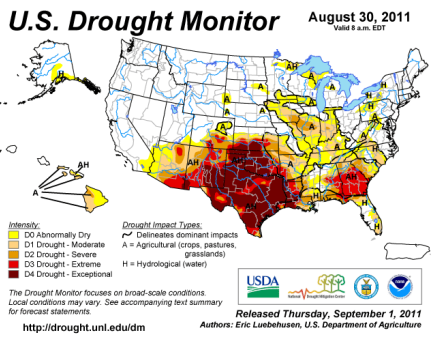


Drought

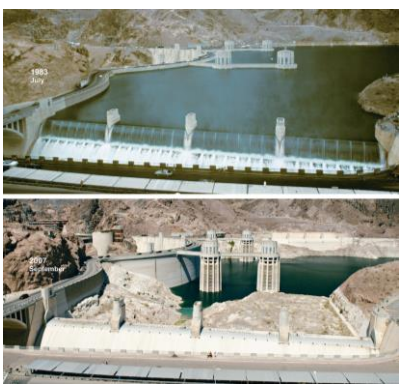
- Not enough water available to meet demand
- Several types of drought:
  - Meteorological drought: Lower precipitation, higher temperatures and reduction in soil moisture
  - Agricultural drought: Changes in soil moisture and weather as they affect crop yields
  - Hydrologic drought: Reservoir levels drop, stream flow decreases and groundwater mining increases
  - Socioeconomic drought: Water rationing, wildfires, and other problems affecting the economy and society
- Recent droughts around the world (e.g. Australia and southwestern US) possibly linked to global climate change

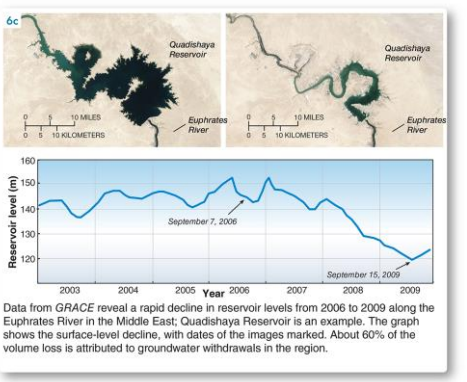
U.S. Drought Monitor





Hoover Dam And Decade-long Drought In The Western United States





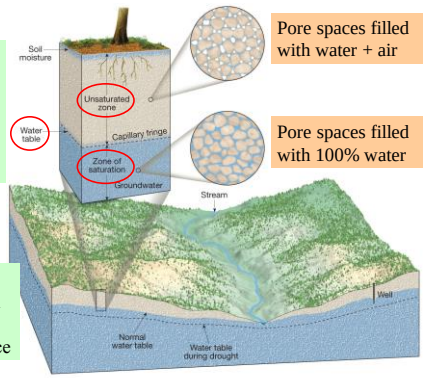
Groundwater Resources

- Groundwater Profile and Movement
- Aquifers, Wells, and Springs
- Overuse of Groundwater
- Pollution of Groundwater

Groundwater

- Groundwater is water found in the pores of soil and sediment, plus narrow fractures in bedrock
- Groundwater is the largest reservoir of fresh water that is readily available to humans:
  - About 50% of U.S. population derives a portion of its freshwater from groundwater sources
  - Groundwater supplies up to 100% of freshwater in some rural areas

The water table is the upper surface of the saturated zone

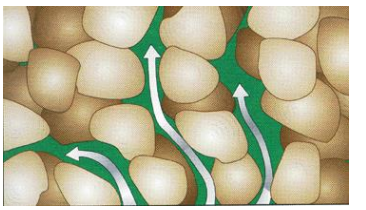


Pore spaces filled with water + air

Pore spaces filled with 100% water

Groundwater occurs within ~4 km of the Earth's surface

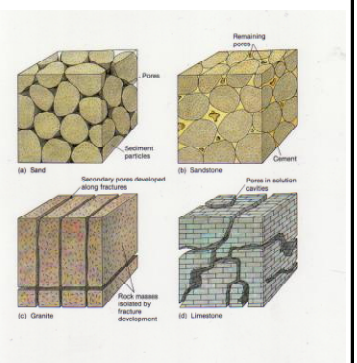
How Groundwater Moves



- Groundwater percolates through soil, regolith and rock through open pore spaces or fractures
- Water moves slowly through pores along parallel, thread-like paths

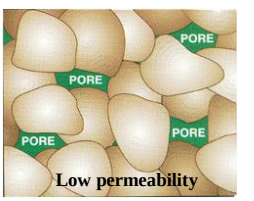
Porosity

- Porosity is the percentage of open spaces within a given volume of regolith or rock
- Porosity in most rocks usually less than 20% but can be as high as 50%



Permeability

- Permeability is a measure of how easily a rock allows fluids to pass through it
- Sandstones are typically more permeable than clays



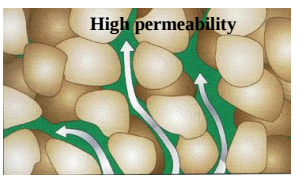
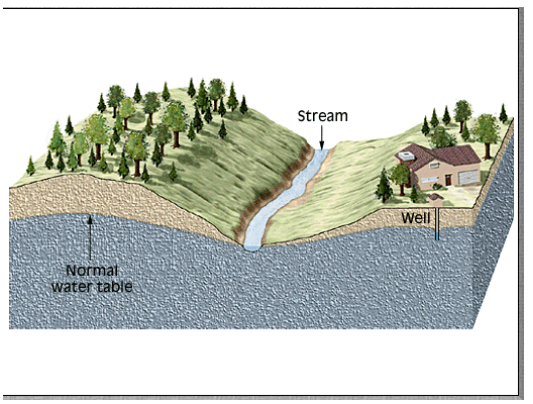


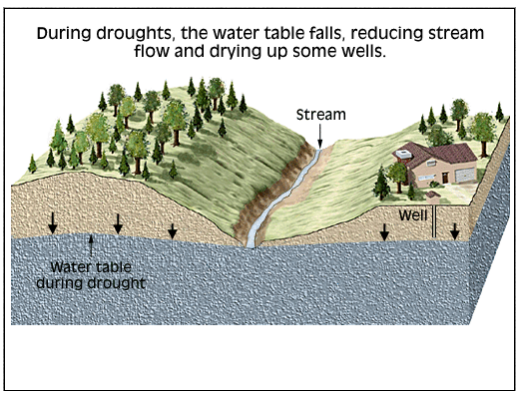
Table 12.2 Porosity and Permeability of Aquifer Rock Types

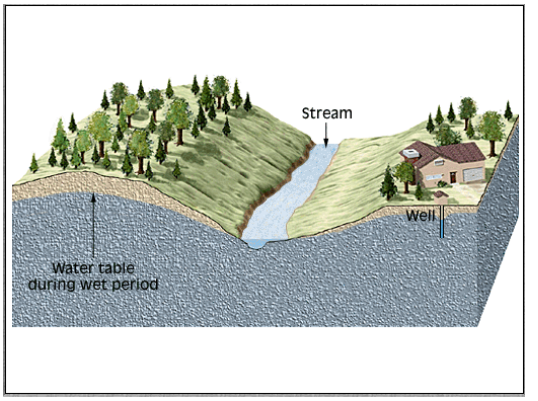
Rock Type	Porosity (Pore Space That May Hold Fluid)	Permeability (Ability to Allow Fluids to Pass Through)
Gravel	Very high	Very high
Coarse- to medium-grained sand	High	High
Fine-grained sand and silt	Moderate	Moderate to low
Sandstone, moderately cemented	Moderate to low	Low
Fractured shale or metamorphic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

Characteristics of Groundwater Table

- **The groundwater table:**
  - **Intersects the land surface at lakes, marshes, springs, and streams**
  - **Somewhat imitates the overlying land surface**
  - **May drop during dry seasons**
  - **Rises after heavy rainfalls**

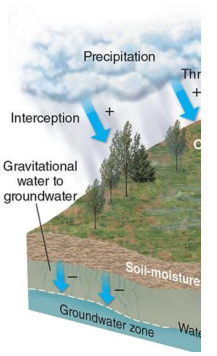






Recharge and Discharge Areas

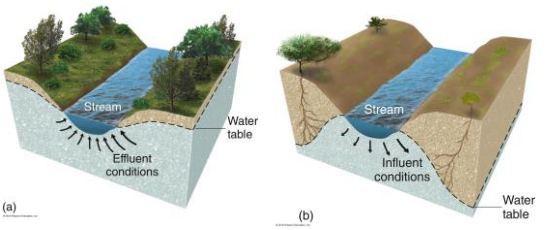
- Recharge of groundwater occurs in areas where precipitation seeps downward to the saturation zone:
  - In areas of abundant rainfall, the recharge area may encompass the entire landscape beyond stream channels
  - In arid regions, recharge occurs beneath an influent stream
- Groundwater then flows to discharge areas



Groundwater and Streamflow

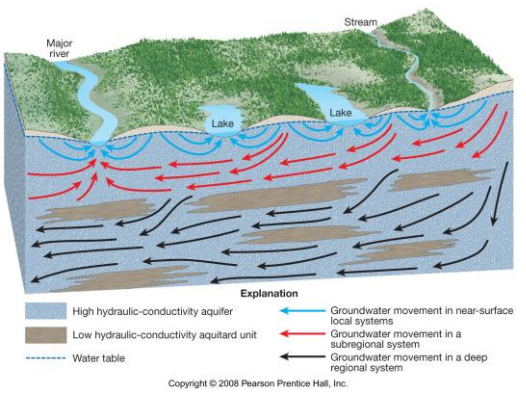
Humid: Stream is site of groundwater discharge

Arid: Stream is site of groundwater recharge



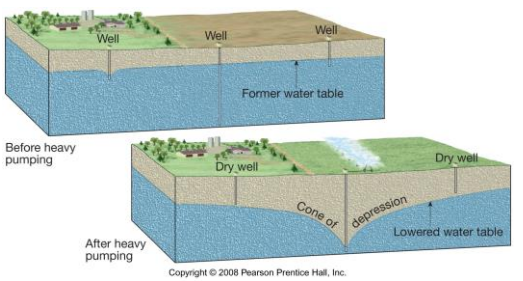
Recharge and Discharge

- **The time water takes to move through the ground from recharge to discharge depends on:**
  - **Permeability of material**
  - **Travel distance**
  - **Path of flow**
- **Can range from days to thousands of years**



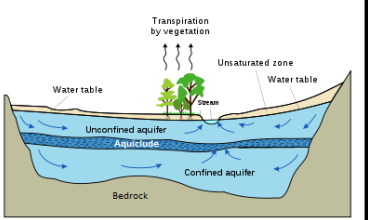
Water Table Formation

A Well Supplies Water When It Penetrates the Water Table and Enters the Zone of Saturation



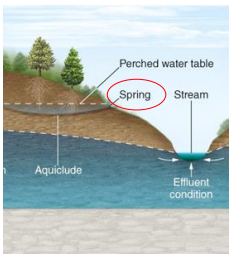
A cone of depression forms when the rate of water withdrawal exceeds the rate of local groundwater flow

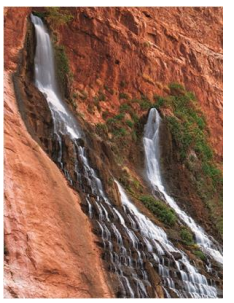
Aquicludes and Aquifers



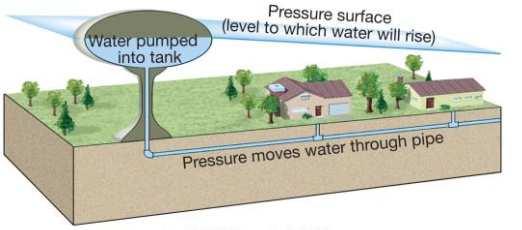
- Aquiclude: Rock layer (e.g. shale) does not transmit water in usable amounts
- Aquifer: Highly permeable rock such as sandstone or porous limestone within the zone of saturation
- Aquifers can be:
  - Unconfined (not bound by aquicludes)
  - Confined (bounded above and below by aquicludes)

Springs Occur Where Groundwater Emerges At The Surface





Hydrostatic Pressure Is The Weight That An Overlying Column Of Water Would Exert At A Particular Depth



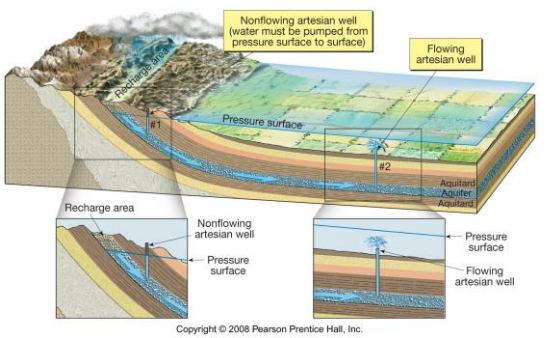
Water under hydrostatic pressure seeks to rise to the same height as its pressure (potentiometric) surface

Artesian Systems

- **Artesian system occurs where groundwater under pressure rises above the level of an aquifer**
- **Two conditions are necessary:**
  - **Aquifer is inclined with one end receiving water (recharge area)**
  - **Aquifer is confined with aquicludes above and below**

Artesian Wells

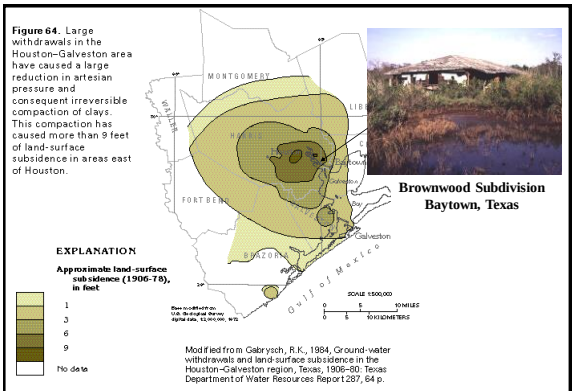
- **In artesian wells, water rises on its own without pumping**
- **Two types of artesian wells:**
  - **Nonflowing occurs when pressure surface is below ground and water does not reach surface**
  - **Pressure surface above ground creates a flowing artesian well**



Flowing Artesian Wells

Changes in the Water Table With Time

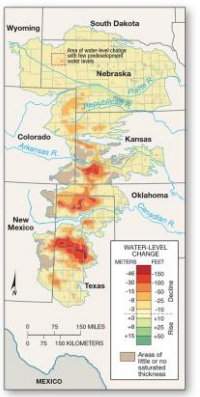
- **In regions where withdrawal of water exceeds recharge, the water table will gradually drop**
- **If the water table is allowed to drop significantly, land subsidence will result**



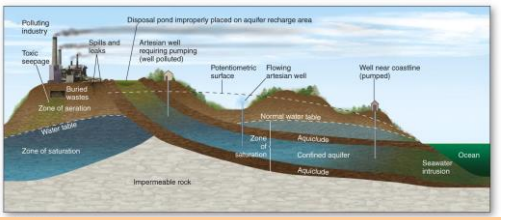
Brownwood Subdivision
Baytown, Texas

High Plains Aquifer

- Located in a region with modest amounts of precipitation, but high evaporation rates:
  - Little rain water available to recharge aquifer
- 170,000 wells irrigate ~65,000 sq/km of land
- Intense irrigation depleted groundwater in many areas:
  - 62% of total decline occurring in Texas



Groundwater Contamination



Groundwater can be contaminated by:

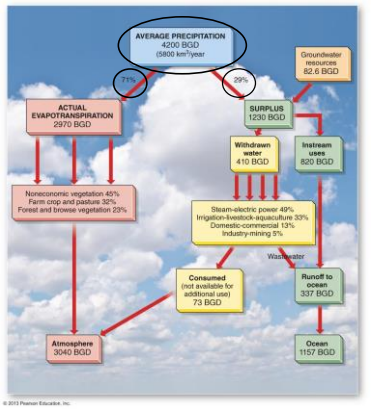
- Drainage from septic tanks, broken sewers and barnyards
- Agricultural poisons
- Highway salts
- Buried hazardous wastes
- Invading seawater along coastal areas

Contaminated Wastewater From Fracking Operations

Our Water Supply

- **Water supply in the United States comes from surface and groundwater sources**
- **In some areas like New England, water supply far exceeds usage**
- **In other areas like the western U.S., water shortages result**

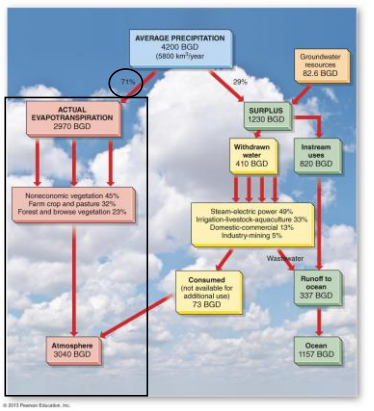
U.S. Water Budget



BGD: Billions of gallons a day

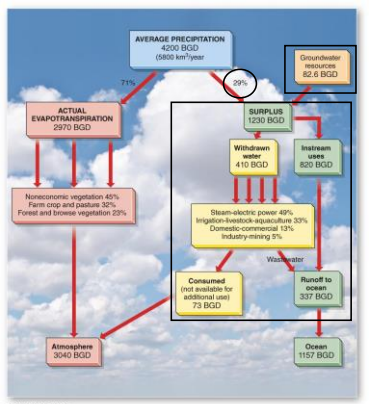
Of the average 4200 BGD precipitation received by the U.S., 71% ends up as ACTET while 29% is surplus

U.S. Water Budget



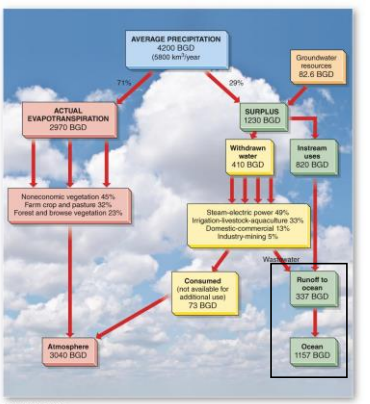
ACTET involves many types of vegetation; all water as ACTET is returned to the atmosphere

U.S. Water Budget



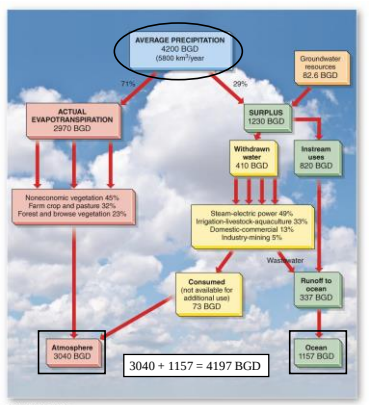
Surplus water is runoff available for withdrawal, consumption, and various instream (navigation, wildlife, hydroelectric power, etc.) uses

U.S. Water Budget



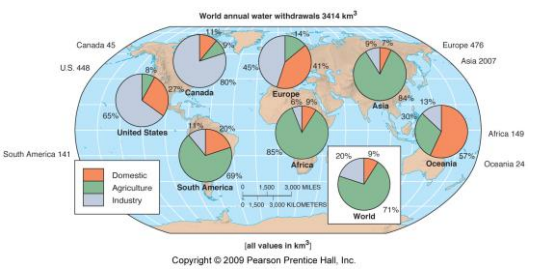
Surplus water that is not consumed eventually ends up in the ocean

U.S. Water Budget



All the precipitation received is eventually returned to the atmosphere and ocean

Water Withdrawal by Sector



Water Desalination

- Desalination of seawater can augment diminishing groundwater supplies
- Drinking water is produced from seawater through a series of filters
- Desalination usage important today in Australia, Middle East, coastal southern California and Florida
- Volume of fresh water produced by desalination worldwide expected to double between 2010-2020

(a) Saudi Arabia

(b) Tampa Bay, Florida

6a

Desalination is an important supplement to water supplies in regions with large variations in rainfall throughout the year and declining groundwater reserves. This plant in Barcelona, Spain, uses the process of reverse osmosis to remove salts and impurities.