ENVIRONMENTAL LITERACY TEACHER GUIDE SERIES

Earth's Freshwater

A Guide for Teaching Freshwater in Grades 3 to 8

NATIONAL GEOGRAPHIC

2 Water Cycle and Water Reservoirs

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Water is arguably the most important resource on our Earth. We depend upon water to survive and are intimately tied to tiny water molecules cycling through our world. Throughout history, the locations in which cities and entire civilizations have developed have been influenced by the location and abundance of freshwater resources. We have come to depend upon seasonal rains, snowmelt from mountains, and water recharging our underground reservoirs.

This chapter covers the processes by which water moves around Earth, and the forms water takes on its journey through the water cycle. Although this cycle receives a great deal of attention in our schools, students still struggle to understand many of the most basic concepts about the water cycle. We explore some of these difficult concepts in more depth and emphasize that throughout their learning of these concepts, it is critical that students come to understand that no new water is created during the water cycle—all of our water on Earth is recycled—and that there is a limited amount of freshwater available in the world.

The Water Cycle

As water moves around Earth, it does so as part of what we call the water cycle. The water cycle is one of the most iconic topics taught to students during the upper elementary and middle school years. Most of Earth's water is present in the ocean. As the sun shines on the water, it heats the water and causes it to evaporate. Note that evaporation is not only caused by heat from the sun, but is also influenced by wind and surface area, as well as other factors. As each molecule of water on the surface of the ocean evaporates into the air, it pulls another water molecule to the surface. Now this next molecule of water is exposed to the heat and drying effects of the air, and it also will evaporate. As the water molecules evaporate, the

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.e-f 3.1.1	Living Things in Changing Environments The Geography of Where We Live
Grade 4	4.5.c 4.1.4-5 4.4.7	Reflections of Where We Live
Grade 5	5.1.g 5.3.a-e 5.4.b	Earth's Water Changing States: Water, Natural Systems, and Human Communities Precipitation, People, and the Natural World
Grade 6	6.2.a-d	The Dynamic Nature of Rivers
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Grade 8	8.3.d-e 8.5.d 8.12.5	Industrialization, Urbanization, and the Conservation Movement

minerals or salts that they may have been carrying are left behind in the salty ocean. During this process, the air becomes more and more humid. This water vapor is an invisible gas and can move quickly. As it moves about, it often travels upward or inland—carried by currents in the air (wind).

As the moister air gains elevation, the molecules become colder and condense, turning into liquid. As more and more of these water molecules condense, they cluster around particles (primarily suspended dust) in the atmosphere and form clouds. Students may be confused if clouds are gas or liquid. However, a cloud is comprised of liquid water droplets, which is why one can see them, as compared to the water vapor, invisible gaseous water molecules suspended in the atmosphere.

When the mass of water molecules is high enough, the clouds will dispense their contents as precipitation. Precipitation can occur as rain or snow or ice, depending on surrounding air temperature. When the precipitation falls onto land, gravity causes it to flow topographically downhill, where

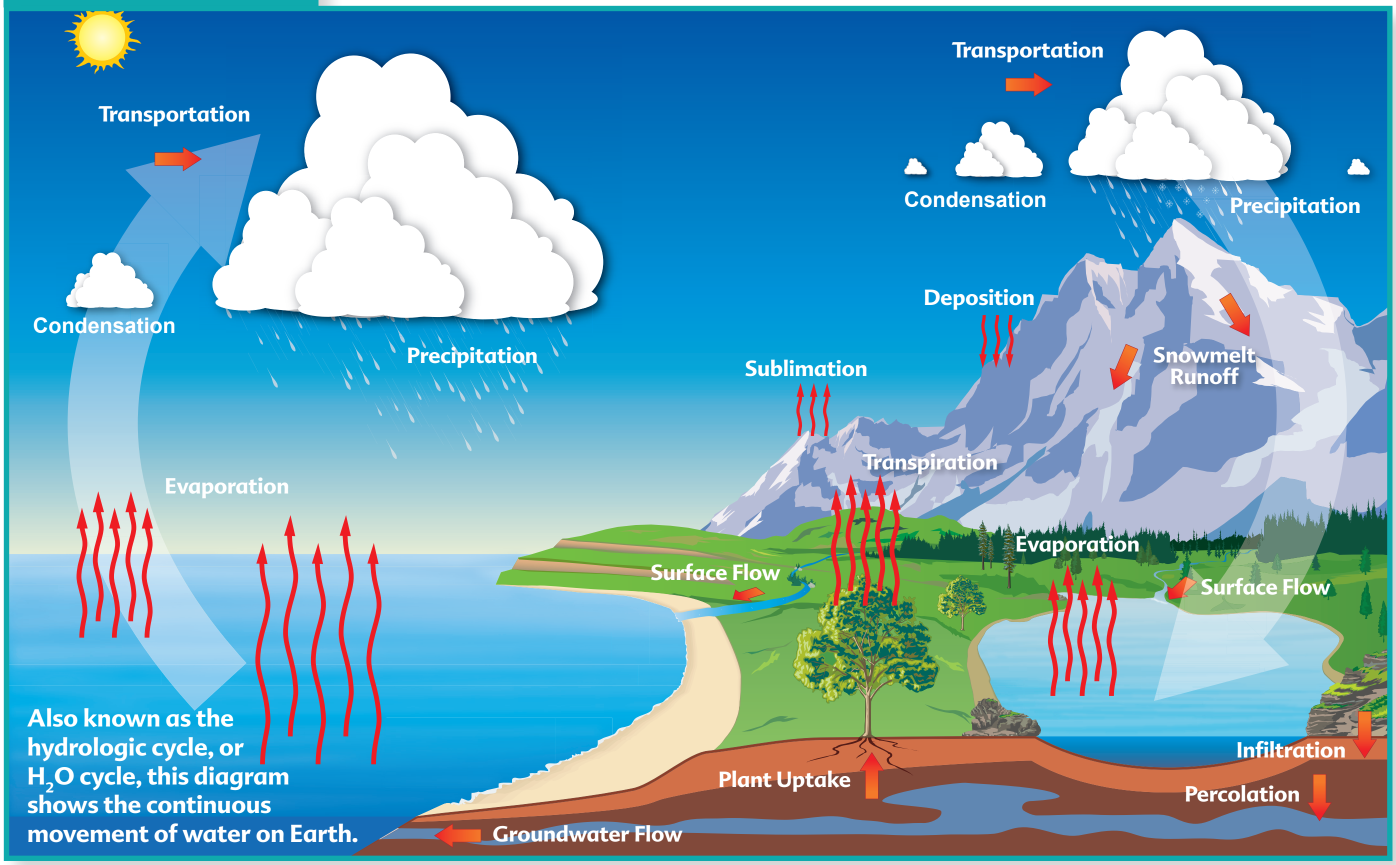
CHAPTER OVERVIEW

Water is all over the world! It is in the atmosphere, underground, running across Earth's surface, and even in the bodies of organisms. Some water moves quickly from one place to another, such as the water that is moving down rivers into oceans or the water at the surface of the ocean that evaporates into the sky. Some water may be trapped below Earth's surface, unable to move or evaporate for millions of years.

In order to know where we can find freshwater and how to keep it clean, we need to understand where water is located on Earth and how it may move from one place to another. This chapter outlines the water cycle by discussing not only how water moves from one reservoir to another, but also the challenges students typically need to overcome to understand this complex system.

In addition, this chapter explores concepts that students typically struggle to understand, such as groundwater and watersheds. The chapter concludes with an in-depth look at the urban water cycle in comparison to the natural water cycle.

HYDROLOGIC CYCLE



Also known as the hydrologic cycle, or H_2O cycle, this diagram shows the continuous movement of water on Earth.

the individual droplets combine to form creeks or streams that, in turn, combine to form rivers. The rivers then continue the water's journey to the lowest topographical point, where they all combine and accumulate the water drops into a lake or an ocean. The process of evaporation from this body of water continues, which demonstrates the basic water cycle.

The more thorough water cycle recognizes that water is sometimes removed from this loop of evaporation, condensation, precipitation, and accumulation for bits of time. It can be removed by **percolation** or infiltration or used by plants and animals. Students in upper elementary and middle school may be ready to explore some of these other processes. In percolation or infiltration, water seeps through the soil and rock, percolating to underground pockets of water. As it infiltrates through the layers, any pollution is removed. This is why underground pockets of water, known as aquifers, are valued as an important source of clean drinking water. When people drill water wells, they are trying to reach these aquifers. Students may wonder how water gets into wells in the first place, so exploring percolation is an important concept to learn. A rare step in the water cycle is when solid water, in the form of ice or snow, sublimates into a water vapor under very warm and sunny conditions. Sublimation tends to occur in snowy mountains in the spring, when it happens at all.

Water can also be used by plants for **photosynthesis** and cellular respiration. Plants absorb most water through their roots, and release it through their leaves. Water released by plants to rejoin the water cycle is known as **transpiration.** The molecule of water that evaporates through the stomata on the underside of a leaf pulls the adjoining molecule of water to the surface. Students may think water only enters and exits plants through the roots. Water is used by animals for cellular respiration and is released from the body through urination, exhalation, and sweat. As water is released from living things, it can evaporate and return to the basic water cycle. So all living things are part of the water cycle!

As freshwater from rain or melting snow descends through a watershed by the force of gravity, it erodes and carries downstream materials from along the edges and bottom of the stream. These materials can include natural items such as small particles of soil and decaying plant and animal materials or unnatural pollution such as chemicals and trash. During a storm, when the volume and force of the water are much greater, the swiftly moving water can carry large rocks, branches, and even trees that have fallen. A watershed is the land area drained by water into a particular

The Colorado River carved Horseshoe Bend in the Grand Canyon of Northern Arizona.

feature, usually a river or stream. For example, in central North America, the Arkansas River watershed consists of all the rivers, creeks, streams, and land surfaces that drain into the Arkansas River as it travels from Colorado to Arkansas, where it spills into the Mississippi River. Many watersheds are made of smaller watersheds. The Mississippi River watershed is made of the Arkansas, Ohio, Red, Tennessee, and Missouri river watersheds, just to name a few. It drains more than a million square miles, carrying with it the pollution and minerals from all its tributary watersheds to the Gulf of Mexico.

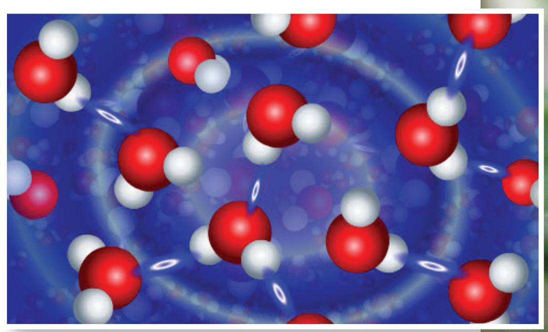
The water cycle is a closed system. Four of the processes in the water cycle are often taught in schools: condensation (water vapor cools and water molecules join together into drops of water), precipitation (water falls from clouds as rain, snow, hail, and so on), evaporation (as the sun heats water, the water changes phase from liquid to gas), and transpiration (water evaporates from plants as they photosynthesize). Although these processes capture important transitions in the water cycle, they do not fully represent the complex journey water takes through this cycle.

To understand the nuances of this cycle more, we must take a closer look at the water molecule itself and the four major processes of the water cycle. As we delve into these concepts, we will explore more detailed diagrams and representations of the water cycle and the trade-offs involved in using these diagrams with your students.

Special Qualities of Water

Some of the special properties of water can be better understood by taking a closer look at the structure of the molecule itself. Water is comprised of one atom of oxygen and two atoms of hydrogen. Each of the hydrogen atoms is bonded at an angle to the oxygen atom, in a *Y* configuration. The shape of the molecule resembles Mickey Mouse's head, with the hydrogen atoms representing the character's ears. Chemists sometimes jokingly refer to it as the Mickey Mouse Molecule.

Because of this architectural skew of the hydrogen bonds, the more positively charged hydrogen atoms form a slightly positive side to the molecule, while the more negatively charged oxygen atom forms a slightly negative side; the molecule overall is a stable one that is ionically balanced, meaning it does not easily bond with other molecules or elements. This **polarity,** or positive/negative charge distribution, allows the water molecule to behave like a magnet, with the negative (oxygen) side attracting positively charged atoms and molecules, and the positive (hydrogen) side attracting negative atoms or molecules. This attraction means that it can act as a powerful **solvent.** Solvents are substances that are good at dissolving or dispersing other chemicals and particles. For example, common table salt, NaCl, is an ionic compound, comprised of a positively charged Na+ (sodium) atom, and a negatively charged Cl- (chloride) atom. In water, this solid salt can dissolve. The Na is attracted to the oxygen side of the water molecule, and the Cl is pulled toward the positively charged hydrogen side. The result is that the salt molecule is pulled apart; it dissolves in the powerful solvent of water. It is water's polarity that allows for salinity in our ocean. Common food items, like Jell-O and Tang, take advantage of water's solvent



The dynamic interactions of water molecules include the forming of links that vary in strength and span.

The dome shape of water droplets demonstrates the cohesion of water molecules.

powers to deliver the other ingredients to us in a tasty form.

The negative (oxygen) side of the water molecule can also lightly bond with the positive (hydrogen) side of other water molecules, a phenomenon known as hydrogen bonding. In this case the water molecule's polarity leads to properties known as cohesion and **surface tension.** Cohesion is the attraction of water molecules to one another. Because of this property, water molecules tend to stick together, forming clumps. Cohesion allows for water to flow through plant tissues and blood vessels by capillary action. At the surface of a container or puddle, water will appear to take on a domed shape. This surface tension is due to the cohesion of water molecules.

Like all compounds, the water molecule is able to exist as a solid (ice), liquid, and a gas (water vapor). Something unique about water is that it is the only substance that is naturally found in all three phases at normal Earth temperatures!

Surface tension allows this insect to walk on water!

The States of Water

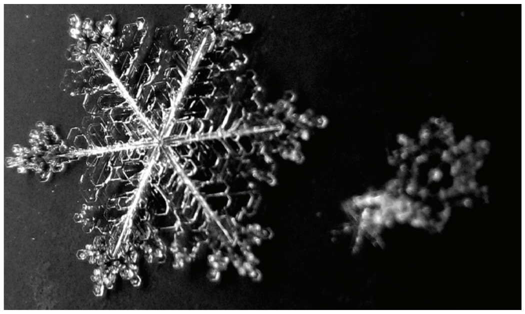
Water makes up 55–78 percent of the human body, is considered a universal solvent (meaning many substances dissolve in it), and is integral to life as we know it on Earth. It has specific temperatures at which it boils, freezes, and melts. The combination of these properties, plus the energy from the sun and the force of gravity, makes the water cycle a continuously renewable system, perpetually cycling water molecules from the land, lakes, and oceans to the air and back again.

Liquid. We most commonly think of water in its liquid phase, which is its most common form on Earth. Water is a liquid, rather than a gas, at room temperature because of hydrogen bonding between water molecules. Oxygen is electronegative (or electron loving) compared to hydrogen, which gives the oxygen atom in a water molecule a partial negative charge and the hydrogen atoms a partial positive charge. As in many cases in chemistry, here "opposites attract"—the oxygen atoms in water molecules are attracted to the hydrogen atoms in other water molecules, and together they create hydrogen bonds. Although the hydrogen bonds are continually forming and breaking as the water molecules move, these relatively strong bonds hold water molecules together and explain why water is a liquid and not a gas at room temperature. Hydrogen bonds are also responsible for many of the other unique properties of water.

Solid. The solid phase of water is known as ice, which commonly takes the structure of hard-amalgamated crystals such as ice cubes, or loosely accumulated granular crystals such as snow. Ice is usually formed when liquid water is cooled below 0 degrees Celsius, or 32 degrees Fahrenheit, at **standard atmospheric pressure** (average air pressure at sea level). Water vapor (a gas) can also turn directly into a solid, skipping the liquid phase. This is how frost forms. Ice appears in nature in many forms, such as snow, hail, icicles, pack ice, mountain glaciers, and polar ice caps.

Because frozen water molecules arrange themselves into a crystal lattice form that has more space between molecules compared to liquid water molecules, water volume actually expands as it changes from a liquid to a solid. This is a very unusual property; most substances decrease in volume when they become a solid. You have probably experienced this property of water if you have ever accidentally left a water bottle in a freezer; the bottle likely cracked as the water's volume increased.

The difference in volume between liquid and frozen water suggests that ice is less dense than liquid water (remember that density is defined as mass per unit volume). As it cools and eventually freezes, liquid water forms hexagonal crystals of ice. These crystals take up more space and are less dense than liquid water, which is why water expands as it freezes, and why ice floats in water. This property of water has some interesting consequences for natural and built environments. For instance, freeze-thaw cycles are important for



Snow falls on Ai-Petri peak in Ukraine. Eventually this snow will melt and supply liquid water to living things at lower elevations in the watershed.

the weathering of rock in nature and for the formation of potholes in roads. This property of water also explains why pipes in buildings often burst when the water in them freezes. Because ice is less dense than water, ice cubes float in a glass of water, icebergs float in the ocean, and we can skate on frozen ponds in the winter. Consider, too, that if ice were denser than water, natural bodies of water would freeze from the bottom up, which would likely kill many plants and animals that live in water year-round.

Vapor. Water vapor (or aqueous vapor) is the gas phase of water. Water vapor is lighter than (i.e., less dense than) air. It is also a greenhouse (or heat-trapping) gas similar to several other gases such as methane and carbon dioxide. In fact, water vapor is a particularly important **greenhouse gas,** meaning it helps our atmosphere to retain heat. In arid locations, less heat is trapped by the atmosphere, which explains why deserts cool more dramatically at night. Locations with high humidity may have very little difference between day and night temperatures as water vapor allows less heat to escape during the nighttime hours. Water vapor can be produced by boiling liquid water or through the sublimation of ice. Under typical atmospheric conditions, water vapor is also continuously produced through evaporation and removed through condensation (see the following descriptions of these processes). In cold air, water vapor can quickly condense and form fog or mist, or can form dew or frost on surfaces. Clouds form when water vapor condenses and creates tiny water droplets or ice crystals in the atmosphere. On average, a water vapor molecule stays in the atmosphere for about nine to ten days. If all of the Earth's water vapor were to fall instantly as rain, the entire surface of the Earth would be covered with about one inch of liquid water.

The Ways Water Moves

Condensation. Condensation is the change in phase from a gas to liquid droplets or solid grains. This process commonly occurs when a vapor is cooled, often by coming into contact with a colder liquid or solid surface. Raindrops and snowflakes often form in clouds in this way—when water vapor condenses on dust particles, water droplets, or ice crystals in the atmosphere. Condensation can also occur when water vapor is compressed. You can easily see condensation occurring all around us. For example water vapor condenses into a liquid after making contact with the surface of a cold bottle or glass or even when you exhale on a cold morning.

Precipitation. Precipitation is perhaps the easiest part of the water cycle for children to understand because rain, snow, and other forms of precipitation are tangible, and students experience them often in their day-to-day lives. Precipitation starts in the atmosphere and falls to Earth's surface. Precipitation occurs when the atmosphere becomes saturated with water vapor and the water condenses and falls to the Earth. Two processes can lead to the air becoming saturated: cooling the air or adding water vapor to the air.

Precipitation is a major component of the water cycle and deposits most of the freshwater on Earth (precipitation falls as freshwater). Approximately 505,000 cubic kilometers, or 121,000 cubic miles, of precipitation fall on Earth each year. Most of it—398,000 cubic kilometers, or 95,000 cubic miles—falls over the oceans. However, it is critical to understand and convey that this falling water is not new water. It is water that came from somewhere else in the water cycle. Note that water can be created or destroyed through chemical reactions—for example, water is a product of the process of cellular respiration. However, water is generally not created or destroyed as part of the processes involved in the water cycle.

Evaporation. Evaporation is the process by which molecules on the surface of a liquid vaporize and change into a gaseous state. To make

Teaching Tip

Students commonly ask about the difference between dry ice and water ice. Dry ice is the solid phase of carbon dioxide (CO_2), whereas water ice is the solid phase of H_2O. Dry ice is commonly used as a coolant or as a fun way to produce a fog-like substance, because it turns directly from solid to gas at room temperature (a process called sublimation). Dry ice is usually much colder than water ice—it becomes a solid at temperatures below −78 degrees Celsius or −108.4 degrees Fahrenheit. It is very useful as a coolant because of its very low temperature and because it does not form a liquid as it "melts." (Dry ice actually does not melt at standard atmospheric pressure, but rather sublimes directly from solid to gas. Note that dry ice will melt into a liquid at a higher air pressure than the standard atmospheric pressure we generally experience). Care should be taken when handling dry ice—it should be used in open-air environments and can cause severe frostbite to skin that comes in contact with it.

In the Classroom

Surface Tension

There are countless classroom demonstrations that can be done to show water's unique properties. One of the most iconic activities is an investigation of surface tension. Water has a very strong surface tension compared to other liquids. Use this activity to spark discussion about the unique qualities of freshwater.

Materials

- 3 one-pint Mason jars with two-piece lid
- 3 six-by-six inch pieces of card stock (cereal boxes work well)
- 1 piece of screen cut to replace the lid in one of the jars
- 1 small tub or sink

Directions

1. For set-up, fill three jars with water, leaving about a half inch at the top.
   a. Jar A—put both lids on (the top and the ring)
   b. Jar B—put only the ring on
   c. Jar C—put the screen and ring on
2. Line up the jars on a table in a row, with cardboard on top of all three jars. Have the tub or sink nearby.
3. Tell students that the class is going to investigate a special property of water. You might take a short side trip in the activity to ask students if they have ever noticed any unusual or unexpected properties of water.
4. Before turning over each jar, stop and ask students to predict what they think will happen. Also, when the demonstration begins, have students record their observations or discuss observations immediately following the demonstration.
5. Grab Jar A first. Place the piece of cardboard on top of the jar with one hand holding the cardboard to the jar. With your hand on the cardboard, flip the jar upside down over the tub or sink and ask students what will happen when you remove your hand from the cardboard. Many students will think that the cardboard will stay stuck to the jar, as they may have seen or done this experiment before. Remove your hand from the cardboard and...Ta-Da; the cardboard falls and the water stays. You've pulled a fast one on them. Show students the lid and explain that we should never come to conclusions without all the information.
6. Now, do the same thing with Jar B. Cover the top of the jar with the cardboard and the palm of your hand, then flip the jar. This time when you remove your hand the cardboard will stay as they had predicted. This is due to the tremendous amount of air around us pressing on us from all sides, known as atmospheric pressure, and this atmospheric pressure is greater than the pressure from that little bit of air in the jar.
7. Now, do the same thing with the screened Jar C. After removing your hand, also remove the cardboard—the water will stay in the jar. In order to convince students that there is no lid on the jar, tilt the jar slightly so that some of the water will run out. If you are careful, you can do this several times. Explain the concept of surface tension.

Discuss

1. Ask students to name at least two things that were unusual or unexpected about the water in this experiment, and have them explain why it was unexpected. What did they expect initially?

this transition from liquid to vapor, a water molecule must absorb energy. Liquid water that becomes water vapor takes a parcel of heat with it—referred to as **evaporative cooling.** In the United States, the National Weather Service measures the actual rate of evaporation in a standardized pan of open water outdoors at various locations nationwide. The data are compiled into an annual evaporation map, and the measurements range from less than 30 to more than 120 inches of evaporation per year.

Note that your students may not understand that when water evaporates, other substances do not evaporate with it. Because of this, evaporation is a major process in the water cycle that continually changes water mixed with other substances (e.g., salty water in the ocean) into freshwater in the atmosphere. Evaporation is the reason why your rain water is not salty even if you live next to an ocean. The evaporation process also separates water from other substances such as pollutants in lakes or rivers. Other substances do not evaporate with water because their heat of vaporization (energy required to transform a substance into a gas at a given pressure) values are different from that of water. When you discuss this idea, your students may wonder how **acid rain** is formed if water is "pure" when it evaporates into the atmosphere. Acid rain forms when water molecules in the atmosphere react with other substances such as ammonium, nitrogen, and sulfur that have been emitted separately into the atmosphere. It is important to clarify that water evaporates as water alone. However, once in the atmosphere, water may mix with other substances in the atmosphere and then return to the ground as acid rain.

Evaporation is usually a more difficult concept for students to understand than precipitation. When evaporation happens, liquid water becomes a gas, is invisible, and is difficult to see and with which to work. We recommend using firsthand experiences with evaporation, as well as support and thinking questions, to help students understand how evaporation works. Evaporation can be seen throughout a student's daily life: Where do puddles go after a rainstorm? Where does sweat go if it is not trapped by your T-shirt or does not fall off as droplets? What would happen to the water in a pot of boiling water if you kept it over heat? How come I have to refill my dog's water bowl even if he has not drunk any of the water? Evaporation is all around you!

Transpiration. Transpiration is the process by which water evaporates from plants, especially leaves, but also stems, flowers, and roots. Leaf surfaces are dotted with openings called stomata and are bordered by guard cells that open and close the openings. Leaf transpiration occurs through the stomata. Stomata also provide the openings through which plants take in carbon dioxide from the air for photosynthesis. Transpiration helps plants move minerals and water from their roots up to their shoots, leaves, and flowers in much the same way as people suck on a straw—the water escaping from the leaves "pulls" the water up from lower parts of the plant. Transpiration also cools plants.

Plants give off water through transpiration.

It can be helpful to explain and think of transpiration as "plant sweat." Much like how your students sweat when they exercise hard on a hot day, so do plants. Transpiration is often a greatly undervalued part of the water cycle.

Often when students learn about plants, they hear about photosynthesis—how plants make their own food from the sun and CO_2. However, transpiration is also a critical part of understanding how plants work and the role they play in the water cycle. For example, a fully-grown tree may lose several hundred gallons of water through its leaves on a hot, dry day. About 90 percent of the water that enters plants' roots is transpired. Scientists often use the transpiration ratio, or the amount of water transpired compared to the amount of dry matter (i.e., all of the material that comprises the plant, except water) produced, to measure how much water it takes to grow certain plants. For example, crop plants transpire about 200—1,000 kilograms of water for every kilogram of dry matter produced (Postel, 1996). That is a lot of water necessary to grow our food!

Teaching Tip

You can show evaporation occurring in your classroom. Consider doing something as simple as a solar still activity, in which your students can observe not only evaporation, but also distillation. Solar still activities can demonstrate that when water evaporates, substances such as food coloring, salt, or other pollutants are left behind. Visit http://pbskids.org/zoom/activities/sci/solarstill.html and http://www.teachersdomain.org/resource/ess05.sci.ess.watcyc.solarstill1/ to see examples of solar-still activities.

Student Thinking

Water-Cycle Processes

While even very young children are exposed to the water cycle and its basic processes, they often develop incorrect ideas about its nature, and the nature of matter in general. For instance, young students often explain that water "disappears" into air during evaporation, without understanding that water has changed from a visible liquid phase to an invisible gaseous phase. Older students may think that it is the water molecules themselves that expand during melting or evaporation, rather than picturing the molecules moving apart. Students may also believe that the heat-intensive process of boiling results in the breaking apart of water molecules, and that they reform through condensation once in the air. Studies show that misconceptions such as these persist through middle school and beyond (Henriques 2002; Osborne & Cosgrove 1983; Tytler 2000). Many adults do not know that clouds are not water vapor, but rather liquid water droplets and ice crystals. One way to discuss this distinction is to explain that gases are invisible, yet we can see clouds. Therefore, clouds are not comprised of gas.

	Common Student Ideas	Scientific Concepts
Condensation	Droplets of water on the outside of a cold glass of liquid come from the glass "sweating" or water moving through the glass from the inside to the outside.	Droplets of water on the outside of a cold glass of liquid come from water in the atmosphere that cools and condenses when it encounters the cold glass.
Precipitation	Precipitation is new water that comes from clouds.	Precipitation is not new water—it happens after water vapor molecules condense and fall to the ground.
Evaporation	Evaporation is when water disappears or goes away. Salt can evaporate with water and make salty or polluted rain.	Evaporation is changing from liquid to vapor. It does not change the water molecules themselves. When water evaporates, only water molecules evaporate. Other substances are either left behind or will vaporize separately from water molecules evaporating.
Transpiration	Transpiration and evaporation are the same thing. Transpiration is water drying on the leaves of plants.	Transpiration is a special kind of evaporation from a specific source—plants. A fully-grown tree may lose several hundred gallons of water through its leaves on a hot, dry day through stomata (or pores) on leaves.

Ask Your Students

1. Show students a cold glass of water and ask from where the droplets of water on the glass come.
2. How do clouds form?
3. One day you notice a puddle on concrete in the school parking lot. The next day you return and the puddle is gone. What happened to the water in the puddle?
4. If you live by the ocean, will your rain be salty? Why or why not?

Pictures of Practice

Learning About Evaporation

Evaporation and condensation are two particularly difficult concepts for students to understand, especially young students who have not yet learned about atoms and molecules. To these learners, evaporation happens when water dries up or disappears. These students do not have a better way of explaining what happens to the water, so they default to explaining that the water disappears. Teaching about evaporation or other water-cycle processes can be particularly difficult because students can only see the visible parts of the process but not what is occurring at the molecular level. Evaporation, however, is an important process that brings freshwater to natural and human communities, and all students should understand how this happens and why it is important to our survival.

Students: Grade 3

Location: Auburn, California (an inland community)

Goal of Video: The purpose of watching this video is to hear and think about student ideas about evaporation and how best to teach this concept.

Classroom Context

Ms. Watkins's third-grade students have already talked about the water cycle as a general story of how water moves in a sequence, beginning with evaporation. This is the most basic story about water taught in schools. Yet, Ms. Watkins suspects that many students need additional instruction on what words such as *evaporation* and *condensation* mean. In the context of her daily oral language activity (DOL), Ms. Watkins asks what the word *evaporation* means.

Video Analysis

Evaporation may mean different things to different students. This is the case among students in Ms. Watkins's class. When asked what *evaporation* means, students share their understanding of the word, which reveals a diversity that Ms. Watkins must deal with throughout her water-cycle unit. Evaporation happens when solar energy (sunlight) is absorbed by water molecules, causing the molecules to move more rapidly. When enough sunlight has been absorbed, the molecules eventually spread apart, changing from liquid to gas form. To students, however, *evaporation* means something very different. In student preinterviews, they use descriptions such as "disappear" and "get dry." During the classroom discussion, one student describes water disappearing, another says "evaporation" means "to go to clouds," and yet another says it changes into a gas. Ms. Watkins recognizes that this word has different meaning to each student, so she continues to work on the concept throughout her unit. Even after discussion, students seem to have a new understanding of evaporation that uses the idea that water changes from liquid into gas, but the word "disappears" is still commonly used.

Reflect

How would you teach evaporation?

In this video you see a diverse set of ideas about evaporation, as well as patterns among what students describe. If these ideas were shared during a classroom discussion, how would you respond to students? How would you help student develop a shared, scientific meaning for the word given that students are starting with different informal meanings?

In the Classroom

Cloud in a Bottle

To form a cloud, vapor condenses to create water droplets. When the water droplets are too big to stay in the atmosphere, they fall to Earth. Clouds can be composed of microscopic droplets of liquid water (warm clouds), tiny crystals of ice (cold clouds), or both (mixed-phase clouds). The "ingredients" of any given cloud depend on altitude and temperature. A simple demonstration such as "Steve Spangler Science: Cloud in a Bottle" can help students explore clouds in their own classroom. (Note that the activity below is adapted from http://www.stevespanglerscience.com/experiment/00000030, where you can find additional information to conduct this activity in your classroom.)

Materials

- 1-liter clear plastic bottle with cap
- Foot pump with rubber stopper attached
- Warm water
- Safety glasses

Directions

1. First pour just enough warm water into the soda bottle to cover the bottom of the bottle. Swirl the water around the bottle and then seal with the rubber stopper.
2. Pump the foot pump at least five times. The rubber stopper may try to pop out of the bottle, so hold the bottle and stopper securely.
3. Then pull the stopper out of the bottle. When pulling out the stopper you may see a "poof" of a cloud. Seeing this poof means that there wasn't enough pressure in the bottle to make a sufficient cloud.
4. Repeat the experiment, but this time, pump the foot pump at least ten times to increase the pressure. Continue to hold the bottle and stopper tightly as you pump because of the increase in pressure, and point the rubber stopper away from anything that could be harmed or damaged if it were to pop out. Pull out the stopper when ready to observe a more substantial cloud.
5. Repeat the experiment again, this time pumping up to 15—20 times. This will help you achieve about 9 kilograms (20 pounds) of pressure in the bottle. Remove the stopper to observe a cloud in your classroom!

Discuss

1. Where and when have students seen condensed water molecules? (Remember that rain, snow, and sleet are precipitation—water vapor that condensed in the sky and fell. Try to encourage thinking about condensation occurring before it precipitates.)
2. What would happen to the molecules if they warmed?
3. What is the relationship between pressure, temperature, and condensation based on what we observed?

Student Thinking

What Makes Up a Cloud?

Students may be confused about the form of water found in clouds. Although clouds can be seen just about every day, is the water in them vapor, liquid, or solid? Clouds are not invisible like water vapor, but clouds are also not like liquid water found in lakes and ponds. Students may struggle to decide how to describe clouds because clouds are an experience of water that does not fall neatly into one form of water or another. In this activity, you will look at the descriptions students completed on a quickwrite to think about how you would conduct a follow-up classroom discussion about clouds.

Scenario

You have just completed your unit on water cycling and you know that your students are still confused about the form of water found in clouds. Your goal is for students to see clouds as being made of tiny liquid water droplets or tiny solid water particles, instead of water vapor, which is invisible. You have your students respond to a short quickwrite because you want to plan a follow-up classroom discussion to address their incorrect ideas. Look at some of the responses below and brainstorm how to use this information to plan your discussion.

Question

What are clouds made of?

Scientific Answer

Clouds form when water vapor condenses and create tiny water droplets or ice crystals in the atmosphere.

Student Answers

Ruby: I think clouds are made of fog and fog is mist. If I looked at a cloud through a microscope I would see a bubble.

Abby: I think clouds are made of gases and waters because gas would make them float and water is how it rains. If I looked at a cloud through a microscope I would probably see a lot of gas.

Olivia: I think clouds are made of steam because water comes up and then it makes steam. It forms together a big cloud and then the water comes up into the clouds.

Thomas: I think clouds are made of gas and water vapor. We can see clouds because the water vapor has turned into mist, and when the clouds reach to the ground they turn into fog.

Justin: Clouds are made of tiny water droplets, and when they get bigger and bigger it rains.

What Would You Do?

1. Think about what your students still do not understand. Which misconceptions would you focus on during the discussion?
2. What additional activities or strategies might you use to help students develop more scientifically correct ideas?

Representations of Science

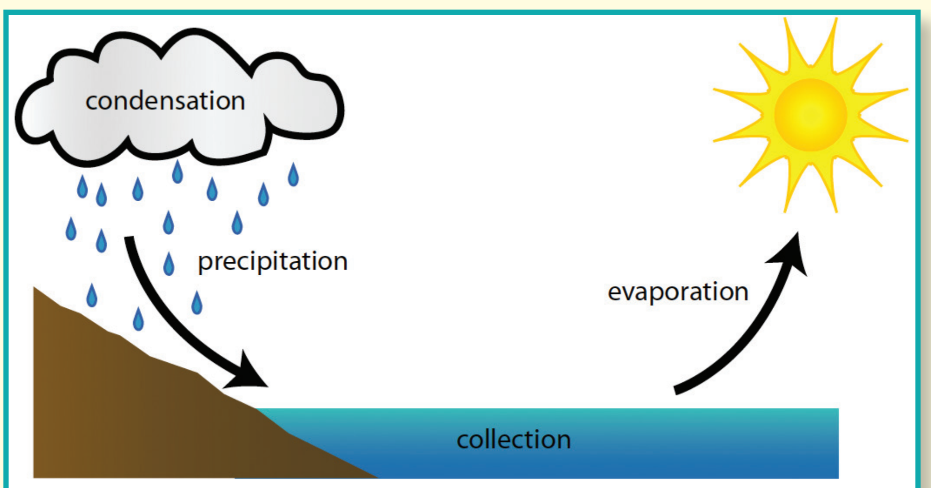
The Water-Cycle Journey

Although the preceding sections explore many details about water, including where water is on Earth and the processes by which it moves around Earth, we often do not fully understand how complex and valuable the water cycle is. Do we fully appreciate that the water we drink is the same water dinosaurs drank millions of years ago? Tell most people this simple fact and it is a good bet they will be astonished.

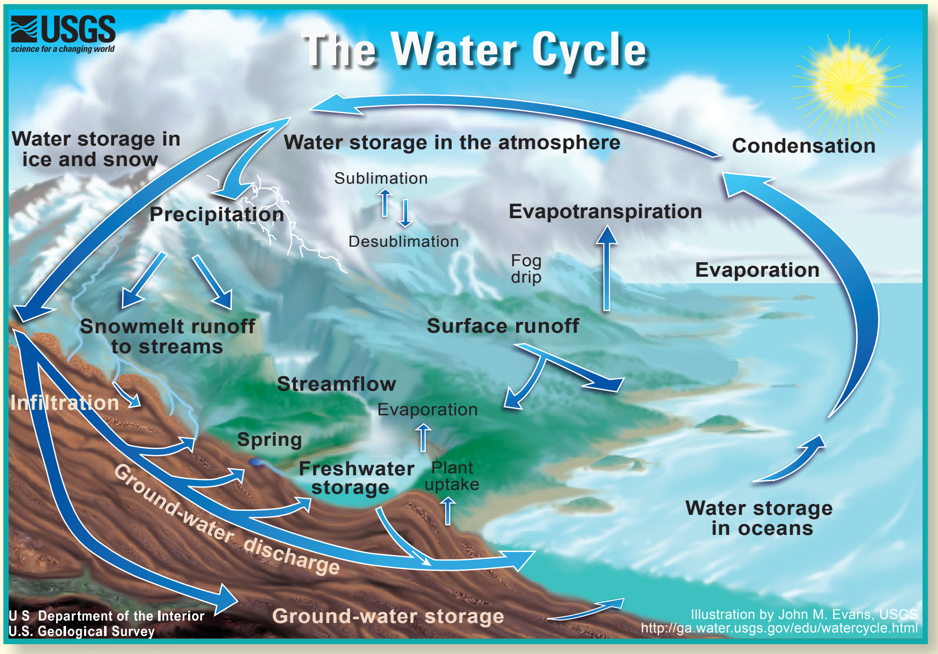
The water cycle is a more complex cycle than is often diagramed for students. Water moves among many locations in this closed Earth system. Water molecules can get "stuck" in certain locations, such as in glaciers or groundwater, for millions of years, whereas surface water can move quite quickly from one location to another. Once presented with some background information and a few firsthand experiences with how the water cycle works, even young students can appreciate and understand a more complex cycle than the basic water-cycle diagrams generally portray. The following diagrams are valuable tools that can help your students achieve a greater understanding of the water cycle. We describe the benefits and drawbacks of each diagram that follows. However, these diagrams may work best as supplements to the most effective ones—diagrams created by students themselves when they take a journey through the water cycle.

Water-Cycle Diagrams

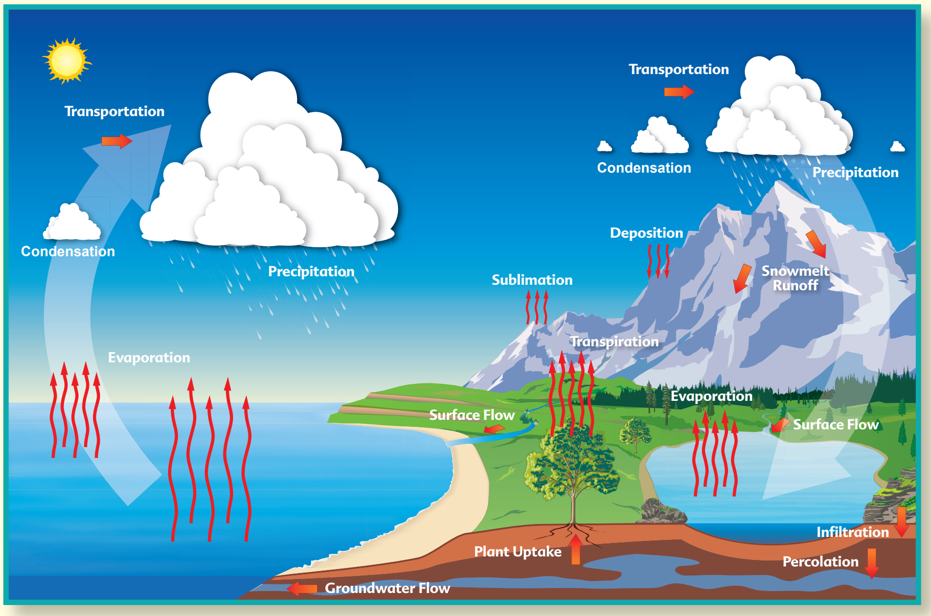
There are many informal conceptions about the water cycle, and some concepts, like groundwater, are particularly difficult for students to understand. Science-education researchers suggest using carefully constructed models and/or visualizations to help students build a more correct understanding of water cycling, especially with respect to our groundwater systems (Dickerson 2004). Some of the following diagrams can be helpful, but pay attention to the strengths and weaknesses of each diagram. What informal conceptions might the diagram support? How would this limit your teaching of the topic? Note that across many different water-cycle diagrams, two informal concepts often fostered are that rivers always start in the mountains and water always flows as rivers underground. If you find that your students have these informal concepts, you may want to choose a diagram that would help students understand these concepts better.



NOAA's basic water-cycle diagram is clear and easy to understand. Notice the sun plays a major role in the overall illustration. While diagrams such as this one are easy to use, especially with younger students, pay attention to whether the diagram is oversimplifying the system. With simple diagrams comes the belief that the cycle is also simple and that water only rises up and falls back to Earth. This type of cycle also does not show the continuous, closed loop.



The USGS Water-Cycle diagram contains a much more complete illustration of the locations and processes in the water cycle, with clean, easy-to-read arrows. The diagram also shows a circular loop. The trade-off of such a diagram is that it may create several misconceptions, such as that streams and rivers always start in the mountains, and that groundwater is an underground river rather than water in porous spaces in the soil.



The illustration by NOAA National Weather Service includes more advanced phase changes (e.g., sublimation). The diagram also shows some of the percentages of phase changes by emphasizing size and numbers of arrows. For example, the diagram shows that a greater amount of water is evaporated from the oceans than from water on land. Like the USGS diagram, this diagram may also perpetuate incorrect ideas about streams flowing from mountains and groundwater being an underground river.

Student Thinking

Groundwater

Students may believe that groundwater is water in underground rivers and pools. They may think if we dig deep enough into the ground, then water must be there. However, this idea is quite far from the truth. Most groundwater resides in soil-pore spaces and fractures in rock formations. Only at springs, where groundwater bubbles up from the surface naturally, is it easy to collect. More generally, wells are dug to access groundwater. How difficult it is to access this water depends on the type of substrate, the permeability (a measure of the ease with which liquids can move through a porous material) of the surrounding geology, the slope of land, the **recharge rate** of the aquifer, and various other factors. **Recharge** is a process by which water infiltrates from the surface down into the groundwater. Another term you may hear in relation to groundwater is **porosity.** Porosity is a measure of the void spaces in a material such as rock. Some types of rock can actually have high levels of porosity, but low levels of permeability. For example, if the rock has many void spaces, but the spaces are not connected to each other, water in the pore spaces cannot flow through the rock with ease. It is important to stress that groundwater is often difficult to measure and access and that human use of groundwater often outpaces the rate at which it is recharged.

Scenario

You have briefly mentioned groundwater in your class, and it seems as if your students understand what was discussed. On a weekly quiz, you include a question about wells and want to evaluate how much your students have learned so far. Consider the following responses and reflect upon the following questions.

Question

Where does water that we get from wells come from?

Scientific Answer

Water from wells is from groundwater—the water found in porous spaces underground that is recharged when rain infiltrates from the surface of the land.

Student Answers

Sam: The water under the ground comes in from an underground river, and then we dig until we can get water from that river.

Christopher: I think it has something to do with an aquifer, but I don't know what exactly that is.

Jessica: There are lakes under the ground, and they stick pipes down into the ground to get it.

Anna: Water goes into the well from precipitation. It rains and fills up the water.

Jeffrey: Wells are drilled into the ground to get water that has seeped into underground aquifers.

What Would You Do?

1. How would you grade these answers given that they appeared on one of your weekly quizzes?
2. Think about activities you could do to reteach these concepts to your students. What misconceptions would you target?

Where is Fresh Water Located?

To understand how valuable freshwater is, it is important to first understand how much freshwater is actually on Earth, where it is located, and in what forms it exists. Ironically, on a planet extensively (71 percent) covered with water, water is one of the main limiting factors for life on Earth. On a global scale, only a small percentage of freshwater is available for living things to use, and it is not distributed equally throughout all areas of the planet. Although some people are surrounded by freshwater that they can easily access, others have extremely limited access to freshwater.

By the numbers: 97.5 percent of the water on Earth is salty (*National Geographic,* April 2010). Two and a half percent of Earth's water is fresh, but about two-thirds of that is frozen, so only about 0.8 percent of the water on Earth is available as freshwater in surface or groundwater. We must be careful about how we use freshwater because it is a finite and limited resource!

Where does your water come from? Often people turn on the tap and have no idea where their water actually comes from, what condition it is in, or the long-term availability of their supply.

The Forgotten Reservoir of Water

Groundwater is among the world's most valuable natural resources. Groundwater aquifers provide half of the U.S. drinking water and also provide water to agriculture, industry, and the environment. Over the past 75 years, population increases, as well as improvements in the amount and effectiveness of drilling and pumping, have drastically increased our use of groundwater. Much of this water is used for irrigation. In contrast to rivers and lakes, groundwater is hidden from view and, thus, often misunderstood and underappreciated. Please refer to Chapter 3 to further understand some of the threats to this valuable resource.

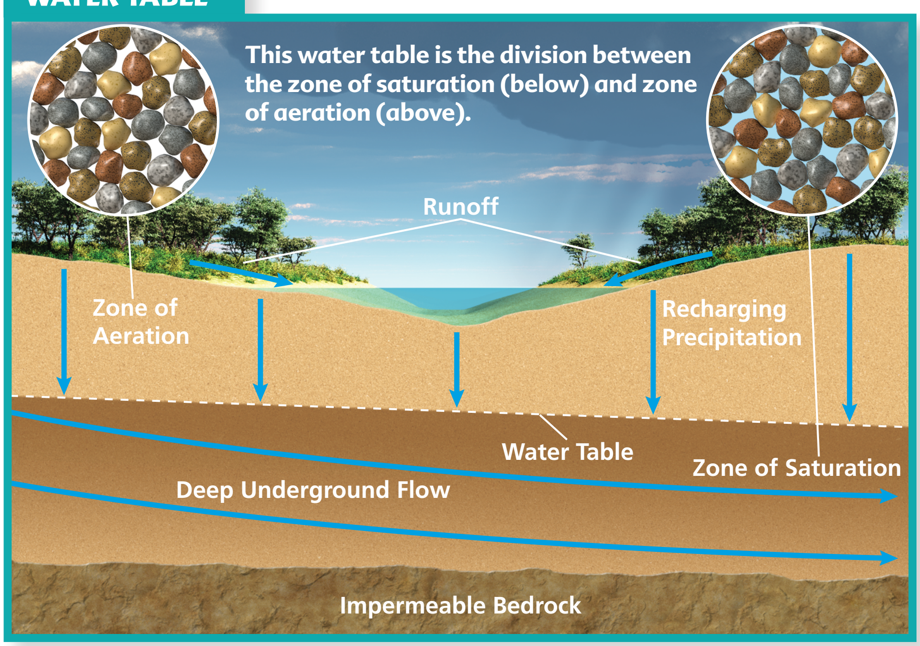
Water Table, Aquifer, and Groundwater—Different Words for the Same Thing?

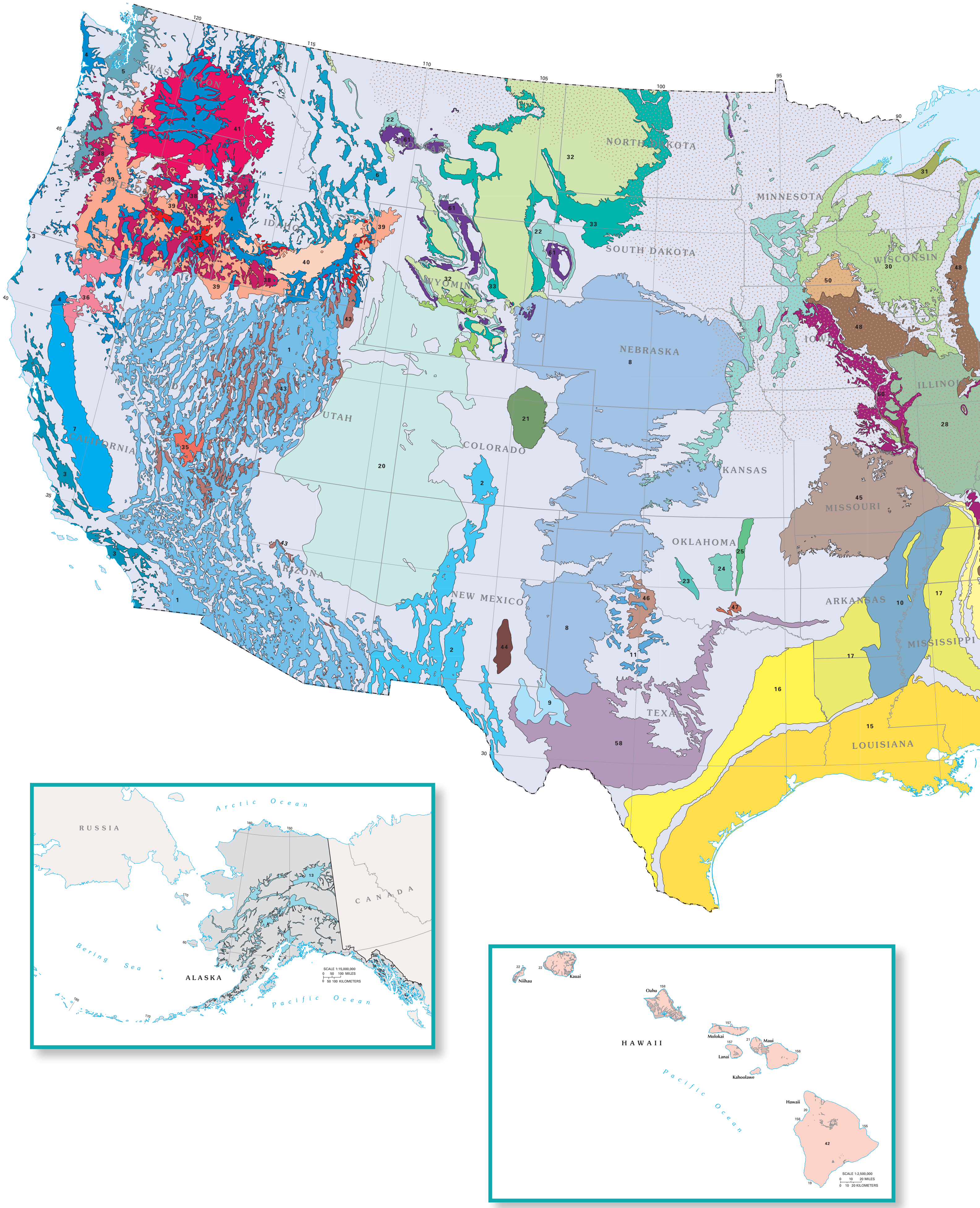
The terms ***water table,*** *aquifer,* and *groundwater* are often confused and sometimes used interchangeably. They are all related—they refer to aspects of water that occurs underground—but they are not the same. The simplest of the terms to understand is *groundwater,* which means just what it says—"water that is found in the ground." "Water table" and "aquifer," though, require a bit more explanation.

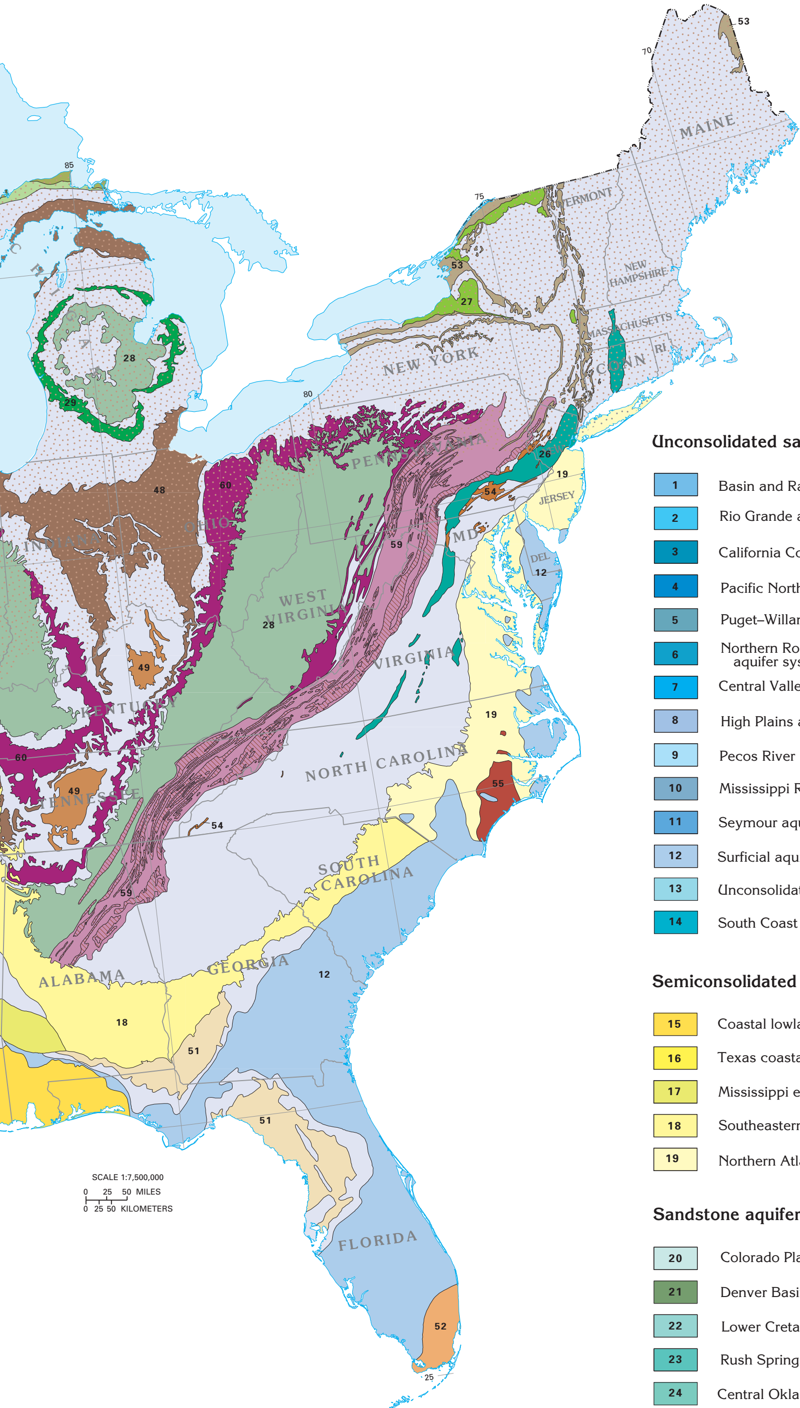
The term aquifer refers to the water underground held within rocks and soils that can be usefully extracted using wells. Water found underground does not commonly occur in underground lakes or rivers (although there are underground rivers in some areas with special geological characteristics), but rather, it occurs in saturated pore spaces in soil and fissures in rock formations. Aquifers are often classified into two types—**unconfined aquifers** and **confined aquifers.** In an unconfined aquifer, the top border of the aquifer is the water table. There is no confining (impermeable layer) above an unconfined aquifer, and for this reason, water that soaks into the ground can infiltrate directly into an unconfined aquifer. In contrast, a confined aquifer is an aquifer that is sandwiched between two impermeable or low-permeability layers of substrate, such as clay.

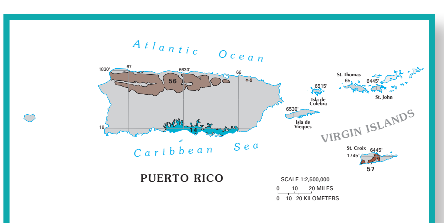
Aquifers come in all shapes and sizes. They can cover hundreds of square miles in area and be hundreds of feet deep, or they may cover only a few square miles and be a few feet deep. The quality and amount of water varies from aquifer to aquifer, and sometimes varies even in the same aquifer system. Some aquifers can yield millions of gallons of water per day, while others may yield only a very small amount of water per day. Much of this variation depends upon the recharge rate of the aquifer, or how fast water from the surface enters this groundwater layer. The amount of time water spends underground also varies from aquifer to aquifer. An unconfined surface aquifer

WATER TABLE




WASHINGTON
IDAHO
OREGON
CALIFORNIA
NEVADA
UTAH
ARIZONA
WYOMING
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
MISSISSIPPI
WISCONSIN
ILLINOIS
RUSSIA
CANADA
ALASKA
Arctic Ocean
Bering Sea
Pacific Ocean
SCALE 1:15,000,000
0 50 100 MILES
0 50 100 KILOMETERS
HAWAII
Niihau
Kauai
Oahu
Molokai
Maui
Lanai
Kahoolawe
Hawaii
Pacific Ocean
SCALE 1:2,500,000
0 10 20 MILES
0 10 20 KILOMETERS





This map shows the different types and locations of underground aquifers in the United States. Use this map to help gauge your students' understanding of groundwater and aquifers.

Unconsolidated sand and gravel aquifers

- 1 Basin and Range aquifers
- 2 Rio Grande aquifer system
- 3 California Coastal Basin aquifers
- 4 Pacific Northwest basin-fill aquifers
- 5 Puget–Willamette Lowland aquifer system
- 6 Northern Rocky Mountains Intermontane Basins aquifer system
- 7 Central Valley aquifer system
- 8 High Plains aquifer
- 9 Pecos River Basin alluvial aquifer
- 10 Mississippi River Valley alluvial aquifer
- 11 Seymour aquifer
- 12 Surficial aquifer system
- 13 Unconsolidated-deposit aquifers (Alaska)
- 14 South Coast aquifer (Puerto Rico)

Semiconsolidated sand aquifers

- 15 Coastal lowlands aquifer system
- 16 Texas coastal uplands aquifer system
- 17 Mississippi embayment aquifer system
- 18 Southeastern Coastal Plain aquifer system
- 19 Northern Atlantic Coastal Plain aquifer system

Sandstone aquifers

- 20 Colorado Plateaus aquifers
- 21 Denver Basin aquifer system
- 22 Lower Cretaceous aquifers
- 23 Rush Springs aquifer
- 24 Central Oklahoma aquifer
- 25 Ada–Vamoosa aquifer
- 26 Early Mesozoic basin aquifers
- 27 New York sandstone aquifers
- 28 Pennsylvanian aquifers
- 29 Mississippian aquifer of Michigan
- 30 Cambrian–Ordovician aquifer system
- 31 Jacobsville aquifer
- 32 Lower Tertiary aquifers
- 33 Upper Cretaceous aquifers
- 34 Upper Tertiary aquifers (Wyoming)

Basaltic and other volcanic-rock aquifers

- 35 Southern Nevada volcanic-rock aquifers
- 36 Northern California volcanic-rock aquifers
- 37 Pliocene and younger basaltic-rock aquifers
- 38 Miocene basaltic-rock aquifers
- 39 Volcanic- and sedimentary-rock aquifers
- 40 Snake River Plain aquifer system
- 41 Columbia Plateau aquifer system
- 42 Volcanic-rock aquifers—Overlain by sedimentary deposits where patterned (Hawaii)

Carbonate-rock aquifers

- 43 Basin and Range carbonate-rock aquifers
- 44 Roswell Basin aquifer system
- 45 Ozark Plateaus aquifer system
- 46 Blaine aquifer
- 47 Arbuckle–Simpson aquifer
- 48 Silurian–Devonian aquifers
- 49 Ordovician aquifers
- 50 Upper carbonate aquifer
- 51 Floridan aquifer system
- 52 Biscayne aquifer
- 53 New York and New England carbonate-rock aquifers
- 54 Piedmont and Blue Ridge carbonate-rock aquifers
- 55 Castle Hayne aquifer
- 56 North Coast Limestone aquifer system (Puerto Rico)
- 57 Kingshill aquifer (St. Croix)

Sandstone and carbonate-rock aquifers

- 58 Edwards–Trinity aquifer system
- 59 Valley and Ridge aquifers—Carbonate-rock aquifers are patterned
- 60 Mississippian aquifers
- 61 Paleozoic aquifers

Glacial deposit aquifers overlie bedrock aquifers in many areas

Not a principal aquifer

might hold water for a few days, weeks, or months. A deep, confined aquifer (covered by one or more impervious layers) may contain water that has resided underground for hundreds or thousands—or even a million—years!

When precipitation falls, it infiltrates into the ground and creates a stratum of saturated earth called the **zone of saturation.** This same area is also called an aquifer when the water can be usefully extracted by a well). The area of soil above the zone of saturation, where soil is moist but not saturated, is called the **zone of aeration.** The top of the zone of saturation, where groundwater pressure is equal to atmospheric pressure, is called the water table. However, it might be more useful to think of the water table as the point at which, if you were digging, you would hit soil that is completely saturated with water. The water table intersects with the surface of the ground and can be seen above ground wherever there is surface water, such as rivers, springs, wetlands, and oases. People often monitor the water table to judge groundwater availability. The level of the water table depends on the surface topography, the permeability of the rocks and soils within the topography, as well as any fluctuations that might occur.

The shape of the water table may change and vary due to seasonal changes, topography, and structural geology. In regions where people do not have many wells, or in areas of high precipitation, the water-table level generally follows the contour of the overlying land surface and rises and falls with increases or decreases in the amount of precipitation that makes it into the ground. Therefore, there is usually an average water-table level for a given location, but the water table often rises and falls around that average level. A variety of factors affect these fluctuations in the level of the water table.

Seasonal fluctuations depend on the climate of a region. In some regions, such as California or Great Britain, for example, more precipitation falls during the winter than in the summer, so the groundwater is not fully recharged during the summer. Consequently, the water table is usually lower in the summer and higher in the winter.

Some groundwater is affected by tides. On some low-lying oceanic islands with porous soil, freshwater tends to collect in pools on top of the denser seawater intruding from the sides of the island. Thus, the water table of these islands rises and falls with the tides.

The water table can also fluctuate from the use of the groundwater by people and agriculture. As more people demand more water, they look to aquifers to provide this water. If the amount of water added to the aquifer each year cannot keep up with the rate that the people pull the water out of the aquifer (usually through wells), then the water table will go down. If use continues to outstrip new infiltration into the aquifer, then the water-table level will be changed permanently, which may in turn affect soil stability and the hydrology of the area.

Watersheds

Water moves over Earth's surface through a series of watersheds, or drainage basins. Watersheds are something we all live in, are part of, and are affected by. If you imagine a drop of water landing on a high spot in the landscape and running over the ground and eventually rolling into a water body, such as a pond or lake, all of the land that drains into that water body is considered the watershed. Watersheds are sometimes also called catchment basins, catchment areas, water basins, or drainage basins. A watershed acts like a funnel, channeling all of the water in an area into a waterway. The watershed contains the streams, rivers, or water bodies that channel the water, as well as the land surfaces from which water drains into these channels. Each watershed is separated from another watershed by a drainage divide. Drainage divides can be mountains, ridges, or hills—basically the highest points of land surrounding the water body. Watersheds are named after the water body that the water flows into, and they are nested within one another in a hierarchical pattern. Smaller basins that drain into larger ones are considered to be a part of the larger watershed. Thus, in California, the Pit River Watershed and the McCloud River Watershed are both smaller basins nested within the larger Sacramento River Watershed. Small basins—from water bodies such as streams, tributaries, and ponds—are called subbasins and drain into larger ones, such as larger water bodies like major rivers or oceans.

We know that a drop of water on its journey down the land and into a water

Teaching Tip

Project WET has developed an activity, "The Incredible Journey," which is a game that uses special dice that depict different water-cycle reservoirs. As students roll the dice, they have an opportunity to journey through the water cycle and learn that there is no "one path" through the cycle. The game also introduces the idea that water resides in some places (e.g., groundwater) longer than in other places (e.g., the atmosphere). For more information, see the Project WET website at http://www.projectwet.org/.

body does not stay in one water body forever—it continues on into another larger stream; the stream links to a larger river; and the river flows into the ocean. You can think of this structure of watersheds as being like a set of growing concentric circles. Looking at the map below, if people were enjoying a leisurely boat ride on Lake Mead, they would be in the Lake Mead Watershed. But because Lake Mead flows into the Colorado River, they would also be in the Colorado River Watershed. The Colorado River flows into the Gulf of California (Sea of Cortez), which is connected to the Pacific Ocean. You get the idea—at the same time, you could consider yourself part of the Lake Mead, Colorado River, Gulf of California, and Pacific Ocean watersheds.

There is one type of watershed that is a bit different than the rest. **Endorheic drainage basins** are watersheds that do not drain into oceans. The Lake Tahoe-Truckee River-Pyramid Lake system on the border of California and Nevada is an example of one such watershed. Endorheic watersheds drain into inland bodies of water that are disconnected from oceans. Around 18 percent of all land drains into these kinds of watersheds. The largest of these types of watersheds are in Asia and drain into the Caspian and Aral Seas. Because these endorheic water bodies have no outflows, most of their water is lost through evaporation. This generally leaves the water in these lakes and seas saltier than other water bodies because their water continually evaporates, but the dissolved salts that drain in with their water stay behind. The Dead Sea provides an extreme example of how salty an endorheic water body can get. Endorheic water bodies are, of course, still part of the water cycle, but their watersheds are not linked to one another in the same direct way as a watershed in which a stream flows into a larger river, which flows into an ocean.

Teaching Tip

To convey the concept that you live in more than one watershed at a time, it can be helpful to use the analogy that you live in more than one political unit at a time. For example, a student in Los Angeles lives in Los Angeles, California, the United States, North America, the Western Hemisphere, and Earth all at the same time. We tend to think of living in watersheds based on the closest water body to us, but it is helpful to remember, especially when thinking about ecology and conservation, that all of the watersheds are connected in some way, and the water droplets, along with the nutrients or pollutants dissolved in them, move among all of the watersheds. If you show maps of watersheds to your students, it is important to remember that many students will need an introduction to how topographic maps work. If they are not familiar with topographic maps, tracing the outline of a watershed or tracing the branching pattern of a river might be difficult. It can be helpful to have students start by building their own watershed models and drawing their own maps from these models. See an example of such an activity at Project WET's website "Branching Out:" http://projectwet.org/.

The Colorado River is visible as dark blue in the lower right of of the photo. According to the NASA description of their aerial photograph, a hundred years ago the river would have continued across the entire area, flowing into the Gulf of California. Nearly all the water that flows into the Colorado River is now siphoned off for crop irrigation and residential use. In the upper left of the photograph, the patchwork of colors shows farmland and homes at the base of the Sierra de Juarez Mountains. In fact only about 10 percent of all the water that flows into the Colorado River finds its way into Mexico, and most of that is used by the Mexican people for farming.
(See full text http://earthobservatory.nasa.gov/IOTD/view.php?id=1288.)

It is also important to highlight that watersheds are divided by high points of land, not by **geopolitical boundaries.** Nor are you necessarily in the watershed of the water body that is closest to you. For example, if you lived in Ecuador, no matter which part of Ecuador you lived in it would be a much shorter walk to the Pacific Ocean than to the Atlantic Ocean. However, if you were a drop of water that landed on the eastern slope of the Andes Mountains, you would journey into the Amazon River, and then all the way across South America to the Atlantic Ocean. Watersheds are most often formed by landforms and follow the shape of Earth's surface as it was carved millions of years ago, not by the borders people have placed on Earth's surface for our own purposes.

Although the borders of some states and countries fall along the lines created by rivers and lakes, geopolitical boundaries rarely follow the boundaries of watersheds. Rivers, for example, often serve as borders, like the Ohio River does between Ohio and West Virginia. However, parts of both Ohio and West Virginia, as well many other states, are within the Ohio River Watershed. This means that the way Ohio treats the land on "their side" of the river affects the quality and amount of water that makes it to the river, which has important consequences for folks in West Virginia on the other side of the river. Similarly, the way West Virginia treats its land affects people in Ohio. Historically, a few treaties have considered watersheds and their use. For example, the English Crown gave the Hudson's Bay Company fur trading rights in the entire Hudson Bay watershed. Today, many towns, states, and countries are designing conservation policies based on watershed boundaries—not political ones. Watersheds are a critical way to think about water flow, the water cycle, history, ecology, and many of our conservation efforts.

Why Teach About Watersheds?

Watersheds are natural ways of dividing and connecting landscapes. They provide a great tool for thinking about the ecology and land use of a region, because as water flows over and through the ground, it can pick up sediment, nutrients, and pollutants and carry them downstream. Like the water, the nutrients and pollutants that flow to the outlet of the watershed can affect ecological processes along the way. Nutrients such as nitrogen, phosphorous, and potassium—found in many household items, including cleaning products, fertilizers, road sediment, and so on—can accumulate at the mouth of a watershed and disturb the natural balance of nutrients and plant and animal life. In addition, management practices and land use changes can have a significant impact on a region's water resources by changing the quality, quantity, and flow of the water. Understanding how watersheds function, learning how water connects the landscape (e.g., an action such as introducing a pollutant into a river in one place affects water downstream), and recognizing trends in how people have changed how watersheds function, all help students appreciate the importance of watershed management.

Teaching Tip

Creating three dimensional watershed models can help your students visualize and understand how watersheds work. Students can build watershed models out of clay, and use spray bottles filled with water to simulate rain and watch how surface water moves through their watershed models. You can also extend this activity further by having students create watershed models from topographic maps, or vice versa. If students can turn a topographic map into an accurate clay model or draw a topographic map from a clay model, they should be able to look at a map and understand which way surface water will flow in the represented area. This is an important skill for thinking about questions such as, "if a toxic substance were accidentally spilled into a river, where would the toxic pollution go?" An online tutorial for learning about topographic maps is available at http://geology.isu.edu/geostac/Field_Exercise/topomaps/index.htm. You can download topographic maps of your local area or other locations your students are interested in, using the Acme Mapper website available at http://mapper.acme.com/.

Student Thinking

Watersheds and Rivers

While students are generally more familiar with rivers than with watersheds, they often have informal ideas about both. Because they are more familiar with rivers, students tend to have more ideas about rivers that are rooted in their personal experiences. For example, students' experiences with rivers may be crossing a river on a bridge or seeing a river on a map. Crossing a river on a bridge provides just a glimpse of a very small length of a river, while seeing a river on a map provides a landscape scale overview. It is interesting to think about how the difference between seeing a river in person and seeing a river on a map might help explain why students hold common informal ideas about rivers.

	Common Student Ideas	Scientific Concepts
Which way do rivers flow?	Rivers flow south because this is "downhill" or "down the page" on a map. Water flows from larger bodies of water (lakes) into rivers (Dove, et al. 1999). Water can flow in all directions not paying attention to topographic clues (Covitt, et al. 2009).	The direction of river flow is based on landscape topography. Rivers flow downhill, which may be in any compass direction. Rivers meander (change direction) to follow the topography. While rivers may flow from larger bodies of water, rivers starting from large bodies of water is not the norm.
Where are rivers located?	Rivers are only found in rural and natural environments and not in cities. Or all rivers start in the mountains (Dove, et al. 1999).	Rivers are found in all types of landscapes—including natural, rural, and urban landscapes. While the headwaters of a river are always at a higher elevation than the mouth, headwaters do not have to be in mountains.
How does water get into a river?	Rain falls directly into a river and is the only source of water. Or water comes from the ocean and travels up the river. (Dove, et al. 1999).	Commonly, surface runoff, groundwater discharge, and flow from upstream feed rivers with water. Melting ice and snow can also feed rivers. Precipitation directly into a river is a relatively minor source of water.
What is a watershed?	A watershed is a building or tower where water is stored. Or a watershed is a natural storage area for water such as a lake (Shepardson, et al. 2007).	A watershed is an area of land that drains into a body of water. For a detailed description of watersheds and how they work, see **Watersheds,** on page 44.

Ask Your Students

1. Do rivers always begin in mountains? Explain why you think yes or no.
2. What is a watershed?
3. Can you tell which way a river flows by looking at a map? What information would the map need to include?

In the Classroom

Splish, Splash: Water's Journey to My Glass

Water moves continuously through the stages of the hydrologic cycle (e.g., evaporation, condensation, and so on). How does our drinking water fit into the hydrologic cycle? Where does the water we drink come from? This lesson will explore the hydrologic cycle, and students will map the path of drinking water from the origin of precipitation to the tap.

Materials

- Topographic map of your region
- Blank map of your region
- Information from your local water provider (location of aquifer, reservoir, or well where the school tap water comes from)
- Paper, pencil/pen

Directions

1. Review the basic principles of the water cycle.
2. Brainstorm and list the various types of water sources found on Earth.
3. Explain that the water they drink probably traveled a great distance to end up in their drinking glass. Identify the aquifer, reservoir, or well where the school tap water comes from. Tell students they will work back from this point to trace the water source origin.
4. Ask students to predict where the headwater, or source of origin, for their drinking water might be.
5. Using the topographic map of your region, challenge students to explore the path the water travels. Encourage students to consider the role of the water cycle in this journey.
6. Working from the immediate source of your drinking water (a reservoir, for instance), students will follow rivers and streams back to their headwaters. Students may want to work in groups for this. Be sure to discuss water flow, such as elevation changes that might send a stream flowing in another direction!
7. Students will finish by using the blank regional map to highlight boundaries that define the drainage basin or watershed from which their drinking water comes. Students will also label the paths and names of the waterways within this area.
8. Reinforce the idea that precipitation that falls within the boundaries might also wind up in their drinking glass or water fountain, without following the elaborate path from the headwaters.

Discuss

1. How did your prediction compare to the actual water source origin?
2. What path does local water follow in order to get to your tap?
3. Name something you learned about water that you did not know before.

Explore more National Geographic Society Freshwater activities at: http://environment.nationalgeographic.com/environment/freshwater/.

Case Study

The Urban Water Cycle

The water cycle is one of the most iconic educational topics taught in schools today. But how accurate is this traditional water cycle given the present-day alterations humans have made to our landscape? Where water once slowly absorbed into the ground, it now runs off paved streets and concrete sidewalks. Ask yourself these questions: "If water is not sinking into the ground to recharge our groundwater, how will groundwater continue to be a viable water source? If water is not seeping into the ground, where is it going?"

Citizens in today's age of sprawling cities and towns that dot the countryside need to also understand how human water-and-waste systems function to keep water flowing in our towns and cities and what this change means for the natural cycle. When looking at urban areas consisting of neighborhoods and cities in particular, these changes become so significant that the natural water cycle is not a true depiction of what happens. Another term used to describe this altered cycle is the urban water cycle.

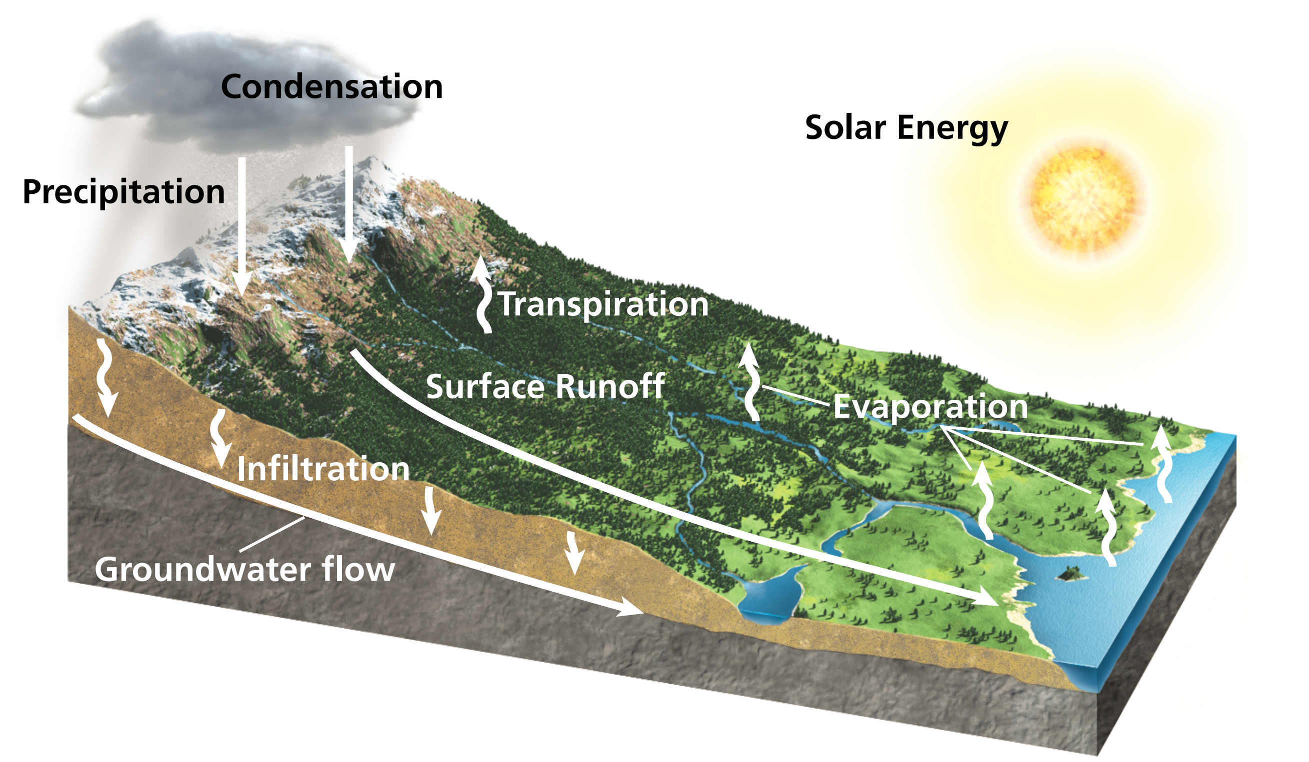
The urban water cycle describes a landscape filled with impermeable surfaces forcing water to runoff through complex drainage systems. In many locations, including California, there are two systems for drainage: **wastewater** treatment and storm drain. The wastewater treatment system collects water that flows down your drains from inside your home, school, or building, carrying it through underground sewage pipes to a wastewater treatment plant. This treatment plant cleans the sewage water through primary and secondary treatment and then releases it into a creek, river, lake, or ocean. All wastewater should be treated and cleaned before entering our waterways. Sometimes a portion of the treated wastewater will go to a water recycling facility where it will go through a tertiary process creating even cleaner water that is then known as non-potable or recycled water. This recycled water can be used for watering street center dividers, parks, golf courses, and more. When an area uses recycled water, a sign is posted and easily identifiable purple pipes and sprinkler heads are used. On the other hand, the storm-drain system captures water that runs off our sidewalks, parking lots, and streets and through drain openings often called gutters or catchbasins, to carry this water out of our cities as fast as possible. This storm-drain system leads to a network of underground pipes and tunnels, dumping water through outfall pipes along creeks, rivers, channels, lakes, and the ocean. This storm-drain water is almost never cleaned or treated before it enters our waterways, carrying whatever pollutants it picks up along the way.

These drainage systems change how water would naturally flow. In fact, human-made drainage systems may cause problems for our communities. One of the most important concerns is the decrease in the process of filtration and the increase in sporadic storm runoff on impermeable surfaces.

Consider the natural water cycle, powered by the sun—a cycle of water that evaporates, condenses, and precipitates on a constant basis. Less well-known processes include infiltration and transpiration. When precipitation falls onto a natural field or forest, much of the water enters the living ecosystem. It rains onto plants, is taken in by root systems, and transpires into the air again or remains as part of the plant. When the precipitation permeates the ground, a great deal of it percolates into underground pockets of space. This is what we call groundwater.

Now imagine that people cut down the forest and clear the field. In place of soil and vegetation, people construct buildings, paved roads, and concrete sidewalks. When precipitation falls, it must go somewhere once it reaches the ground. **Permeable** surfaces, such as soil, can be infiltrated by water, but pavement and concrete are impermeable surfaces that do not allow water to pass. Impermeable surfaces not only create an problem for builders, but they also change how water infiltrates the ground. Builders construct storm-drain systems so falling precipitation can drain into underground pipes and has a

NATURAL WATER CYCLE



place to run, preventing our streets from flooding. In fact, some cities with outdated or inadequate storm-drain systems have problems with flooding every time the city gets a heavy rainstorm.

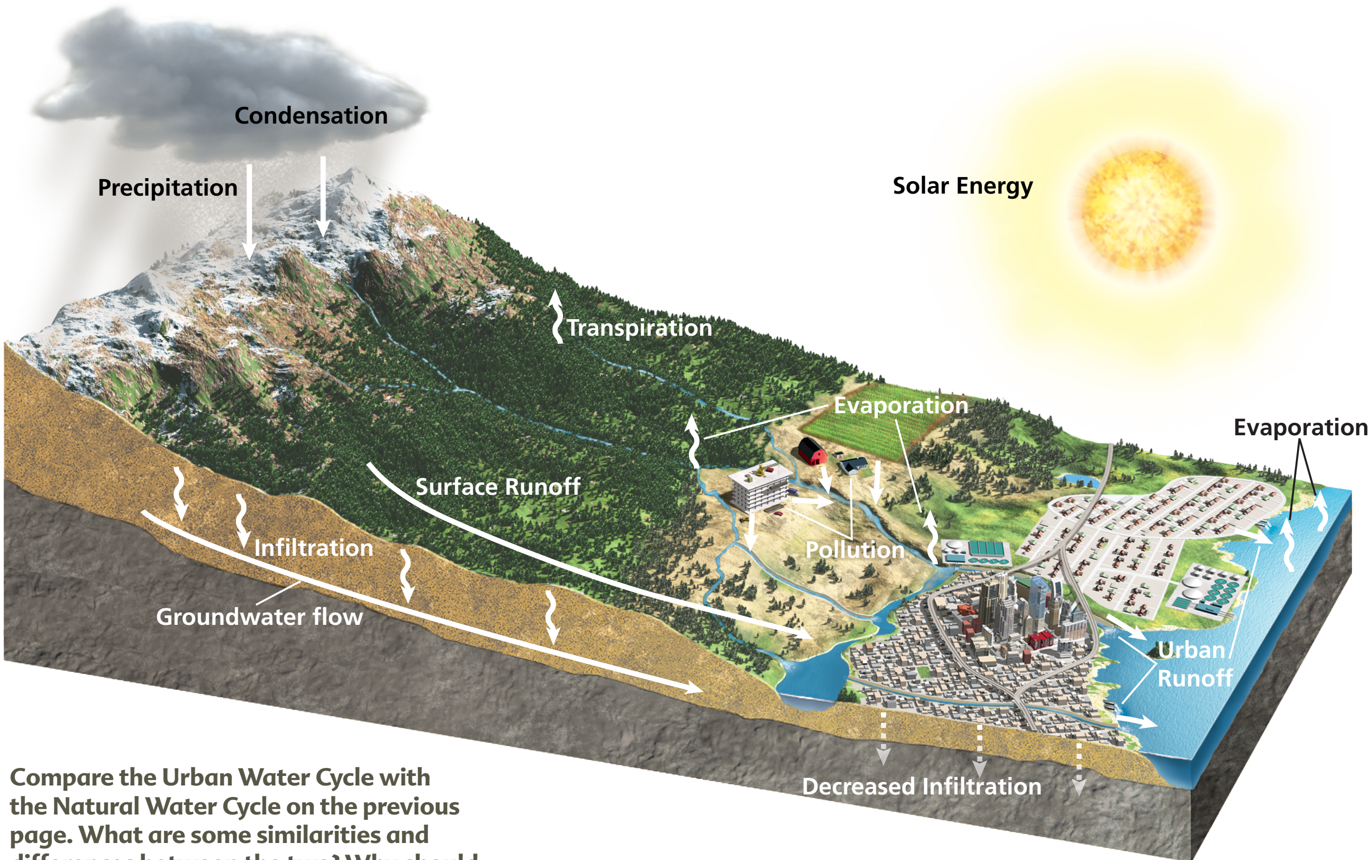
While these storm-drain systems seem like engineering wonders, they can wreak havoc on the natural flow of water. Water that would normally infiltrate the ground and recharge groundwater reservoirs can no longer penetrate the surface. Interestingly, the act of infiltration slows down the movement of water. Streams at lower elevations would continue to run because groundwater would slowly seep into the stream. Thus, the ground acts as a mechanism to control water flow. However, human-made drainage systems, such as channelized rivers and storm-drain systems, see periods of droughts and floods because water runs quickly across impermeable surfaces trying to reach lower ground. When it's not raining, surface waters may dry up because they are not receiving their steady sources of water from the ground. During heavy rains, some drains can flood due to increased water flows.

Humans also engineer complex systems to channel water through our cities. A river that may naturally flow through a riparian habitat often gets channelized when cities are built on top of the river's natural course. The Los Angeles River is an example of one with extensive human-made channels.

In addition to changing the flow and location of water, impermeable surfaces also contain substances and debris that are picked up by the moving water. This water then flows—often untreated—to the ocean or other natural bodies of water. This changes the water chemistry, especially where the water is discharged, which inevitably alters the natural environment. Water quality and water pollution will be discussed further in Chapter 4.

Many cities have recognized that the alterations in surfaces and natural flow are important concerns for freshwater resources. Cities that are looking for better management of water have been promoting an increase in permeable surfaces through use of permeable pavements, rain gardens, green roofs, and landscaping around homes, businesses, and streets.

URBAN WATER CYCLE



Compare the Urban Water Cycle with the Natural Water Cycle on the previous page. What are some similarities and differences between the two? Why should students be familiar with both?

Permeable pavement allows storm water to seep through the pavement, where it can infiltrate the ground below. Rain gardens are planted depressions in the landscape that may be dry, but rains allow water to collect and slowly seep into the ground. The gardens contain natural soil and vegetation to help with soaking up the additional rainwater. Some cities also sell rain barrels at low costs to residents in order to collect rainwater. With new innovations, and support from city officials, we can find solutions that increase permeable surfaces in our cities and return rivers and streams to more natural flows.

Pictures of Practice

The Urban Water Cycle

When students hear the words “water cycle,” many immediately think about the traditional water-cycle concepts taught in schools—evaporation, condensation, and precipitation. However, the water cycle also includes two important concepts often overlooked: infiltration and runoff. More importantly, given the development in human communities, our water cycle has been altered in numerous ways, but most especially in infiltration and runoff. In urban communities, rain hits concrete and pavement and is collected into storm wastewater systems. The rain no longer soaks into the ground to recharge groundwater reservoirs. Water may be brought to communities via **aqueducts,** and leave communities through sewage or storm-water systems. The water cycle looks quite different in these communities, and it is important for students to be aware of those key differences.

Students: Grade 6

Location: San Diego, California (an urban, coastal community)

Goal of Video: The purpose of watching this video is to hear student ideas about the urban water cycle and to think about key concepts you would teach to your students.

Classroom Context

Ms. Fortunato engages her students in an extensive water unit that takes approximately a month of instructional time. Today, Ms. Fortunato’s class is going to take a closer look at water pollution and treatment. In this video, students are preparing for their water-pollution investigation, and Ms. Fortunato has students do a visualization activity to think about where water pollution may originate.

Video Analysis

Students have a strong grasp of traditional water-cycle processes, and students also know something about water pollution—focusing mainly on visible debris. As you watch students’ preinterviews, you see that they are aware of storm-drain systems. Students were asked to explain what happens to rain that falls onto city streets, and most students include a description of storm drains. Zachary, however, still believes water may seep underground through cracks, as opposed to running into storm systems. During the class discussion, Ms. Fortunato has students visualize a giant pouring water on the city of San Diego. The first student—Celeste—describes water entering a natural system (i.e., mountains, rivers, and then to an ocean), while the second student—Ben—brings up the idea of an urban drainage system, which is a more accurate depiction of what might happen to rainwater in a city. Think about how these two stories are different. In student post-interviews, both Zachary and Thomas appear to have developed a new understanding about how cities alter our water cycle.

Reflect

What would you teach about the urban water cycle?

The urban water cycle may be a more accurate depiction of water cycling that connects to the lives of your students. How could you integrate this cycle into your teaching of the traditional water cycle? What concepts would be most important for you to teach to your students (e.g., storm runoff, groundwater pumping, aqueducts, and so on)? Why is it important for students to have a good understanding of both the natural water cycle and how we alter this natural cycle of water?

References

Covitt, B. A., K. L. Gunckel, and C. W. Anderson. (2009). Students' developing understanding of water in environmental systems. *Journal of Environmental Education*, 40(3), 37–51.

Dove, J. E., L. A. Everett, and P.F.W. Preece. (1999). Exploring a hydrological concept through children's drawings. *International Journal of Science Education,* 21(5), 485–497.

Henriques, L. "Children's ideas about weather: A review of the literature." *School Science and Mathematics* 102.5 (2002): 202–215.

Osborne, R., and M. Cosgrove. "Children's conceptions of the changes of state of water." *Journal of Research in Science Teaching* 20.9 (1983): 825–838.

Pankratz, Tom. "Get the Salt Out." *National Geographic* April 2010: 32. Print.

Postel, Sandra L., et. al. "Human Appropriation of Renewable Fresh Water." *Science,* New Series, Vol. 271, No. 5250 (Feb. 9, 1996), 785–788.

Shepardson, D., B. Wee, M. Priddy, L. Schellenberger, and J. Harbor. (2007). What is a watershed? Implications of student conceptions for environmental science education and the national science education standards. *Science Education,* 91(4), 523–553.

Tytler, R. "A comparison of year 1 and year 6 students' conceptions of evaporation and condensation: dimensions of conceptual progression." *International Journal of Science Education* 22.5 (2000): 447–467.

Teaching Resources

California's Education and Environment Initiative: http://www.calepa.ca.gov/education/eei/

EPA's teaching resources on water: http://www.epa.gov/students/teachers.html#epawater

Heal the Bay resources on watersheds: http://sites.healthebay.org/watersheds/

National Geographic Society freshwater initiative: http://environment.nationalgeographic.com/environment/freshwater/

NOAA and NSTA water-cycle interactive: http://oceanservice.noaa.gov/education/pd/oceans_weather_climate/welcome.html

PBS solar still classroom activity: http://pbskids.org/zoom/activities/sci/solarstill.html

Project WET Curriculum and Activity Guide K–12: http://projectwet.org/

Steve Spagler's Science Cloud in a Bottle activity: http://www.stevespanglerscience.com/experiment/00000030

Teacher domain solar-still classroom activity: http://www.teachersdomain.org/resource/ess05.sci.ess.watcyc.solarstill1/

Surface-tension demonstration video: http://www.youtube.com/watch?v=u5AxlJSiEEs

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