

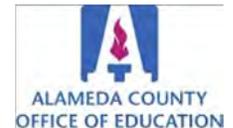
The Water Cycle

1. The Earth System
2. The Water Cycle
3. Earth's Water Budget

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CALIFORNIA STATE
UNIVERSITY
E A S T B A Y



1. The Earth System

What's the first thing that you notice about our planet when you see this image?

The Earth is composed of several integrated parts (spheres) that interact with one another:

- atmosphere
- hydrosphere
- geosphere
(lithosphere)
- biosphere
- (cryosphere)



The Earth System

Hydrosphere: the global ocean is the most prominent feature of our (blue) planet. The oceans cover ~71% of our planet and represent 97% of all the water on our planet.

Atmosphere: the swirling clouds of the atmosphere represent the very thin blanket of air that covers our planet. It is not only the air we breathe, but protects us from harmful radiation from the sun.



The Earth System

Biosphere: includes all life on Earth - concentrated at the surface. Plants and animals don't only respond to their environment but also exercise a very strong control over the other parts of the planet.

Solid Earth: represents the majority of the Earth system. Most of the Earth lies at inaccessible depths. However, the solid Earth exerts a strong influence on all other parts (ex. magnetic field).

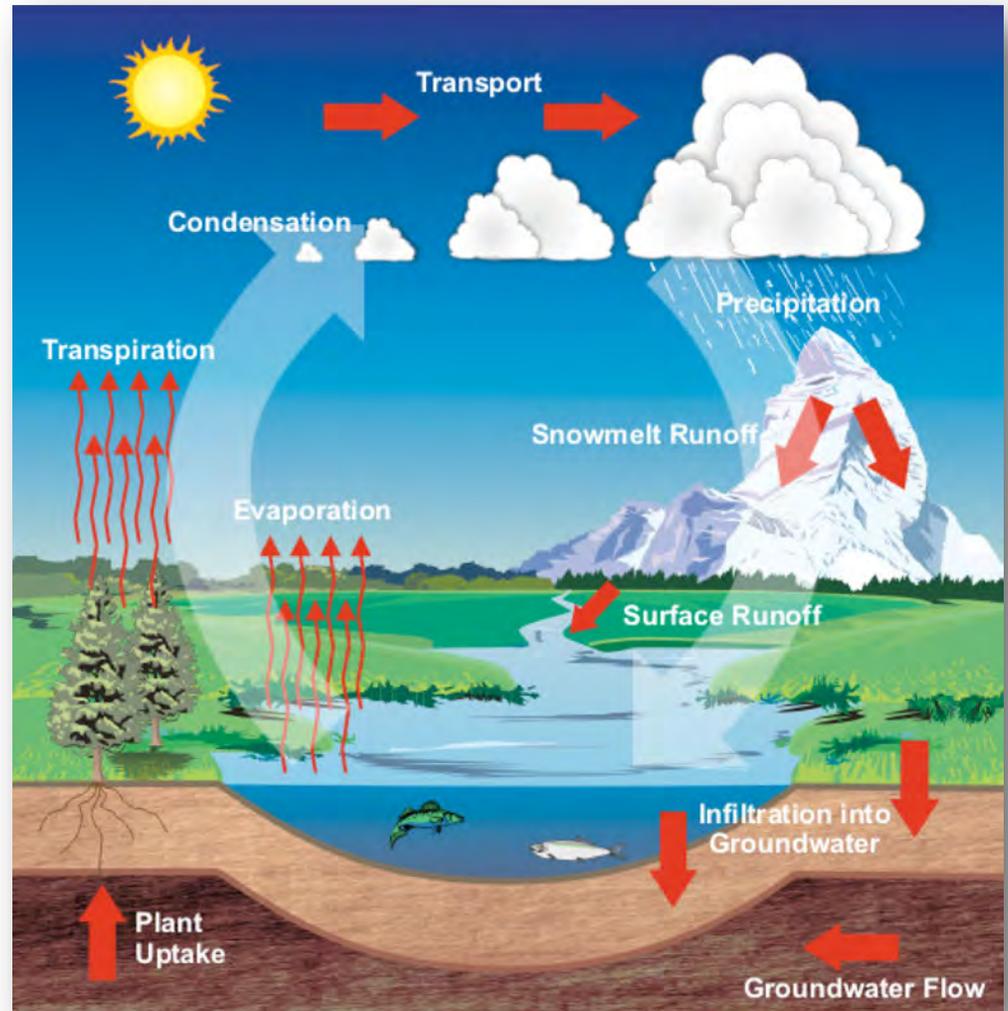
Cryosphere: represents the icy parts of Earth including glaciers, sea ice and ice caps. The cryosphere is commonly thought of as part of the *hydrosphere*.



2. The Water Cycle

Water is essential to life and is the driving force of many processes on Earth.

Water is responsible for the transfer of a tremendous amount of environmental energy between colder regions (polar regions and upper atmosphere) and warmer regions (tropical regions and lower atmosphere).



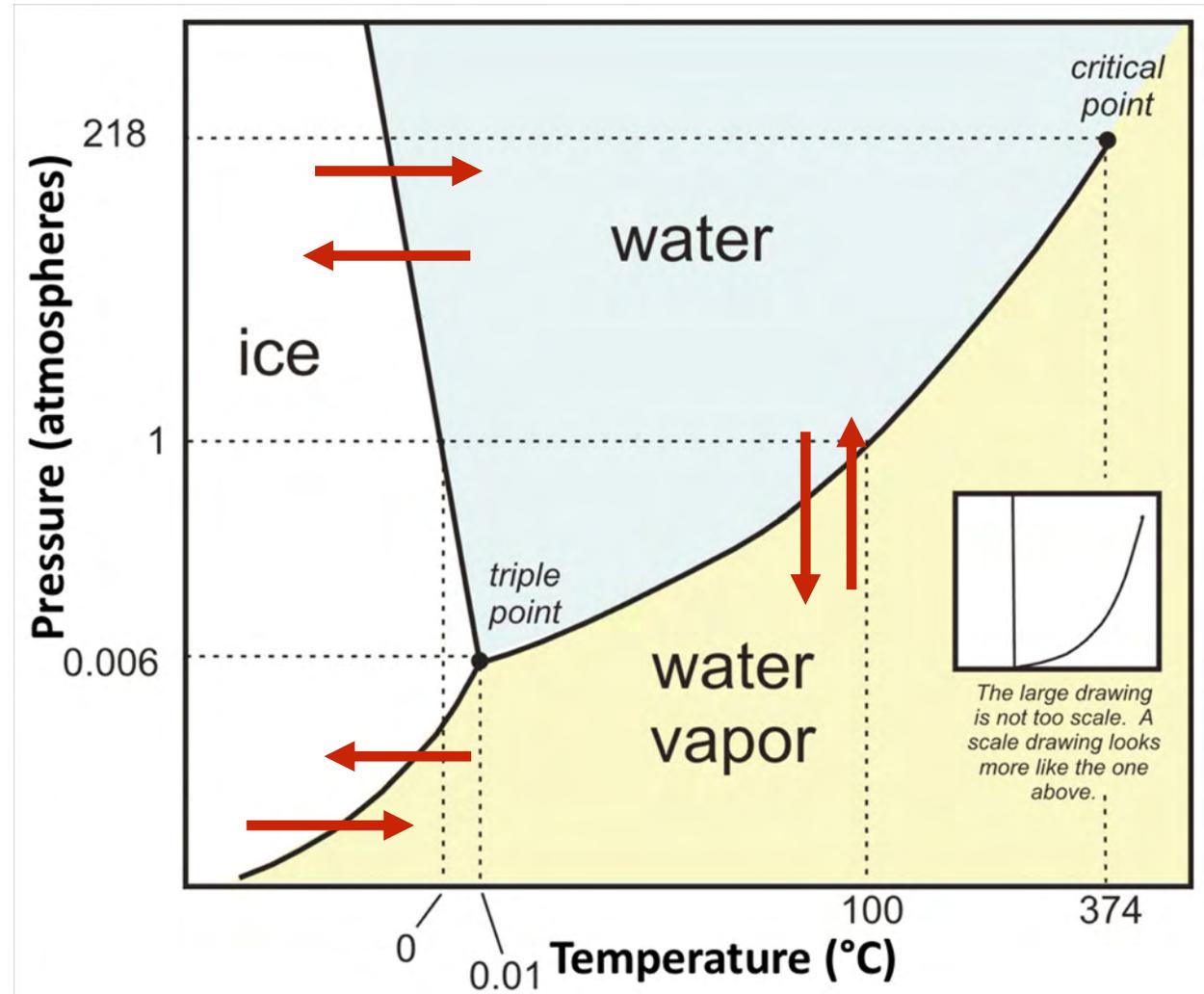
[NOAA](#)

Ultimately, the energy that is being distributed is from the Sun since it is the Sun's energy that drives the processes of the water cycle such as evaporation.

The diagram is a phase diagram for water and shows the stable form (phase) of water at different pressure and temperature conditions.

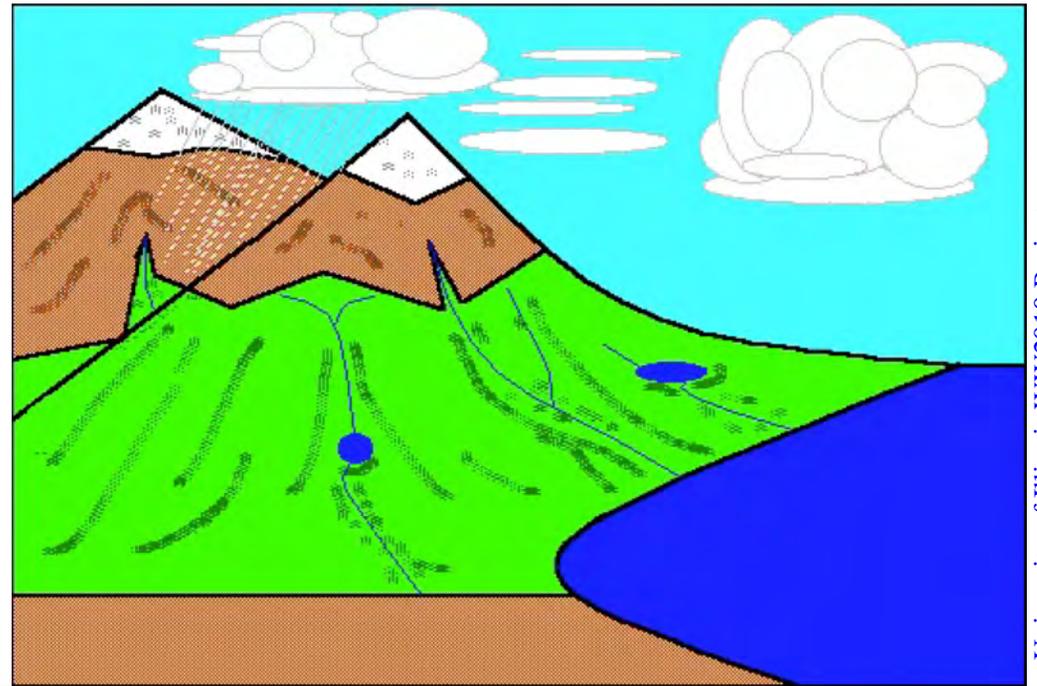
What are the fundamental phase changes that water may undergo?

- evaporation
- condensation
- melting
- freezing
- sublimation
- deposition



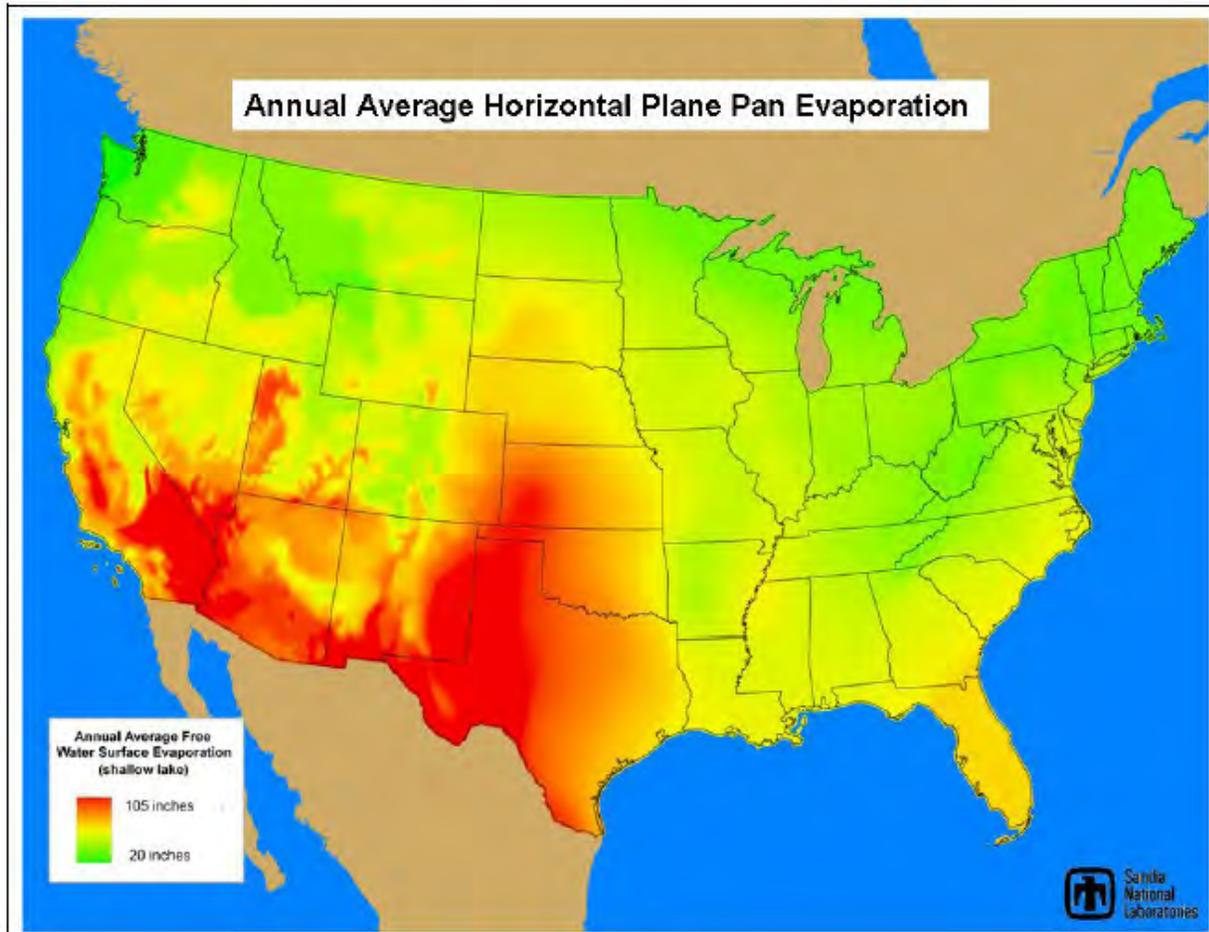
Evaporation

Evaporation is the physical process of converting liquid water into vapor — this is the process by which water is transferred from the Earth's surface to the atmosphere.



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About 71% of our planet is covered by the oceans - evaporation from the oceans accounts for ~80% of the total. The remaining 20% comes from evaporation of inland water and vegetation (transpiration).



[Pate, Sandia National Lab](#)

This map shows the evaporation rate in the U.S.

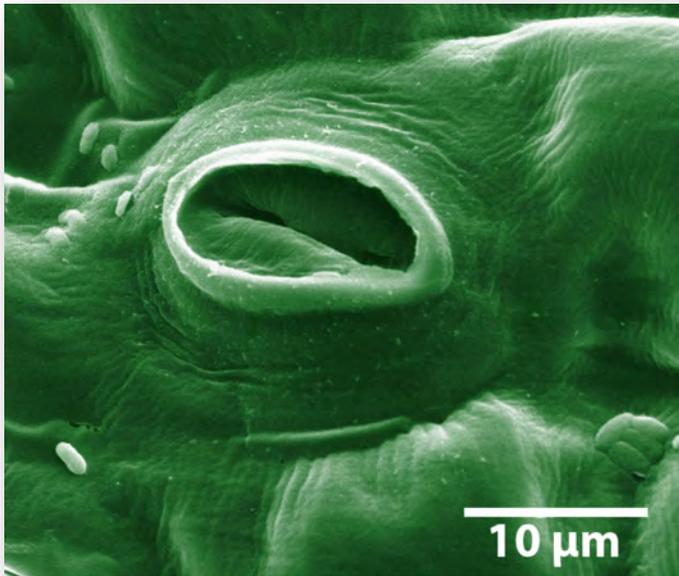
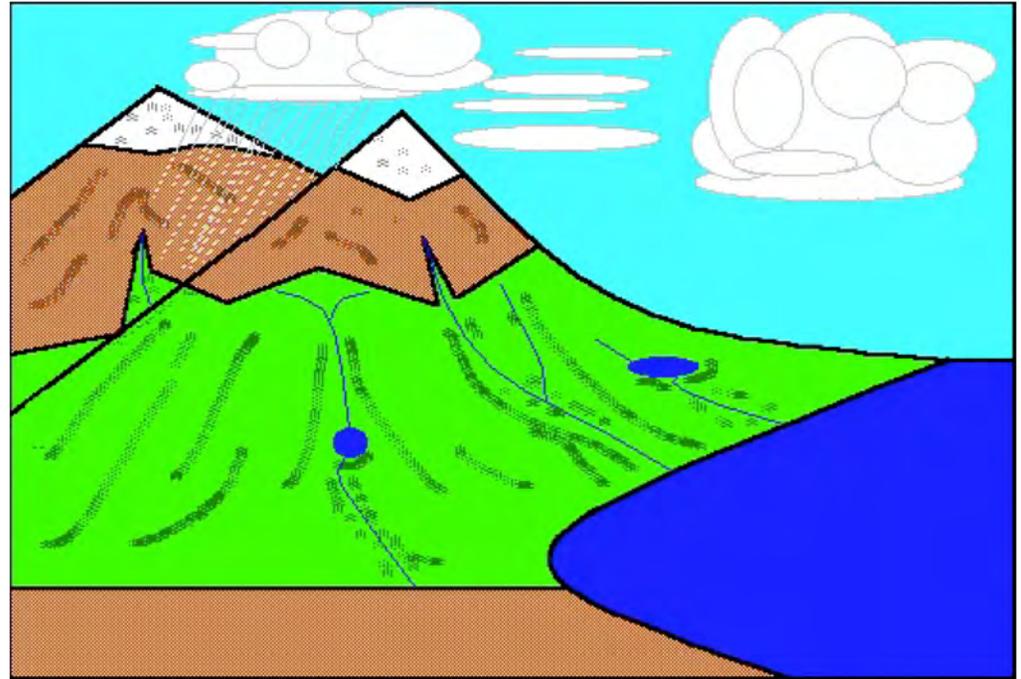
Note that the evaporation rate is greatest in regions that the solar irradiance (amount of sunlight) and temperature are high such as in the desert southwest.

This indicates that evaporation is enhanced where there is a lot of sunlight and temperatures are high.

Transpiration

Transpiration is the evaporation of water into the atmosphere from the leaves and stems of plants.

Plants absorb water through their roots (some desert plants have roots that extend 20 meters into the ground).



Plants pump water from their roots to deliver nutrients to their leaves. This pumping is driven by the evaporation of water through small pores called "stomates", which are found on the undersides of leaves.

Transpiration accounts for approximately 10% of all evaporating water.

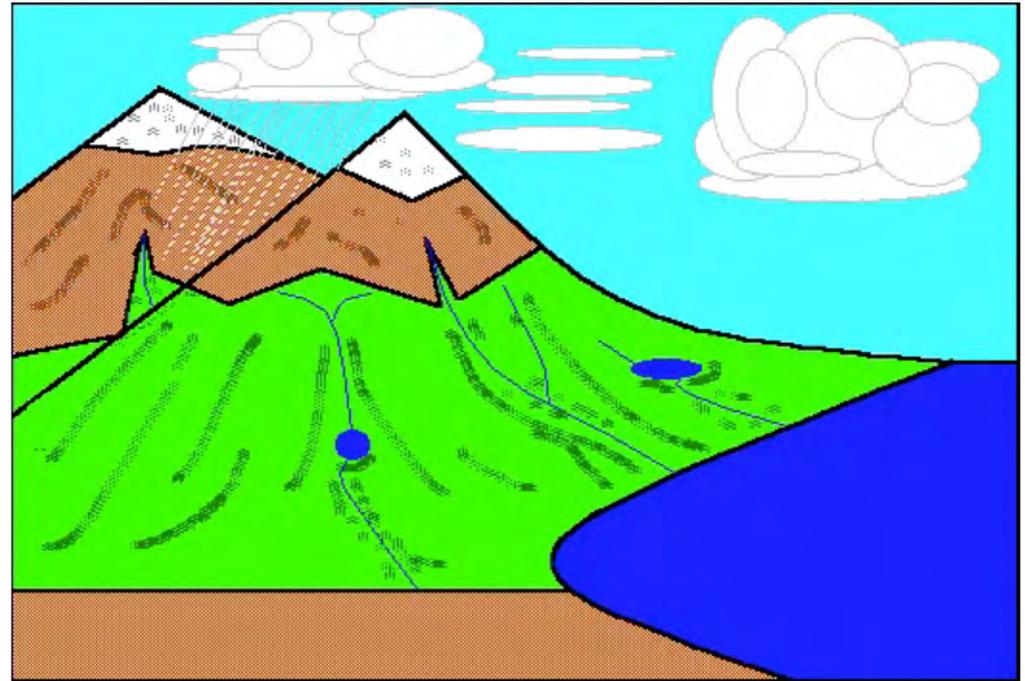
Condensation

Condensation is the change of water from its gaseous form (water vapor) into liquid water.

Condensation generally occurs in the atmosphere when warm air rises, cools and loses its capacity to hold water vapor.

In the atmosphere, this results in cloud formation.

The movie shows the development of clouds by condensation during the upward motion of warm, moist air.



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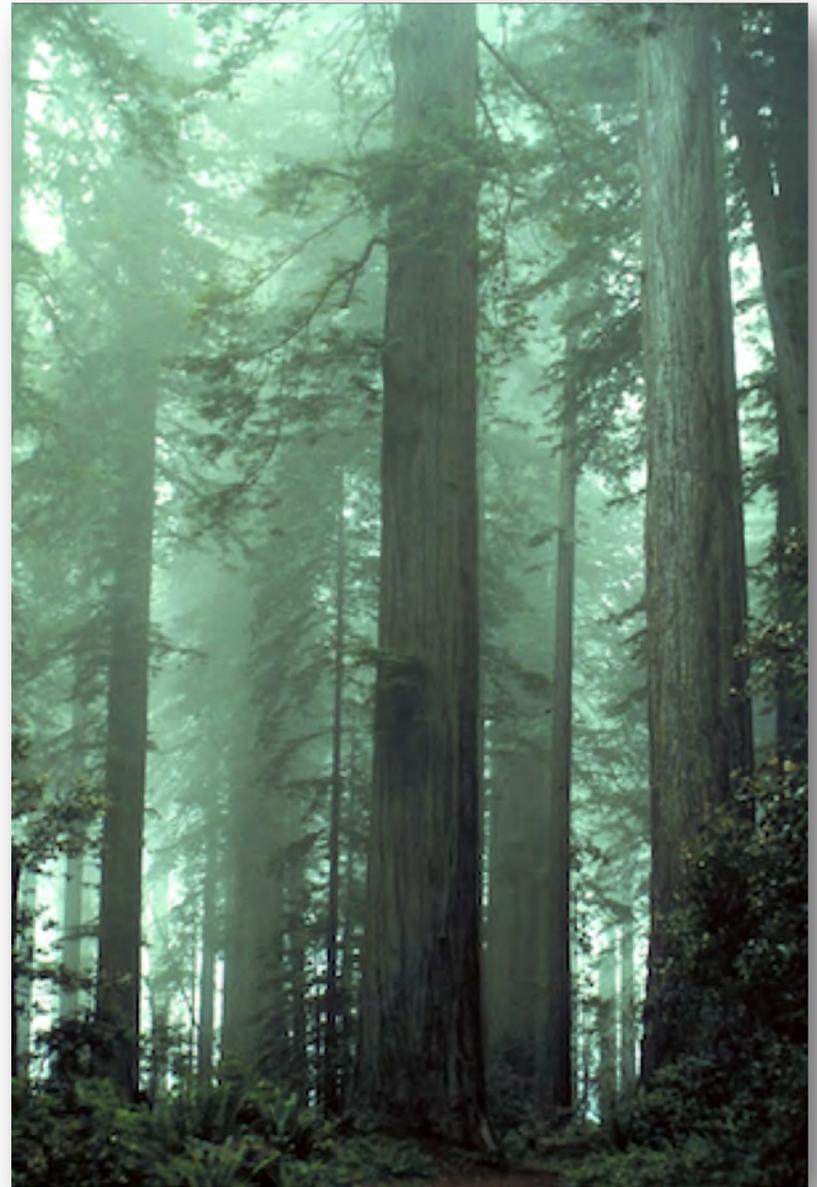
[YouTube: Charles Russell](#)

Fog can be thought of as a low level cloud where the water vapor in the atmosphere condenses close to the ground.

Conditions in California are conducive to the production of fog, especially along the coast.

Redwoods have evolved to take advantage of fog as a water source.

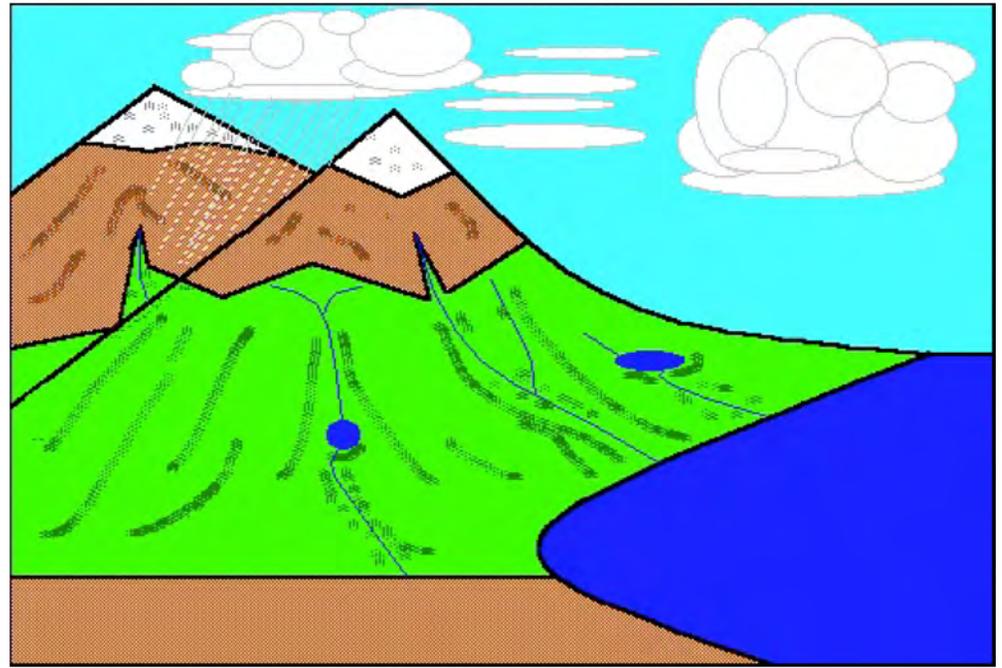
1. fog covers the leaves, enters the stomata, and is drawn down through the branches to the roots. This is the reverse of *transpiration*, the normal flow of water from the roots to the leaves that exists in most trees.
2. Fog drips off of the redwood leaves to the forest floor nourishing the roots.



Transport

In the *water cycle*, *transport* is the movement of water through the atmosphere.

Much of the *transport* in the water cycle is visible as clouds, which consist of ice crystals and/or tiny water droplets.



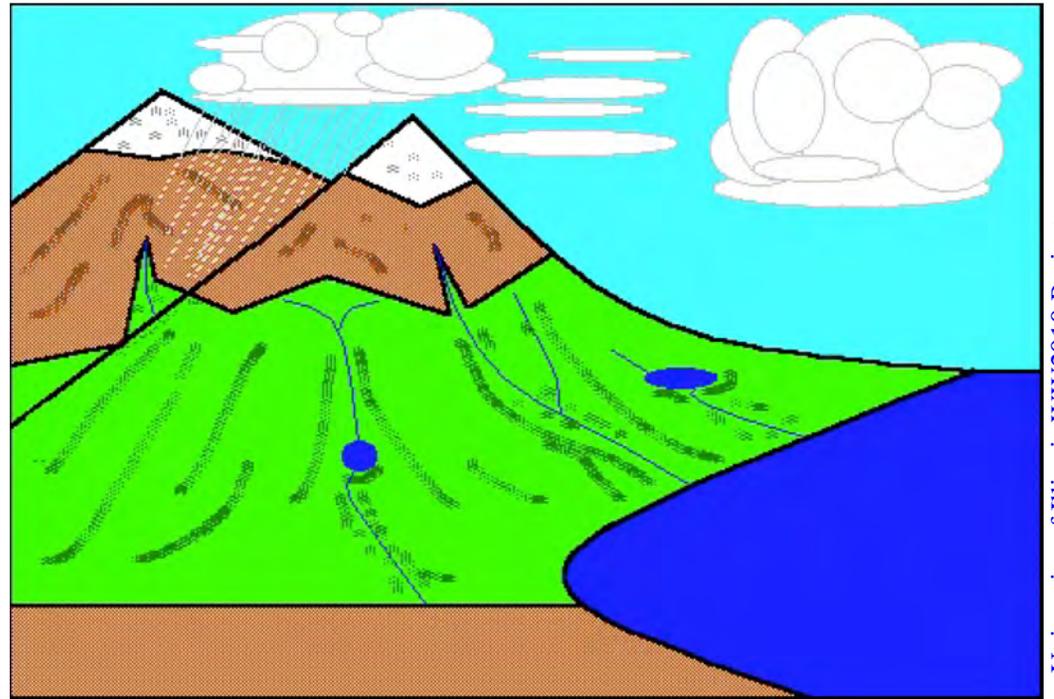
Clouds are moved from one place to another by global winds such as the jet stream.

Most water is transported in the form of water vapor — the third most abundant gas in the atmosphere.

Water vapor is an invisible gas — clouds are visible because they are composed of tiny liquid droplets or ice crystals.

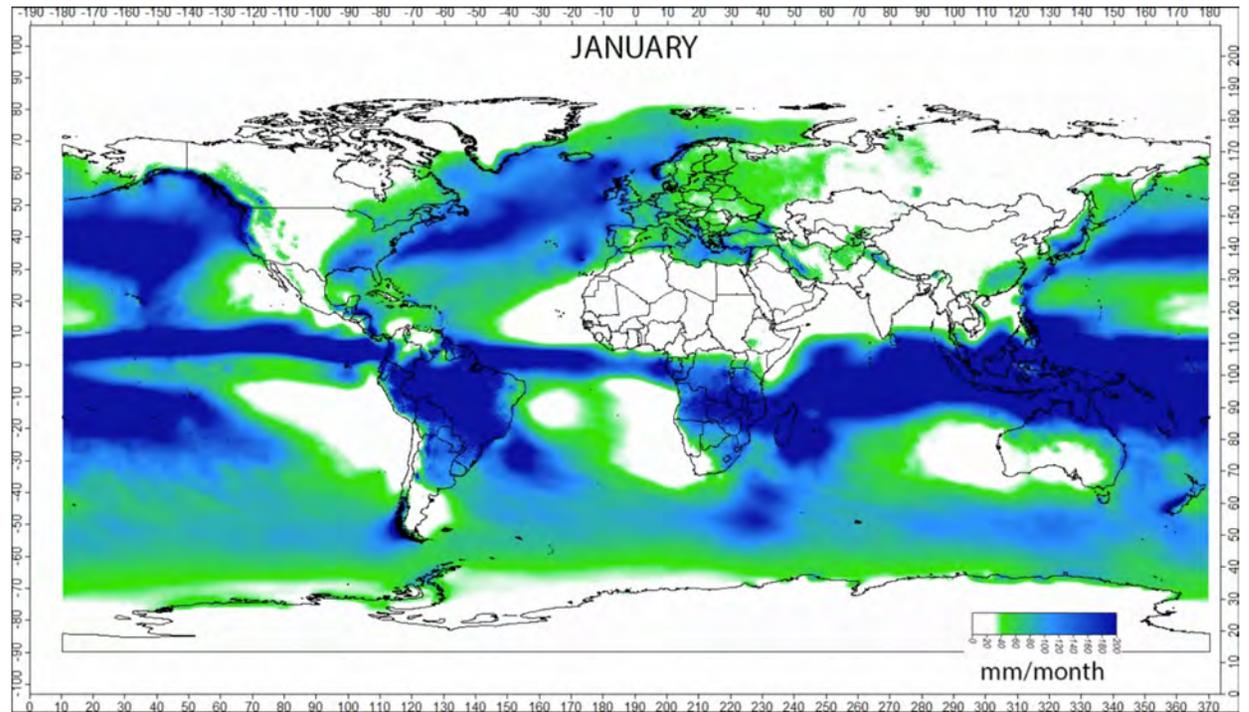
Precipitation

Precipitation is the primary mechanism for transporting water from the atmosphere to the surface of the earth.



The most common form of *precipitation* in the United States is rain, but other forms include hail and snow.

The animation shows the long-term mean precipitation by month. Note that the patterns of precipitation migrate north and south with the seasons.

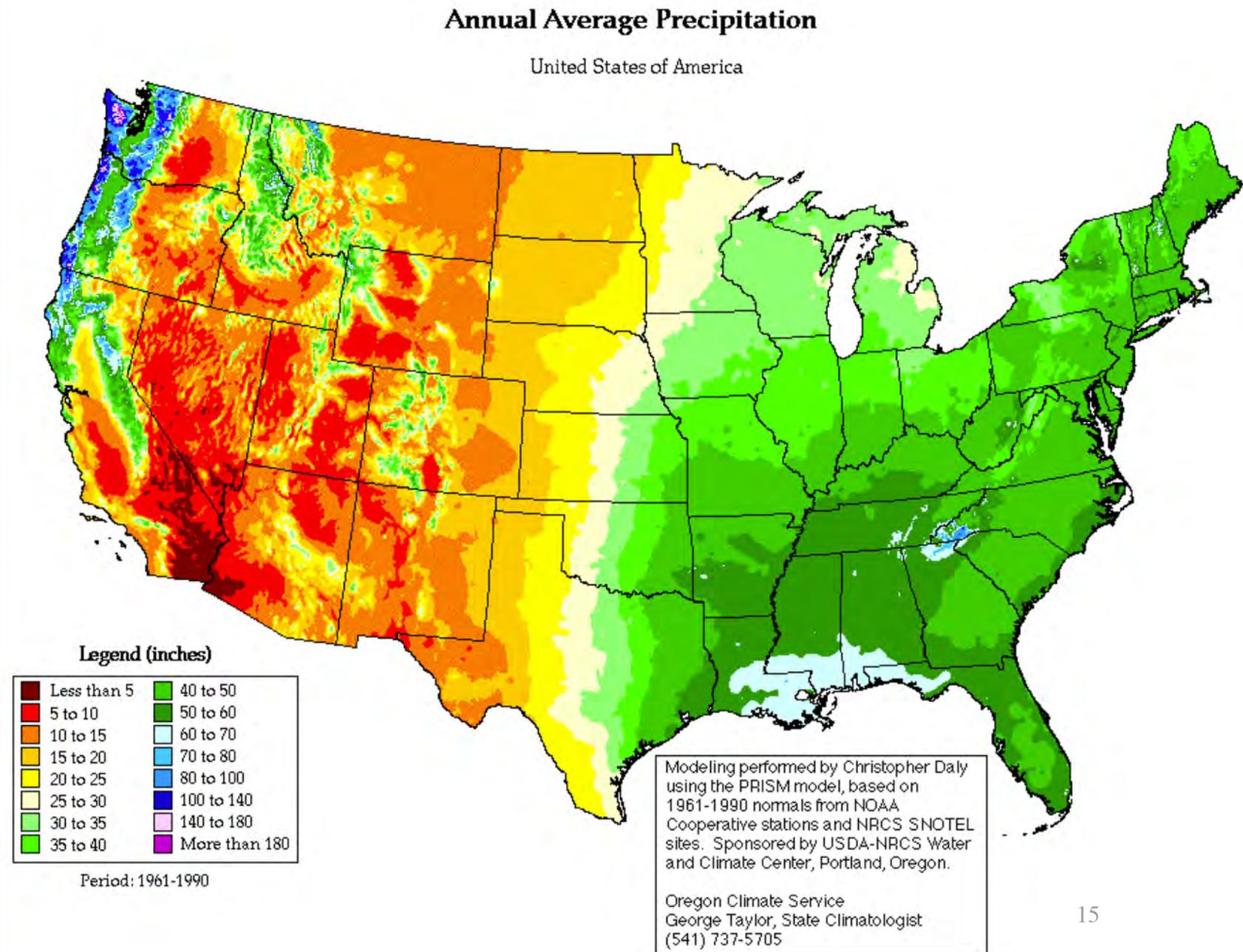


[Greenmind1980 \[CC BY-SA 4.0\] via Wikimedia Commons](#)



The blue bands represent the regions with abundant rain around the equator and at mid-latitudes. The regions between the blue bands represent a predominantly drier region that where the Earth's deserts are found. The discontinuity of bands of precipitation are due to interference with the continents and local effects such as mountains.

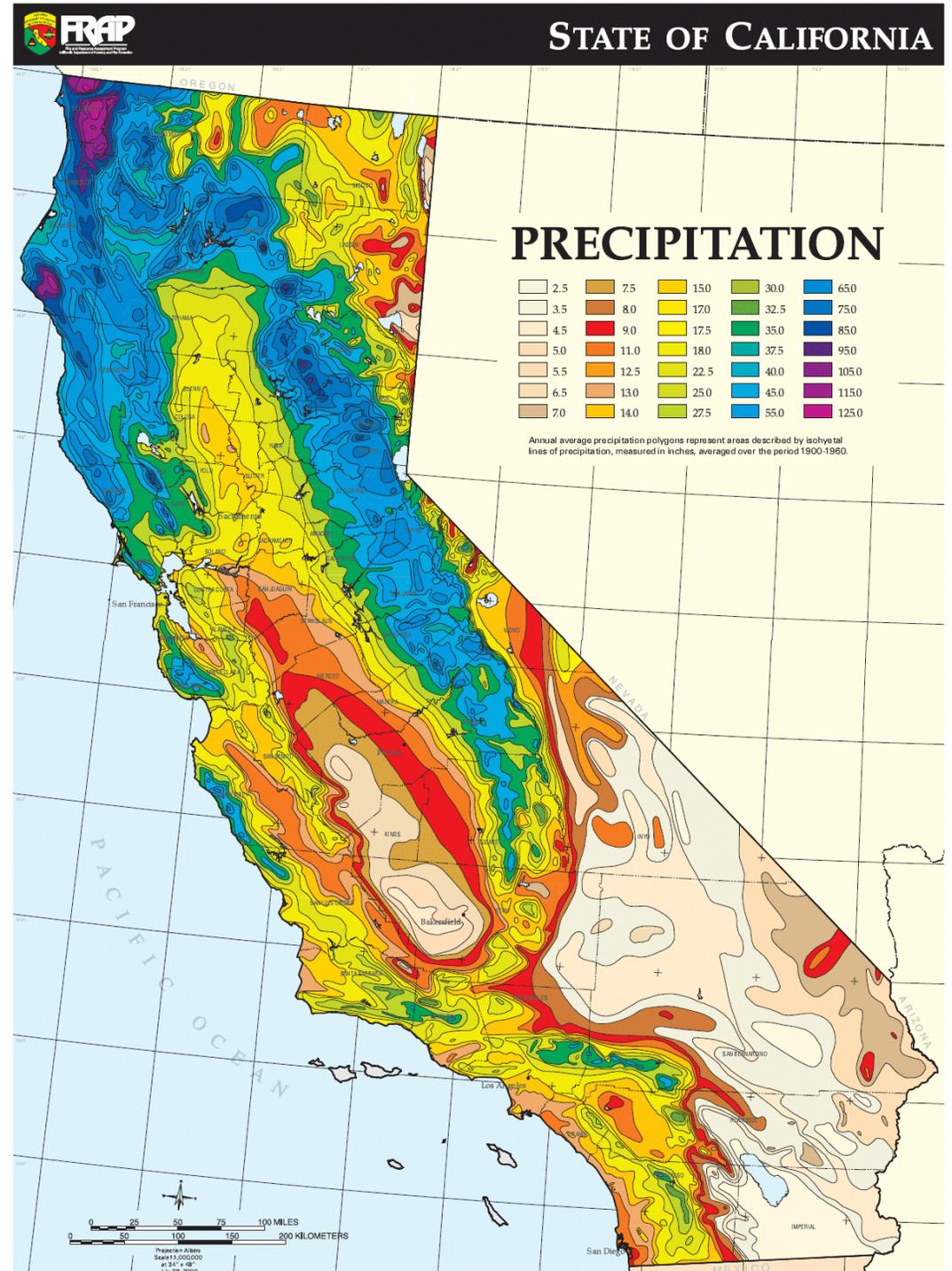
Precipitation in the U.S. varies widely by region.



This figure shows the distribution of *precipitation* in California.

Note that the annual *precipitation* is strongly affected by topography.

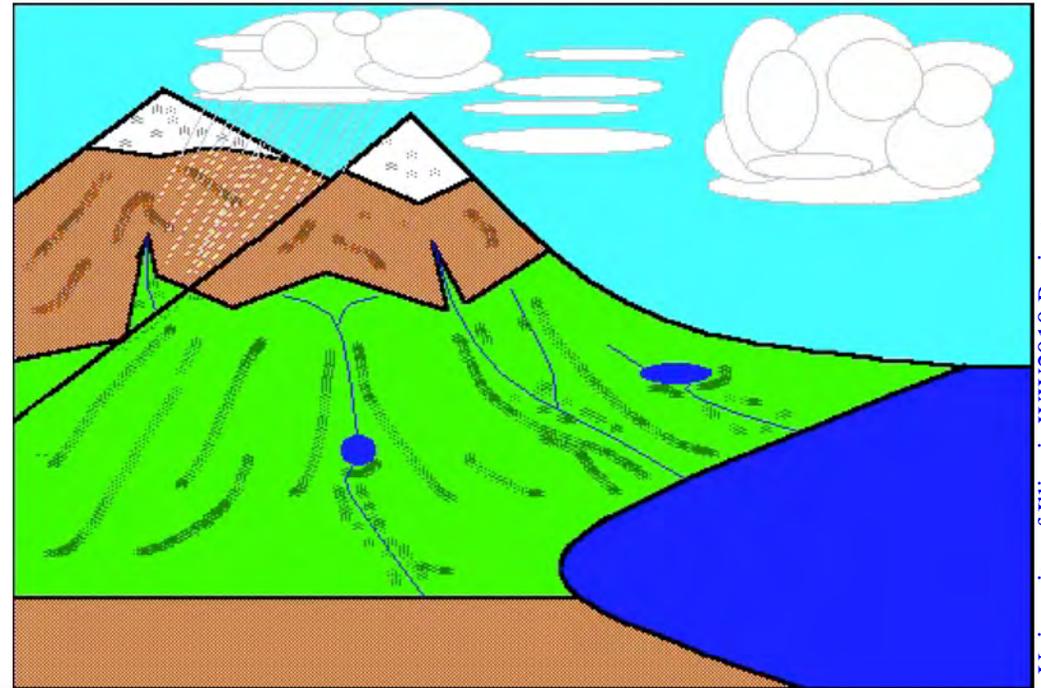
The amount of precipitation can vary by as much as 60 inches/year within ~100 miles.



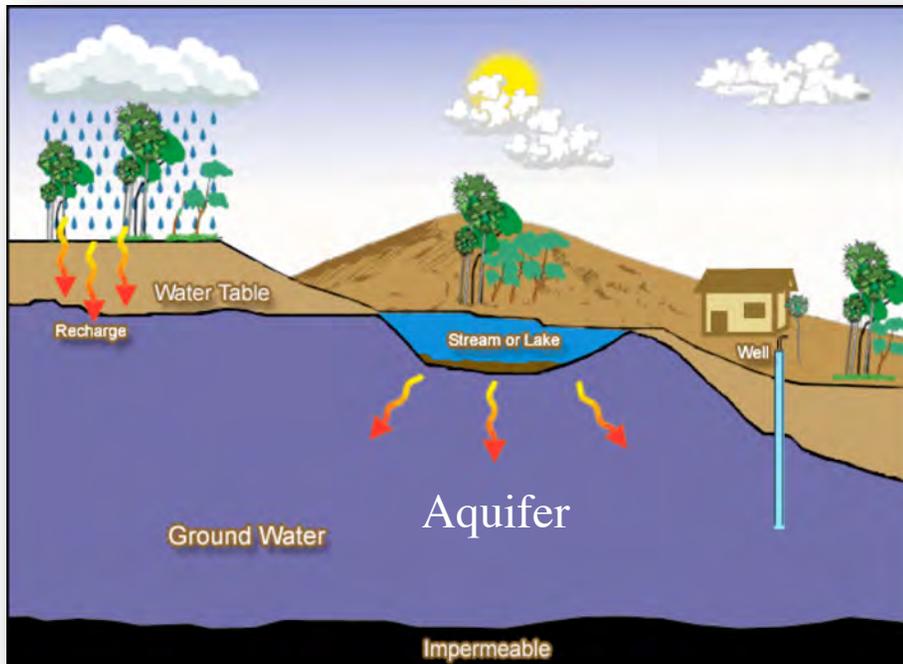
Groundwater

Groundwater is water that has permeated into the ground through a process known as *infiltration*.

An *aquifer* is a body of permeable rock that stores and transmits groundwater.



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The *water table* is the surface where the soil/rock is saturated with water. As the amount of groundwater water increases or decreases, the water table rises or falls.

Groundwater is an abundant water resource, however, the overdraft of water is causing a number of problems:

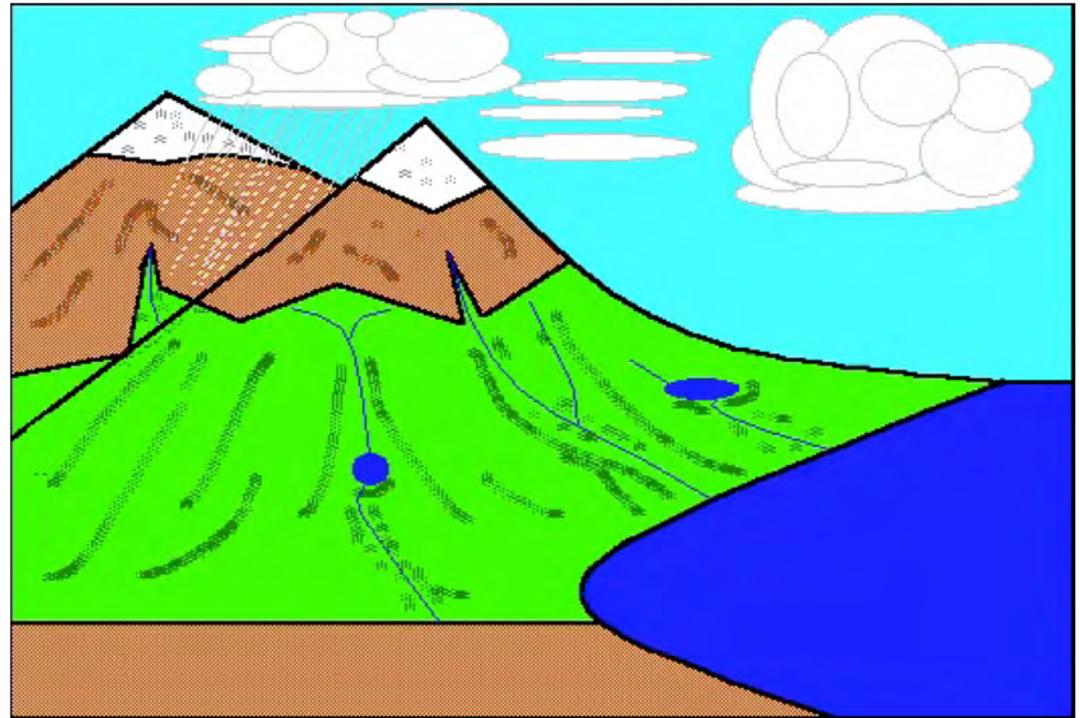
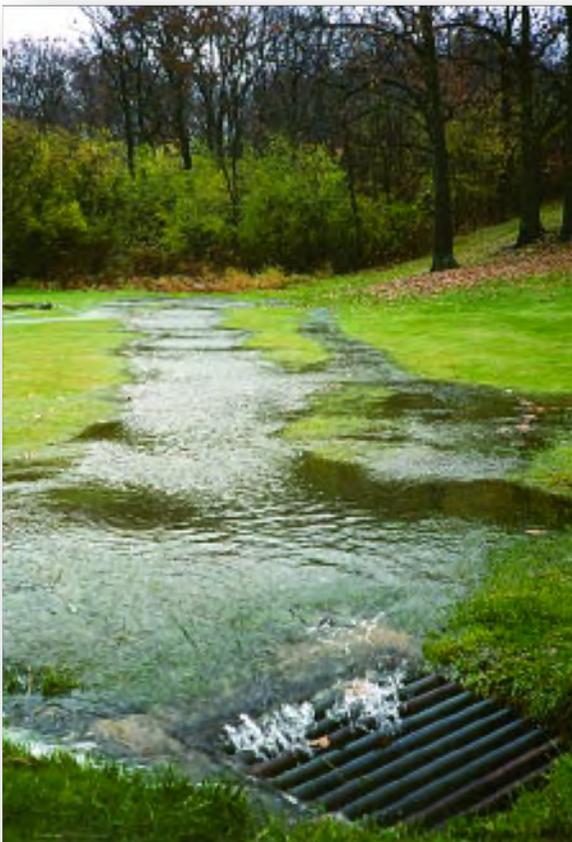
1. As the depth to the water table increases, it is beyond the reach of existing wells. In California, the water table has dropped hundreds of feet in the central valley.
2. As water is pumped out of the ground, it causes the ground to collapse or subside. In portions of the central valley in California, the surface has subsided 28 feet.
3. In coastal regions, the depletion of groundwater has resulted in the intrusion of salt water into the aquifer.
4. Surface contamination can be carried by infiltration into groundwater where the pollution is very difficult to treat.

[Dick Ireland, USGS](#)



Runoff

Runoff is the movement of water on the land surface to the oceans. This occurs primarily by rivers, lakes, and streams.



Runoff consists of precipitation that does not evaporate, transpire or penetrate into the soil to form groundwater.

Runoff is enhanced when the soil is saturated with water from rain.

During a storm when there is a large quantity of precipitation, flooding is common.

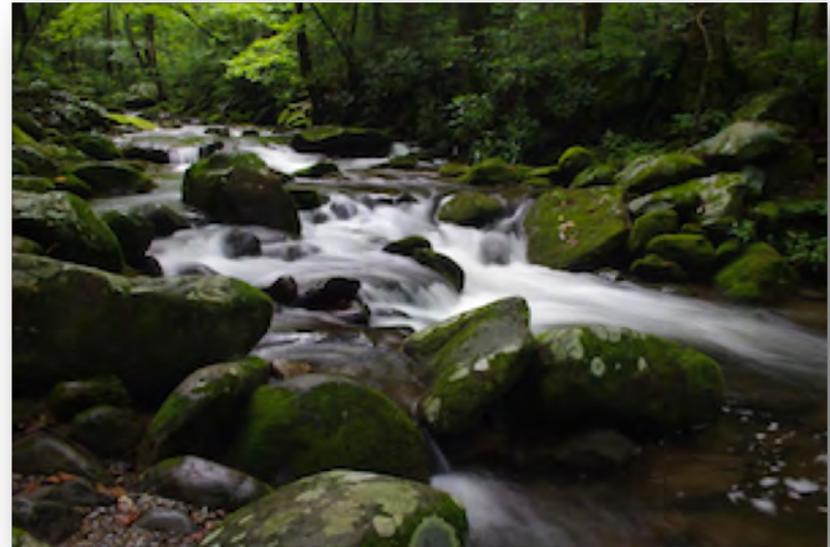
These images show flooding along the Mississippi, Missouri and Illinois Rivers in 1993 from weeks of heavy rain.



The runoff of precipitation on the Earth's surface results in erosion (transport of sediment) and the deposition of sediment.

These are important processes that modify the Earth's surface. Erosion can form valleys and canyons.

Deposition of sediment results in new landforms such as deltas and alluvial fans.



[Samuel H Austin, Virginia Water Science Center. Public domain.](#)

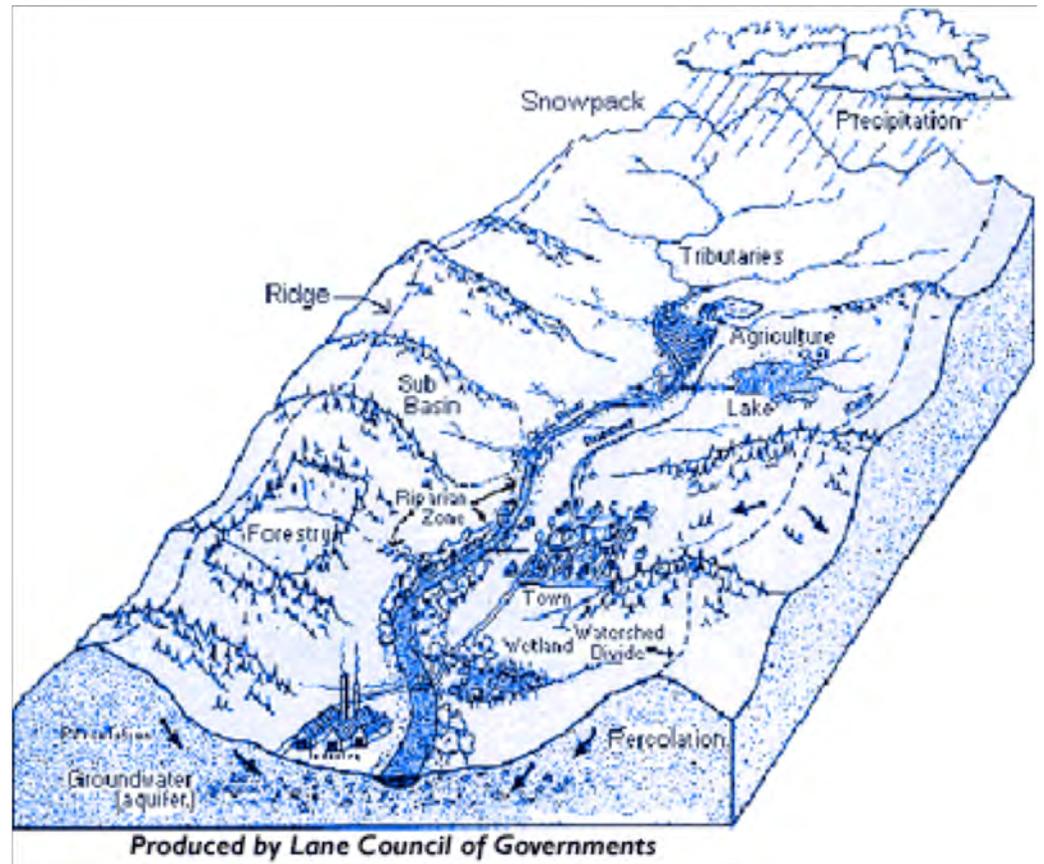
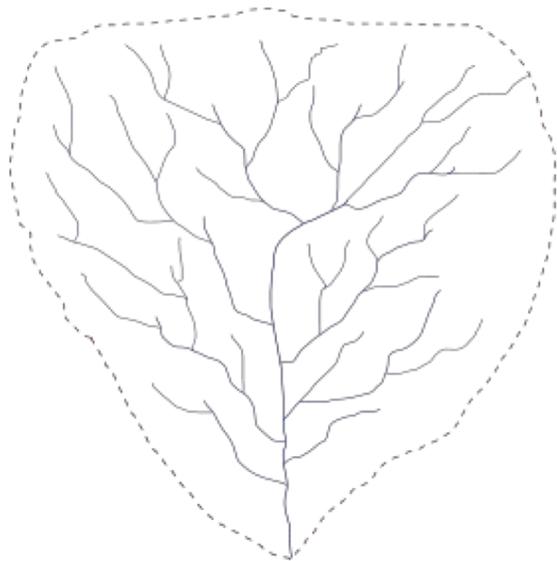


[NPS](#)



[USGS](#)

A **watershed** (drainage basin or catchment) is the area of land where water from *precipitation* and *runoff* converges to a single point where it may exit the basin to the ocean.
In the continental U.S., there are 2,110 watersheds.



Drainage basins are separated from one another by topographic features (geographical barriers) such as mountains.

This map shows the major watersheds in North America.



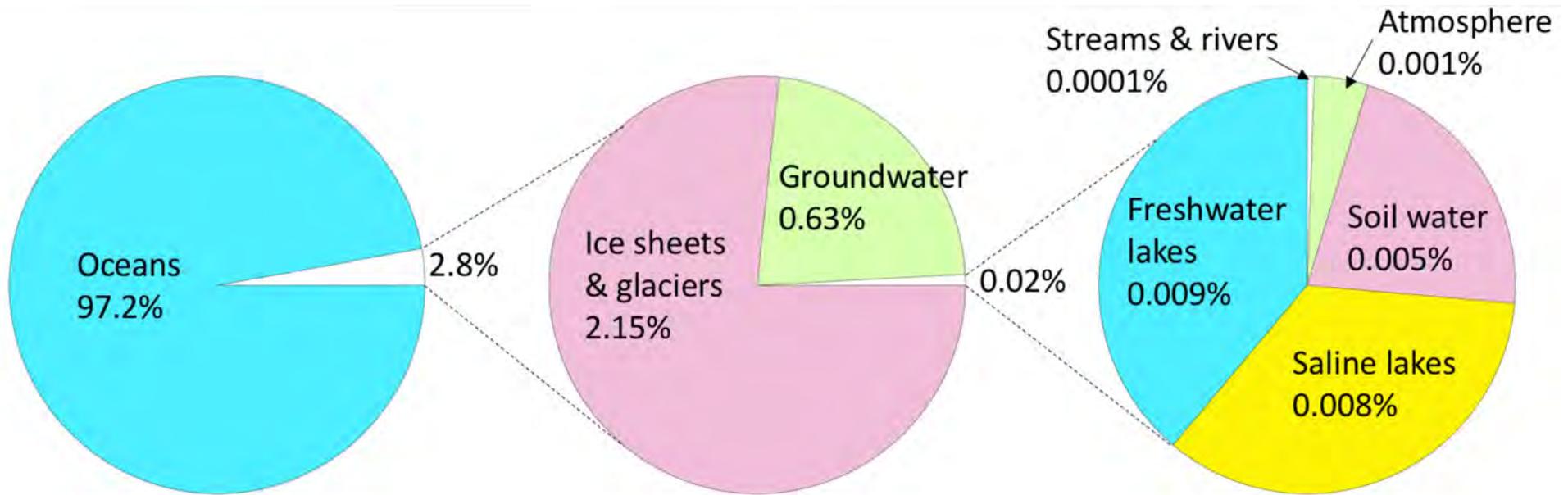
The Mississippi River has the world's fourth largest watershed (3,220,000 km²). It is found in 32 U.S. states and two Canadian provinces and empties into the Gulf of Mexico.

40% of the landmass of the continental United States is covered by the Mississippi watershed.



Any precipitation that falls in the Mississippi watershed will move into one of the river's tributaries, eventually enter the Mississippi River and finally discharge into the Gulf of Mexico.

3. Earth's Water Budget



About 97% of the Earth's water is found in the oceans.

Only ~2.5% of the Earth's water is freshwater.

Most of the Earth's freshwater is locked up in ice (glaciers) and groundwater.

Note how little water is actually in the Earth's atmosphere, streams, and rivers.

The figure shows the amount of water in the three major reservoirs on the Earth: ocean, atmosphere and continents.

The oceans are the largest reservoir of water making up ~97% of all water on Earth.

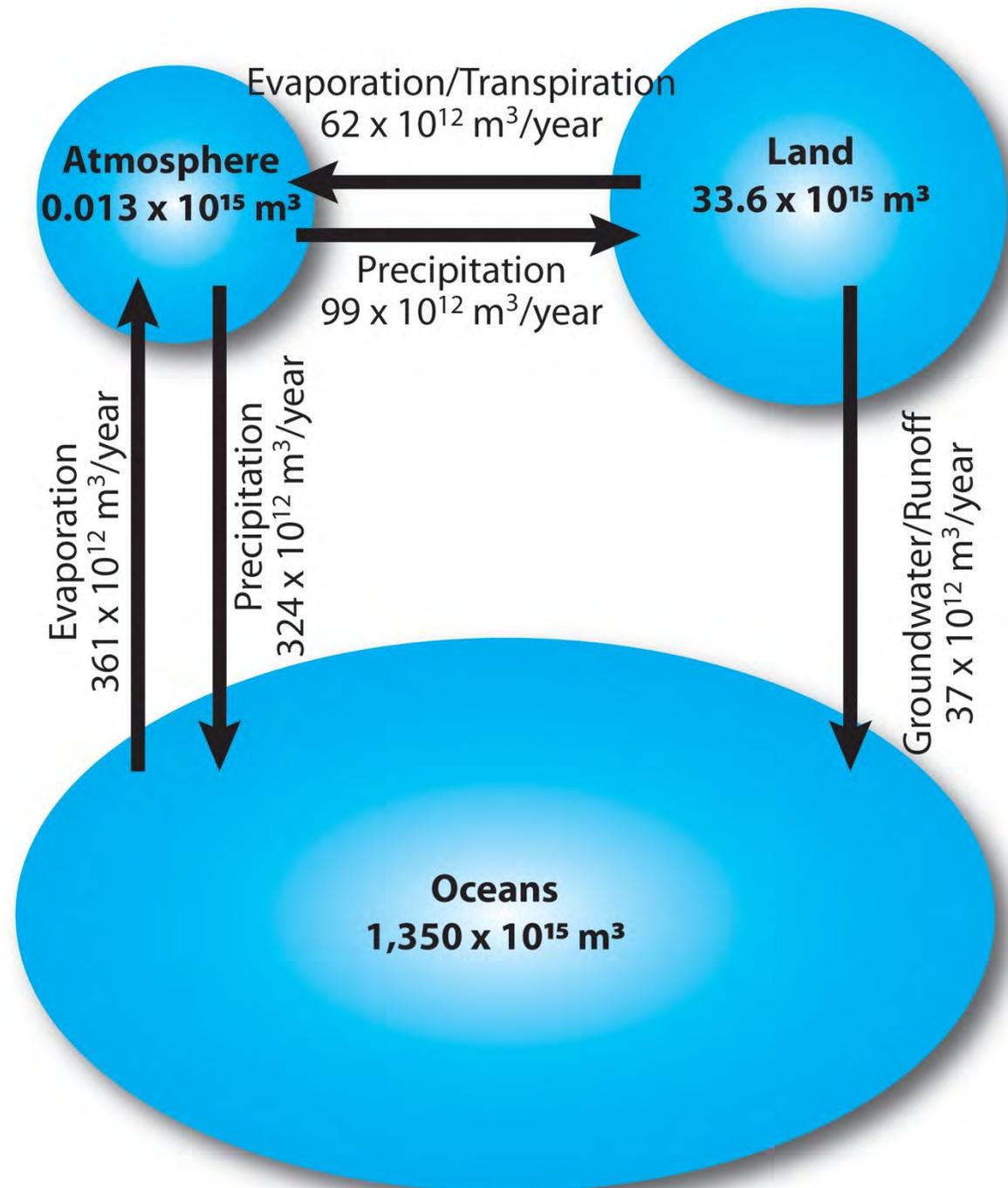


Figure adapted from University of Illinois WW2010 Project

In addition, the arrows show the exchange of water between these different reservoirs.

Evaporation and transpiration add water to the atmosphere.

Precipitation removes water from the atmosphere and adds it to the oceans and land.

Groundwater from the land and runoff (rivers) add water to the oceans.

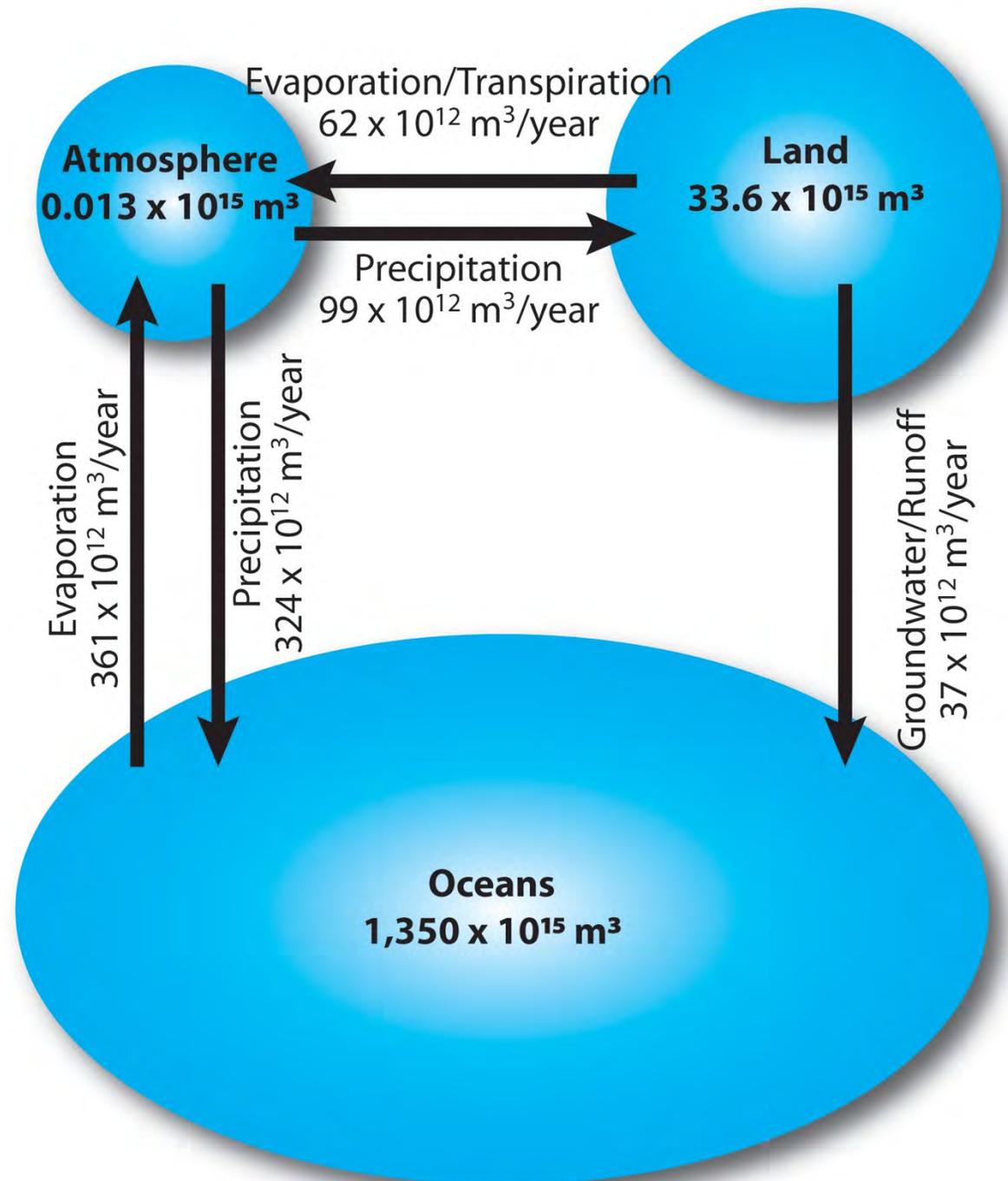


Figure adapted from University of Illinois WW2010 Project

The atmosphere contains only $\sim 0.001\%$ of the Earth's water, which is surprising considering how important water is to driving atmospheric processes and weather.

The total amount of precipitation is ~ 32 times the total amount of water held in the atmosphere at any one time.

This means that there must be rapid recycling of water between the atmosphere and the surface of the Earth.

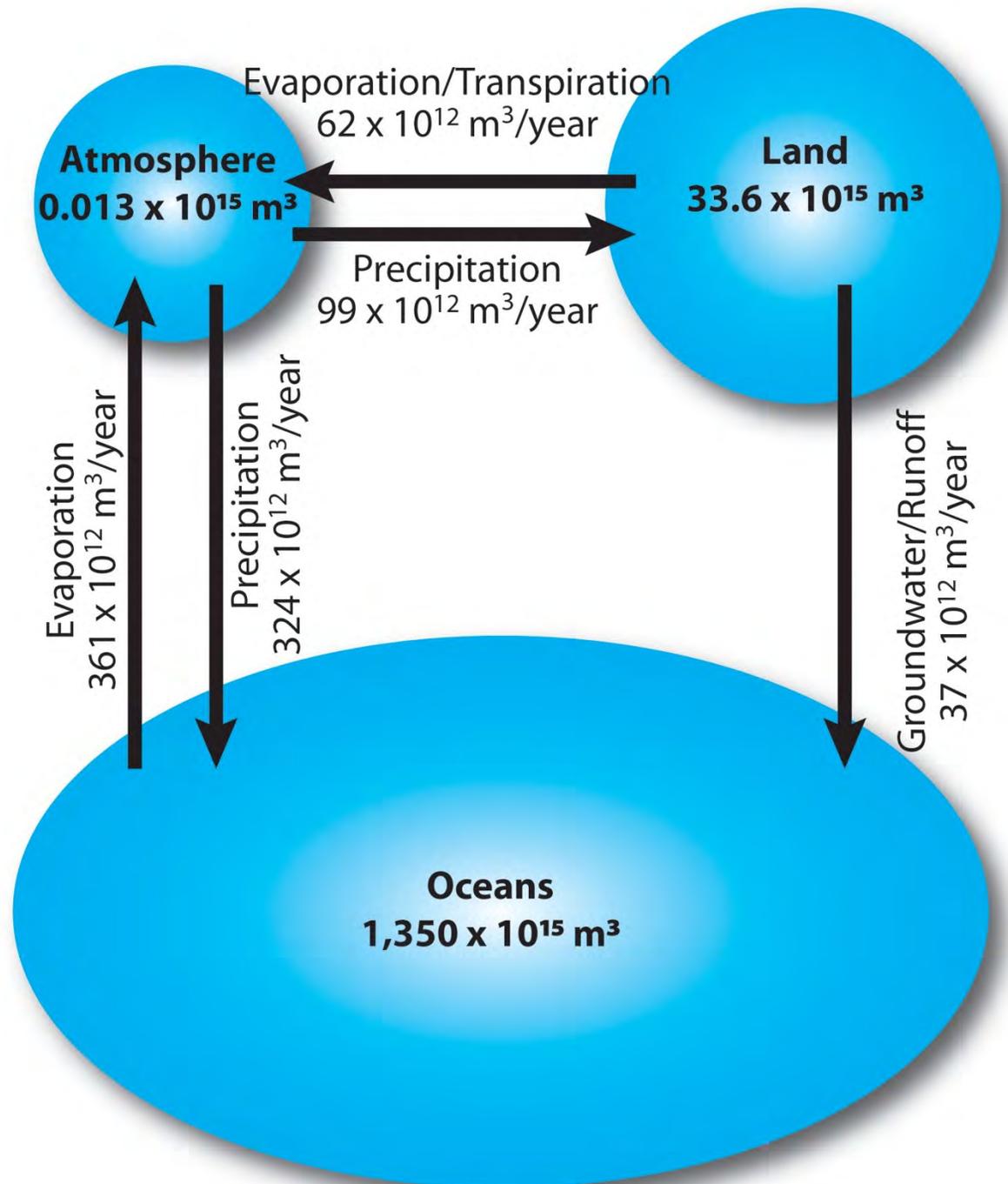


Figure adapted from University of Illinois WW2010 Project