

What is the water cycle?



What is the water cycle? I can easily answer that—it is "me" all over! The water cycle describes the existence and movement of water on, in, and above the Earth. Earth's water is always in movement and is always changing states, from liquid to vapor to ice and back again. The water cycle has been working for billions of years and all life on Earth depends on it continuing to work; the Earth would be a pretty stale place to live without it.

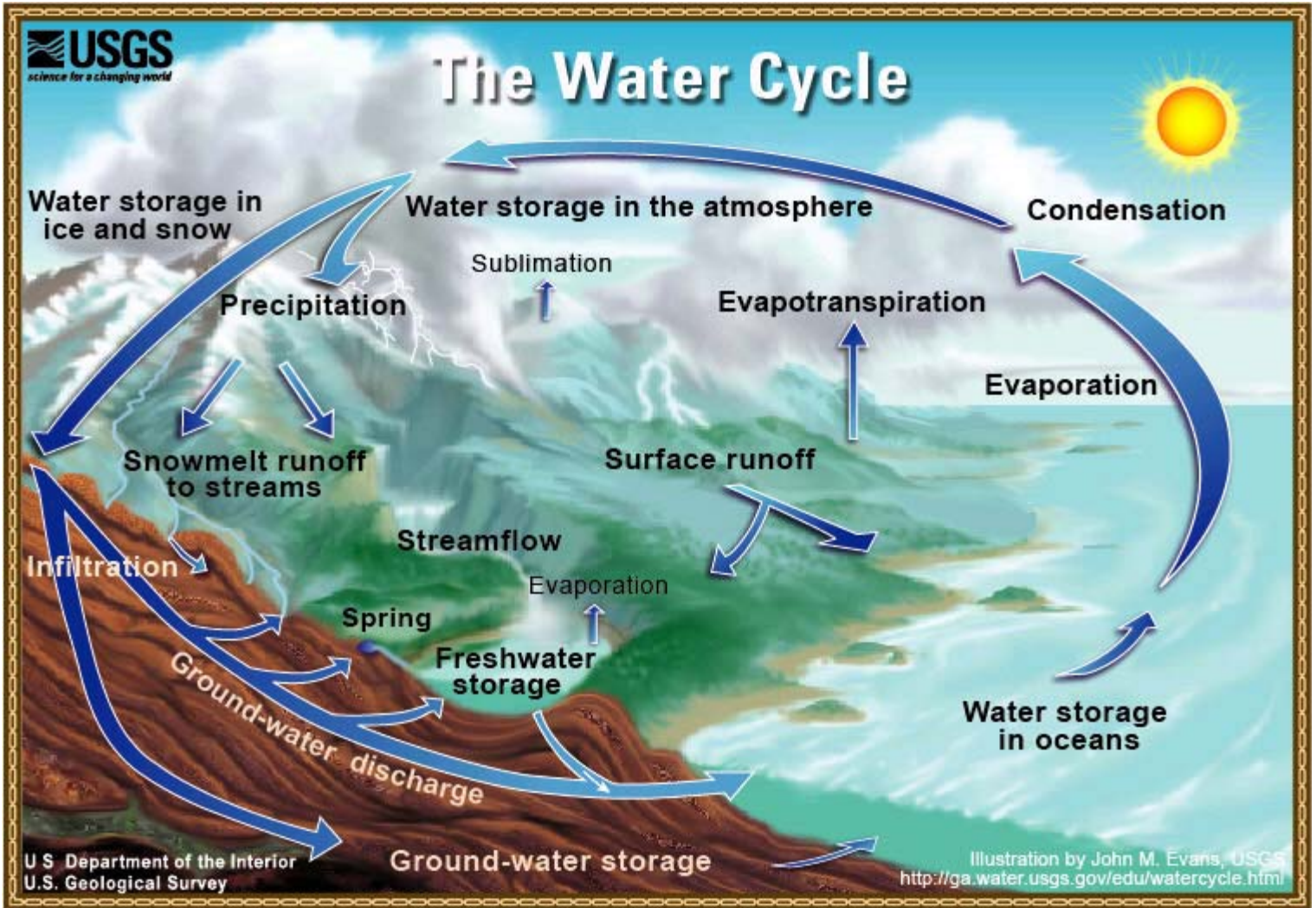


Illustration by John M. Evans, USGS, Colorado District

A quick summary of the water cycle

Where does all the Earth's water come from? Primordial Earth was an incandescent globe made of magma, but all magmas contain water. Water set free by magma began to cool down the Earth's atmosphere, until it could stay on the surface as a liquid. Volcanic activity kept and still keeps introducing water in the atmosphere, thus increasing the surface- and ground-water volume of the Earth.

The water cycle has no starting point. But, we'll begin in the oceans, since that is where most of Earth's water exists. The sun, which drives the water cycle,

heats water in the oceans. Some of it [evaporates](#) as vapor into the air. Ice and snow can [sublimate](#) directly into water vapor. Rising air currents take the vapor up into the [atmosphere](#), along with water from [evapotranspiration](#), which is water transpired from plants and evaporated from the soil. The vapor rises into the air where cooler temperatures cause it to [condense](#) into clouds. Air currents move clouds around the globe, cloud particles collide, grow, and fall out of the sky as [precipitation](#). Some precipitation falls as snow and can accumulate as [ice caps and glaciers](#), which can store frozen water for thousands of years. Snowpacks in warmer climates often thaw and melt when spring arrives, and the melted water flows overland as [snowmelt](#). Most precipitation falls back into the oceans or onto land, where, due to gravity, the precipitation flows over the ground as [surface runoff](#). A portion of runoff enters rivers in valleys in the landscape, with [streamflow](#) moving water towards the oceans. Runoff, and ground-water seepage, accumulate and are [stored as freshwater](#) in lakes. Not all runoff flows into rivers, though. Much of it soaks into the ground as [infiltration](#). Some water infiltrates deep into the ground and replenishes [aquifers](#) (saturated subsurface rock), which store huge amounts of freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as [ground-water discharge](#), and some ground water finds openings in the land surface and emerges as freshwater [springs](#). Over time, though, all of this water keeps moving, some to reenter the ocean, where the water cycle "ends" ...

oops - I mean, where it "begins."

The water cycle: Evaporation

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Evaporation - The process by which water is changed from a liquid to a gas or vapor.



Evaporation cools hot water produced by power plants.

Evaporation is the process by which water changes from a liquid to a gas or vapor. Evaporation is the primary pathway that water moves from the liquid state back into the water cycle as atmospheric water vapor. Studies have shown that the oceans, seas, lakes, and rivers provide nearly 90 percent of the moisture in the

atmosphere via evaporation, with the remaining 10 percent being contributed by plant [transpiration](#).

A very small amount of water vapor enters the atmosphere through sublimation, the process by which water changes from a solid (ice or snow) to a gas, bypassing the liquid phase. This often happens in the Rocky Mountains as dry and warm Chinook winds blow in from the Pacific in late winter and early spring. When a Chinook takes effect local temperatures rise dramatically in a matter of hours. When the dry air hits the snow, it changes the snow directly into water vapor, bypassing the liquid phase. Sublimation is a common way for snow to disappear quickly in arid climates. (Source: [Mount Washington Observatory](#))

Why evaporation occurs

Heat (energy) is necessary for evaporation to occur. Energy is used to break the bonds that hold water molecules together, which is why water easily evaporates at the boiling point (212° F, 100° C) but evaporates much more slowly at the freezing point. Net evaporation occurs when the rate of evaporation exceeds the rate of condensation. A state of saturation exists when these two process rates are equal, at which point the relative humidity of the air is 100 percent. [Condensation](#), the opposite of evaporation, occurs when

saturated air is cooled below the dew point (the temperature to which air must be cooled at a constant pressure for it to become fully saturated with water), such as on the outside of a glass of ice water. In fact, the process of evaporation removes heat from the environment, which is why water evaporating from your skin cools you.

Evaporation drives the water cycle



Credit: Kidzone Fun Facts

Evaporation from the oceans is the primary mechanism supporting the surface-to-atmosphere portion of the water cycle. After all, the large surface area of the oceans (over 70 percent of the Earth's surface is covered by the oceans) provides the opportunity for large-scale evaporation to occur. On a global scale, the amount of water evaporating is about the same as the amount of water delivered to the Earth as precipitation. This does vary geographically, though. Evaporation is more prevalent over the oceans than precipitation, while over the land, precipitation routinely exceeds evaporation. Most of the water that evaporates from the oceans falls back into the oceans as precipitation. Only about 10 percent of the water evaporated from the oceans is transported over land and falls as precipitation. Once evaporated, a water molecule spends about 10 days in the air. The process of evaporation is so great that without precipitation runoff, and ground-water discharge from aquifers, oceans would become nearly empty.

Less evaporation takes place during periods of calm winds than during windy times. When the air is calm, evaporated water tends to stay close to the water body, as the picture above shows; when winds are present, the more moist air close to the water body is moved away and replaced by drier air which favors additional evaporation.

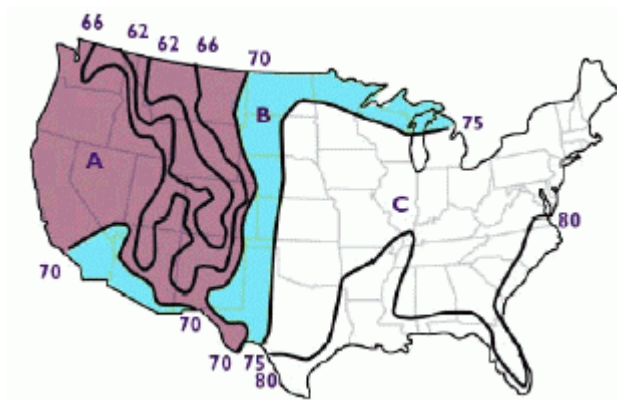
People make use of evaporation



Dead Sea evaporation ponds, EXACT

If you ever find yourself stranded on an island in need of some salt, just grab a bowl, add some seawater, and wait for the sun to evaporate the water. In fact, much of the world's table salt is produced within evaporation ponds, a technique used by people for thousands of years. Salt is not the only product that people obtain using evaporation. Seawater contains other valuable minerals that are easily obtained by evaporation. The Dead Sea is located in the Middle East within a closed watershed and without any means of outflow, which is abnormal for most lakes. The primary mechanism for water to leave the lake is by evaporation, which can be quite high in a desert—upwards of 1,300 - 1,600 millimeters per year. The result is that the waters of the Dead Sea have the highest salinity and density (which is why you float "higher" when you lay in the water) of any sea in the world, too high to support life. The water is ideal for locating evaporation ponds for the extraction of not only table salt, but also magnesium, potash, and bromine. (Source: [Overview of Middle East Water Resources](#), Middle East Water Data Banks Project).

Evaporative cooling: Cheap air conditioning!



We said earlier that heat is removed from the environment during evaporation, leading to a net cooling; notice how cold your arm gets when a physician rubs it with alcohol before pulling out a syringe with that scary-looking needle attached. In climates where the humidity is low and the temperatures are hot, an evaporator cooler, such as a "swamp cooler" can lower the air temperature by 20 degrees F., while it increases humidity. As this map shows, evaporative coolers work best in the dry areas of the United States (red areas marked A) and can work somewhat in the blue areas marked B. In the humid eastern U.S., normal air conditioners must be used. Evaporative coolers are really quite simple devices, at least compared to air conditioners. Swamp coolers pull in the dry, hot outdoor air and pass it through an evaporative pad that is kept wet by a supply of water. As a fan draws the air through the pad, the water in the pad evaporates, resulting in cooler air which is pumped through the house. Much less energy is used as compared to an air conditioner. (Source: [California Energy Commission](#))

The water cycle: Sublimation

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Sublimation - *The conversion between the solid and the gaseous phases of matter, with no intermediate liquid stage.*



Cobden Unit School District #17, Illinois

Sublimation is the conversion between the solid and the gaseous phases of matter, with no intermediate liquid stage. For those of us interested in the water cycle, sublimation is most often used to describe the process of snow and ice changing into water vapor in the air without first melting into water. The opposite of sublimation is "deposition", where water vapor changes directly into ice—such a snowflakes and frost.

It is not easy to actually see sublimation occurring, at least not with ice. One way to see the results of sublimation is to hang a wet shirt outside on a below-freezing day. Eventually the ice in the shirt will disappear. Actually, the best way to visualize sublimation is to not use water at all, but to use carbon dioxide instead. If you don't know what I mean, then look at this picture of dry ice. "Dry ice" is actually solid, frozen carbon dioxide, which happens to sublimate, or turn to gas, at a chilly $-78.5\text{ }^{\circ}\text{C}$ (-109.3°F). The fog you see is actually a mixture of cold carbon dioxide gas and cold, humid air, created as the dry ice "melts" ... oops, I mean sublimates.



Sublimation occurs more readily when certain weather conditions are present, such as low relative humidity and dry winds. Sublimation also occurs more at higher altitudes, where the air pressure is less than at lower altitudes. Energy, such as strong sunlight, is also needed. If I was to pick one place on Earth where sublimation happens a lot, I might choose the south face of Mt. Everest. Low temperatures, strong winds, intense sunlight, very low air pressure—just the recipe for sublimation to occur.

Sublimation and Chinook winds

Dave Thurlow of the Mount Washington Observatory offers a good explanation of sublimation in [The Weather Notebook](#):

"There's more than one way for Mother Nature to get rid of a fresh blanket of snow. The most common way, of course, is by melting—which gives everyone the pleasure of trudging through slush, mud, and water. But in the western U.S., there's a wind called the Chinook, or "snow eater," that vaporizes snow before it even has a chance to melt."

"Chinook winds are westerlies from the Pacific whose moisture gets wrung out as it passes over the Rocky Mountains. Once these winds come down from the mountains onto the high plains, they can be quite mild and extremely dry—as warm as 60 or 70 degrees Fahrenheit -- over 15 Celsius -- with a relative humidity of 10% or less. The air is so dry that when it hits a snowpack, the frozen water evaporates, going directly from the ice to vapor and bypassing the liquid phase entirely. This is called sublimation, and it's a common way for snow to disappear in the arid West."

Can't sublimate without the heat




Without the addition of energy (heat) to the process, ice would not sublimate into vapor. That is where sunlight plays a large role in the natural world. Water has a physical property

called the "heat of vaporization," which is the amount of heat required to vaporize water. If you want an exact amount of heat, the heat of vaporization of water is 540 calories/gram, or 2,260 kilojoules/kilogram. That is a lot more energy than is needed to convert water to ice (the latent heat of fusion), which is 80 calories/gram. And, it is also about five times the energy needed for heating water from the freezing point to the boiling point. In summary, the energy for sublimation of ice to vapor is the sum of the heat of vaporization and the heat of fusion.

The water cycle: Water storage in the atmosphere

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 *Water storage in the atmosphere* - Water stored in the atmosphere as vapor, such as clouds and humidity.

The atmosphere is full of water



The water cycle is all about storing water and moving water on, in, and above the Earth. Although the atmosphere may not be a great storehouse of water, it is the superhighway used to move water around the globe. [Evaporation](#) and [transpiration](#) change liquid water into vapor, which ascends into the atmosphere due to rising air currents. Cooler temperatures aloft allow the vapor to [condense](#) into clouds and strong winds move the clouds around the world until the water falls as [precipitation](#) to replenish the earthbound parts of the water cycle. About 90 percent of water in the atmosphere is produced by evaporation from water bodies, while the other 10 percent comes from transpiration from plants.

There is always water in the atmosphere. Clouds are, of course, the most visible manifestation of atmospheric water, but even clear air contains water—water in particles that are too small to be seen. One estimate of the volume of water in the atmosphere at any one time is about 3,100 cubic miles (mi³) or 12,900 cubic kilometers (km³). That may sound like a lot, but it is only about 0.001 percent of the total Earth's water volume of about 332,500,000 mi³ (1,385,000,000 km³), as shown in the table below. If all of the water in the atmosphere rained down at once, it would only cover the ground to a depth of 2.5 centimeters, about 1 inch.

How much does a cloud weigh?



Do you think clouds have any weight? How can they, if they are floating in the air like a balloon filled with helium? If you tie a helium balloon to a kitchen scale it won't register any weight, so why should a cloud? To answer this question, let me ask if you think air has any weight—that is really the important question. If you know what air pressure and a barometer are, then you know that air does have weight. At sea level, the weight (pressure) of air is about 14 ½ pounds per square inch (1 kilogram per square centimeter).

Since air has weight it must also have density, which is the weight for a chosen volume, such as a cubic inch or cubic meter. If clouds are made up of particles, then they must have weight and density. The key to why clouds float is that the density of the same volume of cloud material is less than the density of the same amount of dry air. Just as oil floats on water because it is less dense, clouds float on air because the moist air in clouds is less dense than dry air.

We still need to answer the question of how much a cloud weighs. For an example, let's use your basic "everyday" cloud—the cumulus cloud with a volume of about 1 cubic kilometer (km) located about 2 km above the ground. In other words, it is a cube about 1 km on each side. The [National Oceanic and Atmospheric Administration](#) (NOAA) provides some estimates of air and cloud density and weight. NOAA found that dry air has a density of about 1.007 kilograms/cubic meter (kg/m^3), moist air comes in at about 0.627 kg/m^3 , and the density of the actual cloud droplets is about 0.0005 kg/m^3 . The density of the cloud is thus about 62 percent of dry air. In the final calculations, the 1 km^3 cumulus cloud weighs a whopping 1.4 billion pounds (635 million kilograms)! But the cloud floats because the weight of the same volume of dry air is even more, about 2.2 billion pounds (1 billion kilograms). Still, remember that it is the lesser density of the cloud that allows it to float on the dryer and more-dense air.

Global distribution of atmospheric water

One estimate of global water distribution

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of total freshwater	Percent of total water
Atmosphere	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%

Source: 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.

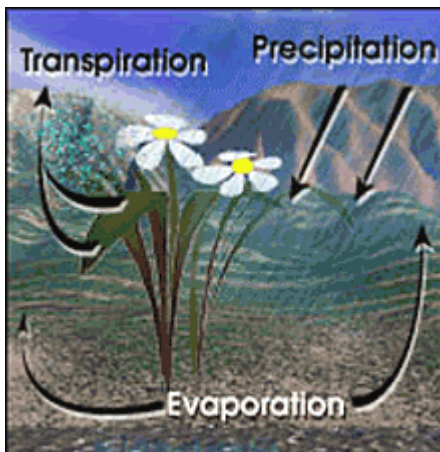
The water cycle: Evapotranspiration

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Evapotranspiration - The process by which water is discharged to the atmosphere as a result of evaporation from the soil and transpiration by plants.

What is evapotranspiration?



Hailey King, NASA, GFSC

If you search for the definition of evapotranspiration, you will find that it varies. In general, evapotranspiration is the sum of evaporation and transpiration. Some definitions include evaporation from surface-water bodies, even the oceans. But, since we have a Web page just about evaporation, our definition of evapotranspiration will not include evaporation from surface water. On this site, evapotranspiration is defined as the water lost to the atmosphere from the ground surface, evaporation from the capillary fringe of the groundwater table, and the transpiration of groundwater by plants whose roots tap the capillary fringe of the groundwater table. The banner at the top of this page offers an even more simple definition. The transpiration aspect of evapotranspiration is essentially evaporation of water from plant leaves. Studies have revealed that transpiration accounts for about 10 percent of the the moisture in the atmosphere, with oceans, seas, and other bodies of water (lakes, rivers, streams) providing nearly 90 percent, and a tiny amount coming from sublimation (ice changing into water vapor without first becoming liquid).

Transpiration: The release of water from plant leaves



Credit: Ming kei College, Hong Kong

Just as you release water vapor when you breath, plants do, too – although the term "transpire" is more appropriate than "breath." This picture shows water vapor transpired from plant leaves after a plastic bag has been tied around the stem for about an hour. If the bag had been wrapped around the soil below it, too, then even more water vapor would have been released, as water also evaporates from the soil.

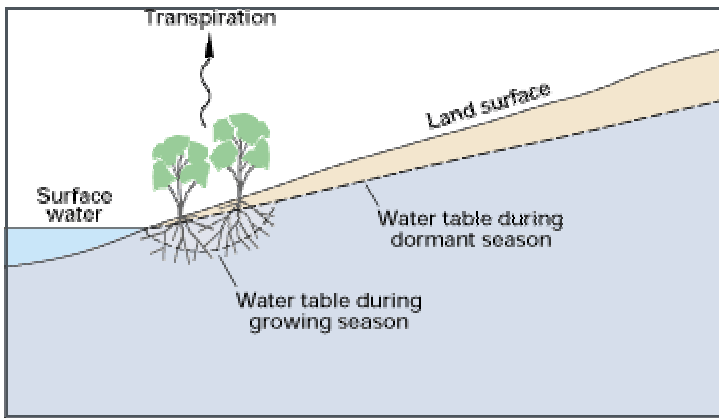
Plants put down roots into the soil to draw water and nutrients up into the stems and leaves. Some of this water is returned to the air by transpiration. Transpiration rates vary widely depending on weather conditions, such as temperature, humidity, sunlight availability and intensity, precipitation, soil type and saturation, wind, and land slope. During dry periods, transpiration can contribute to the loss of moisture in the upper soil zone, which can have an effect on vegetation and food-crop fields.

How much water do plants transpire?

Plant transpiration is pretty much an invisible proces – since the water is evaporating from the leaf surfaces, you don't just go out and see the leaves "breathing". Just because you can't see the water doesn't mean it is not being put into the air, though. One way to visualize transpiration is to put a plastic bag around some plant leaves. As this picture shows, transpired water will condense on the inside of the bag. During a growing season, a leaf will transpire many times more water than its own weight. An acre of corn gives off about 3,000-4,000 gallons (11,400-15,100 liters) of water each day, and a large oak tree can transpire 40,000 gallons (151,000 liters) per year.

Atmospheric factors affecting transpiration

The amount of water that plants transpire varies greatly



geographically and over time. There are a number of factors that determine transpiration rates:

- Temperature: Transpiration rates go up as the temperature goes up, especially

during the growing season, when the air is warmer due to stronger sunlight and warmer air masses. Higher temperatures cause the plant cells which control the openings (stoma) where water is released to the atmosphere to open, whereas colder temperatures cause the openings to close.

- Relative humidity: As the relative humidity of the air surrounding the plant rises the transpiration rate falls. It is easier for water to evaporate into dryer air than into more saturated air.
- Wind and air movement: Increased movement of the air around a plant will result in a higher transpiration rate. This is somewhat related to the relative humidity of the air, in that as water transpires from a leaf, the water saturates the air surrounding the leaf. If there is no wind, the air around the leaf may not move very much, raising the humidity of the air around the leaf. Wind will move the air around, with the result that the more saturated air close to the leaf is replaced by drier air.
- Soil-moisture availability: When moisture is lacking, plants can begin to senesce (premature ageing, which can result in leaf loss) and transpire less water.
- Type of plant: Plants transpire water at different rates. Some plants which grow in arid regions, such as cacti and succulents, conserve precious water by transpiring less water than other plants.

Transpiration and ground water

In many places, the top layer of the soil where plant roots are located is above the water table and thus is often wet to some

extent, but is not totally saturated, as is soil below the water table. The soil above the water table gets wet when it rains as water [infiltrates](#) into it from the surface, But, it will dry out without additional precipitation. Since the water table is usually below the depth of the plant roots, the plants are dependent on water supplied by precipitation. As this diagram shows, in places where the water table is near the land surface, such as next to lakes and oceans, plant roots can penetrate into the saturated zone below the water table, allowing the plants to transpire water directly from the ground-water system. Here, transpiration of ground water commonly results in a drawdown of the water table much like the effect of a pumped well (cone of depression—the dotted line surrounding the plant roots in the diagram).

The water cycle: Precipitation

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Precipitation - the discharge of water, in liquid or solid state, out of the atmosphere, generally upon a land or water surface.



Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth. Most precipitation falls as rain.

How do raindrops form?



Storm near Elko, Nevada. NOAA

The clouds floating overhead contain water vapor and cloud droplets, which are small drops of condensed water. These droplets are way too small to fall as precipitation, but they are large enough to form visible clouds. Water is continually [evaporating](#) and [condensing](#) in the sky. If you look closely at a cloud you can see some parts disappearing (evaporating) while other parts are growing (condensation). Most of the condensed water in clouds does not fall as precipitation because their fall speed is not large enough to overcome updrafts which support the clouds. For precipitation to happen, first tiny water droplets must condense on even tinier dust, salt, or smoke particles, which act as a nucleus. Water droplets may grow as a result of additional condensation of water vapor when the particles collide. If

enough collisions occur to produce a droplet with a fall velocity which exceeds the cloud updraft speed, then it will fall out of the cloud as precipitation. This is not a trivial task since millions of cloud droplets are required to produce a single raindrop. A more efficient mechanism (known as the Bergeron-Findeisen process) for producing a precipitation-sized drop is through a process which leads to the rapid growth of ice crystals at the expense of the water vapor present in a cloud. These crystals may fall as snow, or melt and fall as rain.



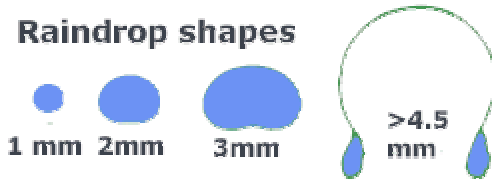
Care to guess how many gallons of water fall when 1 inch (2.5 cm) of rain falls on 1 acre of land?

What do raindrops look like?



Let me introduce myself - I am Drippy, the (un)official USGS water-science icon. It is obvious that I am a raindrop, right? After all, all of you know that raindrops are shaped, well ... like me. As proof, you've probably seen me on television, in magazines, and in artists' representations. Truth is, I am "Drippy" and actually I am shaped more like a drip falling from a water faucet than a raindrop. The common raindrop is actually shaped more like a hamburger bun.

Raindrop shapes



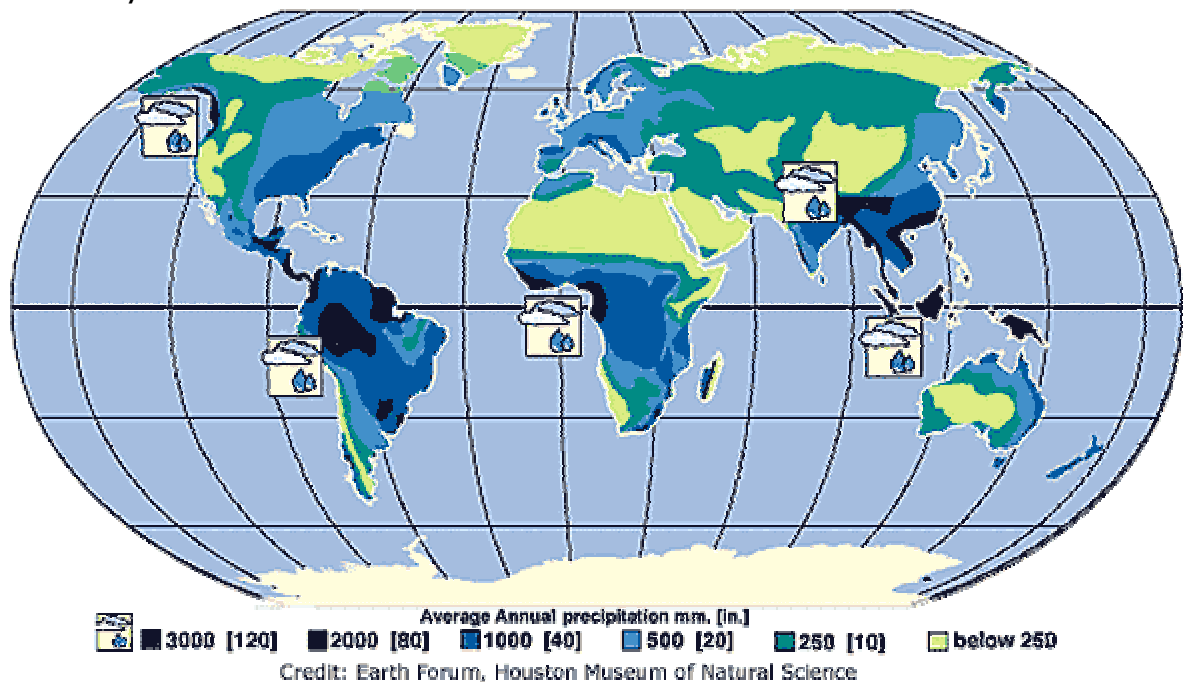
As Alistair Frasier explains in his web page, [Bad Rain](#), small raindrops, those with a radius of less than 1 millimeter (mm), are spherical, like a round ball. As droplets collide and grow in size, the bottom of the drop begins to be affected by the resistance of the air it is falling through. The bottom of the drop starts to flatten out until at about 2-3 mm in diameter the bottom is quite flat with an indentation in the middle - much like a hamburger bun. Raindrops don't stop growing at 3 millimeters, though, and when they reach about 4-5 mm, things really fall apart. At this size, the indentation in the bottom greatly expands forming something like a parachute with two smaller droplets at the bottoms. The

parachute doesn't last long, though, and the large drop breaks up into smaller drops.

Precipitation rates vary geographically and over time

Precipitation does not fall in the same amounts throughout the world, in a country, or even in a city. Here in Georgia, USA, it rains fairly evenly all during the year, around 40-50 inches (102-127 centimeters (cm)) per year. Summer thunderstorms may deliver an inch or more of rain on one suburb while leaving another area dry a few miles away. But, the rain amount that Georgia gets in one month is often more than Las Vegas, Nevada observes all year. The world's record for average-annual rainfall belongs to Mt. Waialeale, Hawaii, where it averages about 450 inches (1,140 cm) per year. A remarkable 642 inches (1,630 cm) was reported there during one twelve-month period (that's almost 2 inches (5 cm) every day!). Is this the world record for the most rain in a year? No, that was recorded at Cherrapunji, India, where it rained 905 inches (2,300 cm) in 1861. Contrast those excessive precipitation amounts to Arica, Chile, where no rain fell for 14 years, and in Bagdad, California, where precipitation was absent for 767 consecutive days from October 1912 to November 1914.

The map below shows average annual precipitation, in millimeters and inches, for the world. The light green areas can be considered "deserts". You might expect the Sahara area in Africa to be a desert, but did you think that much of Greenland and Antarctica are deserts?



On average, the 48 continental United States receives enough precipitation in one year to cover the land to a depth of 30 inches (0.76 meters).

Precipitation size and speed


Have you ever watched a raindrop hit the ground during a large rainstorm and wondered how big the drop is and how fast it is falling? Or maybe you've wondered how small fog particles are and how they manage to float in the air. The table below shows the size, velocity of fall, and the density of particles (number of drops per square foot/square meter of air) for various types of precipitation, from fog to a cloudburst.

	Intensity inches/hour (cm/hour)	Median diameter (millimeters)	Velocity of fall feet/second (meters/second)	Drops per second per square foot (square meter)
Fog	0.005 (0.013)	0.01	0.01 (0.003)	6,264,000 (67,425,000)
Mist	.002 (.005)	.1	.7 (.21)	2,510 (27,000)
Drizzle	.01 (.025)	.96	13.5 (4.1)	14(151)
Light rain	.04 (1.02)	1.24	15.7 (4.8)	26 (280)
Moderate rain	.15 (.38)	1.60	18.7 (5.7)	46 (495)
Heavy rain	.60 (1.52)	2.05	22.0 (76.)	46 (495)
Excessive rain	1.60 (4.06)	2.40	24.0 (7.3)	76 (818)
Cloudburst	4.00 (10.2)	2.85	25.9 (7.9)	113 (1,220)

Source: Lull, H.W., 1959, Soil Compaction on Forest and Range Lands, U.S. Dept. of Agriculture, Forestry Service, Misc. Publication No.768

The water cycle: Water storage in ice and snow

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 **Water storage in ice and snow** - Freshwater stored in frozen form, generally in glaciers, icefields, and snowfields.

Stored water as part of the water cycle

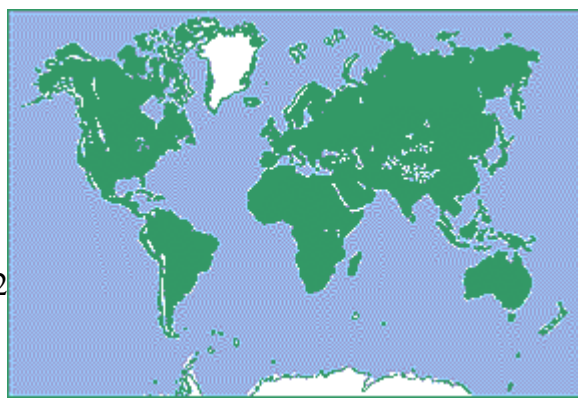


NASA

The water cycle describes how water moves above, on, and through the Earth. But, in fact, much more water is "in storage" at any one time than is actually moving through the cycle. By storage, we mean water that is locked up in its present state for a relatively long period of time. Short-term storage might be days or weeks for water in a lake, but it could be thousands of years for [deep ground-water storage](#) or even longer for water at the bottom of an ice cap, such as in Greenland. In the grand scheme of things, this water is still part of the water cycle.

Ice caps around the world

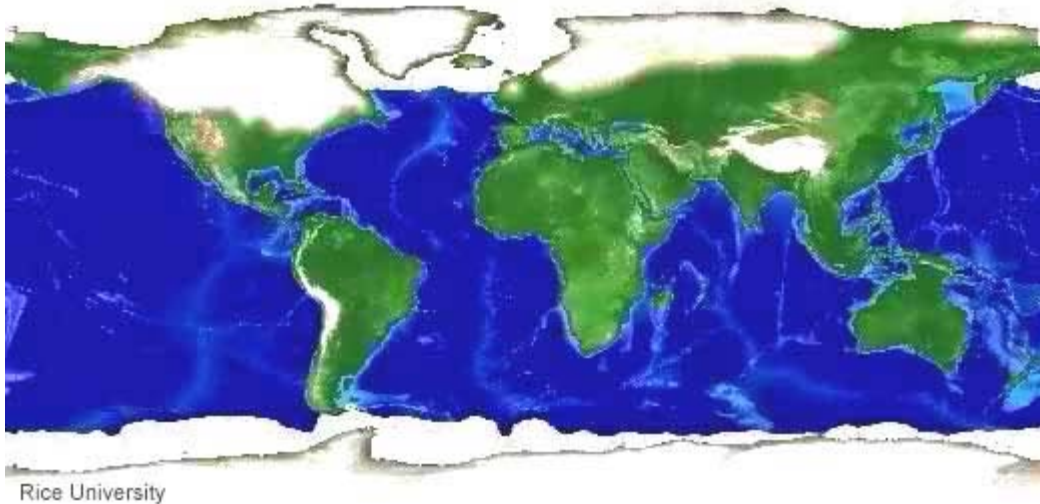
The white areas in this map show glaciers and ice sheets around the world (reproduced from National Geographic WORLD, February 1977, no. 18, p. 6, with permission). The vast majority,



almost 90 percent, of Earth's ice mass is in Antarctica, while the Greenland ice cap contains 10 percent of the total global ice mass. The Greenland ice cap is an interesting part of the water cycle. The ice cap became so large over time (about 600,000 cubic miles (mi³) or 2.5 million cubic kilometers (km³)) because more snow fell than melted. Over the millennia, as the snow got deeper, it compressed and became ice. The ice cap averages about 5,000 feet (1,500 meters) in thickness, but can be as thick as 14,000 feet (4,300 meters). The ice is so heavy that the land below it has been pressed down into the shape of a bowl. In many places, glaciers on Greenland reach to the sea, and one estimate is that as much as 125 mi³ (517 km³) of ice "calves" into the ocean each year—one of Greenland's contributions to the global water cycle. Ocean-bound icebergs travel with the currents, melting along the way. Some icebergs have been seen, in much smaller form, as far south as the island of Bermuda.

Ice and glaciers come and go

The climate, on a global scale, is always changing, although usually not at a rate fast enough for people to notice. There have been many warm periods, such as when the dinosaurs lived (about 100 million years ago) and many cold periods, such as the last ice age of about 18,000 years ago. During the last ice age much of the northern hemisphere was covered in ice and glaciers, and, as this map from the University of Arizona shows, they covered nearly all of Canada, much of northern Asia and Europe, and extended well into the United States.



Glaciers are still around today; tens of thousands of them are in Alaska. Climatic factors still affect them today and during the current warmer climate, they can retreat in size at a rate easily measured on a yearly scale.

Ice caps influence the weather

Just because water in an ice cap or glacier is not moving does not mean that it does not have a direct effect on other aspects of the water cycle and the weather. Ice is very white, and since white reflects sunlight (and thus, heat), large ice fields can determine weather patterns. Air temperatures can be higher a mile above ice caps than at the surface, and wind patterns, which affect weather systems, can be dramatic around ice-covered landscapes.

Some glacier and ice cap facts

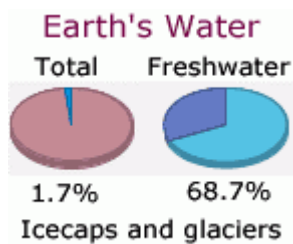


Stephens Glacier, Alaska.
Photo by Bruce Molina, USGS

- Glacial ice covers 10-11 percent of all land.

- According to the [National Snow and Ice Data Center \(NSIDC\)](#), if all glaciers melted today the seas would rise about 230 feet (70 meters).
- During the last ice age (when glaciers covered more land area than today) the sea level was about 400 feet (122 meters) lower than it is today. At that time, glaciers covered almost one-third of the land.
- During the last warm spell, 125,000 years ago, the seas were about 18 feet (5.5 meters) higher than they are today. About three million years ago the seas could have been up to 165 feet (50.3 meters) higher.
- Largest surface area of any glacier in the contiguous United States: Emmons Glacier, Washington (4.3 square miles or 11 square kilometers)

ice caps and global water distribution



Even though the amount of water locked up in glaciers and ice caps is a small percentage of all water on (and in) the Earth, it represents a large percentage of the world's total freshwater. As these charts and the data table show, the amount of water locked up in ice and snow is only about 1.7 percent of all water on Earth, but the majority of total freshwater on Earth, about 68.7 percent, is held in ice caps and glaciers.

One estimate of global water distribution

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of total water	Percent of total freshwater
Ice caps, Glaciers, & Permanent snow	5,773,000	24,064,000	1.7%	68.7%
Total global freshwater	8,404,000	35,030,000	2.5%	--
Total global water	332,500,000	1,386,000,000	--	--

Source: 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.

The water cycle: Snowmelt runoff to streams

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Snowmelt runoff to streams - Movement of water as surface runoff from snow and ice to surface water.



Spring snowmelt, Sonora Pass, California, USA
Photograph by Cagan Hakki Sekercioglu,
naturalphotos.com

If you live in Florida or on the French Riviera you might not wake up everyday wondering how melting snow contributes to the water cycle. But, in the world-wide scheme of the water cycle, runoff from snowmelt is a major component of the global movement of water. Of course, the importance of snowmelt varies greatly geographically, and in warmer climates it does not directly play a part in water availability. In the colder climates, though, much of the springtime [runoff](#) and [streamflow](#) in rivers is attributable to melting snow and ice.

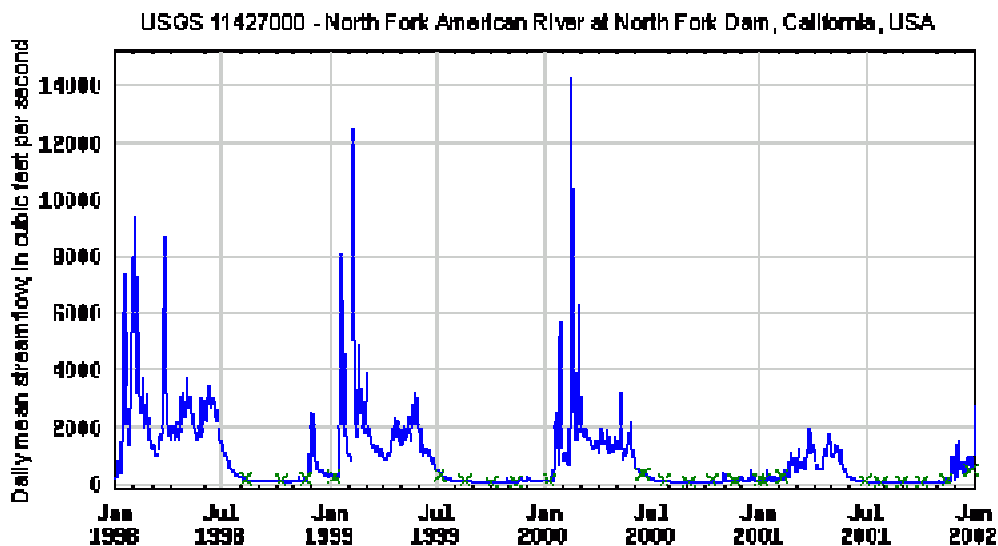
Mountain snow fields act as natural reservoirs for many western United States water-supply systems, storing precipitation from the cool season, when most precipitation falls and forms snowpacks, until the warm season when most or all snowpacks melt and release

water into rivers. As much as 75 percent of water supplies in the western states are derived from snowmelt.

During certain times of the year water from snowmelt can be responsible for almost all of the streamflow in a river. An example is the South Platte River in Colorado and Nebraska. Historically, the South Platte River was essentially "turned off" after the supply of water coming from melting snow was exhausted in late spring. Today, though, seepage of irrigation water from ditches and fields replenishes the alluvial aquifer (water-bearing deposit of sand and gravel left behind by a river) during spring and summer, and the aquifer slowly drains during fall and winter by [discharging ground water](#) to the South Platte River. Indirectly, your buying a loaf of wheat bread in the grocery store helps to keep water flowing in the South Platte River all year long.

Contribution of snowmelt to streamflow

A good way to visualize the contribution of snowmelt to streamflow in rivers is to look at the hydrograph below, which shows daily mean streamflow (average streamflow for each day) for four years for the North Fork American River at North Fork Dam in California ([USGS real-time streamflow data](#)). The large peaks in the chart are mainly the result of melting snow, although storms can contribute runoff also. Compare the fact that minimum mean-daily streamflow during March of 2000 was 1,200 cubic feet per second (ft³), while during August streamflows ranged from 55-75 ft³.



Note that runoff from snowmelt varies not only by season but also by year. Compare the high peaks of streamflows for the year 2000

with the much smaller streamflows for 2001. It looks like a major drought hit that area of California in 2001. The lack of water stored as snowpack in the winter can affect the availability of water for the rest of the year. This can have an effect on the amount of water in reservoirs located downstream, which in turn can affect water available for irrigation and the water supply for cities and towns.

Snowmelt and flooding



Hetch-Hetchy basin near Yosemite, California. Photo by David Gay


The effect of snowmelt on potential flooding, mainly during the spring, is something that causes concern for many people around the world. Besides flooding, rapid snowmelt can trigger landslides and debris flows. In alpine regions like Switzerland, snowmelt is a major component of runoff. In combination with specific weather conditions, such as excessive rainfall on melting snow for example, it may even be a major cause of floods. In Switzerland, snowmelt forecasting is being used as a flood-warning tool to predict snowmelt runoff and potential flooding. In some parts of the world, such as in Washington State in the Pacific Northwest of the United States, annual springtime flood events occur when rain falls on existing snowpacks, known as a "rain-on-snow event." Runoff during rain-on-snow events has been associated with mass-wasting of hillslopes, damage to riparian (areas alongside streams) zones, downstream flooding and associated damage, and loss of life. [Some studies](#) suggest that the amount of forest cover can have an influence on the magnitude of rain-on-snow events.



Conodoguinet Creek, Pennsylvania. NOAA, Jason Nolan In January 1996, a combination of factors contributed to massive flooding in the northeastern United States. Heavy snowfall followed by a sudden thaw and heavy rain caused floods along rivers from New York through Pennsylvania to Virginia, producing water levels not seen since a major hurricane, Hurricane Agnes, hit the area in June 1972. Major rivers in Pennsylvania and the Potomac River were affected. The raging rivers, sometimes jammed with ice, caused a number of deaths and required many people to evacuate their homes. Ice blocks carried by the floodwaters exacerbated the damage done to buildings, bridges, and dams.

The water cycle: Surface runoff

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 **Surface runoff** - Precipitation runoff which travels over the soil surface to the nearest stream channel.

Surface runoff is precipitation runoff over the landscape

In our section about [water storage in the oceans](#) we describe how the oceans act as a large storehouse of water that [evaporates](#) to become [atmospheric moisture](#). The oceans are kept full by [precipitation](#) and also by runoff and discharge from rivers and [the ground](#). Many people probably have an overly-simplified idea that precipitation falls on the land, flows overland (runoff), and runs into rivers, which then empty into the oceans. That is "overly simplified" because rivers also gain and lose water to the ground. Still, it is true that much of the water in rivers comes directly from runoff from the land surface, which is defined as surface runoff.



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

When rain hits saturated or impervious ground it begins to flow overland downhill. It is easy to see if it flows down your driveway to the curb and into a storm sewer, but it is harder to notice it flowing overland in a natural setting. During a heavy rain you might notice small rivulets of water flowing downhill. Water will flow along channels as it moves into larger creeks, streams, and rivers. This picture gives a graphic example of how surface runoff (here flowing off a road) enters a small creek. The runoff in this case is flowing over bare soil and is

depositing sediment into the river (not good for water quality). The runoff entering this creek is beginning its journey back to the ocean. As with all aspects of the water cycle, the interaction between precipitation and surface runoff varies according to time and geography. Similar storms occurring in the Amazon jungle and in the desert Southwest of the United States will produce different surface-runoff effects. Surface runoff is affected by both meteorological factors and the physical geology and topography of the land. Only about a third of the precipitation that falls over land runs off into streams and rivers and is returned to the oceans. The other two-thirds is evaporated, [transpired](#), or soaks ([infiltrates](#)) into ground water. Surface runoff can also be diverted by humans for their own uses.

The small creek shown in the picture above will merge with another creek, eventually flowing into a larger river. Thus, this creek is a tributary to a river somewhere downstream, and the water in that river will eventually flow into an ocean. The concept is not that much different from the small capillaries in your body carrying blood to larger arteries, eventually finding its way to your heart, analagous to the ocean.

Meteorological factors affecting runoff:

- Type of precipitation (rain, snow, sleet, etc.)
- 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
- Other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season

Physical characteristics affecting runoff:

- 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 activities can affect runoff



Erosion caused by surface runoff

As more and more people inhabit the Earth, and as more development and urbanization occur, more of the natural landscape is replaced by impervious surfaces, such as roads, houses, parking lots, and buildings that reduce infiltration of water into the ground and accelerate runoff to ditches and streams. In addition to increasing imperviousness, removal of vegetation and soil, grading the land surface, and constructing drainage networks increase runoff volumes and shorten runoff time into streams from rainfall and snowmelt. As a result, the peak discharge, volume, and frequency of floods increase in nearby streams.

Urban development and flooding



Impervious surfaces and urbanization affect runoff characteristics in the metro Atlanta, Georgia area.

Urbanization can have a great effect on hydrologic processes, such as surface-runoff patterns. Imagine it this way: in a natural environment, think of the land in the watershed alongside a stream as a sponge (more precisely, as layers of sponges of different porosities) sloping uphill

away from the stream. When it rains some water is absorbed into the sponge (infiltration) and some runs off the surface of the sponge into the stream (runoff). Assume a storm lasting one hour occurs and one-half of the rainfall enters the stream and the rest is absorbed by the sponges. Now, gravity is still at play here, so the water in the sponges will start moving in a general downward direction, with most of it seeping out and into the streambanks during the next day or two.

The water cycle: Streamflow

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***Streamflow** -Movement of water in a natural channel, such as a river.*



Gunnison River, Colorado, USA. BLM

If you read our discussion on the role the [oceans](#) play in the water cycle, you know that [evaporation](#) from the oceans is the primary way that water returns to the [atmosphere](#) from the Earth's surface. Water returns to the Earth from [precipitation](#) falling on the land, where gravity either takes it into the ground as [infiltration](#) or it begins running downhill as [surface runoff](#). But how does much of the water get back into the oceans to keep the water cycle going? A lot of runoff ends up in creeks, streams, and rivers, flowing downhill towards the oceans. Unless the river flows into a closed lake, a rare occurrence, or is diverted for humans' uses, a common occurrence, they empty into the oceans, thus fulfilling their water-cycle duties.

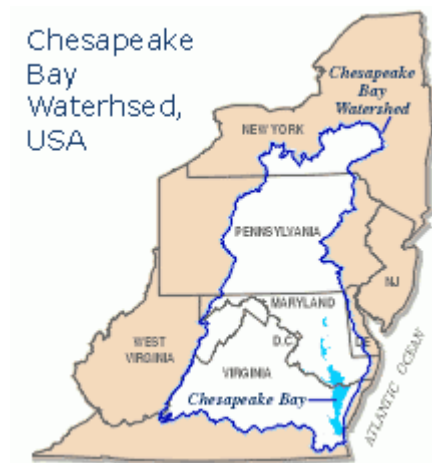
The U.S. Geological Survey (USGS) uses the term "streamflow" to refer to the amount of water flowing in a river. Although USGS usually uses the term "stream" when discussing flowing water bodies, in these pages we'll use "rivers" more often, since that is probably what you are more familiar with.

Importance of rivers

Rivers are invaluable to not only people, but to life everywhere. Not only are rivers a great place for people (and their dogs) to play, but

people use river water for drinking-water supplies and irrigation water, to produce electricity, to flush away wastes (hopefully, but not always, treated wastes), to transport merchandise, and to obtain food. Rivers are major aquatic landscapes for all manners of plants and animals. Rivers even help keep the aquifers underground full of water by discharging water downward through their streambeds. And, we've already mentioned that the oceans stay full of water because rivers and runoff continually refreshes them.

Watersheds and rivers



One word can explain why any river exists on Earth—gravity. You've heard that "water seeks its own level," but really water is seeking the center of the Earth, just like everything else. In practical terms, water generally seeks to flow to the oceans, which are at sea level. So, no matter where on Earth water is, it tries to flow downhill. With the Earth being a very unlevel place, water ends up occupying the valleys and depressions in the landscape as rivers and lakes.

When looking at the location of rivers and the amount of streamflow in rivers, the key concept is the river's "watershed". What is a watershed? Easy, if you are standing on the ground right now, just look down. You're standing, and everyone is standing, in a watershed. A watershed is the area of land where all of the water that falls in it and drains off of it goes to the same place. Watersheds can be as small as a footprint or large enough to encompass all the land that drains water into rivers that drain into Chesapeake Bay, where it enters the Atlantic Ocean. Larger watersheds contain many smaller watersheds. It all depends on the outflow point; all of the land that drains water to the outflow point is the watershed for that outflow location. Watersheds are important because the streamflow and the water quality of a river are affected by things, human-

induced or not, happening in the land area "above" the river-outflow point

Streamflow is always changing



Streamflow is always changing, from day to day and even minute to minute. Of course, the main influence on streamflow is precipitation runoff in the watershed. Rainfall causes rivers to rise, and a river can even rise if it only rains very far up in the watershed - remember that water that falls in a watershed will eventually drain by the outflow point. The size of a river is highly dependent on the size of its watershed. Large rivers have watersheds with lots of surface area; small rivers have smaller watersheds. Likewise, different size rivers react differently to storms and rainfall. Large rivers rise and fall slower and at a slower rate than small rivers. In a small watershed, a storm can cause 100 times as much water to flow by each minute as during base-periods, but the river will rise and fall possibly in a matter of minutes and hours. Large rivers may take days to rise and fall, and flooding can last for a number of days. After all, it can take days for all the water that fell hundreds of miles upstream to drain past an outflow point.



If you have ever wondered how many gallons of water falls during a storm, use our [interactive rainfall calculator](#) to find out.

Hydrologists study streamflows with hydrographs

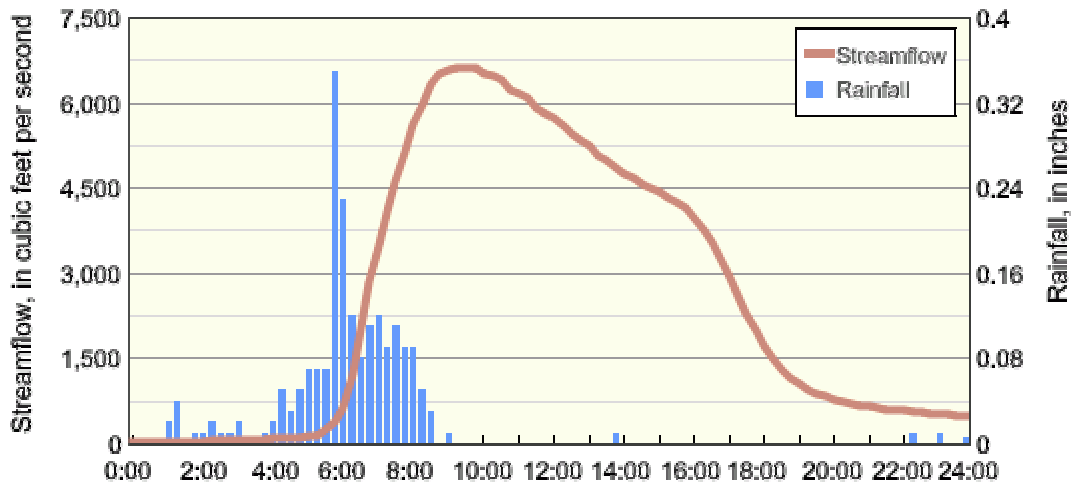
USGS uses a hydrograph to study streamflow in rivers. A hydrograph is a chart showing, most often, river stage (height of the water above an arbitrary altitude) and streamflow (amount of water, usually in cubic feet per second). Other properties, such as rainfall and water-quality parameters can also be plotted. The hydrograph below shows rainfall and streamflow for a single day for Peachtree Creek at Atlanta, Georgia (USGS station number 02336300).

Precipitation influences streamflow

On Dec. 24, 2002, about two inches of rainfall fell in the Peachtree Creek watershed. This provides a good example to describe streamflow characteristics during a storm since the rain fell for only a few hours on that day and Peachtree Creek was at base-flow

conditions before the rain started. The chart below shows rainfall, in inches, during each 15-minute increment on Dec. 24th and the continuous measure of streamflow, in cubic feet per second (ft³/s).

Rainfall and streamflow at Peachtree Creek, Dec. 24, 2002



The brown line in the chart shows that streamflow is much higher during the flood period than just before it. The line shows that the baseflow was about 50 ft³/s before the river started to rise, but that just a few hours later, at 9:00 AM streamflow was over 6,000 ft³/s - that is about 150 times the amount of water flowing by as during baseflow conditions. This is characteristic of small streams, especially urban streams where runoff enters the river very quickly.

Comparison of streamflow before and during the flood of Dec. 24, 2002
(Data are rounded)

		Instantaneous streamflow		
Time	Stream stage, in feet	Cubic feet per second	Gallons per second	Streamflow, in gallons, during 15-minute interval
Midnight	2.81	43	322	289,000
10:00	17.33	6,630	49,600	44,600,000

It is possible to estimate the total amount of water that flowed during Dec. 24, 2002, and compare it to a day when the streamflows are at base-flow conditions (stream stage of about 2.81 feet). At base flow, an estimated 27,800,000 gallons of water will flow by the Peachtree Creek measurement station in one day. Using mean streamflows for each 15-minute period during the storm of Dec. 24th, an estimated 4,290,000,000 gallons flowed by. That would be about 154 times more water than during a day of base flow.

Mechanisms that cause changes in streamflow

Rivers are always moving, which is good for everything, as stagnant water doesn't stay fresh and inviting very long. There are many factors, both natural and human-induced, that cause rivers to continuously change:

Natural mechanisms

- Runoff from rainfall and snowmelt
- Evaporation from soil and surface-water bodies
- Transpiration by vegetation
- Ground-water discharge from aquifers
- Ground-water recharge from surface-water bodies
- Sedimentation of lakes and wetlands
- Formation or dissipation of glaciers, snowfields, and permafrost

Human-induced mechanisms

- Surface-water withdrawals and transbasin diversions
- River-flow regulation for hydropower and navigation
- Construction, removal, and sedimentation of reservoirs and stormwater detention ponds
- Stream channelization and levee construction
- Drainage or restoration of wetlands
- Land-use changes such as urbanization that alter rates of erosion, infiltration, overland flow, or evapotranspiration
- Wastewater outfalls
- Irrigation wastewater return flow

Streamflow and global water distribution

Even though the water flowing in rivers is tremendously valuable to not only people but also to much of life on Earth, it makes up just a [miniscule amount of Earth's water](#). Considering just the freshwater on Earth, streamflow in rivers only accounts for about six-one thousandths of one percent (0.006%)! The first table below shows that about 0.002 percent of all Earth's water is contained in rivers, and only 0.006 percent of the world's freshwater is in rivers.

One estimate of global water distribution

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of total freshwater	Percent of total water
Streamflow in rivers	509	2,120	0.006%	0.0002%
Total global freshwater	8,404,000	35,030,000	2.5%	--
Total global water	332,500,000	1,386,000,000	--	--

Source: 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.

The water cycle: Freshwater storage

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Freshwater storage - Freshwater existing on the Earth's surface.



Emerald Bay, Lake Tahoe, CA. Photo by Dale Borland

One part of the water cycle that is obviously essential to all life on Earth is the freshwater existing on the land surface. Just ask your neighbor, a tomato plant, a trout, or that pesky mosquito. Surface water includes the streams (of all sizes, from large rivers to small creeks), ponds, lakes, reservoirs and canals (man-made lakes and streams), and freshwater wetlands. The definition of freshwater is water containing less than 1,000 milligrams per liter of dissolved solids, most often salt.

As a part of the water cycle, Earth's surface-water bodies are generally thought of as renewable resources, although they are very dependent on other parts of the water cycle. The amount of water in our rivers and lakes is always changing due to inflows and outflows. Inflows to these water bodies will be from [precipitation](#), overland [runoff](#), ground-water [seepage](#), and tributary inflows. Outflows from lakes and rivers include [evaporation](#) and discharge to ground water. Humans get into the act also, as people make great use of surface water for their needs. So, the amount and location of surface water changes over time and space, whether naturally or with human help. Certainly during the last ice age when [glaciers](#) and snowpacks covered much more land surface than today, life on Earth had to

adapt to different hydrologic conditions than those which took place both before and after. And the layout of the landscape certainly was different before and after the last ice age, which influenced the topographical layout of many surface-water bodies today. Glaciers are what made the Great Lakes not only "great, " but also such a huge storehouse of freshwater.

Surface water keeps life going



Source: The Nile River (<http://www.mbarron.net>)

As this picture of the Nile Delta in Egypt shows, life can even bloom in the desert if there is a supply of surface water (or ground water) available. Water on the land surface really does sustain life, and this is as true today as it was millions of years ago. I'm sure dinosaurs held their meetings at the local watering hole 100 million years ago, just as antelopes in Africa do today. And, since ground water is supplied by the downward percolation of surface water, even aquifers are happy for water on the Earth's surface. You might think that fish living in the saline oceans aren't affected by freshwater, but, without freshwater to replenish the oceans they would eventually evaporate and become too saline for even the fish to survive.



As we said, everybody and every living thing congregates and lives where they can gain access to water, especially freshwater. Just ask the 6 billion people living on Earth! Here's a satellite picture of the Mediterranean region during night (the [full picture of the Earth](#) is available from NASA). The most obvious thing you can see is that people live near the coasts, which, of course, is where water, albeit saline, is located. But the interesting thing in this picture are the lights following the Nile River and Nile

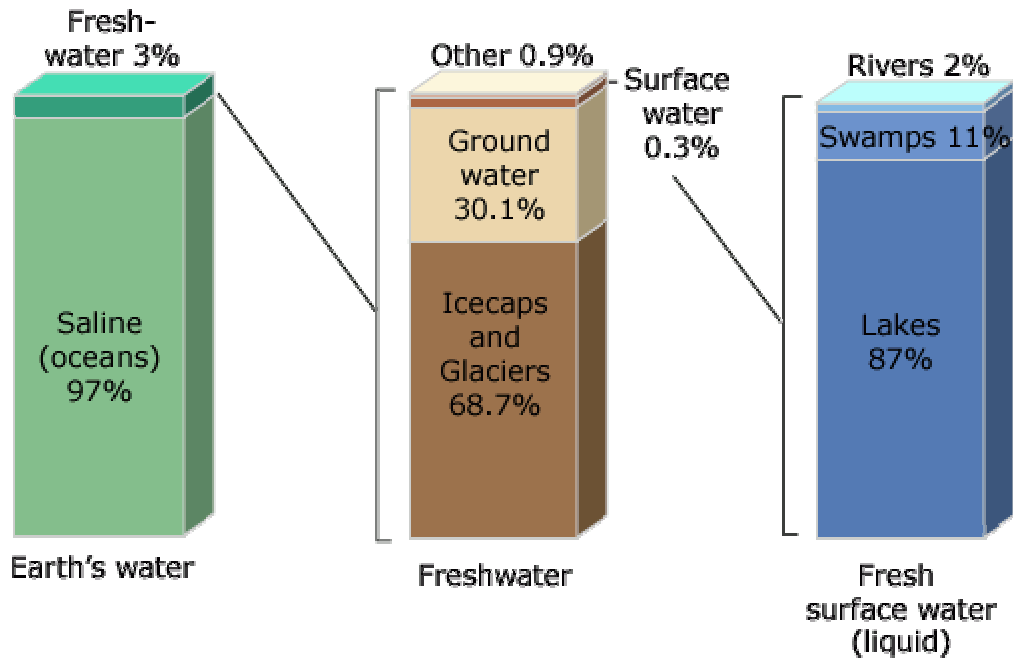
Delta in Egypt (the circled area). In this dry part of the world, surface-water supplies are essential for human communities. And if you check the price of lakefront property in your part of the world, it probably sells for much more than other land.

Usable freshwater is relatively scarce



To many people, streams and lakes are the most visible part of the water cycle. Not only do they supply the human population, animals, and plants with the freshwater they need to survive, but they are great places for people to have fun. You might be surprised at how little of Earth's water supply is stored as freshwater on the land surface, as shown in the diagram and table below. Freshwater represents only about three percent of all water on Earth and freshwater lakes and swamps account for a mere 0.29 percent of the Earth's freshwater. Twenty percent of all freshwater is in one lake, Lake Baikal in Asia. Another twenty percent is stored in the Great Lakes (Huron, Michigan, and Superior). Rivers hold only about 0.006 percent of total freshwater reserves. You can see that life on Earth survives on what is essentially only a "drop in the bucket" of Earth's total water supply! People have built systems, such as large reservoirs and small water towers (like this one in South Carolina, created to blend in with the peach trees surrounding it) to store water for when they need it. These systems allow people to live in places where nature doesn't always supply enough water or where water is not available at the time of year it is needed.

Distribution of Earth's Water



Source: 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.

One estimate of global fresh-water distribution

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of freshwater	Percent of total water
Lakes, swamps	24,600	102,500	0.29%	0.008%
Rivers	509	2,120	0.006%	0.0002%
Total global fresh water	8,404,000	35,030,000	100%	2.5%
Total global water	332,500,000	1,386,000,000	--	100%

Source: 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.

The water cycle: Infiltration

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Infiltration - The downward movement of water from the land surface into soil or porous rock.

Ground water begins as precipitation



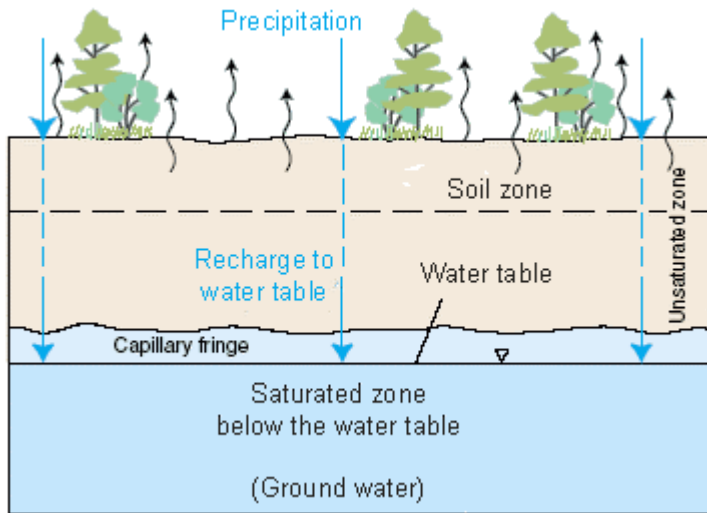
Anywhere in the world, a portion of the water that falls as rain and snow infiltrates into the subsurface soil and rock. How much infiltrates depends greatly on a number of factors. Infiltration of precipitation falling on the ice cap of Greenland might be very small, whereas, as this picture of a stream disappearing into a cave in southern Georgia, USA shows, a stream can act as a direct funnel right into ground water!

Some water that infiltrates will remain in the shallow soil layer, where it will gradually move vertically and horizontally through the soil and subsurface material. Eventually, it might enter a stream by seepage into the stream bank. Some of the water may infiltrate deeper, recharging ground-water aquifers. If the aquifers are porous enough to allow water to move freely through it, people can drill wells into the aquifer and use the water for their purposes. Water may travel long distances or remain in [ground-water storage](#) for long periods before returning to the surface or seeping into other water bodies, such as streams and the oceans.

Factors affecting infiltration

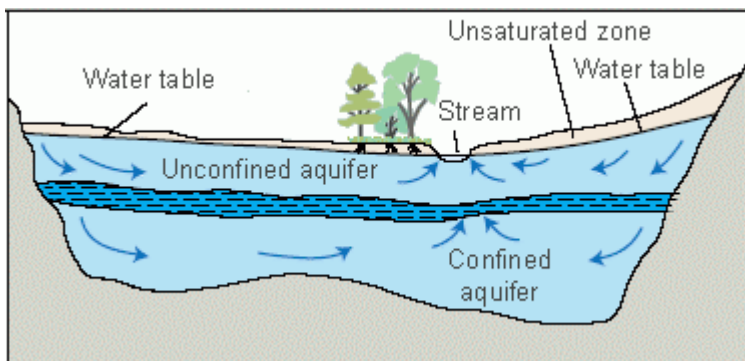
- Precipitation: The greatest factor controlling infiltration is the amount and characteristics (intensity, duration, etc.) of precipitation that falls as rain or snow. Precipitation that infiltrates into the ground often seeps into streambeds over an extended period of time, thus a stream will often continue to flow when it hasn't rained for a long time and where there is no direct runoff from recent precipitation.
- Soil characteristics: Some soils, such as clays, absorb less water at a slower rate than sandy soils. Soils absorbing less water result in more runoff overland into streams.
- Soil saturation: Like a wet sponge, soil already saturated from previous rainfall can't absorb much more ... thus more rainfall will become [surface runoff](#).
- Land cover: Some land covers have a great impact on infiltration and rainfall runoff. Vegetation can slow the movement of runoff, allowing more time for it to seep into the ground. Impervious surfaces, such as parking lots, roads, and developments, act as a "fast lane" for rainfall - right into storm drains that drain directly into streams. Agriculture and the tillage of land also changes the infiltration patterns of a landscape. Water that, in natural conditions, infiltrated directly into soil now runs off into streams.
- Slope of the land: Water falling on steeply-sloped land runs off more quickly and infiltrates less than water falling on flat land.
- Evapotranspiration: Some infiltration stays near the land surface, which is where plants put down their roots. Plants need this shallow ground water to grow, and, by the process of [evapotranspiration](#), water is moved back into the atmosphere.

Subsurface water



As precipitation infiltrates into the subsurface soil, it generally forms an unsaturated zone and a saturated zone. In the unsaturated zone, the voids—that is, the spaces between grains of gravel, sand, silt, clay, and cracks within rocks—contain both air and water. Although a lot of water can be present in the unsaturated zone, this water cannot be pumped by wells because it is held too tightly by capillary forces. The upper part of the unsaturated zone is the soil-water zone. The soil zone is crisscrossed by roots, openings left by decayed roots, and animal and worm burrows, which allow the precipitation to infiltrate into the soil zone. Water in the soil is used by plants in life functions and leaf transpiration, but it also can evaporate directly to the atmosphere. Below the unsaturated zone is a saturated zone where water completely fills the voids between rock and soil particles.

Infiltration replenishes aquifers



Natural refilling of deep aquifers is a slow process because ground water moves slowly through the unsaturated zone and the aquifer. The rate of recharge is also an important consideration. It has been estimated, for

example, that if the aquifer that underlies the High Plains of Texas and New Mexico—an area of slight precipitation—was emptied, it would take centuries to refill the aquifer at the present small rate of replenishment. In contrast, a shallow aquifer in an area of substantial precipitation such as those in the coastal plain in south Georgia, USA, may be replenished almost immediately.

Artificial recharge gives natural infiltration a push

People all over the world make great use of the water in underground aquifers all over the world. In fact, in some places, they pump water out of the aquifer faster than nature replenishes it. In these cases, the water table, below which the soil is saturated and possibly able to yield enough water that can be pumped to the surface, can be lowered by the excessive pumping. Wells can "go dry" and become useless.

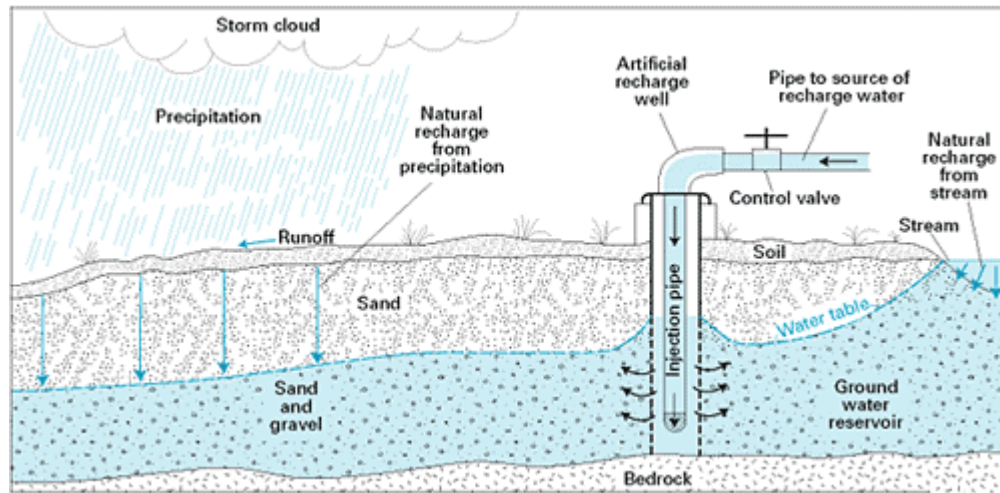


In places where the water table is close to the land surface and where water can move through the aquifer at a high rate, aquifers can be replenished artificially. For example, large volumes of ground water used for air conditioning are returned to aquifers through recharge wells on Long Island, New York. Aquifers may be artificially recharged in two main ways:

- Rapid-infiltration pits: One way is to spread water over the land in pits, furrows, or ditches, or to erect small dams in stream channels to detain and deflect surface runoff, thereby allowing it to infiltrate to the aquifer
- Ground-water injection: The other way is to construct recharge wells and inject water directly into an aquifer

This picture shows rapid infiltration basins (photograph courtesy of Water Conserv II facility, Orlando, Florida) in Orlando, Florida. The water put into these basins recharges the shallow surficial aquifer and is used to irrigate local citrus crop fields.

Natural and artificial recharge of ground water



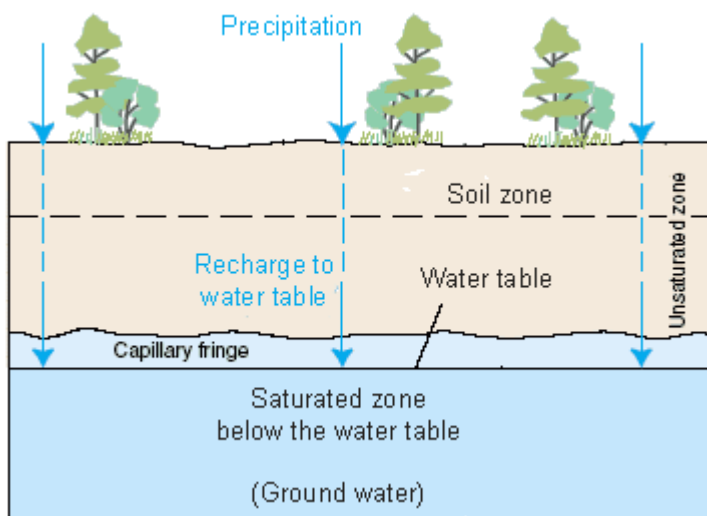
The water cycle: Ground-water storage

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Ground-water storage - Water existing for an extended period below the Earth's land surface.

Water in the ground is part of the water cycle



Large amounts of water are stored in the ground. The water is still moving, possibly very slowly, and it is still part of the water cycle. Most of the water in the ground comes from precipitation that infiltrates downward from the land surface. The upper layer of the soil is the unsaturated zone, where water is present in varying amounts that change over time, but does not saturate the soil. Below this layer is the saturated zone, where all of the pores, cracks, and spaces between rock particles are saturated with water. The term ground water is used to describe this area. Another term for ground water is "aquifer," although this term is usually used to describe water-bearing formations capable of yielding enough water to supply peoples' uses. Aquifers are a huge storehouse of Earth's water and people all over the world depend on ground water in their daily lives.

The top of the surface where ground water occurs is called the water table. In the diagram, you can see how the ground below the water table is saturated with water (the saturated zone). Aquifers are replenished by the seepage of [precipitation](#) that falls on the land, but there are many geologic, meteorologic, topographic, and human

factors that determine the extent and rate to which aquifers are refilled with water. Rocks have different porosity and permeability characteristics, which means that water does not move around the same way in all rocks. Thus, the characteristics of ground-water recharge vary all over the world.

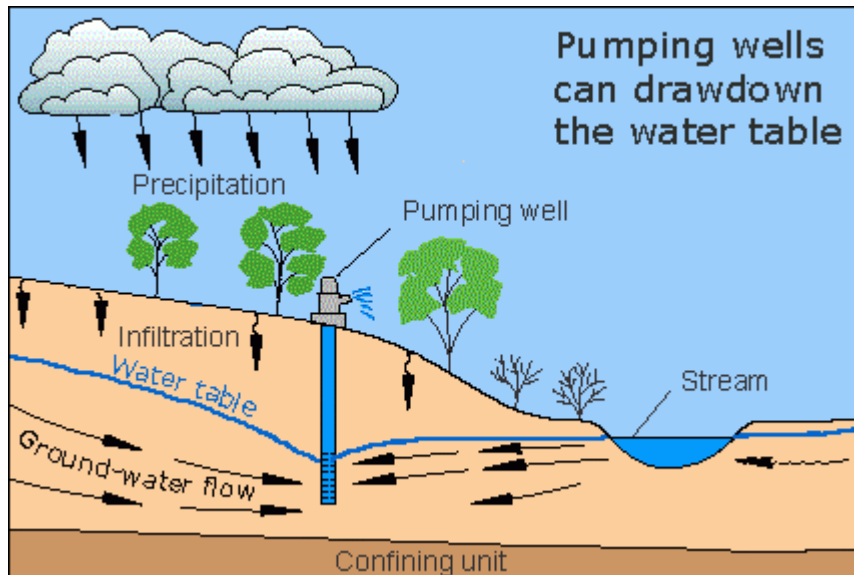
To find water underground, look under the (water) table



I hope you appreciate my spending an hour in the blazing sun to dig this hole at the beach. It is a great way to illustrate the concept of how at a certain depth the ground, if it is permeable enough to allow water to move through it, is saturated with water. The top of the pool of water in this hole is the water table. The breaking waves of the ocean are just to the right of this hole, and the water level in the hole is the same as the level of the ocean. Of course, the water level here changes by the minute due to the movement of the tides, and as the tide goes up and down, the water level in the hole moves, too. Just as with this hole, the level of the water table is affected by other environmental conditions.

In a way, this hole is like a dug well used to access ground water, albeit saline in this case. But, if this was freshwater, people could grab a bucket and supply themselves with the water they need to live their daily lives. You know that at the beach if you took a bucket and tried to empty this hole, it would refill immediately because the sand is so permeable that water flows easily through it, meaning our "well" is very "high-yielding" (too bad the water is saline). To access freshwater, people have to drill wells deep enough to tap into an aquifer. The well might have to be dozens or thousands of feet deep. But the concept is the same as our well at the beach—access the water in the saturated zone where the voids in the rock are full of water.

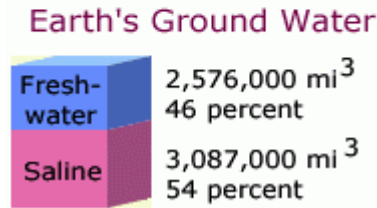
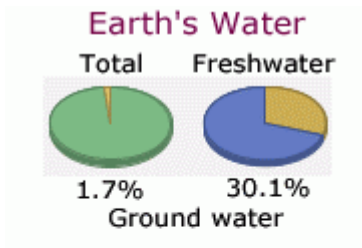
Pumping can affect the level of the water table



In an aquifer, the soil and rock is saturated with water. If the aquifer is shallow enough and permeable enough to allow water to move through it at a rapid-enough rate, then people can drill wells into it and withdraw water. The level of the water table can naturally change over time due to changes in weather cycles and precipitation patterns, streamflow and geologic changes, and even human-induced changes, such as the increase in impervious surfaces, such as roads and paved areas, on the landscape.

The pumping of wells can have a great deal of influence on water levels below ground, especially in the vicinity of the well, as this diagram shows. If water is withdrawn from the ground at a faster rate that it is replenished by precipitation infiltration and seepage from streams, then the water table can become lower, resulting in a "cone of depression" around the well. Depending on geologic and hydrologic conditions of the aquifer, the impact on the level of the water table can be short-lived or last for decades, and the water level can fall a small amount or many hundreds of feet. Excessive pumping can lower the water table so much that the wells no longer supply water—they can "go dry."

Ground water and global water distribution



Ground water occurs only close to the Earth's surface. There must be space between the rock particles for ground water to occur, and the Earth's material becomes denser with more depth. Essentially, the weight of the rocks above condense the rocks below and squeeze out the open pore spaces deeper in the Earth. That is why ground water can only be found within a few miles of the Earth's surface.

As these charts show, even though the amount of water locked up in ground water is a small percentage of all of Earth's water, it represents a large percentage of total freshwater on Earth. The pie chart shows that about 1.7 percent of all of Earth's water is ground water and about 30.1 percent of freshwater on Earth occurs as ground water. As the bar chart shows, about 5,614,000 cubic miles (mi³), or 23,400,000 cubic kilometers (km³), of ground water exist on Earth. About 54 percent is saline, with the remaining 2,526,000 mi³ (10,530,000 km³), about 46 percent, being freshwater.



Water in aquifers below the oceans is generally saline, while the water below the land surfaces (where freshwater, which fell as precipitation, infiltrates into the ground) is generally freshwater. There is a stable transition zone that separates saline water and freshwater below ground. It is fortunate for us that the relatively shallow aquifers that people tap with wells contain freshwater, since if we tried to irrigate corn fields with saline water I suspect the stalks would refuse to grow.

One estimate of global water distribution

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of total water	Percent of total freshwater
Fresh ground water	2,526,000	10,530,000	0.8%	30.1%
Ground water	5,614,000	23,400,000	1.7%	--
Total global water	332,500,000	1,386,000,000	--	--

Source: 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.

The water cycle: Ground-water discharge


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Ground-water - Movement of water out of the ground. discharge

There's more water than just what you can see



Ground-water discharge in Snake River Plain, Idaho, USA You see water all around you every day as lakes, rivers, ice, rain and snow. There are also vast amounts of water that are unseen—water existing in the ground. And even though ground water is unseen, it is moving below your feet right now. As part of the water cycle, ground water is a major contributor to flow in many streams and rivers and has a strong influence on river and wetland habitats for plants and animals. People have been using ground water for thousands of years and continue to use it today, largely for drinking water and irrigation. Life on Earth depends on ground water just as it does on surface water.

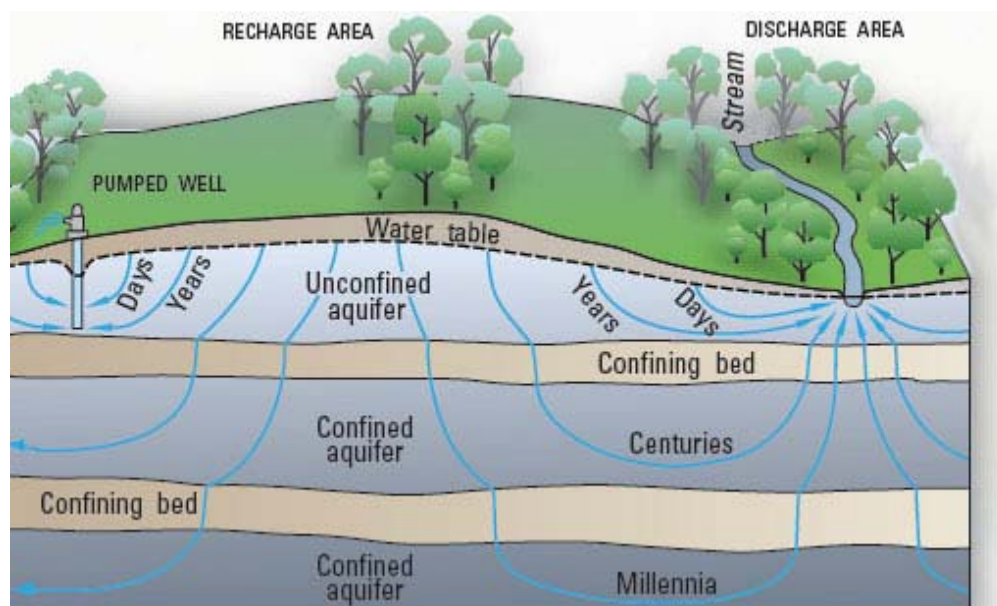
 Does it take days, months, years, or millennia for water to move through the ground-water system?

There are rivers flowing below our feet ... a myth?

Have you ever heard that there are rivers of water flowing underground? Do you think it is true? Actually, it is pretty much a myth. Even though there are some caverns, lava and ice tubes, and

horizontal springs that can carry water, the vast majority of underground water occupies the spaces between rocks and subsurface material. Some rivers, such as the Alapaha River in northern Florida, USA, can disappear underground during low-flow periods. Generally, water underground is more like water in a sponge. It occupies the spaces between soil and rock particles. At a certain depth below the land surface, the spaces between the soil and rock particles can be totally filled with water, resulting in an aquifer from which ground water can be pumped and used by people.

Ground water flows underground



Some of the [precipitation](#) that falls onto the land [infiltrates](#) into the ground to become ground water. Once in the ground, some of this water travels close to the land surface and emerges very quickly as discharge into streambeds, but, because of gravity, much of it continues to sink deeper into the ground. If the water meets the water table (below which the soil is saturated), it can move both vertically and horizontally. Water moving downward can also meet more dense and water-resistant non-porous rock and soil, which causes it to flow in a more horizontal fashion, generally towards streams, the ocean, or deeper into the ground. If ground water wants to be a member in good standing of the water cycle, then it can't be totally static and stay where it is. As the diagram shows, the direction and speed of ground-water movement is determined by the various characteristics of aquifers and confining layers of subsurface rocks (which water has a difficult time

penetrating) in the ground. Water moving below ground depends on the permeability (how easy or difficult it is for water to move) and on the porosity (the amount of open space in the material) of the subsurface rock. If the rock has characteristics that allow water to move relatively freely through it, then ground water can move significant distances in a number of days. But ground water can also sink into deep aquifers where it takes thousands of years to move back into the environment, or even go into deep ground-water storage, where it might stay for much longer periods.

Sometimes when you dig a hole ... watch out!



Well flowing under artesian pressure

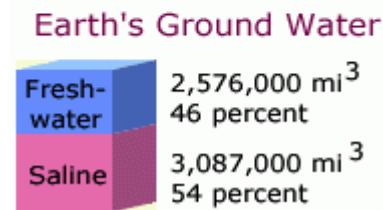
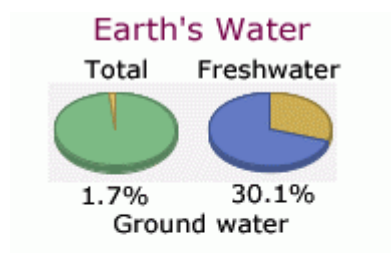
Bottled water is a very popular beverage nowadays all over the world. Sometimes it is because the local drinking water is of lower quality and sometimes it is just a convenience. Some bottled water is advertised as "artesian well water". Is the water really any different than other ground water? Artesian well water is not really different from non-artesian well water - but it comes to the surface in a different manner. In the diagram above, you can see that there are unconfined and confined aquifers in the ground. The confinement of water in an aquifer, which can result in pressure, determines if water coming from it is artesian or not. Wells drilled into confined aquifers can yield artesian water.

- **Unconfined aquifers:** In unconfined aquifers, water has simply infiltrated from the surface and saturated the subsurface material. If people drill a well into an unconfined aquifer, they have to install a pump to push water to the surface.
- **Confined aquifers:** Confined aquifers have layers of rock above and below it that are not very permeable to water. Natural pressure in the aquifer can exist; pressure which can sometimes be enough to push water in a well above the land

surface. No, not all confined aquifers produce artesian water, but, as this picture of an artesian well in Georgia, USA shows, artesian pressure can force water to the surface with great pressure.

So, in what way is bottled artesian well water different from other well water? Mainly, the company that bottles it doesn't have to go to the expense of installing a pump in their well, so wouldn't you think that artesian water should be cheaper than non-artesian water?

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The water cycle: Springs

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Spring - Place where a concentrated discharge of ground water flows at the ground surface.

What is a spring?

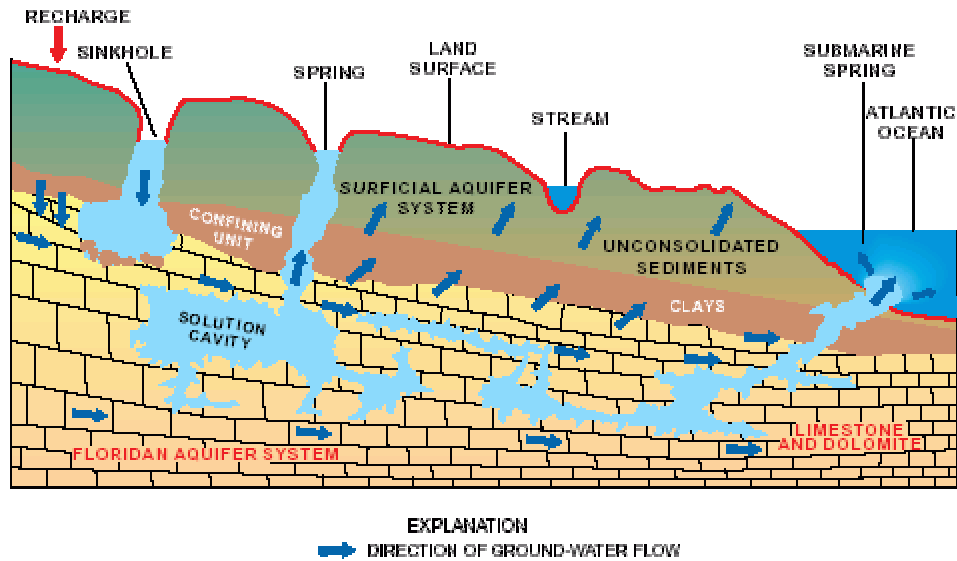


Credit: Jo Schaper, Missouri Springs

A spring is a water resource formed when the side of a hill, a valley bottom or other excavation intersects a flowing body of ground water at or below the local water table, below which the subsurface material is saturated with water. A spring is the result of an aquifer being filled to the point that the water overflows onto the land surface. They range in size from intermittent seeps, which flow only after much rain, to huge pools flowing hundreds of millions of gallons daily.

Springs are not limited to the Earth's surface, though. Recently, scientists have discovered hot springs at depths of up to 2.5 kilometers in the oceans, generally along mid-ocean rifts (spreading ridges). The hot water (over 300 degrees Celsius) coming from these springs is also rich in minerals and sulfur, which results in a unique ecosystem where unusual and exotic sea life seems to thrive.

How are springs formed?



Springs may be formed in any sort of rock. Small ones are found in many places. In Missouri, the largest springs are formed in limestone and dolomite in the karst topography of the Ozarks. Both dolomite and limestone fracture relatively easily. When weak carbonic acid (formed by rainwater percolating through organic matter in the soil) enters these fractures it dissolves bedrock. When it reaches a horizontal crack or a layer of non-dissolving rock such as sandstone or shale, it begins to cut sideways, forming an underground stream. As the process continues, the water hollows out more rock, eventually admitting an airspace, at which point the spring stream can be considered a cave. This process is supposed to take tens to hundreds of thousands of years to complete.

Water flow from springs



Ground water discharges from springs in the Grand Canyon.
Credit: R.D. MacNish, USGS

The amount of water that flows from springs depends on many factors, including the size of the caverns within the rocks, the water pressure in the aquifer, the size of the spring basin, and the amount of rainfall. Human activities also can influence the volume of water that discharges from a spring—ground-water withdrawals in an area can reduce the pressure in an aquifer, causing water levels in the aquifer system to drop and ultimately decreasing the flow from the spring. Most people probably think of a spring as being like a pool of water—and normally that is the case. But, as this picture of the wall of the Grand Canyon in Arizona, USA shows, springs can occur when geologic, hydrologic, or human forces cut into the underground layers of soil and rock where water is in movement.

Spring water is not always clear



Spring in Colorado, USA, USGS

Water from springs usually is remarkably clear. Water from some springs, however, may be "tea-colored." This picture shows a natural spring in southwestern Colorado. Its red iron coloring and metals enrichment are caused by ground water coming in contact with naturally occurring minerals present as a result of ancient volcanic activity in the area. In Florida, many surface waters contain natural tannic acids from organic material in subsurface rocks, and the color from these streams can appear in springs. If surface water enters the aquifer near a spring, the water can move quickly through the aquifer and discharge at the spring vent. The discharge of highly colored water from springs can indicate that water is flowing quickly through large channels within the aquifer without being filtered through the soil.

This water is cold and clear—is it fit to drink?

The quality of the water in the local ground-water system will generally determine the quality of spring water. The quality of water discharged by springs can vary greatly because of factors such as the quality of the water that recharges the aquifer and the type of rocks with which the ground water is in contact. The rate of flow and the length of the flowpath through the aquifer affects the amount of time the water is in contact with the rock, and thus, the amount of minerals that the water can dissolve. The quality of the water also can be affected by the mixing of freshwater with pockets of ancient seawater in the aquifer or with modern seawater along an ocean coast.



Azure Hot Springs, Yellowstone National Park

So, should you feel confident about whipping out your canteen and filling it with cool and refreshing spring water? No, you should be cautious. The temperature of an Ozark spring comes from its passing through rock at a mean annual temperature of 56 degrees Fahrenheit. The water is crudely filtered in the rock, and the time spent underground allows debris and mud to fall out of suspension. If underground long enough, lack of sunlight causes most algae and water plants to die. However, microbes, viruses, and bacteria do not die just from being underground, nor are any agricultural or industrial pollutants removed. By the way, no, this man is not getting a drink from this tempting spring. He is a USGS hydrologist sampling the near-boiling water from a spring in Wyoming.

Thermal springs



Credit: Galen R. Fry singer, <http://www.galenfry singer.com>

Thermal springs are ordinary springs except that the water is warm and, in some places, hot, such as in the bubbling mud springs in Yellowstone National Park, Wyoming. Many thermal springs occur in regions of recent volcanic activity and are fed by water heated by contact with hot rocks far below the surface. Even where there has been no recent volcanic

action, rocks become warmer with increasing depth. In such areas water may migrate slowly to considerable depth, warming as it descends through rocks deep in the Earth. If it then reaches a large crevice that offers a path of less resistance, it may rise more quickly than it descended. Water that does not have time to cool before it emerges forms a thermal spring. The famous Warm Springs of Georgia and Hot Springs of Arkansas are of this type. And, yes, warm springs can even coexist with icebergs, as these happy Greenlanders can tell you.
