# Under Where?

## Underground Water and Its Contribution to Streams

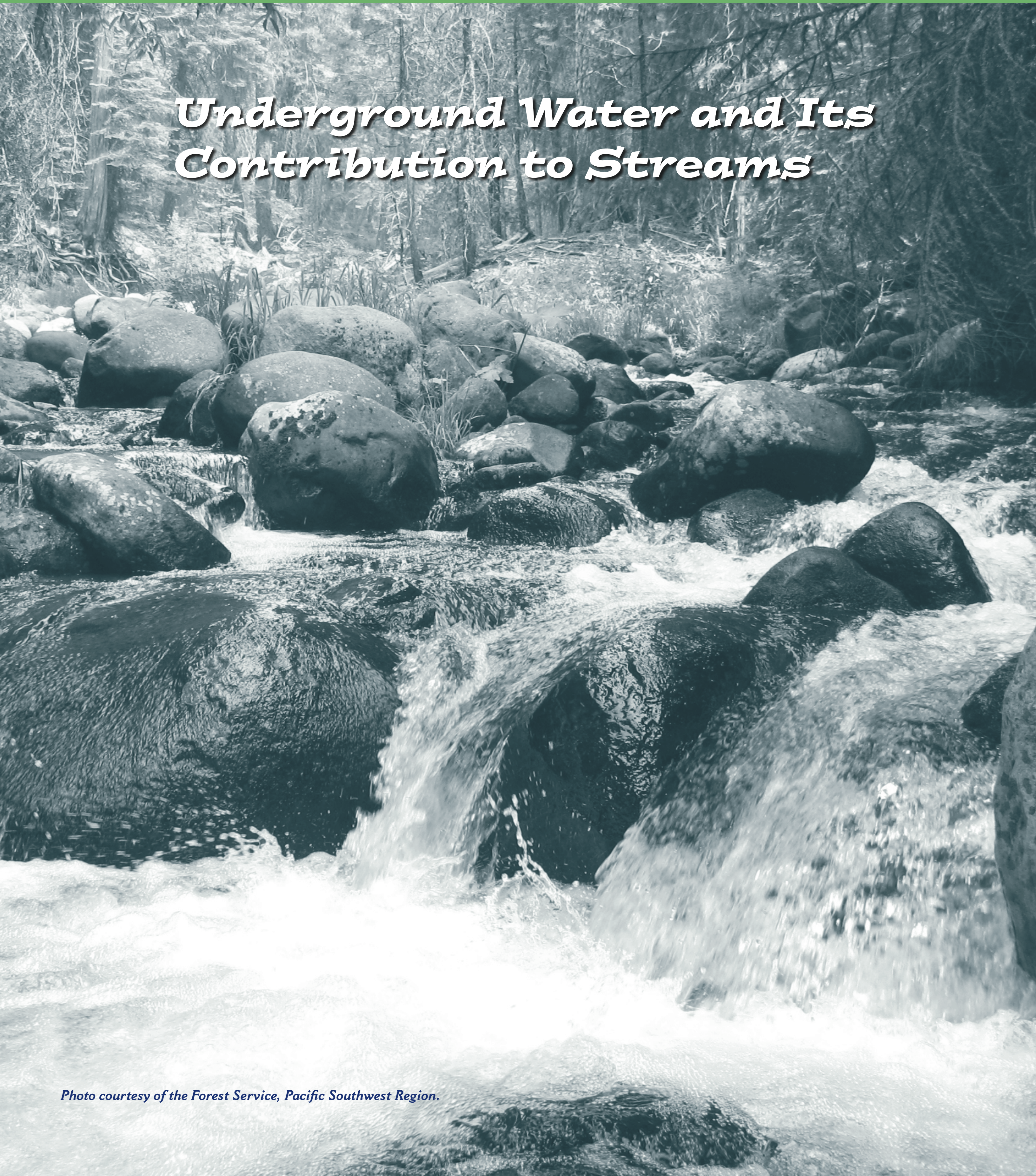


*Photo courtesy of the Forest Service, Pacific Southwest Region.*

# Meet the Scientists

▲ **Dr. Fengjing Liu**, Hydrologist: My favorite science experience is doing research to understand how water and **contaminants** move and how they are linked within a **watershed**.

▶ **Dr. Carolyn Hunsaker**, Ecologist: My favorite science experience was identifying a major gap in knowledge, and designing and implementing a large-scale experiment with a diverse team of people. Our team believes this experiment's findings will make a significant difference for forest health and water supplies in California.

In this photo, I am inside an instrument shed pouring a water sample from the automated sampler in the background. This sampler contains a computer that runs several instruments. These instruments measure **streamflow** and **turbidity** and take automated water samples for later chemical analyses.

The instrument sheds, which are built deep in the forest, provide protection for the instruments. These small sheds also house the solar-powered batteries that run the instruments, and they provide shelter for research technicians during bad weather.

◀ **Dr. Roger Bales**, Environmental Engineering Scientist: In my research, I switch between science and engineering. I get excited when our detailed, difficult measurements of the water cycle are successful and provide insight to predict how the measurements will change in the future. We measure **snowpack, snowmelt**, rainfall, shallow **groundwater**, streamflow, and vegetation water use. I am excited about this research because it provides the foundation to design solutions to the challenges posed by climate change, global population growth, and changing **land cover**. Photo courtesy of Roger Wynan.

Glossary words are **bold** and are defined on page 116.

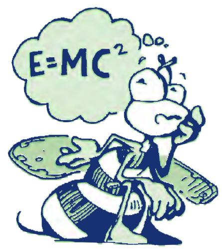
## What Kinds of Scientists Did This Research?

**ecologist:** This scientist studies the relationship of living things with their living and nonliving environment.

**environmental engineering scientist**: This scientist combines biological, chemical, and physical sciences with the field of engineering to protect and restore the natural environment.

**hydrologist:** This scientist studies the distribution, movement, and quality of Earth's waters.

## Thinking About Science




Chemistry is a useful science tool. Environmental scientists can use chemistry to discover how water flows in an ecosystem. In this study, the scientists wanted to understand how much water in a particular stream began as rainfall or snowfall. They also wanted to know what percentage of the stream's flow came from various locations.

The scientists knew that atoms of the same element can have different atomic weights. Different atomic weights are like a signature that helps scientists identify the atom. The scientists also knew that atoms can gain or lose electrons, resulting in a positive or negative charge. This gain or loss creates different chemical compounds, such as calcium or fluoride. These chemical compounds may dissolve in water, but they remain intact as chemical compounds. By testing the water in many places where it enters the ground, and then where water flows in the stream below, scientists can identify where the streamwater originated.

## Thinking About the Environment

The water cycle describes the movement of water from Earth, to the atmosphere, and back (**figure 1**). You can see the water cycle at work in rainfall and snowfall, in rivers and streams, and in the oceans. You can observe evaporation by watching water slowly disappear from a wet roadway.

You cannot, however, see one mysterious part of the water cycle. Much of Earth's **precipitation** moves into the soil, and, without your noticing, it flows underground as groundwater (**figures 2, 3, 4a, 4b, and 5**). This water can surface quickly or stay underground for thousands of years.

Underground water comes to the surface naturally through **artesian** wells, springs, and through seepage to streams and rivers. People bring groundwater to the surface by digging wells that pump water upward for their use. People use groundwater for irrigation, livestock, mining, public use (such as public swimming pools or water in public buildings), and individual household uses. Surface water, such as water in **reservoirs**, streams, rivers, and lakes, is also used for a variety of similar purposes. Plants use the water in the top several feet of soil for growth. This water is called shallow groundwater, or soil water.

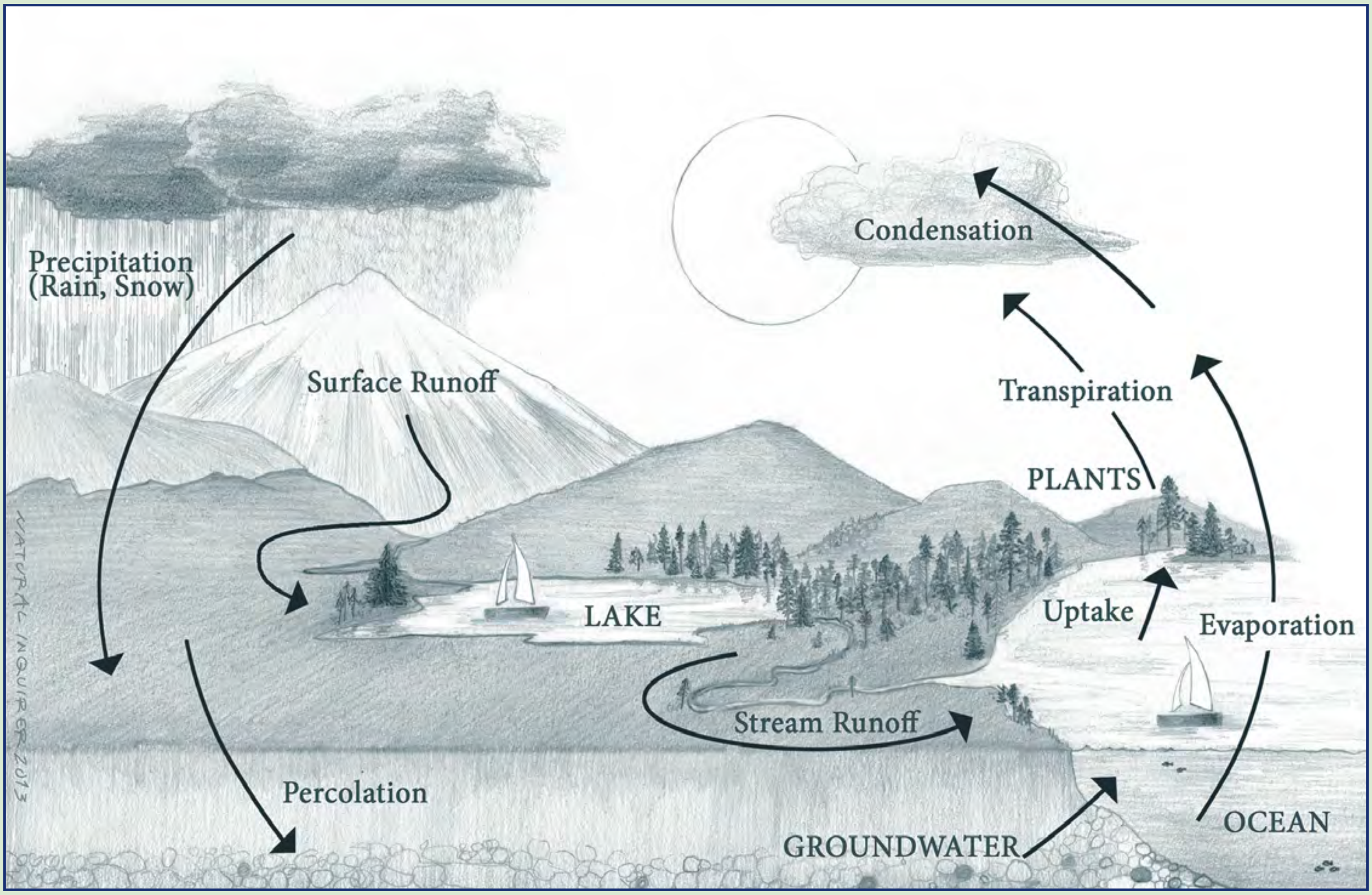



**Figure 1.** The water cycle. Illustration by Stephanie Pfeiffer.

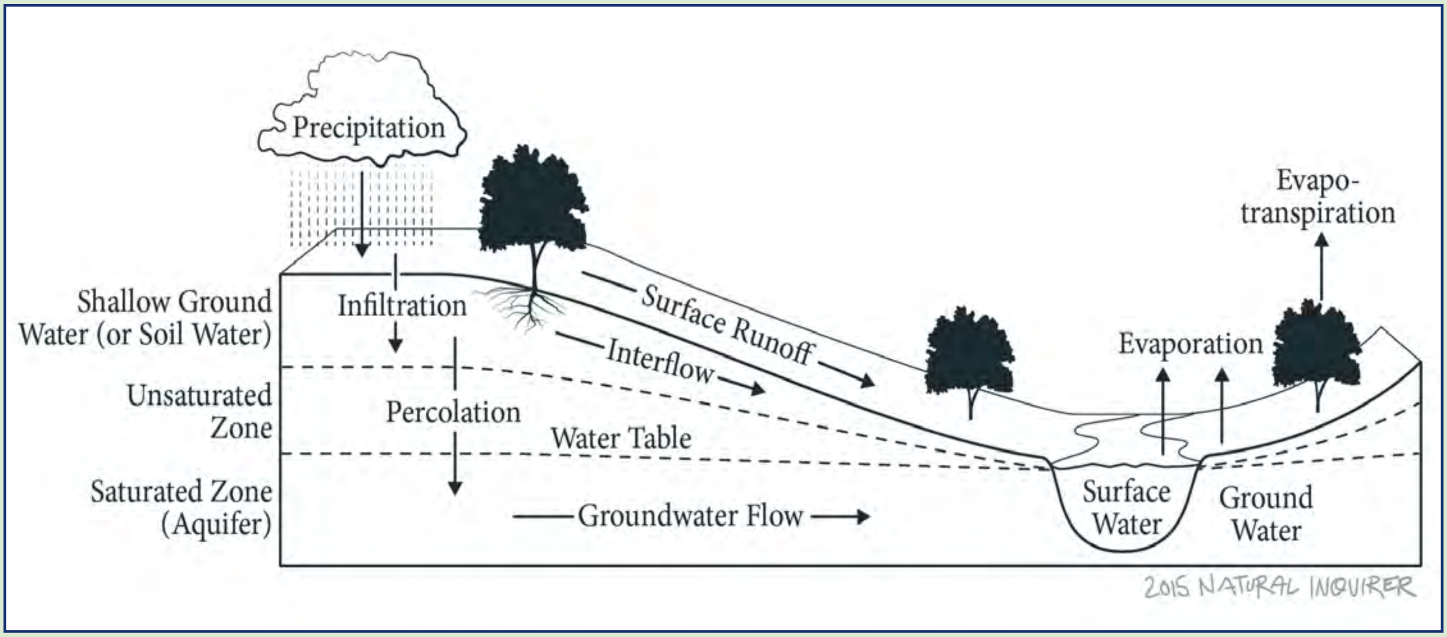



**Figure 2.** Water moves underground as part of the water cycle. Notice that some water stays near the soil surface. This shallow groundwater, or soil water, may be a few feet deep or up to 20 feet deep below the soil surface. Deeper underground water is called deep groundwater or just groundwater. Illustration by Stephanie Pfeiffer.

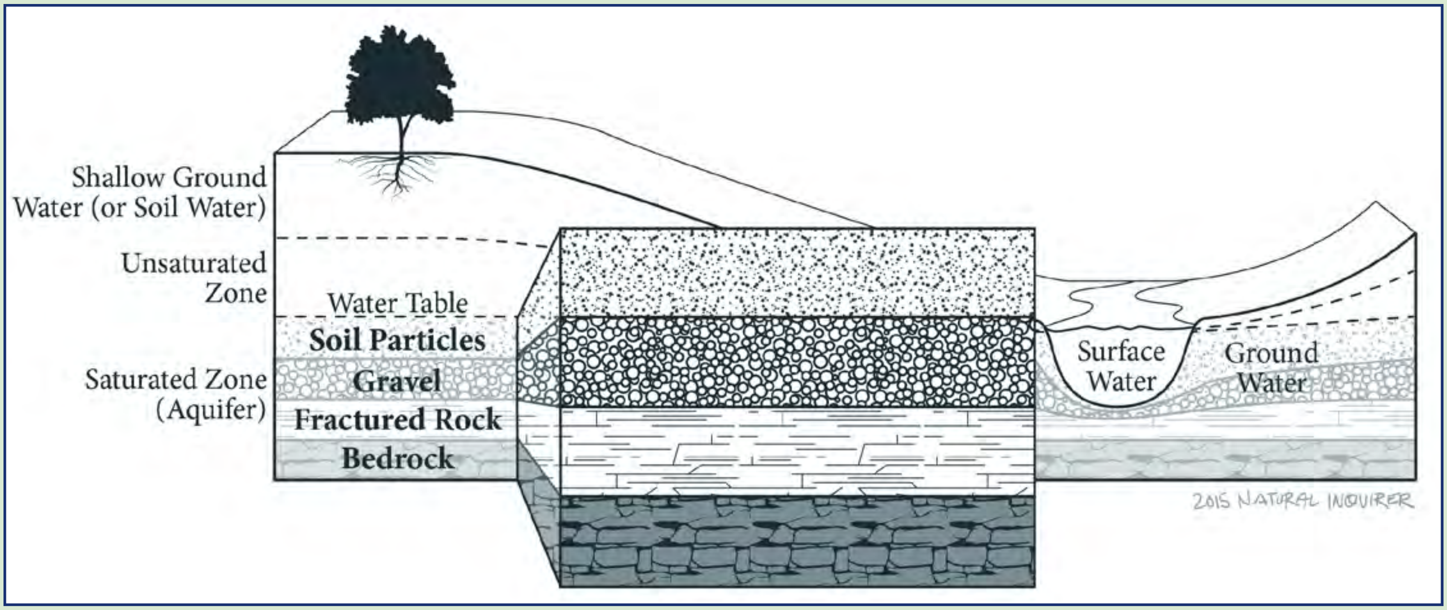



**Figure 3.** Groundwater fills the spaces between soil particles and fractured rock underground. Notice that below the water table, all openings between soil particles and rocks are full of groundwater. Above the water table, some water, held by molecular attraction, may surround particles and rocks. Illustration by Stephanie Pfeiffer, adapted from the Groundwater Foundation and the U.S. Geological Survey.

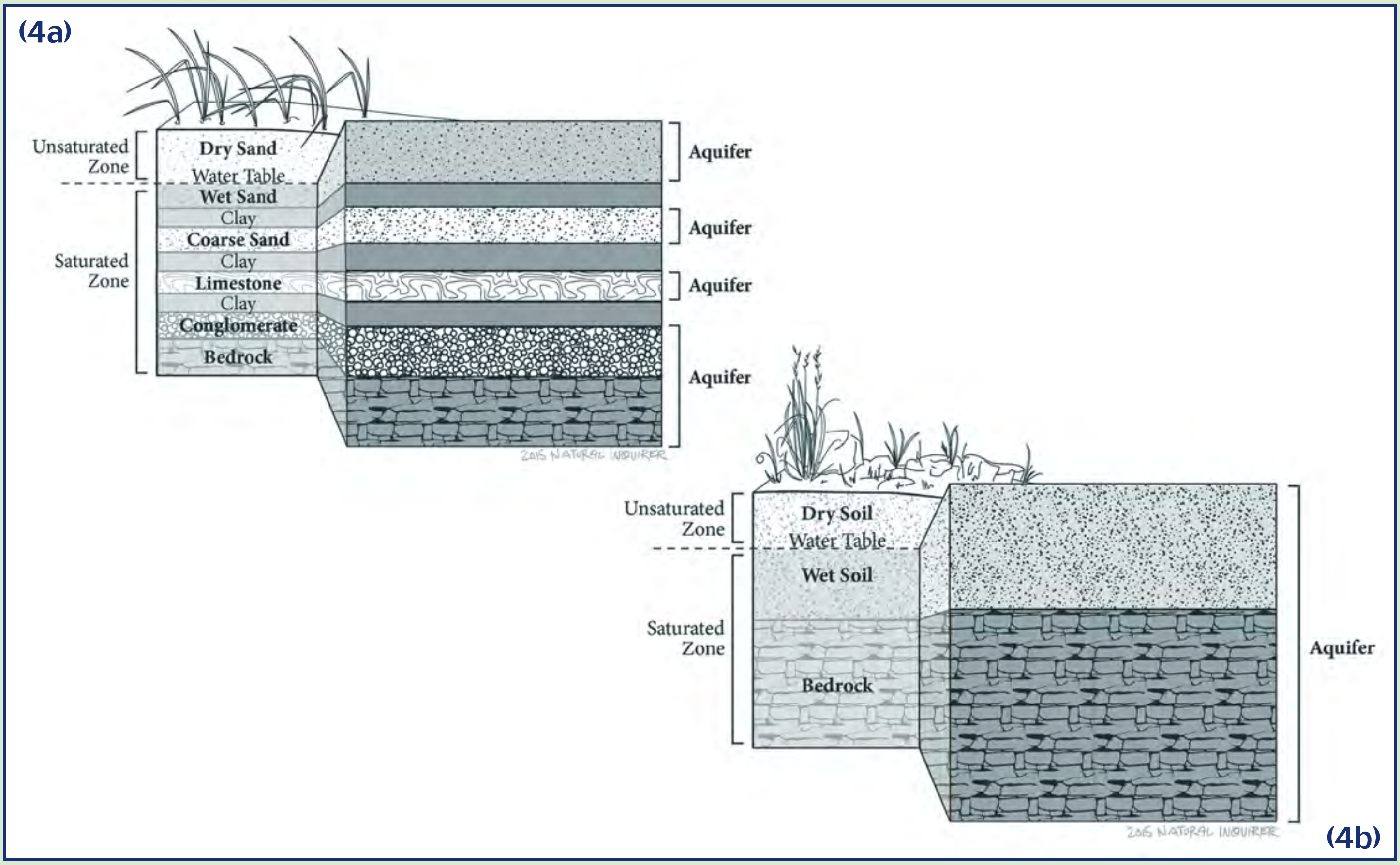



**Figure 4a and 4b.** Aquifers are natural underground water storage areas. Coastal aquifers (4a) are different than aquifers found in hilly or mountainous areas (4b). Illustrations by Stephanie Pfeiffer.

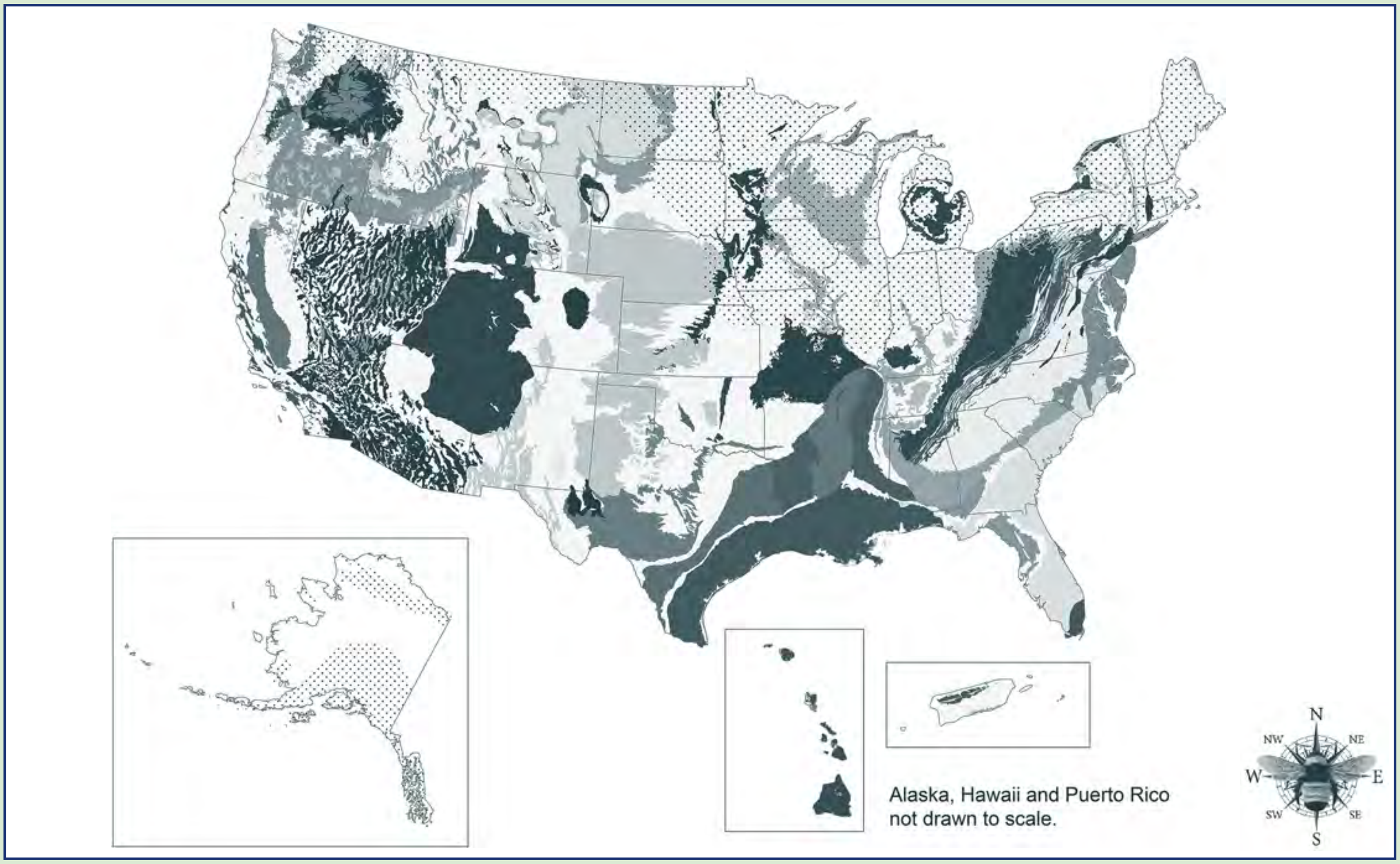



**Figure 5.** Groundwater provides water to underground aquifers or water storage areas. This water provision is called recharge. Most of the United States contains underground aquifers. This map shows the primary aquifers in the United States. Although the areas in white show no aquifers, these areas may have a shallow or more **localized** aquifer. Map courtesy of the U.S. Geological Survey.

## *Introduction*

When snow melts or rain falls, some of the water runs across the ground's surface to nearby streams and rivers. This water movement is called surface flow. Much of the water, however, goes into the soil, and then seeps downward due to the force of gravity. The entrance of water into the soil is called infiltration, and the downward flow is called percolation (**pər kə lā shən**). Some of the water stays in the soil near the soil's surface, instead of percolating. This soil water flows **laterally** and down hillsides, especially in small, steep, forested watersheds called catchments (**figure 6**). This shallow underground water flow is called interflow. (See figure 2 in "Thinking About the Environment.")

Snow is the main source of water in some of these catchments. These catchments are at higher elevations, where snow occurs more frequently (**figures 9 and 10**). In catchments at lower elevations, rain is the main source of water. As the global climate becomes warmer, the percent of total precipitation falling as snow will become less at these higher elevations.

The scientists in this study wanted to answer the following questions: (1) How much does soil water, compared with other water sources, such as rapid snowmelt, rainfall **runoff**, and groundwater, contribute to streamflow in these catchments? (2) Could underground water's contribution to stream flow change as less snow falls in higher elevation catchments?

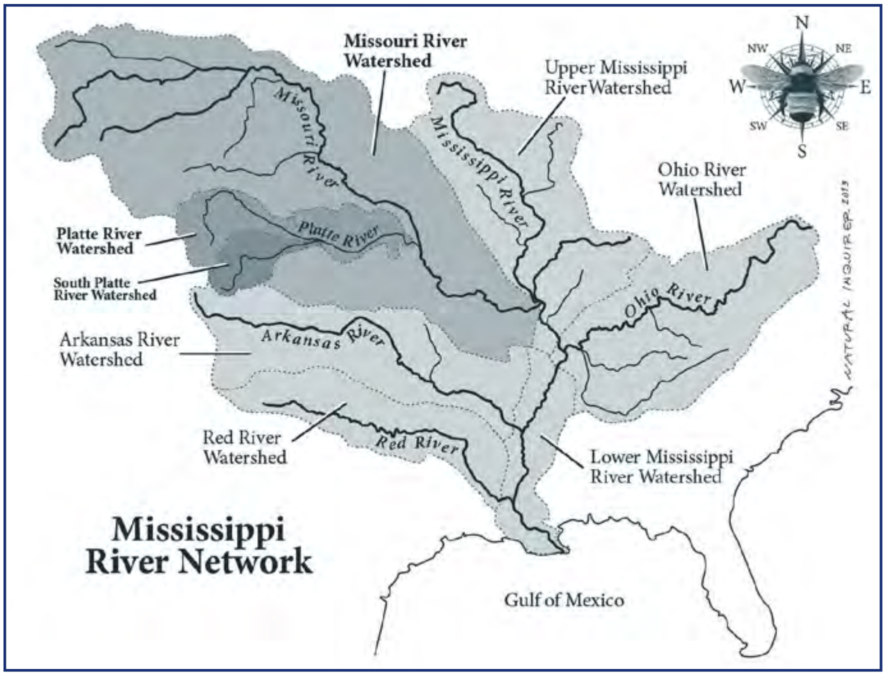



**Figure 6.** Smaller watersheds may be contained within larger watersheds. The scientists in this study were interested in very small, steep, forested watersheds in the Sierra Nevada of California (**figures 7 and 8**). These small watersheds are called catchments. Illustration by Stephanie Pfeiffer.

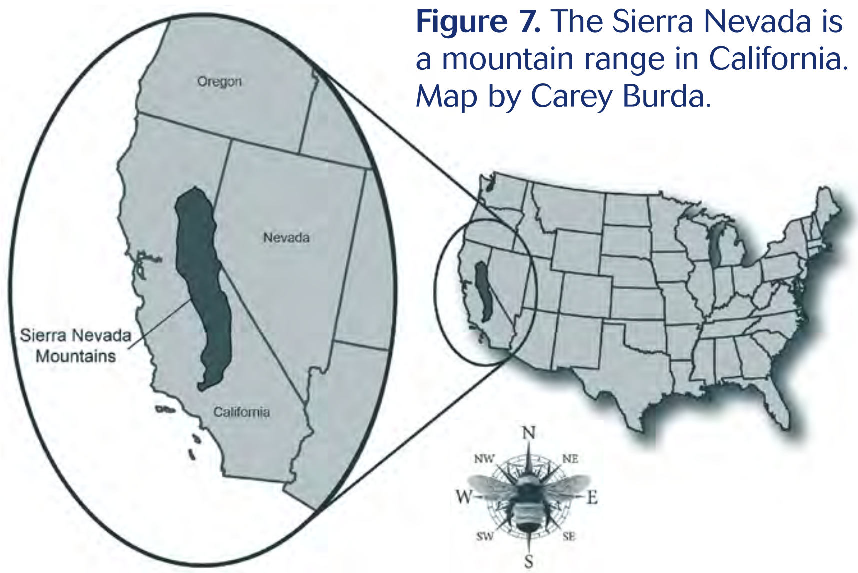



**Figure 7.** The Sierra Nevada is a mountain range in California. Map by Carey Burda.

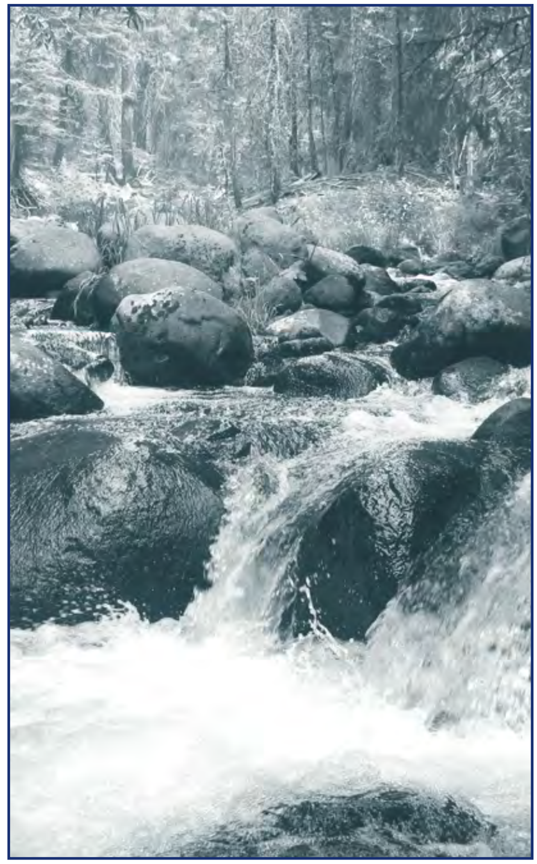


**Figure 8.** The Sierra Nevada has steep, forested slopes and clear mountain streams. Photo courtesy of the Forest Service, Region 5.

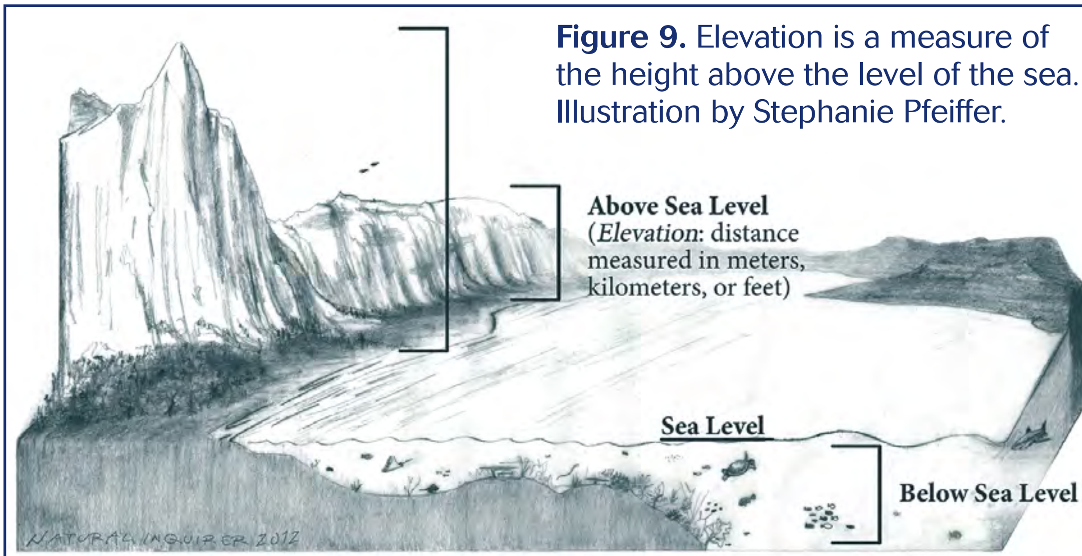



**Figure 9.** Elevation is a measure of the height above the level of the sea. Illustration by Stephanie Pfeiffer.

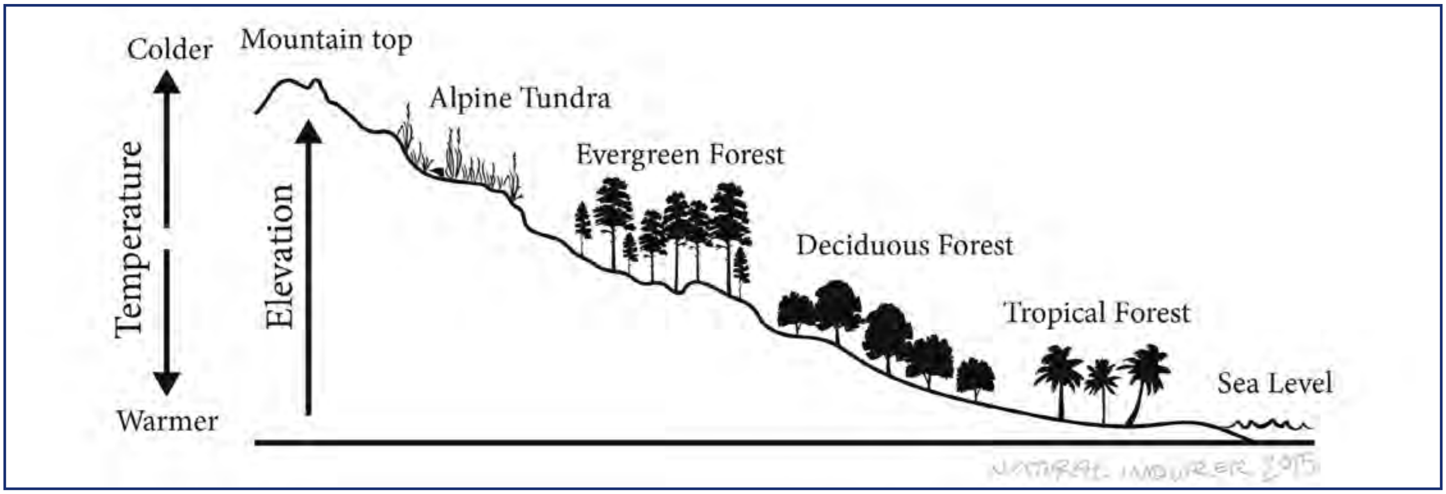



**Figure 10.** As elevation increases, an area's climate gets cooler and snow may fall often in the winter months. Illustration by Stephanie Pfeiffer.

## Reflection Section

- Does water flow underground in your region? Why do you think so?
- What is surprising about figure 5?
- Do you think other areas across the planet have aquifers? Why or why not?
- If you have not read "Thinking About the Environment," do so now. Using the information in "Thinking About the Environment" and in the "Introduction" as clues, how do you think the scientists answered their first research question?

## Methods

The scientists studied eight catchments in the Sierra Nevada. In particular, they studied catchments within the Kings River Experimental Watersheds. This area has been set aside especially to investigate watershed ecology in the Sierra National Forest in California (see figure 7). Four of the catchments were at high elevations in the mountains, and four were located at lower elevations (**table 1**).

The scientists collected water samples from the streams at each of the streams' outlets within each catchment (**figures 11 and 12**).

| Watershed Name | Elevation Range (in m) | Size Range (in km$^2$) | Percentage of Precipitation as Snowfall | Percentage of Precipitation as Rainfall | Average Annual Air Temperature (in °C) |
|---|---|---|---|---|---|
| Providence (four catchments) | 1,479–2,113 | 0.49–1.32 | 20 | 80 | 7.8 |
| Bull (four catchments) | 2,055–2,490 | 0.55–2.28 | 75–90 | 10–25 | 6.8 |

**Table 1.** Characteristics of the catchments studied by the scientists.

**Figure 11.** Dr. Hunsaker holds an instrument that measures water acidity, water temperature, and the amount of dissolved substances in a stream within the Kings River Experimental Watersheds. A **flume** sits in the stream behind her. The flume creates a uniform streamflow so that scientists can measure the amount of water flowing in the stream. Solar-powered instruments automatically measure and record the amount of streamflow every 15 minutes. Photo courtesy of Dr. Carolyn Hunsaker.

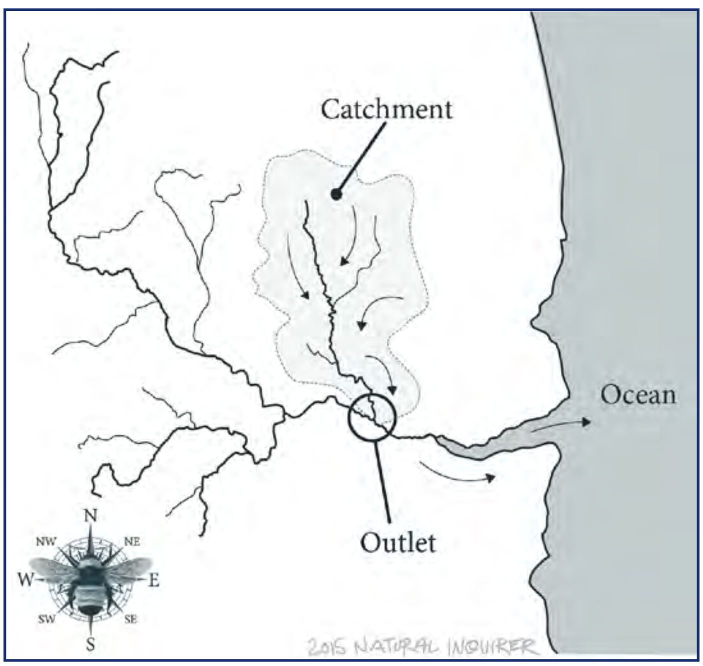



**Figure 12.** All streamwater flowed to one stream outlet in each catchment. Illustration by Stephanie Pfeiffer.

## How Do You Convert the Characteristics of the Catchments to the U.S. Imperial System?

| | | | | |
|---|---|---|---|---|
| meters (m) | x | 3.281 | = | feet |
| kilometers (km) | x | 0.6214 | = | miles |
| °Celsius (°C) | x | 9/5 + 32 | = | °Fahrenheit |
| centimeters (cm) | x | 0.3937 | = | inches |

They collected these samples every other week from the fall of 2003 until the fall of 2007. The scientists collected soil water samples using pumps at depths of 13 cm and 26 cm into the soil (**figure 13**). These samples were taken **upslope** from the streams and at various locations throughout each catchment. The scientists collected snowfall samples using plastic bottles with funnels (**figure 14**). They installed these plastic bottles before winter and collected the melted snow water every other week after snowfall (**figure 15**).

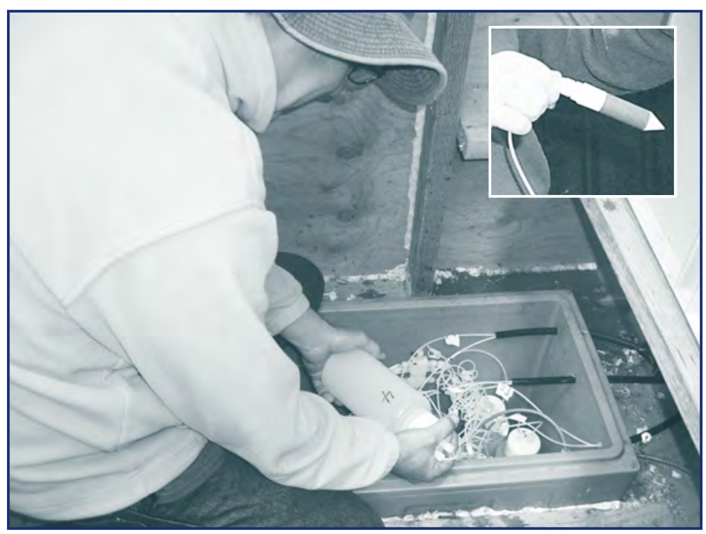


**Figure 13.** This scientist is preparing vacuum pumps that enable him to collect soil water. The tip shown in the inset is inserted into the soil to collect the water. Photo courtesy of Dr. Carolyn Hunsaker.

**Figure 14.** This snowmelt sampler is used to collect snowmelt. These samplers are buried in the soil up to the base of the funnel. An air line and a sample line are connected to the funnel. When it snows and the snow melts, the water sample is pumped out by hand. Photo courtesy of Dr. Carolyn Hunsaker.

**Figure 15.** This scientist is pumping the snowmelt out of the sampler. Photo courtesy of Dr. Carolyn Hunsaker.

The scientists collected 2,239 streamflow, snowmelt, soil water, spring water, and groundwater samples (**table 2**). The scientists analyzed all the samples to determine which chemical compounds, and how much of each chemical compound, each sample contained.

The scientists used math to analyze the chemical characteristics of the water. This analysis enabled them to compare the water samples collected away from the streams with the streamflow samples collected at each catchment's outlet. This procedure enabled the scientists to compare the chemical content of the water samples and to identify how much snowmelt and rainwater contributed to each stream.

| Type of Water Sample | Number of Water Samples Collected |
|---|---|
| Streamflow (collected at the outlets) | 1,342 |
| Snowmelt | 83 |
| Soil Water | 803 |
| Spring Water | 1 |
| Groundwater (collected from drinking water wells) | 10 |
| Total Samples Collected | 2,239 |

**Table 2.** The scientists collected five different types of water samples.

## Number Crunches

- How many times did the scientists collect water samples from the catchment outlets?
- On average, how many streamflow samples did the scientists collect each time from the catchment outlets?

## Reflection Section

- Why did the scientists sample catchments at two different elevations?
- Look at figure 14 and reread its caption. Why do you think an air line was connected to the sampler?

| Watershed | Percent of Streamflow Coming From Underground Water |
|---|---|
| 1 | 63 |
| 2 | 61 |
| 3 | 69 |
| 4 | 66 |
| 5 | 42 |
| 6 | 65 |
| 7 | 60 |
| 8 | 66 |

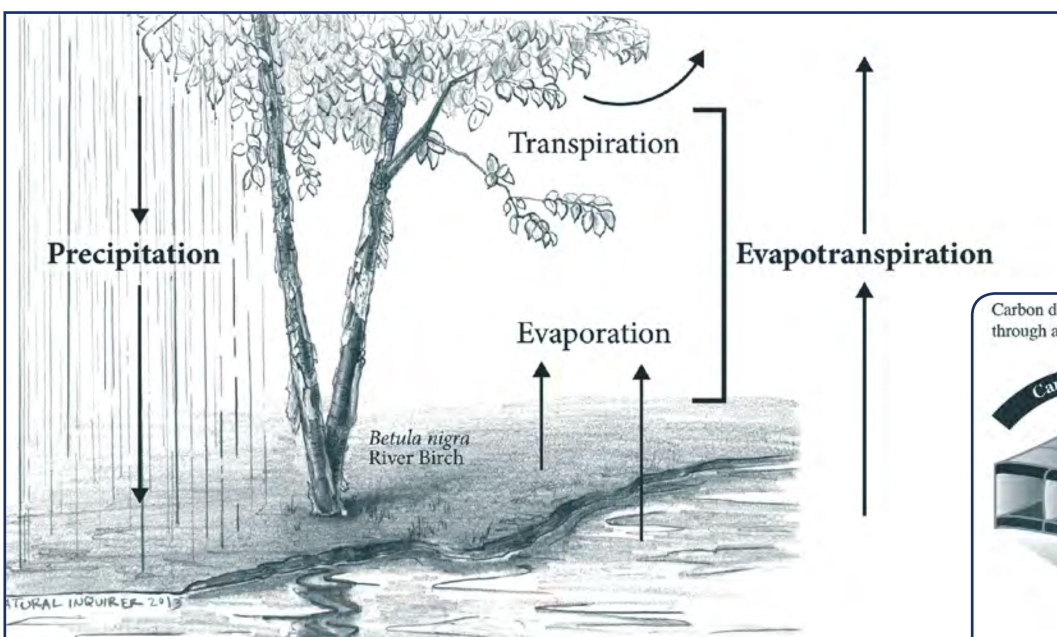
**Table 3.** The percentage of streamflow coming from underground water in each of the eight small catchments.

## Findings

The scientists found that during the study period, over 60 percent of the streamflow came from water flowing underground (**table 3**). Snowmelt and rainwater moved rapidly through the soil to streams following a snowfall or rainfall. This rapid movement of groundwater to streams was likely due to the shallowness of the **bedrock** in this region of the Sierra Nevada.

Soil water above the water table (interflow) did not contribute much water to the streamflow. This finding was consistent with other studies that have found that soil water within 1 meter of the soil surface is taken up by trees and used for transpiration (tran(t) spə **rā** shən) (**figure 16**).

The scientists found that the proportion of groundwater contributing to streamflow compared with surface flow was about the same for snowmelt water and rainwater.



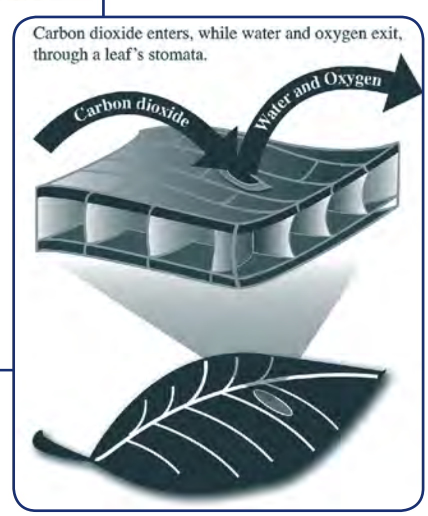




**Figure 16.** Transpiration involves the flow of water into tree roots, up tree trunks, into branches, and out through pores in tree leaves. Illustrations by Stephanie Pfeiffer and Nickola Dudley (inset).

## Number Crunches

- What was the average percentage of groundwater contributing to streamflow in the eight catchments?
- In table 3, find the watersheds with the greatest and least percentage of streamflow coming from underground water. What is the percentage difference between these two amounts of streamflow?

## Reflection Section

- What force is at work in the underground movement of water? Explain how this force affects underground water movement.
- Read the last sentence in the "Findings" section. Based on this finding, what do you think was the answer to the scientists' second research question? (Hint: See the end of the "Introduction" section, page 110.)

## Discussion

The scientists guessed that the shallow bedrock in this region contains large depressions. These depressions are like dimples in the bedrock. The depressions hold groundwater. Following a rainfall or snowfall, water percolates downward and the depressions fill up and spill over. Water then runs along the bedrock underground and into streambeds.

The total amount of streamflow coming from groundwater originating from snow and rain was about the same. The scientists expect, therefore, that a lower percentage of snowfall and a greater percentage of rainfall in the future will not affect streamflow in the higher elevation catchments.

## Reflection Section

- Explain why the scientists expect that a lower percentage of snowfall and a higher percentage of rainfall in the future will not affect the flow of groundwater into streams.
- In a changing climate, some areas might receive less precipitation. Imagine that the scientists had also considered the trend in the total amount of precipitation falling in the area over time. How might their findings change if they discovered a trend toward less total precipitation over time?

## Glossary

**artesian** (är **tē** zhən): Involving, relating to, or supplied by the upward movement of water that is under pressure in rocks beneath Earth's surface.

**bedrock** (**bed** räk): The solid rock that lies under the surface of the ground.

**catchment** (**kach** mənt): A small, steep watershed.

**contaminant** (kən **ta** mə nənt): Something that makes a place or a substance no longer suitable for use.

**flume** (**flüm**): A sloping channel for directing the flow of water.

**groundwater** (**graůnd wä** tər): Water that sinks into the soil and moves or is stored underground.

**intact** (in **takt**): Not broken or damaged.

**land cover** (**land kə** vər): Whatever is covering the land, such as trees, grasses, buildings, or roads.

**laterally** (**la** tə rəl lē): Side to side.

**localized** (**lō** kə līz(d)): Within a limited area.

**precipitation** (pri **si** pə **tā** shən): Rain, hail, snow, mist, or sleet that falls on Earth.

**reservoir** (**re** zə **vwär**): Place where water is collected and stored for use.

**runoff** (**rən** ȯf): The portion of rain or snow that flows over land and into streams.

**snowmelt** (**snō** melt): Water from melting snow that flows over the surface of the ground into streams and rivers.

**snowpack** (**snō** pak): A seasonal accumulation of slow-melting packed snow.

**streamflow** (**strēm** flō): The speed and volume of water flowing in a stream channel.

**turbidity** (tər **bə** də tē): A measure of the cloudiness or muddiness of a water body.

**upslope** (**əp** slōp): Being or moving to or toward the top of a slope.

**watershed** (**wä** tər **shed**): The area that drains to a common waterway, such as a stream, lake, estuary, wetland, aquifer, or even the ocean.

Accented syllables are in **bold**. Marks and definitions are from http://www.merriam-webster.com. Definitions are limited to the word's meaning in the article.

The definition of watershed is taken directly from the U.S. Environmental Protection Agency (http://www.epa.gov).

How does this scene relate to the article you just read?

# FACTivity

## Time Needed

- One class period for research (or assigned as homework)
- One class period for the FACTivity

## Materials (for each student or group of students)

- Water cycle cube (see template on page 120)
- Plain or lined paper
- Pencils
- Scissors
- Tape or glue

## Introduction

In this article, you learned about groundwater and the path water may take as it flows underground. Water may take a number of different paths, depending on the soil type, the type of underground rock, and the slope of the land. Water flow is also dependent upon the climate and recent weather. A drought, for example, may cause water to flow in a different pattern underground from its normal path. Soil water may be taken up by trees and transpired.

In this FACTivity, you will use the knowledge you have gained from the reading "Under Where?" and other articles in this journal, as well as other sources of information about groundwater flow. You will answer the following question: What is one pathway a water droplet may follow as it moves through the water cycle?

## Methods

Your teacher will have you work in pairs. To answer the question, you will need to refer to the following water cycle illustrations:

- Figure 1 on page 108,
- Figure 2 on page 108,
- Figure 3 on page 109,
- Figure 4 on page 109, and
- Figure 6 on page 6 of the "Welcome to the *Natural Inquirer* Freshwater edition."

Take a moment now to review these illustrations. You should have a good idea of how water flows in the water cycle, including surface water as well as soil water and deep groundwater. If you need more information, read "Green Means Clean," "What's the Nonpoint?," "Sediment-al Journey," and "Welcome to the *Natural Inquirer* Freshwater edition" section in this *Natural Inquirer*. You may also do research in the media center. Your teacher may assign this reading and research for homework.

Next, you will build a water cycle cube using the template on page 120. Each side of this cube contains a portion of the illustration on page 119 (**figure 17**). Each pair of students should build one cube. Locate the drop of water shown on each side of the cube. Alternatively, all student pairs in the class may take turns using one cube.

Adapted from Liu, F.; Hunsaker, C.; Bales, R.C. 2012. Controls of streamflow generation in small catchments across the snow—rain transition in the Southern Sierra Nevada, California. Hydrological Process, published online in Wiley Online Library, DOI: 10-1002/hyp.9304, http://www.fs.fed.us/psw/publications/hunsaker/psw_2012_hunsaker002_lui.pdf.

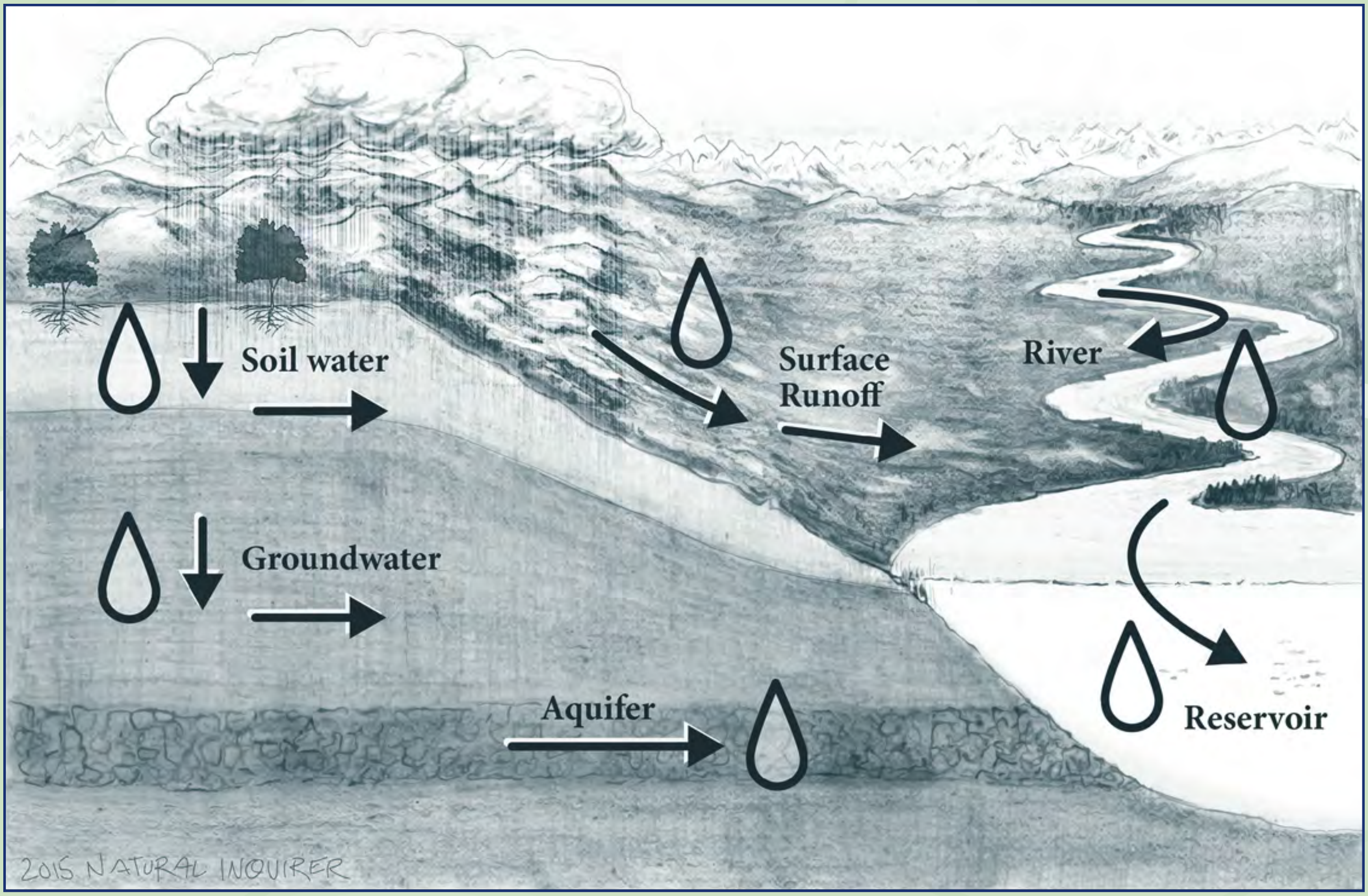



**Figure 17.** Water drops appear in many places throughout the water cycle. Illustration by Stephanie Pfeiffer.

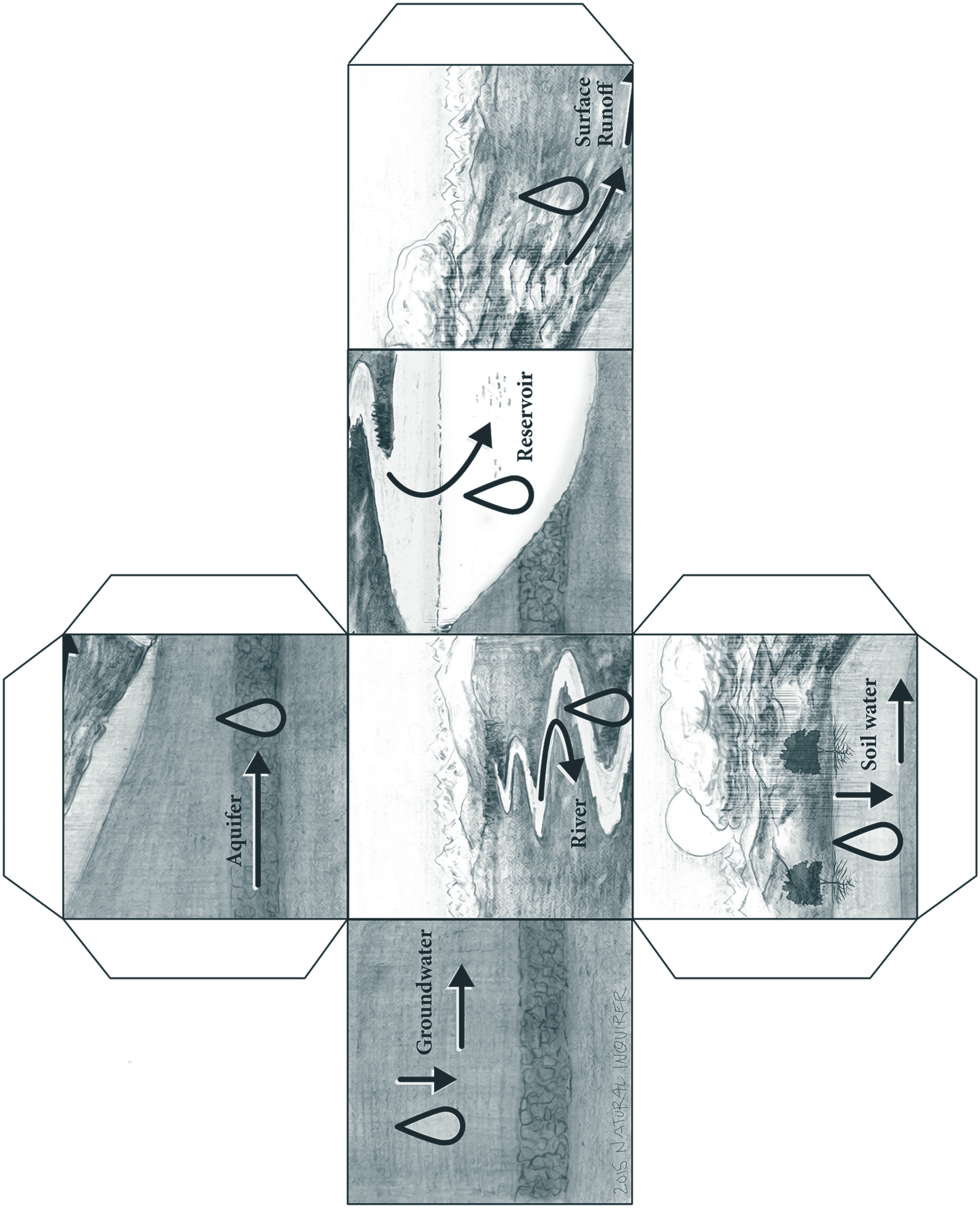
Each student pair will roll the cube. (All student pairs may take turns rolling the same cube.) Each pair will work with whatever portion of the illustration lands on top. Identify the location of the water drop.

The water drop will be located in one of the following:

- In soil water
- In groundwater
- In an aquifer
- In a river
- In a lake or reservoir
- On the soil surface

Using a blank piece of paper, you will outline a story that traces the water drop's journey. Each story begins with the water drop falling from the atmosphere. Trace the water drop's journey to the location shown on the cube, and then eventually back to the atmosphere. Each of the six water drops' journeys might be different. Remember that water is also collected and used by humans, and is used by other animals as a part of the water cycle. See figure 6 on page 6 of this journal.

You may tell your water drop's story in song, rap, narrative, poetry, travel blog, a letter, or other form. Be creative and accurate about the journey your water drop will take.


Surface Runoff
Reservoir
Aquifer
River
Soil water
Groundwater
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# Alternate FACTivity

## Time Needed

- 10 minutes
- 1 day to wait
- 10 minutes for discussion

## Materials

- Potted houseplant with a hole in the bottom
- Saucer
- Small plastic bag, such as a lunch bag with a zip top.
- Water
- Paper
- Pencil

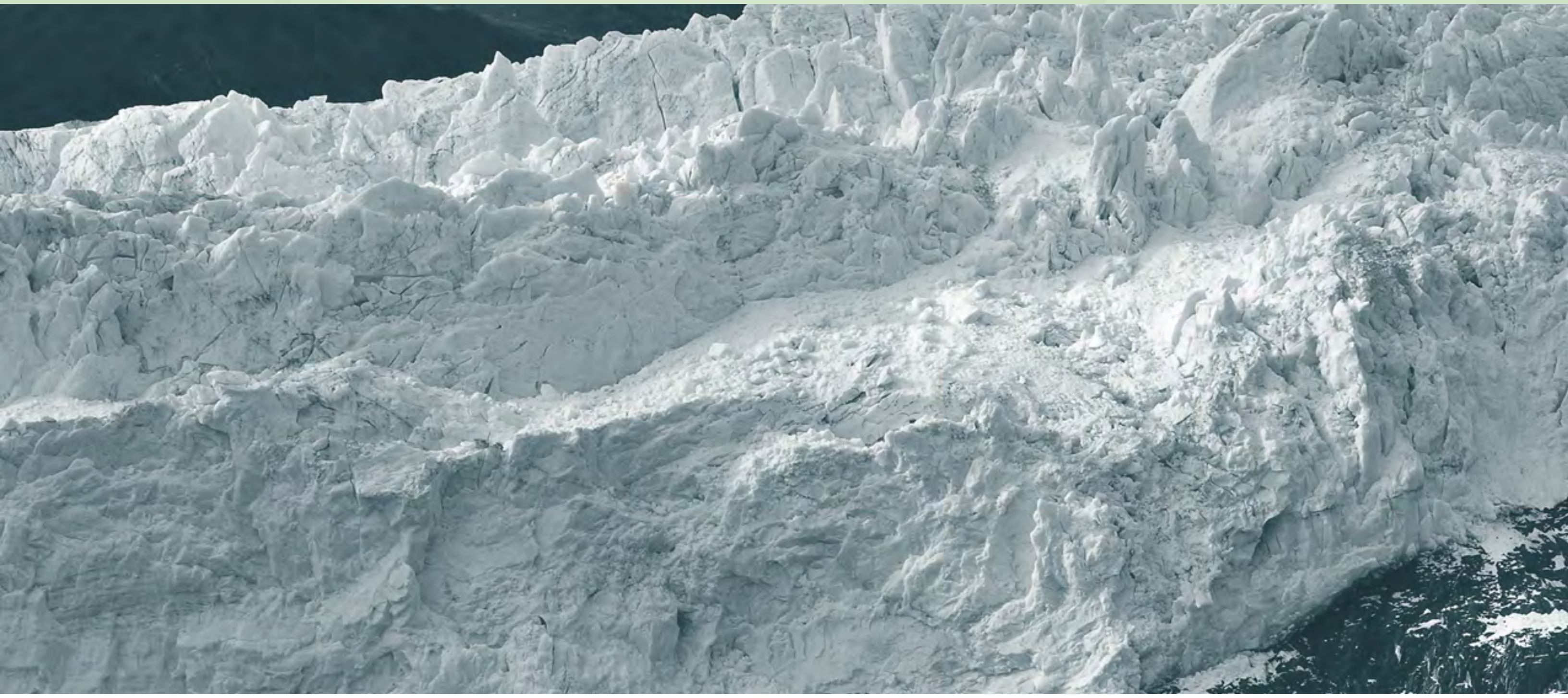
The purpose of this FACTivity is to demonstrate how houseplants use water and to compare this process with an outdoor plant's use of soil water.

## Methods

1. Place the plastic bag on one or more of the plant's leaves and zip the bag as snug as possible without hurting the plant.
2. Water the plant thoroughly until some water flows into the saucer.
3. Empty the saucer.
4. Place the plant in a sunny window.
5. Wait 24 hours.
6. Observe the plastic bag. You may carefully remove the bag, being careful not to spill its contents.
7. Write down what you observed about the plastic bag.

Compare the potted plant with a plant outside. Think about what you learned in this article about underground water.

8. What does the saucer water represent?
9. What does the water inside the pot represent?
10. What do the bag's contents show you about the plant?
11. Does this FACTivity support this article's findings about soil water? Why or why not?



How does this scene relate to the water cycle?

## Natural Inquirer Connections

You may want to reference these *Natural Inquirer* articles for additional information and FACTivities:

- For more on chemistry and energy flow, read "Don't Litter the Stream" in the Hawai`i-Pacific Islands edition of *Natural Inquirer*.
- For more on chemistry in freshwater, read "Sediment-al Journey" on page 58 and "Caribbean Cruise" on page 41 in this *Natural Inquirer* edition.
- For more information on surface water, see "Green Means Clean" on page 7 in this *Natural Inquirer* edition.

These articles, along with others, can be found at http://www.naturalinquirer.org/all-issues.html.

## Web Resources

U.S. Geological Survey: Groundwater
http://water.usgs.gov/edu/earthgw.html

U.S. Geological Survey: Infiltration
http://water.usgs.gov/edu/watercycleinfiltration.html

Kings River Experimental Watersheds
http://www.fs.fed.us/psw/topics/water/kingsriver/

U.S. Geological Survey: Aquifers
http://water.usgs.gov/edu/earthgwaquifer.html

U.S. Geological Survey: Water Basics
http://water.usgs.gov/edu/mwater.html

U.S. Geological Survey: Rivers Contain Groundwater
http://water.usgs.gov/edu/rivers-contain-groundwater.html

U.S. Geological Survey Groundwater Map
http://www.usgs.gov/blogs/features/usgs_top_story/the-quality-of-the-nations-groundwater/

If you are a trained Project Learning Tree educator, you may use "Rain Reasons" and "Water Wonders" as additional resources.