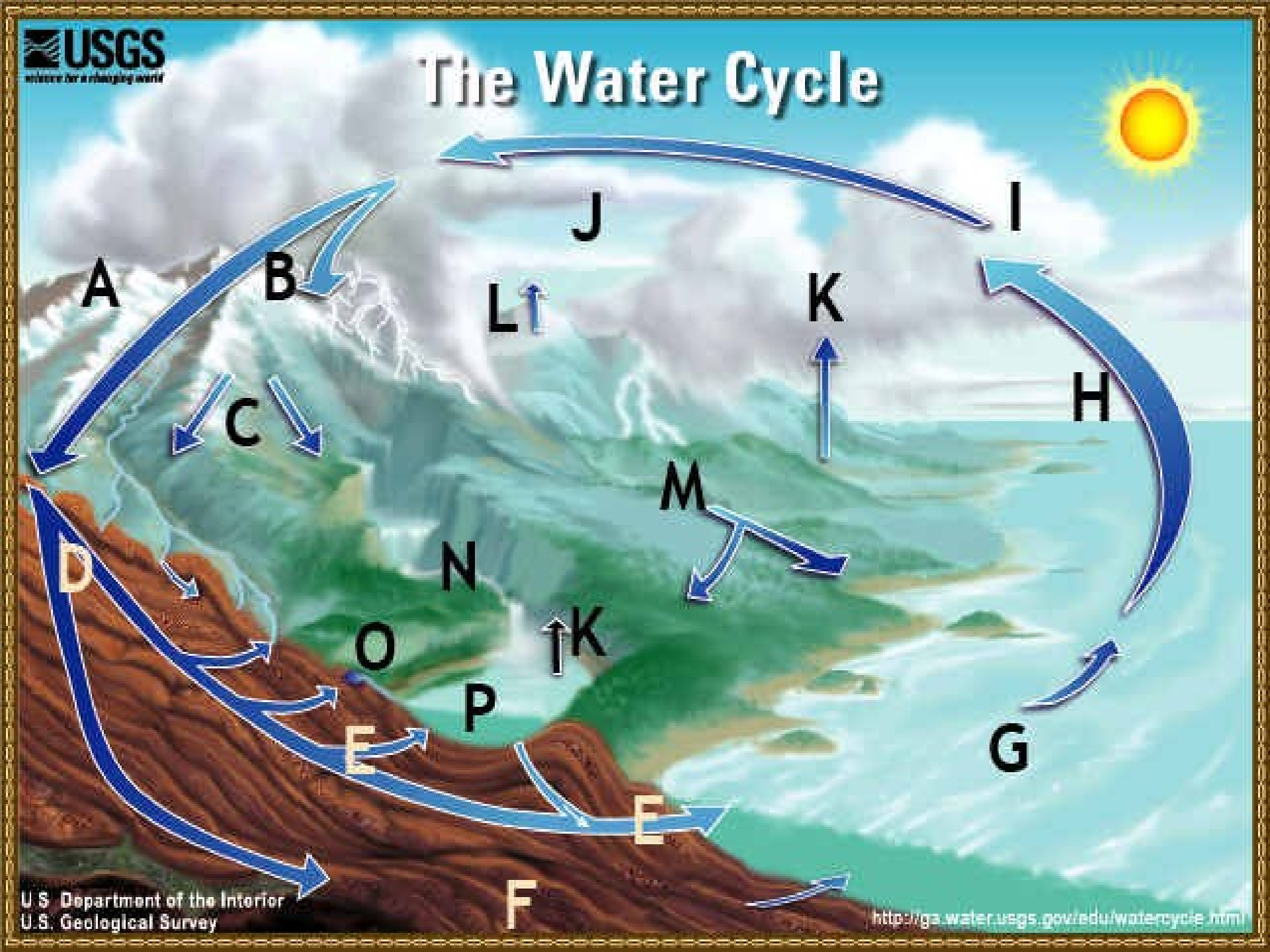
The hydrologic cycle

The story of a drop in the proverbial “bucket”


USGS
science for a changing world
The Water Cycle
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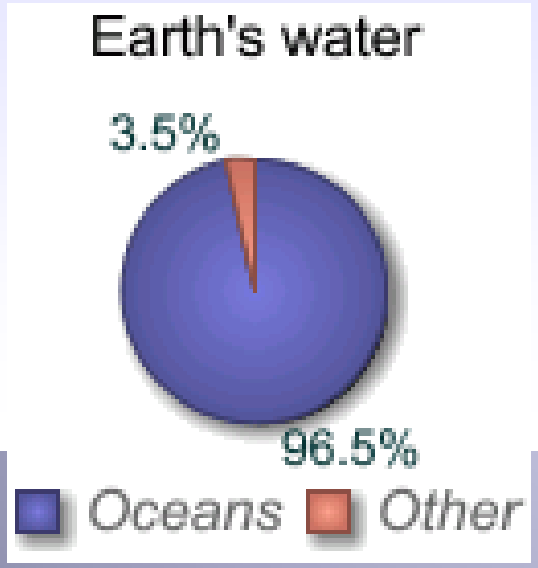
U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html



Ocean Storage

What percent of Earth's water is stored in the oceans?

Water Source	Water Volume (cu. mi.)	Water Volume (cu. km)	% of Total Water
Oceans	321,000,000	1,338,000,000	96.5%
Total global water	332,500,000	1,386,000,000	[illegible]

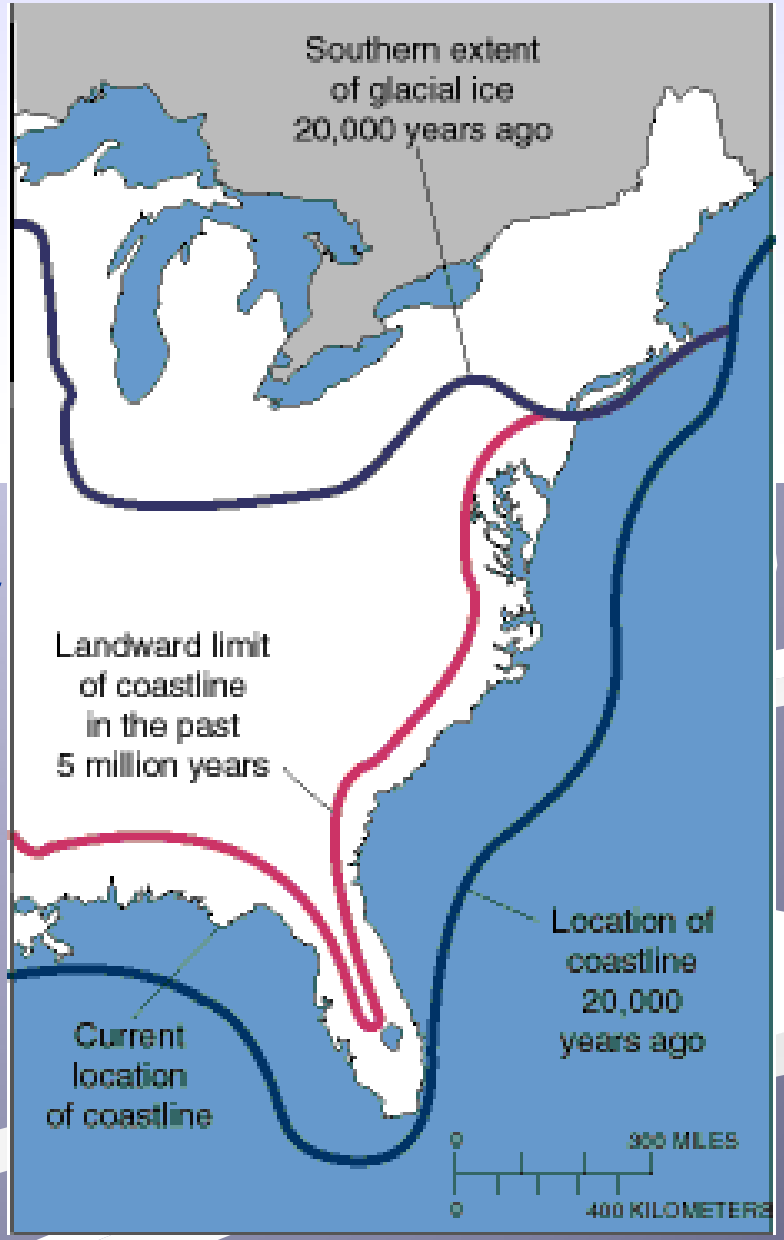
Gleick, P. H., 1996: Water resources. In Encyclopedia of Climate and Weather, ed. by S. H. Schneider, Oxford University Press, New York, vol. 2, pp. 817-823.

Does the volume of the world's oceans ever change?

Last glacial period:
Sea level 400 ft lower than today

Last inter-glacial period:
Sea level 18 ft higher than today

3M years B.P.:
Sea level 165 ft higher



What two processes change liquid water into vapor that can ascend into the atmosphere?

- **Evaporation**
  90%
- **Transpiration**
  10%

What percent of the water in the atmosphere comes from evaporation?

Evaporation

- The process by which liquid water is transformed into a gaseous state
- Evaporation into a gas ceases when the gas reaches saturation

- The molecules that escape the condensed stage have above-average energies.
- Those left behind have below-average energies
- Manifested by a decrease in the temperature of the condensed phase.

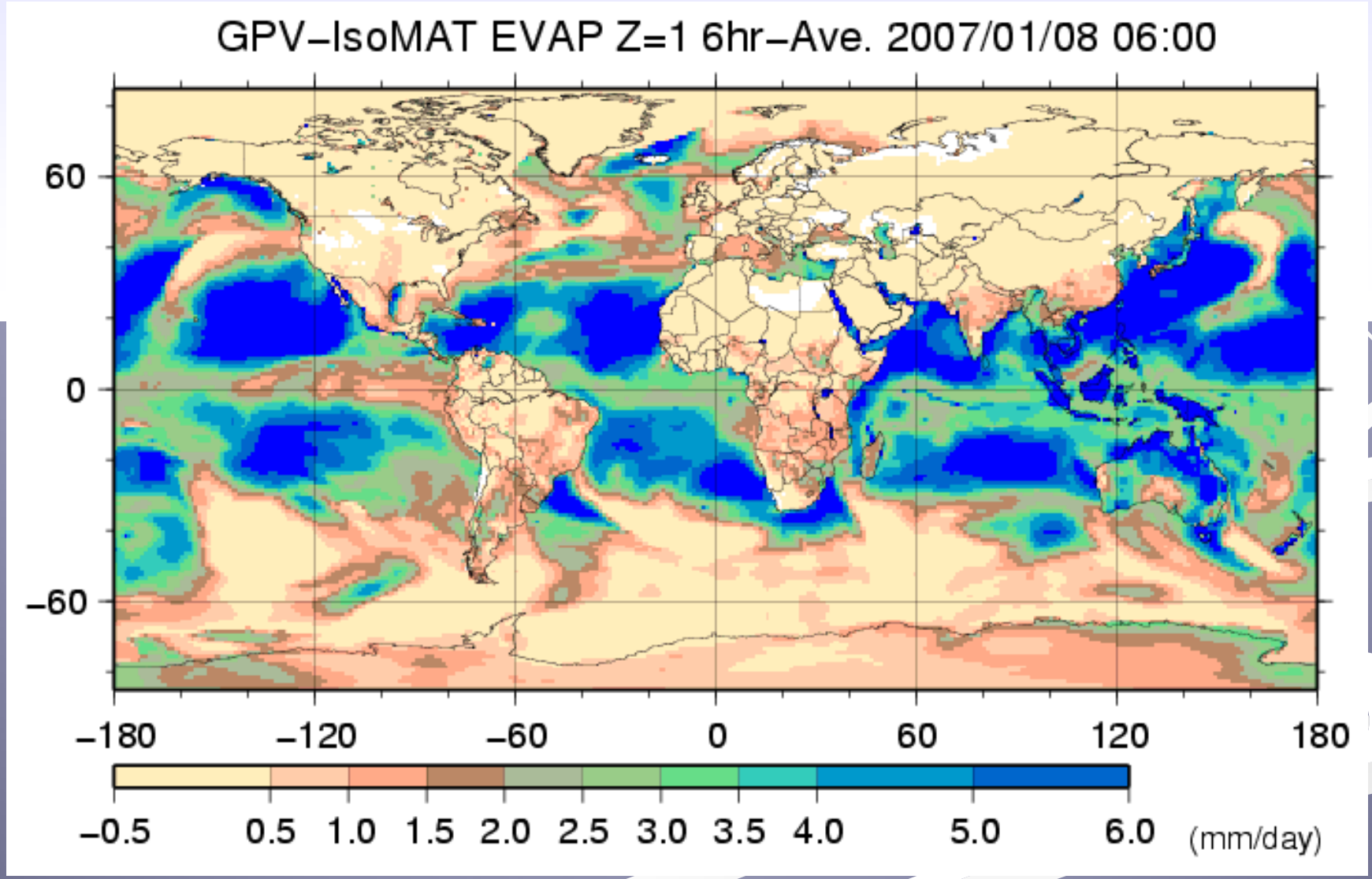
Evaporation

- Energy breaks bonds that hold molecules together
- *Net* evaporation occurs when the rate of evaporation exceeds the rate of condensation
- Removes heat from the environment:

Net Cooling

Primary mechanism for surface-to-atmosphere water transport

Evaporation



Most prevalent over oceans

Evaporation v. Precipitation

- About equal on a global scale
- Evaporation more prevalent over the oceans than precipitation
- Over land, precipitation exceeds evaporation
- Most water evaporated from the oceans falls back into the ocean as precipitation
- 10% of water evaporated from the ocean is transported over land and falls as precipitation
- Once evaporated, a water molecule spends ~ 10 days airborne

Transpiration

The process of water loss from plants through stomata.

(Stomata are small openings found on the underside of leaves that are connected to vascular plant tissues.)

- **passive process that depends on:**
  - **~humidity of the atmosphere**
  - **~the moisture content of the soil**
- **only 1 % of the water transpired used for growth**
- **transports nutrients from the soil into the roots and carries them to the various cells of the plant**
- **keeps tissues from becoming overheated**

Transpiration

Accounts for ~ 10% of the moisture in the atmosphere

Depends on:

- Temperature
- Humidity
- Insolation
- Precipitation
- Soil type and saturation
- Wind
- Land slope

What percent of the Earth's total volume of water is stored in the atmosphere?

- 0.001%
- Water vapor
- Clouds

  (water vapor condensed on particulate)

Global distribution of atmospheric water

Water Source	Volume (cu mi)	Volume(cu km)	% total freshwater	% total water
Atm	3,094	12,900	0.04%	0.001%
Total Global Fresh Water	8,404,000	35,030,000	100%	2.5%
Total Global Water	332,500,000	1,386,000,000	--	100%

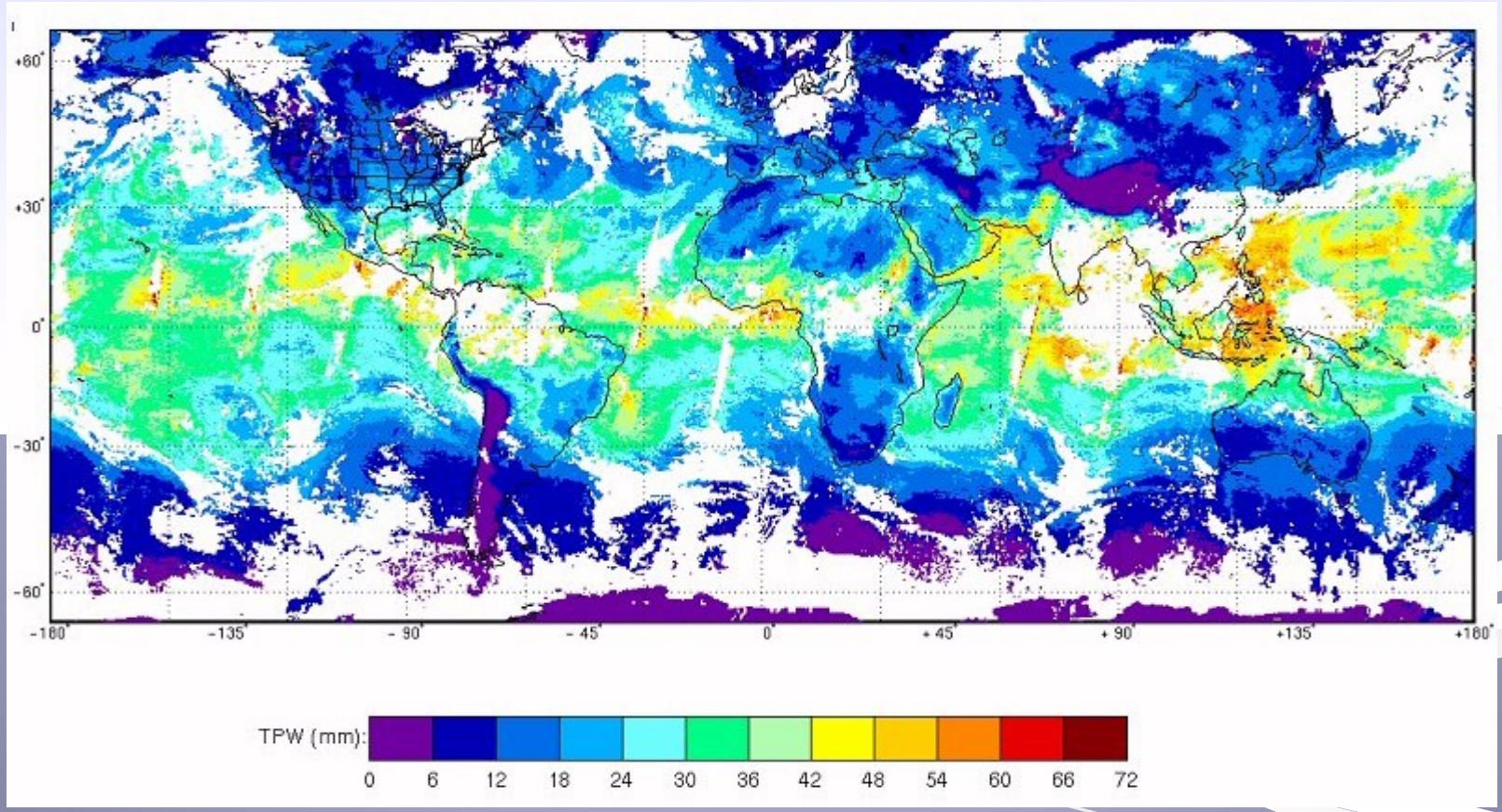
Precipitation

- The vapor that accumulates or freezes on condensation nuclei is acted on by gravity and falls to Earth's surface.

rain, freezing rain, sleet, snow, or hail

primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth

Total precipitable water



The total atmospheric water vapor contained in a vertical column of unit cross-sectional area from the Earth's surface to the "top of the atmosphere"

Height to which water would stand if completely condensed and collected in vessel of same dimensions

How many gallons of water fall when 1 inch of rain falls on 1 acre of land?

About 27,154 gallons (102,800 liters) of water.

On average, the 48 continental United States receives enough precipitation in one year to cover the land to a depth of 30 inches.

Meteorological factors affecting surface (over soil) runoff

- Type of precipitation
- Rainfall intensity
- Rainfall amount
- Rainfall duration
- Distribution of rainfall over the drainage basin
- Direction of storm movement
- Precipitation that occurred earlier and resulting soil moisture
- Meteorological conditions that affect evapotranspiration

Physical characteristics affecting surface runoff

Overland runoff from disturbed areas often contains excessive sediment in addition to water. (USGS)

- Land use
- Vegetation
- Soil type
- Drainage area
- Basin shape
- Elevation
- Topography, especially the slope of the land
- Drainage network patterns
- Ponds, lakes, reservoirs, sinks, etc. in the basin, which prevent or delay runoff from continuing downstream

Human factors affecting surface runoff

- Urbanization -- more impervious surfaces reduce infiltration and accelerate water motion
- Removal of vegetation and soil -- surface grading, artificial drainage networks increases volume of runoff and shortens runoff time to streams from rainfall and snowmelt

Most runoff…

- Drains to a creek
  - To a stream
    - To a river
      - To an ocean
  - Rarely runoff drains to a closed lake
  - May be diverted for human uses

Streamflow…

Makes up a MINISCULE amount of Earth's water

Water source	Water Volume (cu mi)	% of total freshwater	% of total water
Streamflow	509	0.006%	0.0002%
Total Global Freshwater	8,404,000	2.5%	--
Total Global Water	332,500,000	--	--

Lakes & Swamps

- Freshwater makes up ~3% of all water on Earth and lakes and swamps account for a mere 0.29% of that!
- 20% of all freshwater is in Lake Baikal in Siberia (638 km long, 80 km wide, 1,620 m deep)
- Another 20% is in the Great Lakes

Groundwater begins as INFILTRATION

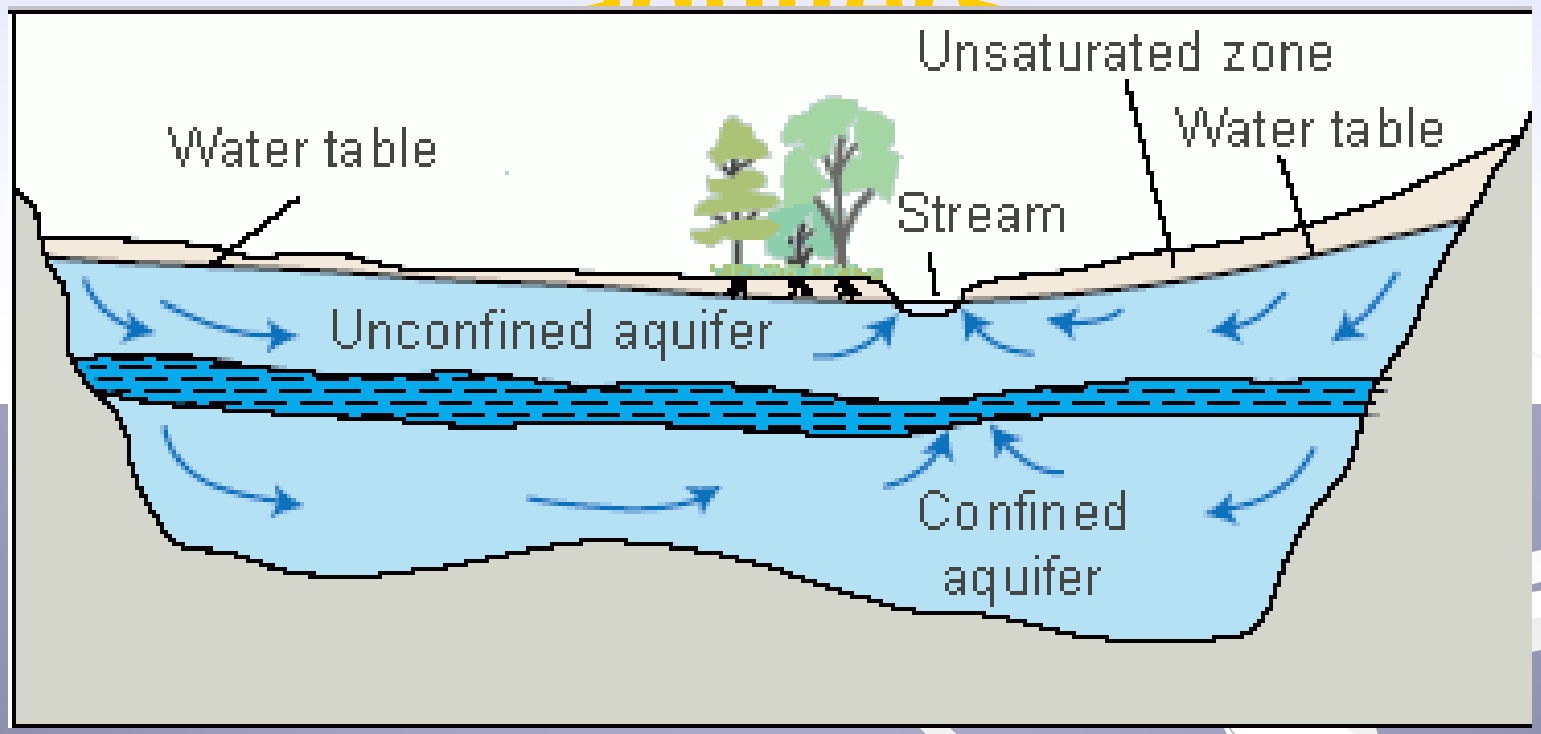
Precipitation falls and infiltrates into the subsurface soil and rock

- Can remain in shallow soil layer
- Might seep into a stream bank
- May infiltrate deeper, recharging an aquifer
- May travel long distances
- May stay in storage as ground water

Factors affecting infiltration

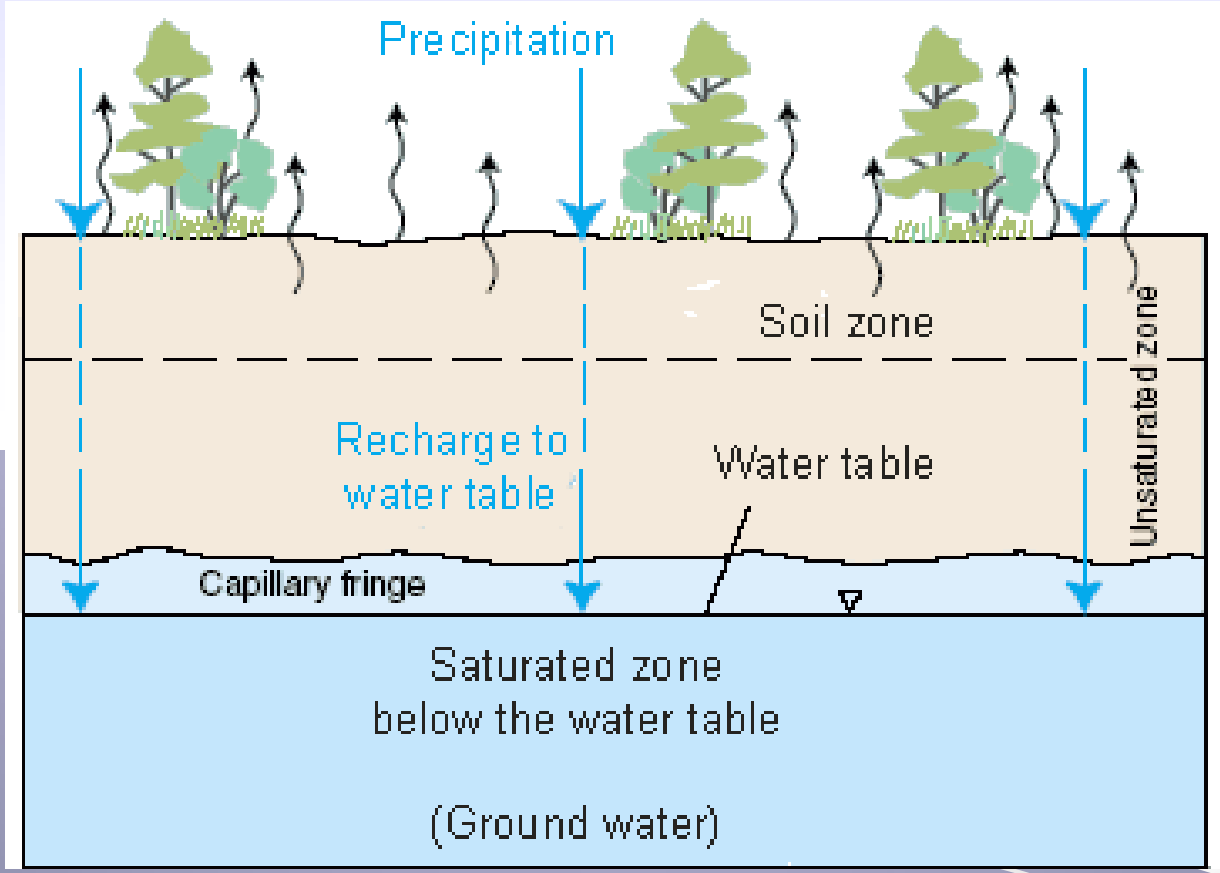
- Precipitation (greatest factor)
  - Magnitude, intensity, duration
  - Characteristics (rain, snow)
- Soil Characteristics
  - Clay absorbs less water at a slower rate than sand
- Soil Saturation
  - Higher saturation leads to more runoff instead
- Land Cover
- Slope of the Land
  - Hills enhance runoff velocity
- Evapotranspiration
  - Plants use soil moisture to grow and transpire

Infiltration replenished aquifers



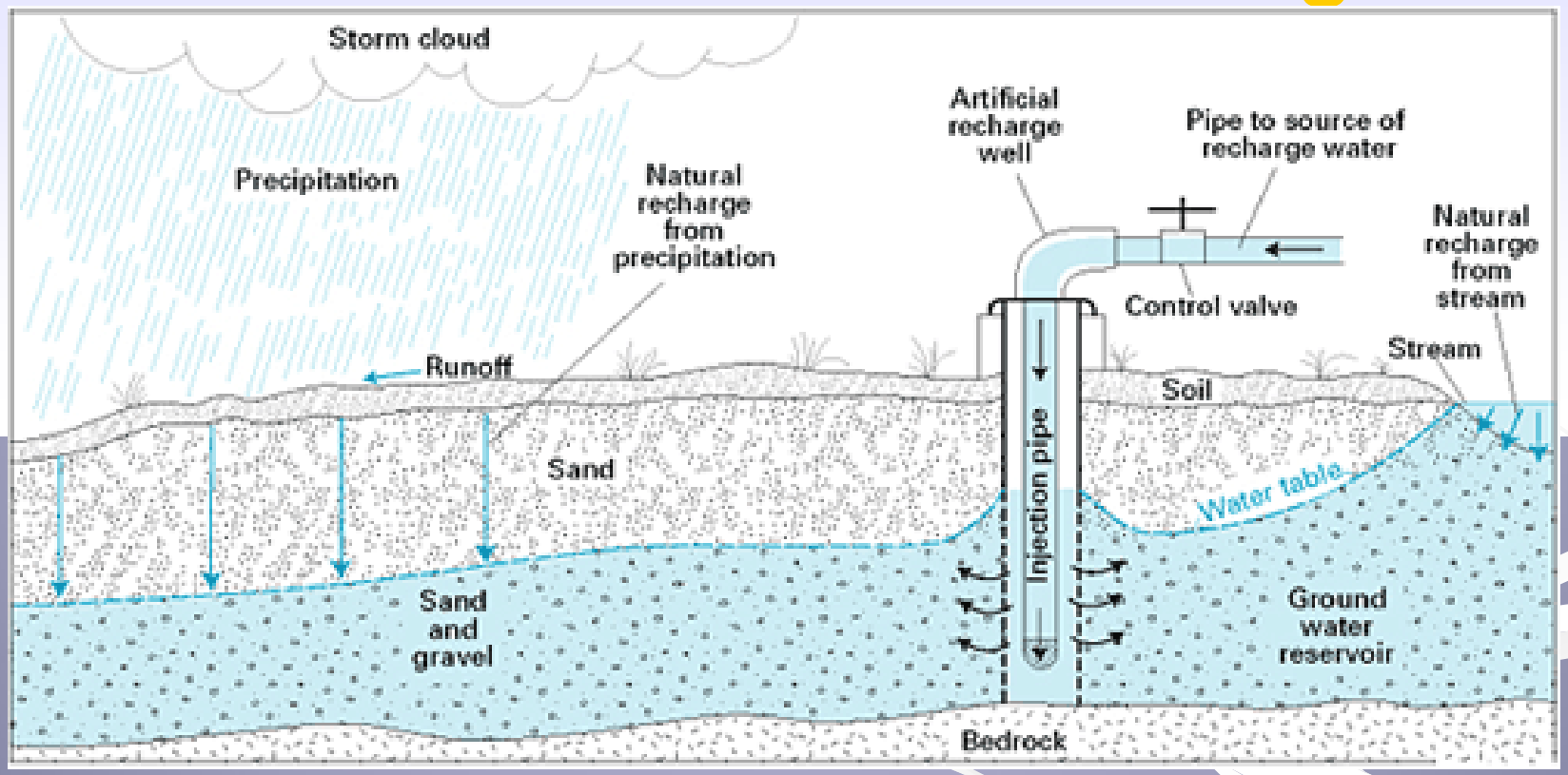
- Slow process -- ground water moves slowly through the unsaturated zone
- Recharge Rate determined by precipitation & depth
  - An aquifer in New Mexico, if emptied, would take centuries to refill whereas a shallow aquifer in south Georgia may be replenished almost immediately

Subsurface Water



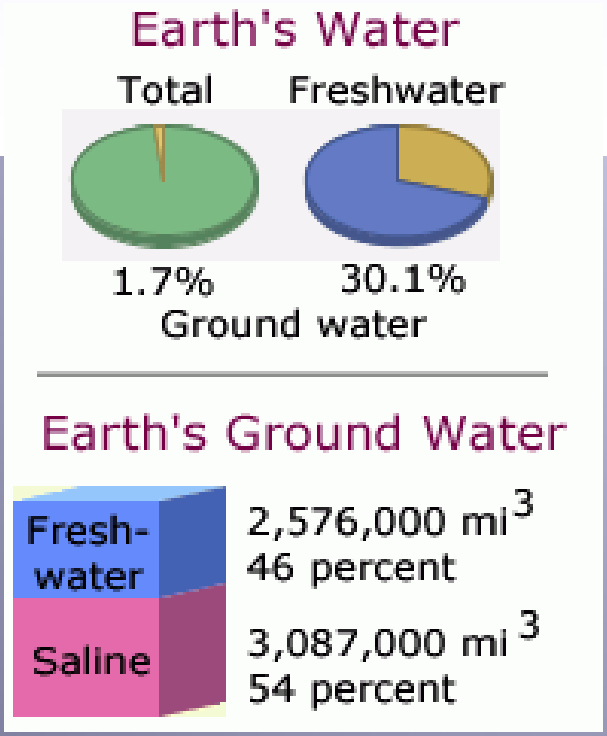
- As precipitation infiltrates subsurface soil, it forms zones:
  - Unsaturated -- interstitial spaces cannot be pumped
  - Saturated -- Water completely fills the voids between rocks and soil particles

Natural & Artificial Recharge



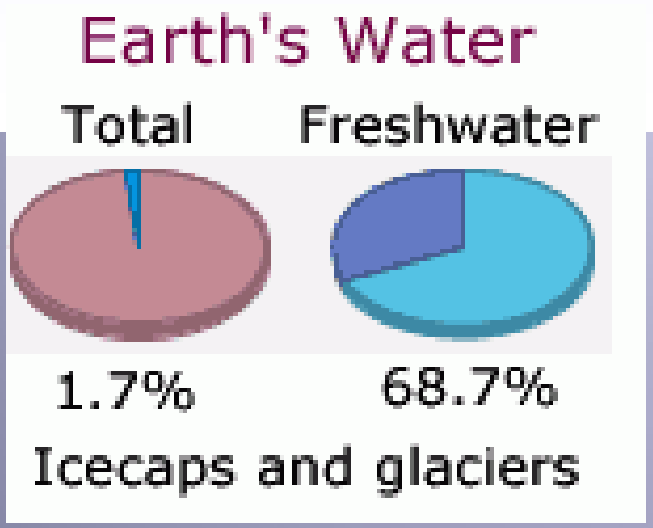
- Rapid-infiltration pits
  - Spread water over the land in pits, furrows, ditches or build small dams in creeks and streams to deflect runoff
- Ground water injection
  - Construct recharge wells and inject water directly into aquifers

How much ground water?



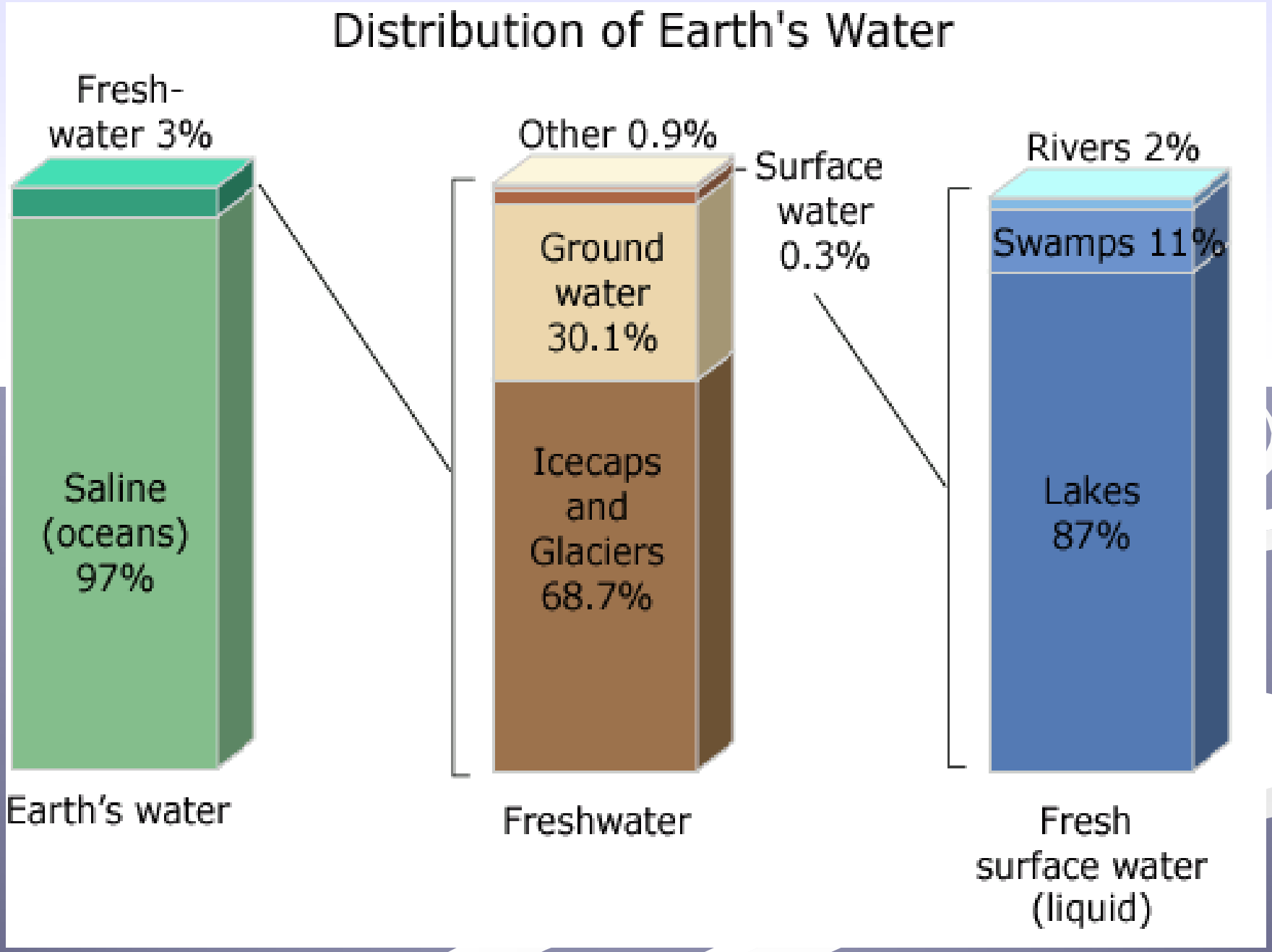
- Ground water occurs only close to the surface (a few miles down)
  - Density of soil/rock increases with depth
  - The weight of the rocks above condense the rocks below and squeeze out the open pore spaces deeper in the Earth

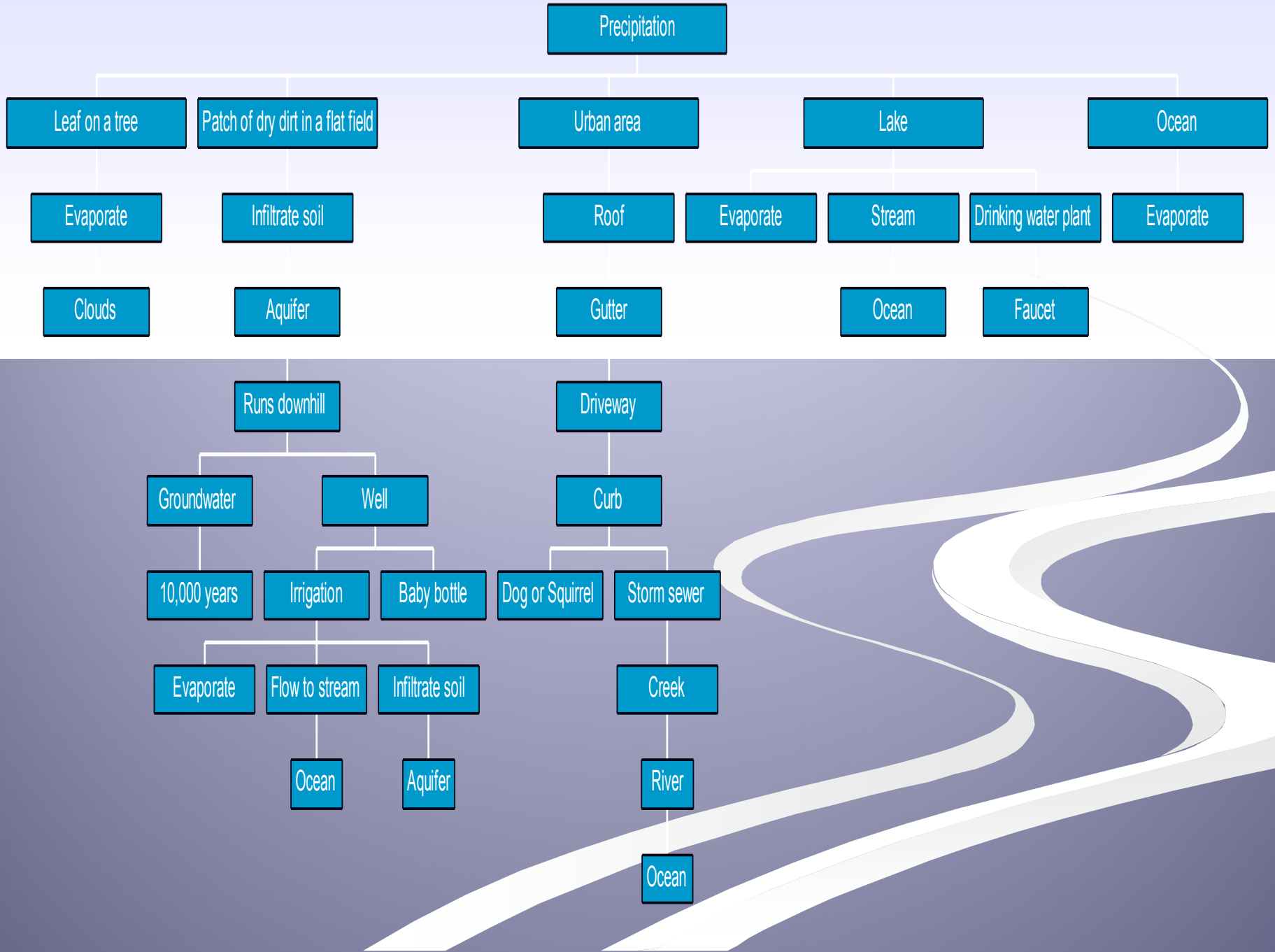
Frozen freshwater stored in glaciers, ice fields, and snowfields

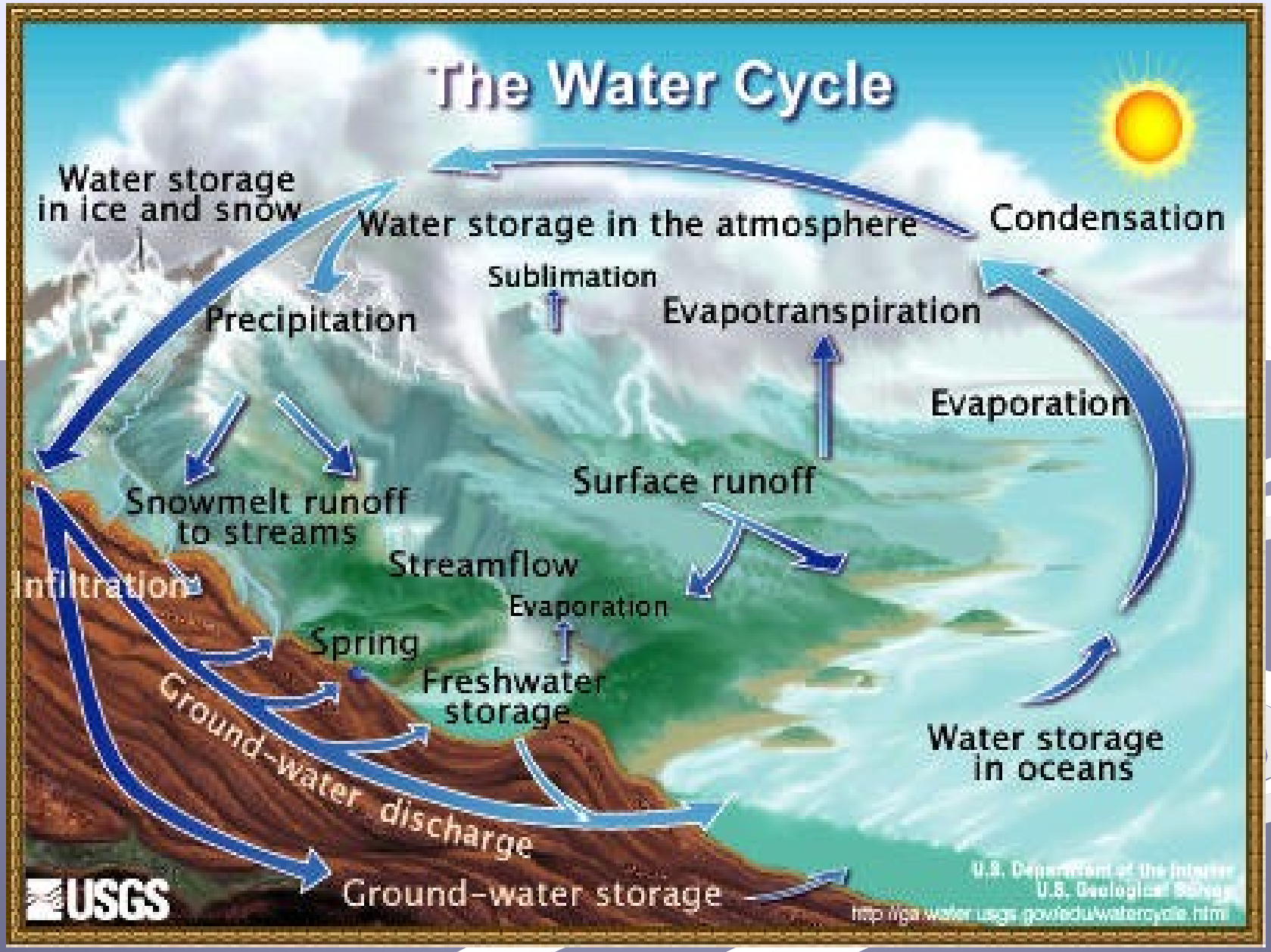


How much of all freshwater?

- Glacial ice covers 11% of all land
- Represents a large % of all freshwater
- Mountain snowfields are “reservoirs” for many water-supply systems
  - 75% in Western States
- “Rain-on-snow” events contribute to high runoff velocities
- “New” Operational Snowmelt Forecasts


Distribution of Earth's Water
Fresh-
water 3%
Saline
(oceans)
97%
Earth's water
Other 0.9%
Ground
water
30.1%
Icecaps
and
Glaciers
68.7%
Freshwater
Surface
water
0.3%
Rivers 2%
Swamps 11%
Lakes
87%
Fresh
surface water
(liquid)


Precipitation
Leaf on a tree
Patch of dry dirt in a flat field
Urban area
Lake
Ocean
Evaporate
Infiltrate soil
Roof
Evaporate
Stream
Drinking water plant
Evaporate
Clouds
Aquifer
Gutter
Ocean
Faucet
Runs downhill
Driveway
Groundwater
Well
Curb
10,000 years
Irrigation
Baby bottle
Dog or Squirrel
Storm sewer
Evaporate
Flow to stream
Infiltrate soil
Creek
Ocean
Aquifer
River
Ocean


The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Surface runoff
Snowmelt runoff to streams
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
USGS