

Natural

INQUIRER

Number 18

THE

FRESHWATER

EDITION

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Natural Inquirer

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Join us in being green! The following Educator Resources are now available exclusively on the *Natural Inquirer* Web site, <http://www.naturalinquirer.org>. These resources can be found with the "Freshwater" journal and on the "Educational Resources" pages.

- Note to Educators
- Lesson Plan
- Reflection Section Answer Guide
- National Education Standards (specific to each article), including:
 - Next Generation Science Standards
 - National Science Education Standards
 - National Curriculum Standards for Social Studies
 - Common Core State Standards

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74



90



Editorial Review Boards



Natural Inquirer editorial review boards hard at work.

Editorial Review Boards' Comments

Bemidji Middle School, Minnesota: Ms. Henry's 7th Grade Life Science Classes

The glossary is helpful. Including color pictures inside the magazine would make it more interesting.

The most important thing I learned was what kinds of things scientists work on.

I think it is cool that you put the scientist's names and told us what they study but I think you should add some fun facts.

The most important thing I learned was that our water that we drink now comes from way back before dinosaurs existed and that water is good for you.

If these magazines are for teenagers, you should give them more excitement like people's opinions or fun facts.

I thought the magazine was going to be boring, but it wasn't. It was fun and educational.

I liked that there were a lot of pictures to show me what the parts of the article were about.

I think that it was a good learning tool but very long so it made it kind of boring at points.

I learned about the water cycle before, but never in detail! It was pretty cool to know exactly where my water comes from!

I think that a little more of what I like to call "pop!" would be appreciated; as well as some simpler summaries at the bottom of each article.

I think you should have more activity pages.



About *Natural Inquirer*

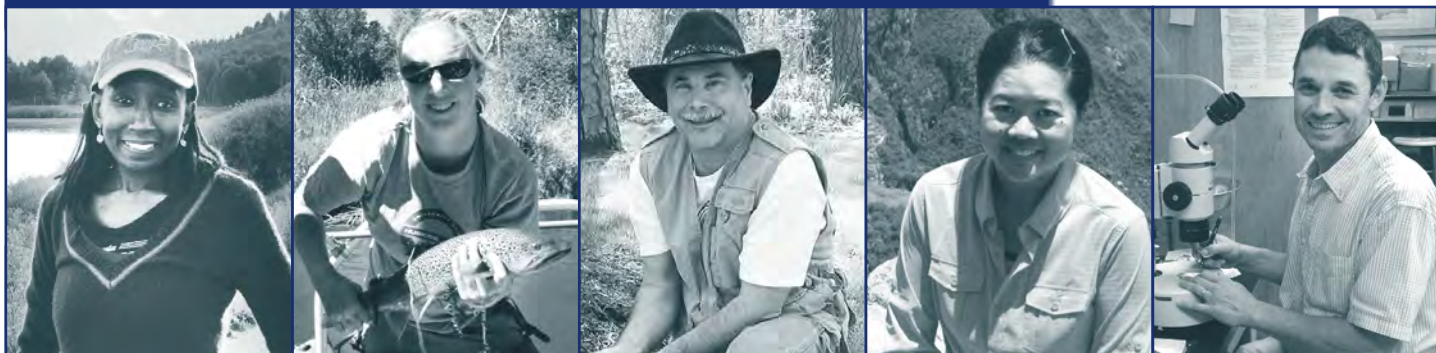
Scientists report their research in journals, which are special booklets that enable scientists to share information with one another and with others. This journal, *Natural Inquirer*, was created so that scientists can share their research with you and other middle school students. This journal presents the research of scientists with the Forest Service and other cooperating organizations. The Forest Service is an agency of the U.S. Department of Agriculture. If you want to know more about the Forest Service, you can read about it on the inside back cover of this journal, or you can visit the *Natural Inquirer* Web site at <http://www.naturalinquirer.org>. Information is also available at <http://www.fs.fed.us>.

All of the research in *Natural Inquirer* is focused on nature, such as trees, forests, animals, insects,

outdoor activities, and water. First, you will “Meet the Scientists” who conducted the research. Then, you will read something special about science and about the natural environment. You will also read about a specific research project, which is written in the format that scientists use when they publish their research in journals. Then, YOU will become the scientist when you conduct the FACTivity associated with each article. Don’t forget to look at the glossary and the special sections highlighted in each article. At the end of each section of the article, you will find a few questions to help you think about what you have read. Your teacher may use these questions in a class discussion.

Be sure to try the Freshwater eyeChallenge and Crossword on pages 124–126!

Who Are Scientists?



Scientists collect and evaluate information about a wide range of topics. Some scientists study the natural environment. To be a successful scientist, you must:

- 🍁 **Be curious**—Are you interested in learning?
- 🍁 **Be enthusiastic**—Are you excited about a particular topic?
- 🍁 **Be careful**—Are you accurate in everything you do?
- 🍁 **Be open-minded**—Are you willing to listen to new ideas?
- 🍁 **Question everything**—Do you think about what you read and observe?

To learn more about scientists and their work, you can find cards and posters for *Natural Inquirer* scientists online at <http://www.naturalinquirer.org>.

Welcome

to the *Natural Inquirer* Freshwater Edition!

Clean water is one of Earth's most important natural resources (**figures 1, 2, and 3**). All the planet's organisms need water. You may know that some small amounts of water can come to Earth from extraterrestrial sources such as meteors. Practically speaking, however, water found today across Earth's environment is also Earth's supply of water for the future. The water you drank today was on Earth even before the dinosaurs lived! Water moves from Earth's atmosphere to its surface and underground, and then back to the atmosphere in a continuous cycle (**figure 4**).

Earth has been called a water planet. Nearly 70 percent of Earth's surface is covered by water. Of this surface area, 97.5 percent is saltwater. Take a look at a globe or a map of Earth. You will see for yourself just how much saltwater is found on our planet.

The remaining 2.5 percent of Earth's water is freshwater. Humans must have clean freshwater to live. Urban and industrialized (in *dās trē ə līz(d)*) societies must provide clean freshwater for a growing human population. Industrialized societies build and operate factories and businesses in a city, region, or country. To provide freshwater, people have developed ways to collect large quantities of freshwater for human use. People have also developed ways to clean polluted freshwater (**figure 5**). Humans unfortunately have also wasted and polluted some of their freshwater resources, and they have neglected to properly protect many of Earth's water resources.



Figures 1, 2, and 3. Water is necessary for all of Earth's organisms.

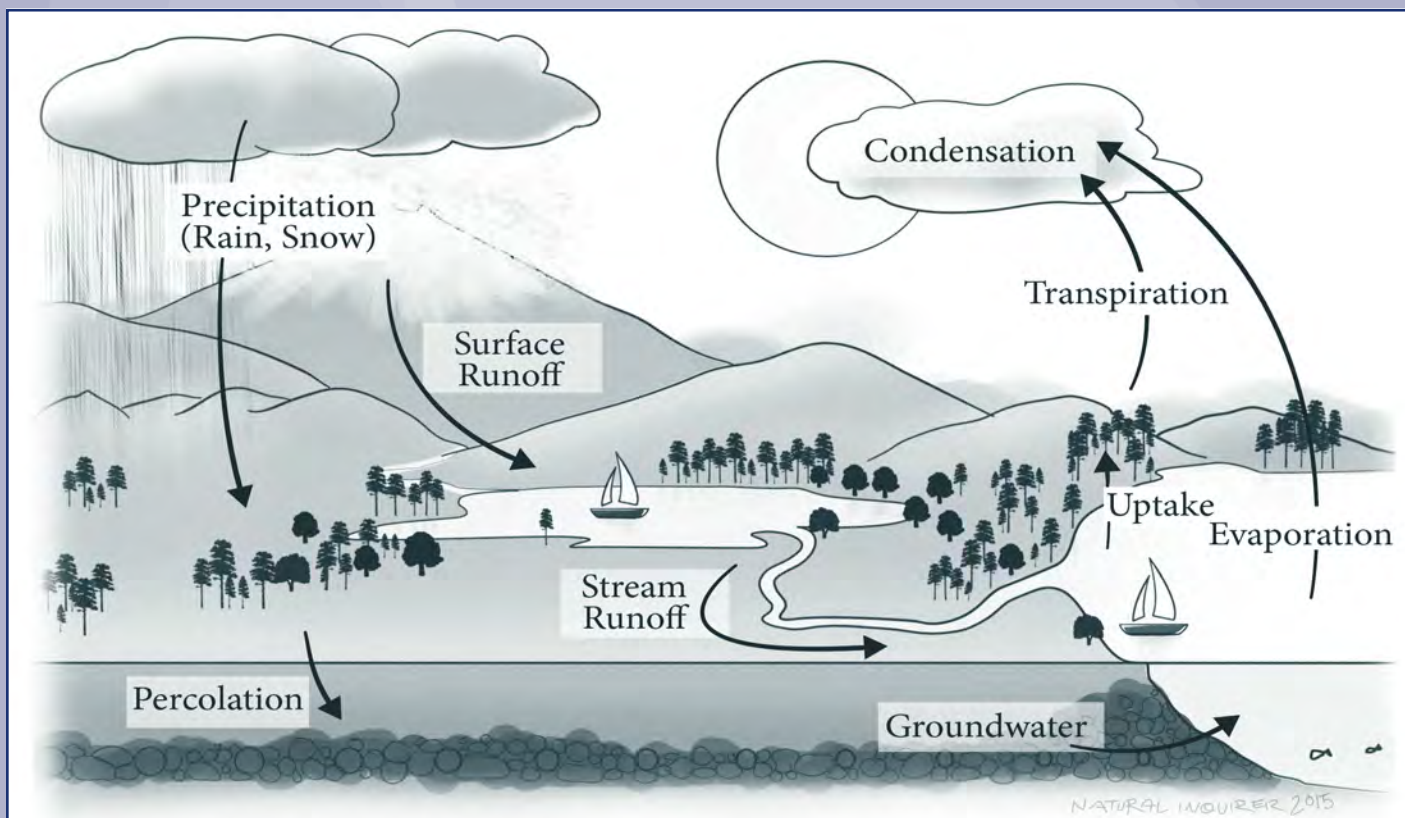


Figure 4. The water cycle. Illustration by Stephanie Pfeiffer.



Figure 5. Wastewater treatment plants clean used water and release it back into waterways. The Middle Oconee Water Reclamation (*re klə mā shən*) Facility is in Athens-Clarke County, GA. Photo courtesy of Elizabeth Cason.

Human activities are changing rainfall and snowfall patterns, resulting in unexpected droughts and floods. It is important, therefore, to understand how human use of large freshwater quantities fits into the water cycle (**figure 6**).

In this *Natural Inquirer* Freshwater edition, you will learn many new things about Earth's freshwater. In "Green Means Clean," you will learn how scientists and managers are protecting U.S. drinking water supplies using better land management practices. Water pollution that cannot be traced to a particular source is the subject of "What's the Nonpoint?" You will learn how the amount and type of living, or once-living, matter in a waterway changes over time in "Caribbean Cruise." Have you ever wondered whether chemicals flowing into urban waterways are

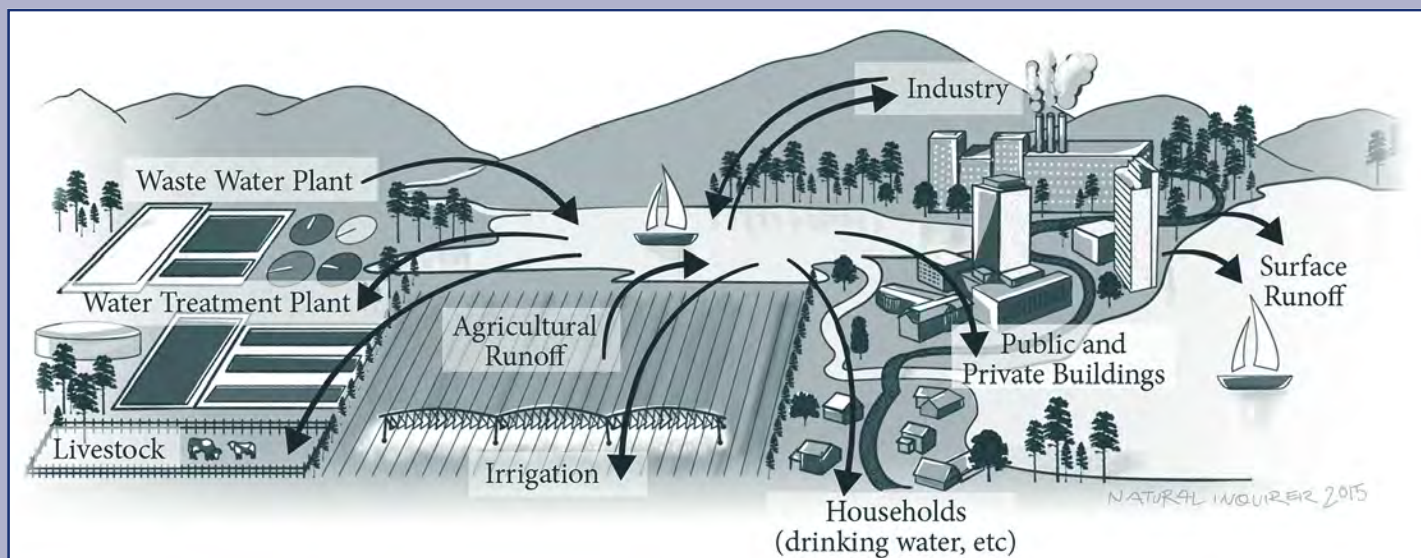


Figure 6. Humans have modified Earth’s natural water cycle by collecting and using large quantities of freshwater for household and industrial use. Illustration by Stephanie Pfeiffer.

dangerous? You will learn whether those chemicals are dangerous in “Sediment-al Journey.” The fascinating world of freshwater mussels and what they tell us about water quality is revealed in “Mussel Mania.” “Timed Travel” will introduce you to the importance of water temperature to young salmon. In “Under Where?” you will explore the unseen but important movement of groundwater below your feet.

As you read each article, think about your daily water use. You use clean freshwater for drinking, bathing, and cooking. Did you know that up to 60 percent of your body weight is water? Water not only keeps you healthy, it keeps the planet healthy!

Be Water Wise!

Here are some tips to help you and your family conserve freshwater:

- ◆ Turn off the faucet when you brush your teeth and only turn it on as you need it.
- ◆ Install low flow toilets and showerheads to reduce the amount of water used.
- ◆ Put a rain barrel outside to collect rainwater. Use this water for your plants.

For more great ideas about what you can do to conserve freshwater, visit <http://www.epa.gov/WaterSense/kids/>.



Are you interested in learning more about freshwater? Check out “FreshWaterLIVE: A Distance Learning Adventure!” FreshWaterLIVE will be available in 2015–2016 at <http://www.freshwaterlive.org/>. Also read the inside back cover of this *Natural Inquirer* for additional information about FreshWaterLIVE.

Green Means Clean!

Assessing the Condition of U.S. Drinking Water Watersheds

Photo courtesy of Babs McDonald

Meet the Scientists

► **Dr. James Wickham, Biologist:** My favorite science experience is studying Earth's environment from space.



◄ **Mr. Timothy Wade, Geographer:** My favorite science experience is using Geographic Information Systems (GIS) to uncover environmental patterns that were not previously known.

► **Dr. Kurt Riitters, Ecologist:** My favorite science experience is asking and answering questions that have not been asked before.



Glossary words are **bold** and are defined on page 21.

What Kinds of Scientists Did This Research?

biologist: This scientist studies living organisms and living systems.

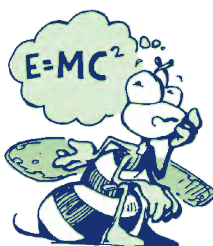
ecologist: This scientist studies the relationship of living things with each other and with the nonliving environment.

geographer: This scientist studies the relationship between Earth's natural environment and human society.

Thinking About Science

Look at the section entitled, "What Kinds of Scientists Did This Research?" What do you notice about the kinds of scientists who are involved with this study? You probably noticed that three different kinds of scientists worked together to study drinking water watersheds in the United States. You might have also noticed that two of the scientists study relationships. When different kinds of scientists come together to conduct a study, each scientist brings a different perspective, a different kind of knowledge, and perhaps different scientific methods. These differences strengthen the study. One person may see or understand things that another person may not.

If you are holding a hard copy of *Natural Inquirer*, take a moment to look at the "What Kinds of Scientists Did This Research?" section of the other articles within the journal. You may also look at this section in more articles by viewing *Natural IQ: Southern United States Climate Change* edition at <http://www.naturalinquirer.org>. Notice that a variety of scientists came together to conduct the other studies. Relate this characteristic of scientific research to your own experiences. Share an experience of when having many different perspectives was an advantage for you.



Thinking About the Environment

A watershed is an area of land where all the water that is underground within the area and all the water that drains off of its surface goes to the same place (**figure 1**).

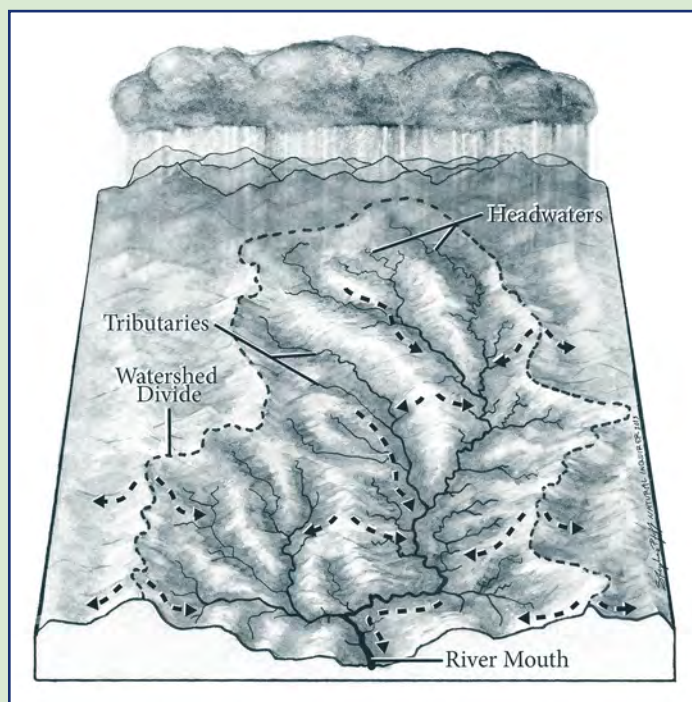


Figure 1. What do you notice about watersheds? Illustration by Stephanie Pfeiffer.

Watersheds contain streams or rivers that carry surface water toward the oceans, and they may contain lakes or reservoirs (**re zə vvärz**) (**figures 2a and 2b**). Watersheds hold **groundwater**, which also flows into streams and rivers. In the United States, the largest watersheds are defined by the Continental Divide (**figure 3**). One of these large watersheds drains into the Pacific Ocean. The other large watershed drains into the Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea. Smaller watersheds are contained within each larger watershed in a nesting pattern (**figure 4**).



Figure 2a. Reservoirs are formed when a river is dammed. Reservoirs are built for many reasons, such as flood control or power generation. Photo courtesy of Babs McDonald.



Figure 2b. Many reservoirs are built to hold water that will be used as drinking water. Notice the drinking water treatment plant on this reservoir in northeast Georgia. For more information on water treatment plants, see page 16. Photo courtesy of Babs McDonald.

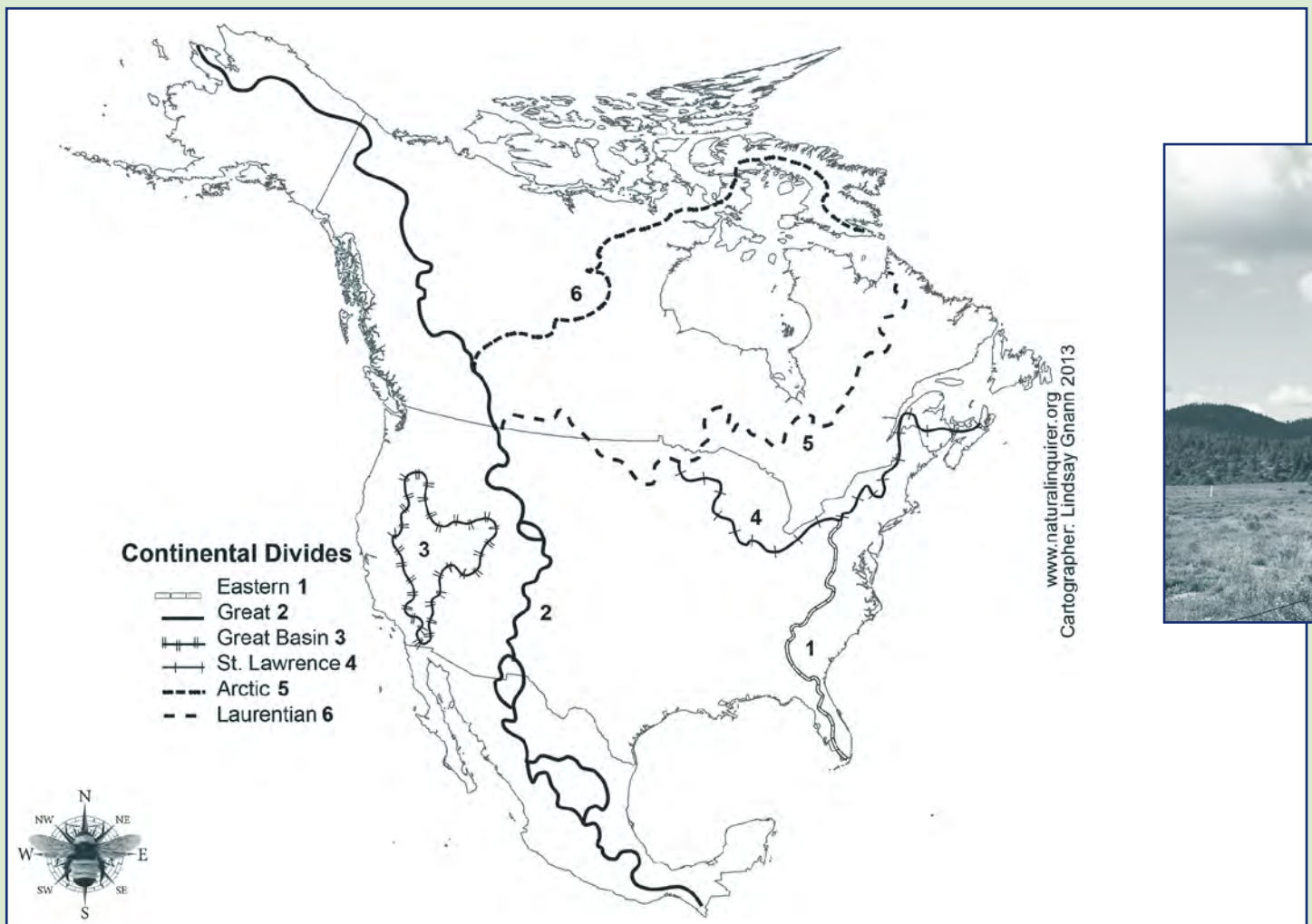


Figure 3. The Great Continental Divide defines two large U.S. watersheds. Notice the other large watersheds of North America. Identify which direction the water flows from the boundary of each watershed. Map by Lindsay Gmann and photo courtesy of Babs McDonald.

Introduction

Scientists estimate that 80 percent of all U.S. freshwater resources begin in forests. Approximately 60 million U.S. citizens rely directly on national forests for their water. About two-thirds of the U.S. population use drinking water from surface sources. Surface sources of drinking water include streams, rivers, lakes, and reservoirs (**figure 5**). People who manage drinking water sources have recognized the relationship between **conservation** of natural land and improved drinking water quality. When land is covered with vegetation, surface water is cleaner. Cleaner water means lower water treatment costs and safer drinking water.

Managers take a number of actions to protect drinking water. Starting in 1974, with the passage of the Safe Drinking Water Act, managers focused on detecting sources of water pollution. By 1996, people had begun to think differently about how to provide clean

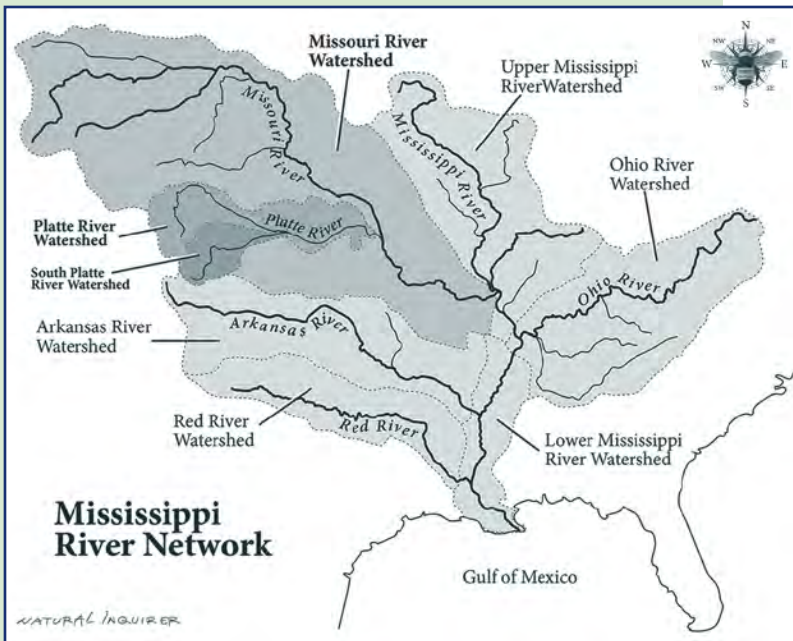


Figure 4. Smaller watersheds may be contained within larger watersheds. Illustration by Stephanie Pfeiffer.

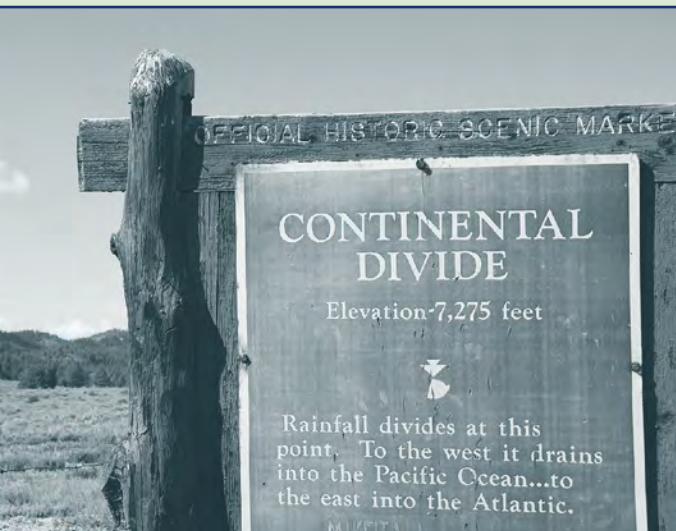
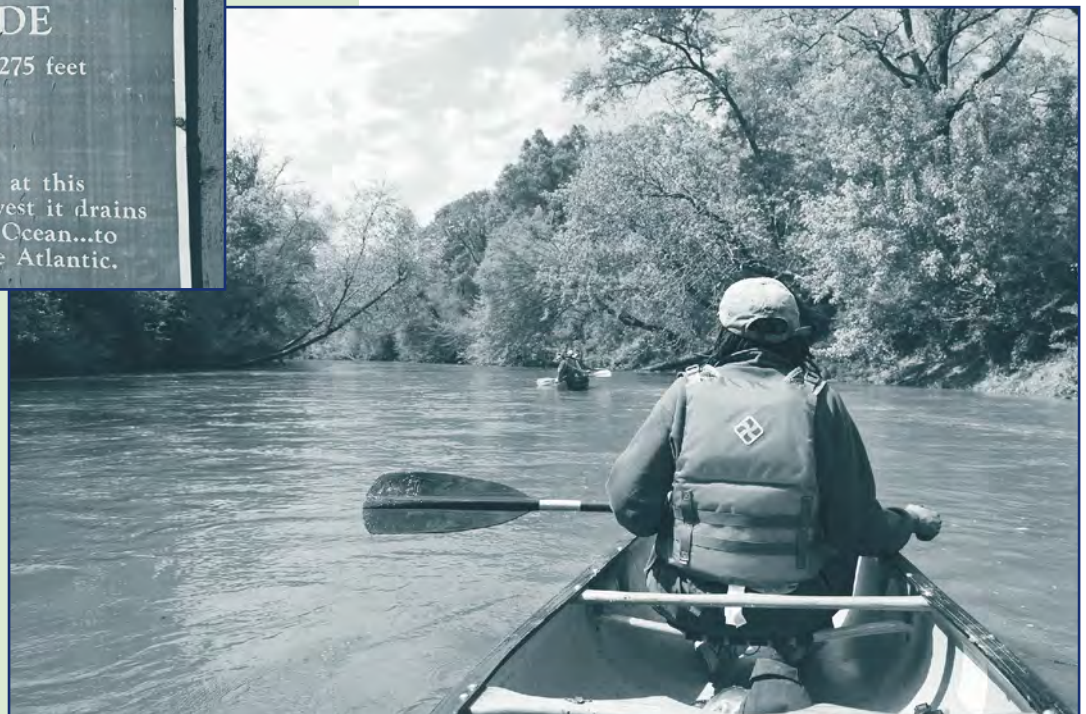


Figure 5. Rivers, as well as lakes and reservoirs, are surface sources of drinking water. Photo courtesy of Babs McDonald.



drinking water. People realized that protecting surface source water was more effective and **efficient** than just detecting pollution. In 1996, **amendments** to the Safe Drinking Water Act shifted the focus from detection of pollution to protection of source water. A big part of protection is managing drinking water watersheds so that the surface water is clean. This kind of management means that the land is purposely managed to protect surface sources of drinking water.

The 1996 Safe Drinking Water Act amendments also required each State to assess the condition of its source water. These assessments are important, as they alert

managers to the condition of drinking water watersheds. If a watershed's natural condition becomes **degraded** or the land is developed for other uses, for example, managers can address the problem to protect water quality. Unfortunately, State-by-State assessments do not provide a regional or national understanding of drinking water watersheds. Each State might do its assessment a little differently. Watersheds often cross State boundaries, and watersheds are managed across State boundaries (**figure 6**). The scientists in this study, therefore, were interested in conducting a national assessment of drinking water watersheds that crossed State boundaries.

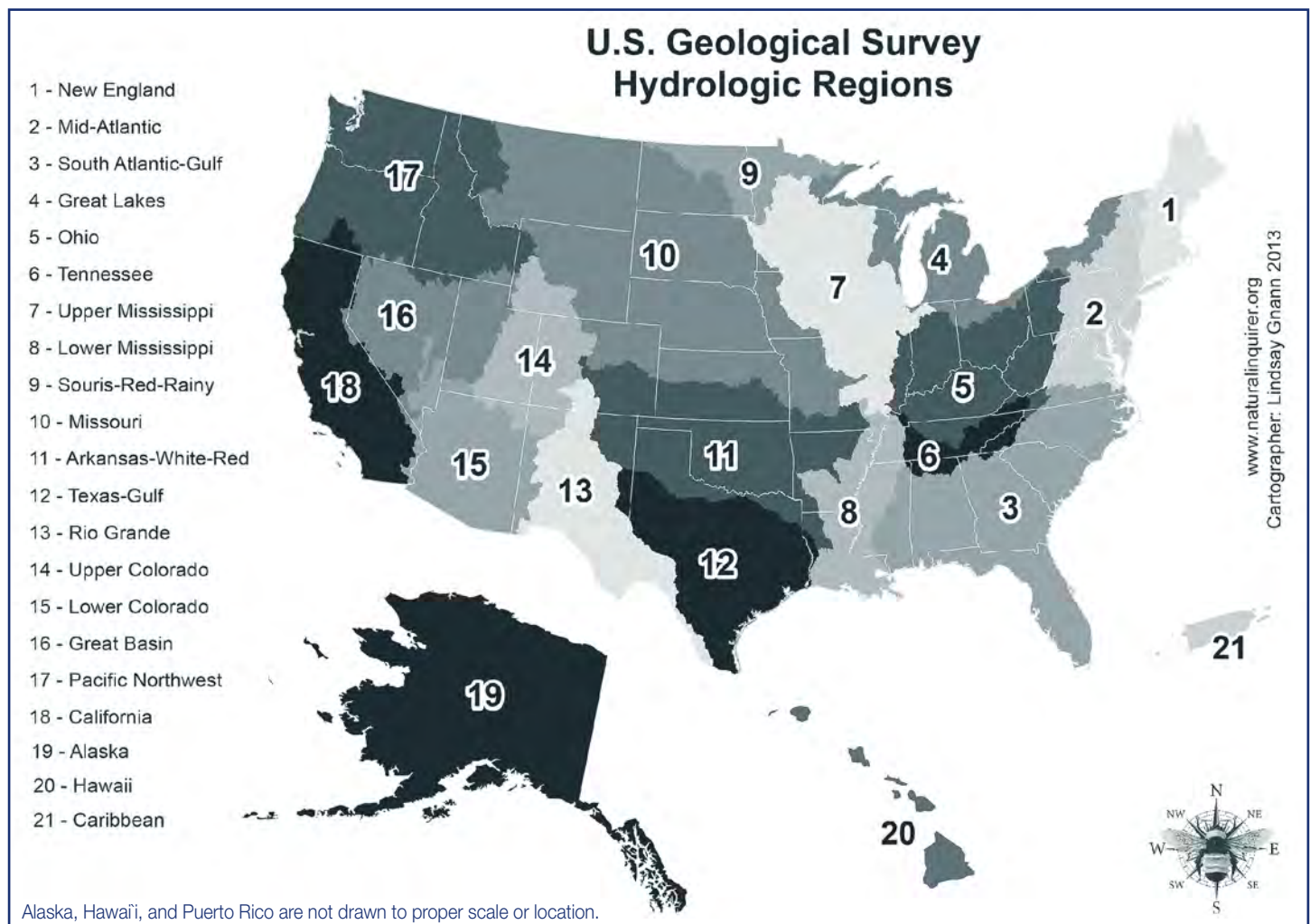


Figure 6. The U.S. Geological Survey divides the United States into 21 **hydrologic** regions. These regions contain either the drainage area of a major river, such as the Missouri region, or the combined drainage areas of a series of rivers, such as the Texas-Gulf region. In which hydrologic region do you live? Map by Lindsay Gnnann.

What Is the Safe Drinking Water Act?

Congress passed the Safe Drinking Water Act in 1974 to protect public health by **regulating** the Nation's public drinking water supply. The law was amended in 1986 and 1996 and requires actions to protect drinking water and its sources. These sources include streams, rivers, lakes, reservoirs, springs, and groundwater wells. Springs and groundwater wells are belowground sources of drinking water. In this study, the scientists were interested in surface drinking water sources.

The Safe Drinking Water Act identifies risks to safe drinking water. These risks include, for example, **pesticide** application, mining, and landfills (**figure 7a**). The act also identifies the many ways drinking water can be protected. These protective actions create barriers to water pollution (**figure 7b**). Examples of barriers to water pollution include sustainable land management and public education programs.



Figure 7a. The Safe Drinking Water Act identifies risks to safe drinking water. Illustration by Stephanie Pfeiffer, adapted from the Safe Drinking Water—Protecting America's Public Health Poster (EPA 816-H-02-001 January 2002).

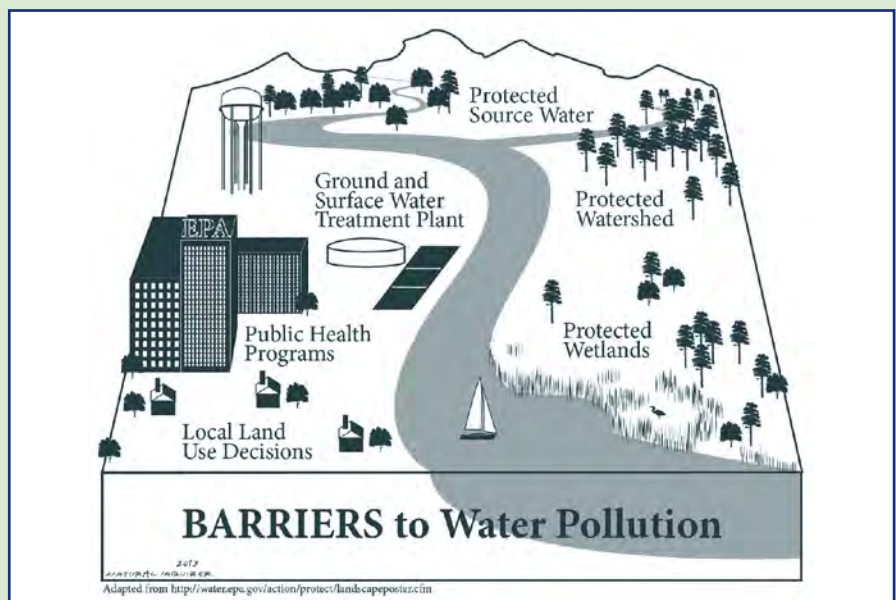


Figure 7b. The Safe Drinking Water Act identifies barriers to water pollution. These barriers are protective actions that directly and **indirectly** protect water quality. Illustration by Stephanie Pfeiffer, adapted from the Safe Drinking Water—Protecting America's Public Health Poster (EPA 816-H-02-001 January 2002).

Reflection Section



- ❦ Do you know where your drinking water comes from? If so, what is the source? If you are not sure of the source of your drinking water, do some research to identify the source. Your source might be a stream, river, lake, or reservoir. You may also have a spring, an individual water well at your home, or a community well.
- ❦ Look at figure 7a. Why do you think **wastewater** treatment plants are identified as a risk to safe drinking water?
- ❦ Explain in your own words why the scientists wanted to conduct a national assessment of drinking water watersheds.

Methods

First, the scientists located all surface drinking water intakes. A surface drinking water intake is a pipe in lakes, streams, rivers, or reservoirs that takes water from the source and carries it to a water treatment plant (**figures 8, 9a, 9b, and 9c**). The scientists found 5,265 of these intakes across the United States.

The scientists then used maps to trace backwards from the water intakes. Tracing backwards from the intakes enabled scientists to identify the watershed for each intake. Each watershed included all the land area supplying water to the intake. Then, the scientists identified in which of the 21 hydrologic regions of the United States each watershed belonged (see figure 6).

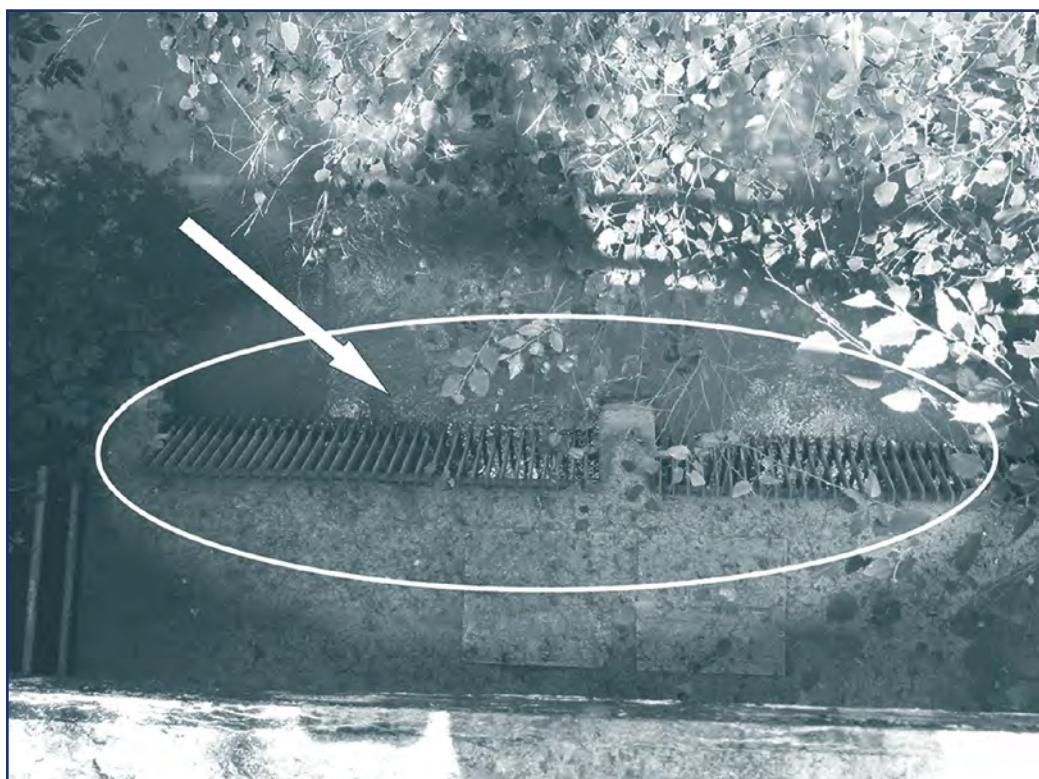
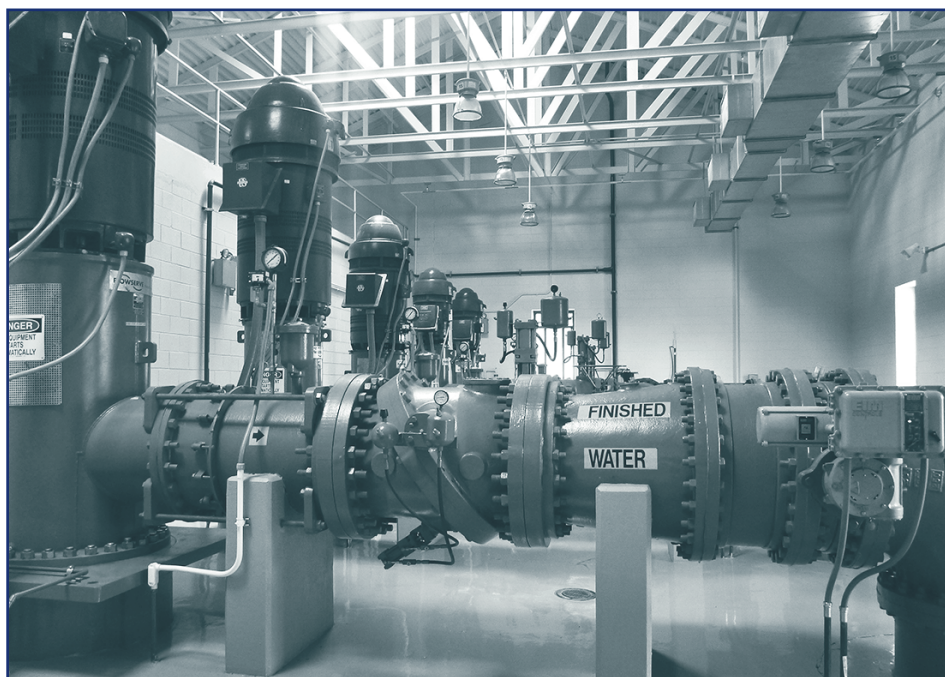


Figure 8. Water enters a water treatment system through drinking water intakes. In this photo, water enters through a grate at a river's edge and into a pipe for transport to the water treatment plant. This photo was taken from above the water intake. Photo courtesy of Babs McDonald.



Figures 9a, 9b, and 9c. Water treatment plants clean the water received from watersheds and water intakes. Photos courtesy of Babs McDonald.



How Is Water Treated So That It Becomes Clean Enough To Safely Drink?

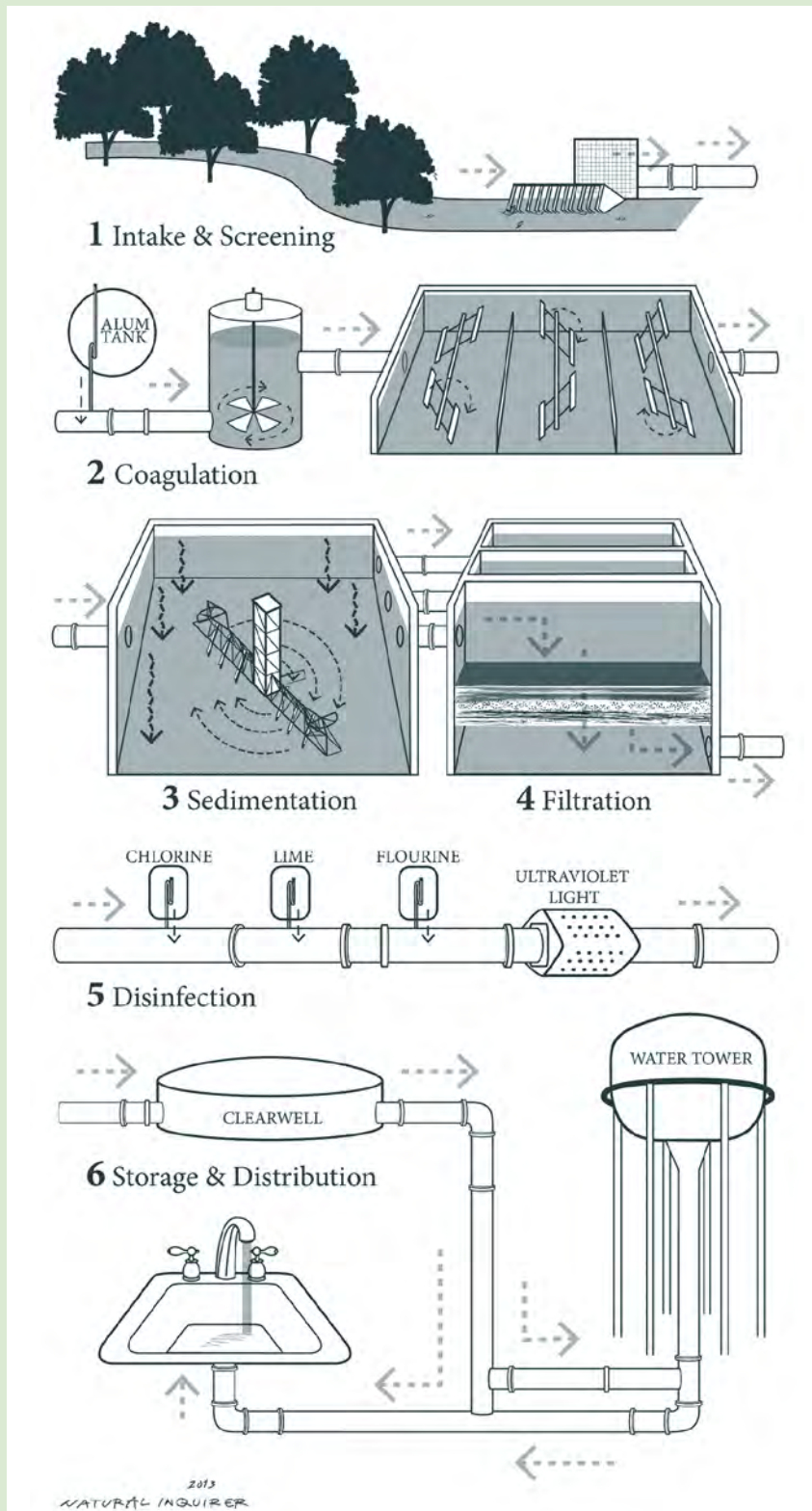


Figure 10. Water entering a drinking water treatment system is treated using a number of steps. Illustration by Stephanie Pfeiffer.

Water entering a drinking water treatment system is treated using a number of steps (**figure 10**). When water is taken from a river (and before it reaches the water treatment plant), the water is filtered through screens to remove sticks and leaves. Water taken from a reservoir does not usually need to be screened. When water reaches the plant, coagulation is often the first step in treatment. Chemicals with a positive electrical charge are added to the water. The positive charge of these chemicals neutralizes the negative charge of dirt and other dissolved particles in the water. When this process occurs, the particles bind with the chemicals and form larger particles, called floc.

Due to its weight, floc settles to the bottom of the water supply. This settling process is called sedimentation.

After the floc has settled to the bottom of the water supply, the clear water on top passes through a filtration process. Filtration uses materials such as sand, gravel, and charcoal to filter the water. Filtration removes dissolved particles, such as dust, parasites, bacteria, viruses, and chemicals.

After the water is filtered, a disinfectant (such as chlorine) is usually added to kill any remaining parasites, bacteria, and viruses. Disinfectant also protects the water from germs when it is piped to homes and businesses.

Water is stored at the water treatment plant in a clearwell before being piped to homes and businesses. Some of the water is piped to and stored in water towers located throughout the community. Most of the water is piped directly to homes and businesses (**figure 11**). Water travels through these pipes and into a building's plumbing system.

Figure 11. Water pipes are laid underground near roads. These pipes bring clean water from the water treatment plant to homes and businesses, including your home and school. The next time you turn on a faucet, think about the journey each drop of water has taken from its surface water source to your faucet. Photo courtesy of Babs McDonald.



The scientists needed more information to do their analysis. The scientists used information from an existing national database on land cover. This database is made up of satellite photographs taken of Earth's surface (**figures 12 and 13**). Land cover is the physical cover at Earth's surface. Examples of land cover include forest, grass, asphalt, water, and buildings. Some of these land covers are classified as urban, such as buildings. Some of these land covers are classified as natural, such as forests.



Figure 12. Landsat satellites take images of Earth's surface. The photographs are used for many purposes. Photo courtesy of National Aeronautics and Space Administration.

Using this database of photographs, the scientists noted changes between 1992 and 2001 in land cover for areas identified as urban, natural, agricultural, and water.

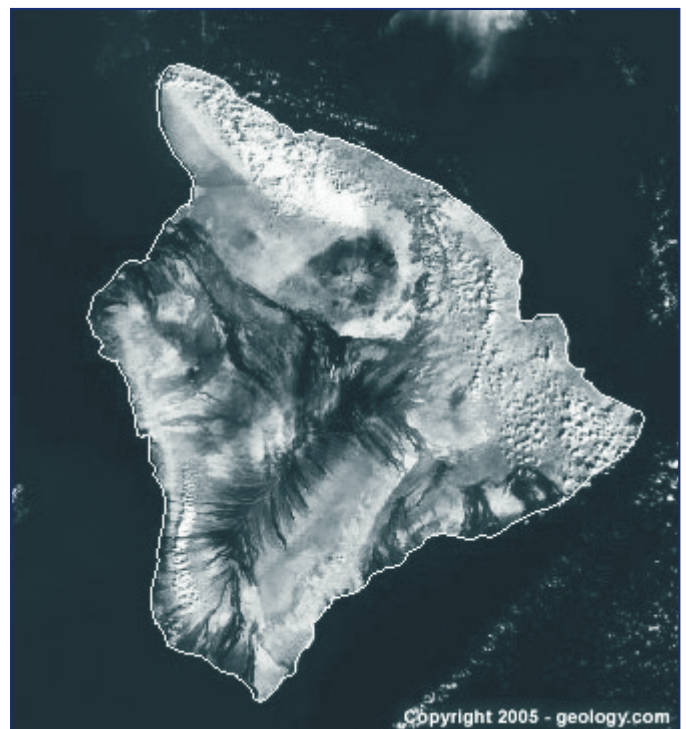


Figure 13. Landsat images are commonly used today. Landsat images help us understand how Earth's surface is changing over time. This Landsat image is of the Island of Hawai'i. Image courtesy of <http://www.geology.com>.

They identified, for example, whether the amount of urban land expanded or got smaller between 1992 and 2001 for each of the drinking water watersheds.

Next, the scientists looked at another database called the Protected Areas Database of the United States. This database identifies land that is protected from development. Development is what happens when land is converted from natural to urban or agricultural uses. The Protected Areas Database identifies public land and conservation land. The scientists figured out how much land in each of the drinking water watersheds was protected. Land that is protected is less likely to be developed into roads and buildings, or used for agriculture.

Finally, the scientists put all of this information together into a computer. For each of the drinking water watersheds, the scientists figured out how much of the land was urban, natural, agricultural, or covered in water. They figured out percentages for 1992 and 2001. By looking at data for 1992 and 2001, the scientists figured out if each watershed was becoming more urban, more agricultural, more natural, or had not changed. Then, the scientists calculated the percentage of land in each watershed that was protected from further urban and agricultural growth.

Findings

Most major U.S. rivers are used to supply drinking water to Americans. The scientists discovered that about two-thirds of surface drinking water intakes are in rivers. One-third of the intakes are in lakes and reservoirs. Nationwide, most of the land in drinking water watersheds is covered with plants and trees. The scientists found that the **median** watershed percentage of natural land cover nationwide was 77.1 percent (**table 1**).

Land Cover	Median Percentage
Natural	77.1
Agricultural	8.1
Urban	5.2

Table 1. Comparison of the median amount of land characterized as natural, agricultural, and urban in U.S. drinking water watersheds.

Number Crunch

- What is the total percentage of drinking water watershed land accounted for in table 1? What could be one reason these numbers do not add up to 100 percent?

Reflection Section



- Explain what kind of information the scientists compared for each of the drinking water watersheds.
- What is the relationship between land cover change and drinking water quality?

The scientists also discovered that about 3 percent of the land in U.S. drinking water watersheds was protected from development. The Western United States, however, has a higher percentage of protected land in drinking water watersheds. This higher percentage is due to the large amount of public land in the Western United States (**figure 14**). Public land is generally kept in a natural condition with limited development.

Between 1992 and 2001, land cover changed in some of the drinking water watersheds.

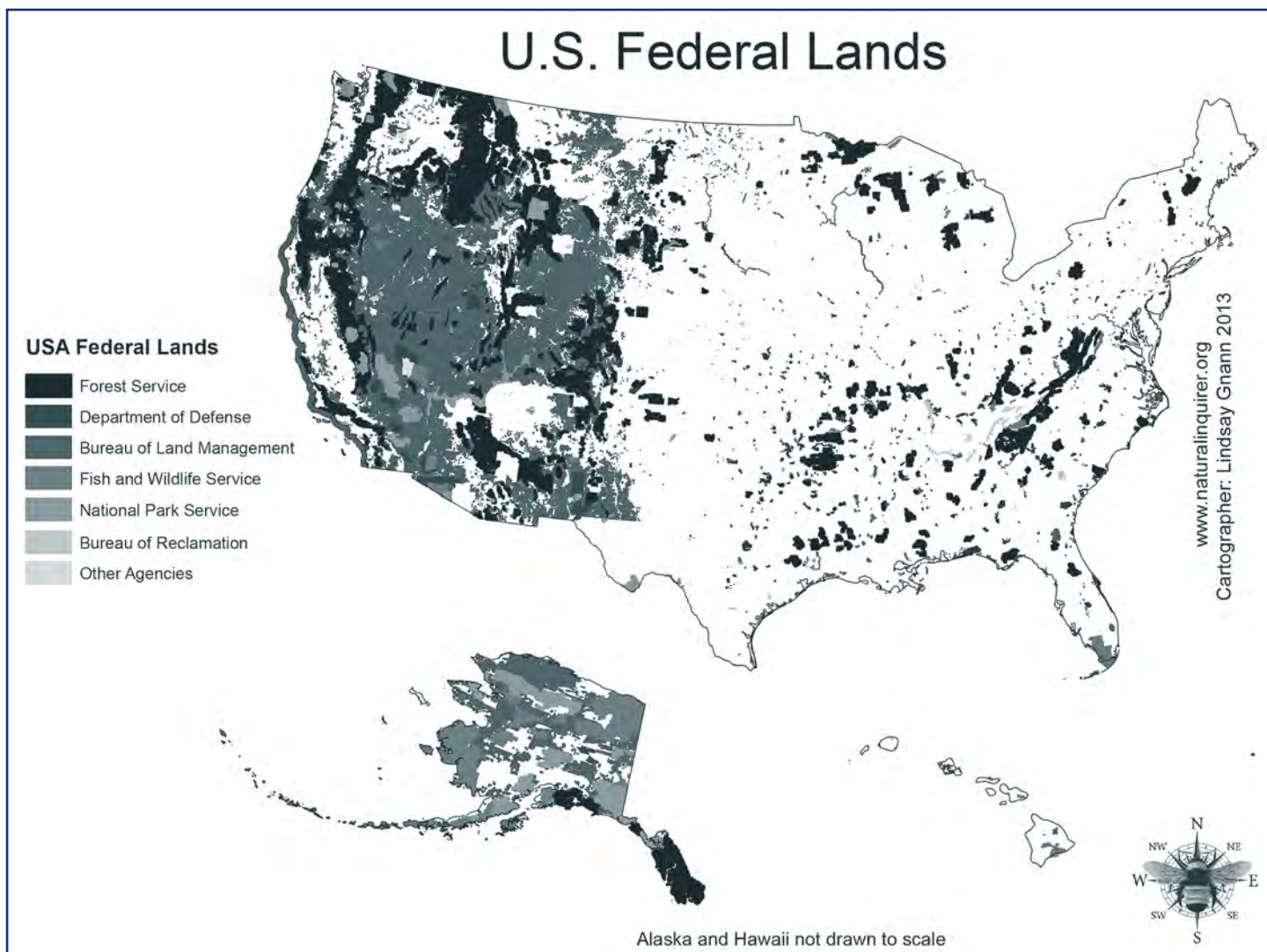


Figure 14. Observe the difference in the amount of western public land as compared with the amount of eastern public land. What do you notice? Map by Lindsay Gnann.

About 23 percent of the watersheds lost at least 1 percent of their natural vegetation. About 5 percent of the watersheds gained at least 1 percent in natural vegetation. In the Southeast and Ohio hydrologic regions (see figure 6), 42 percent of the watersheds lost at least 1 percent of their natural vegetation.

About 9 percent of the drinking water watersheds had at least a 1-percent increase in urban land between 1992 and 2001. Most of this increase was in the Eastern United States. Three-fourths of all watersheds nationwide, however, increased in urban land by some percentage between 1992 and 2001.

Number Crunch

Consider a watershed with a 1-percent increase in urban land. This watershed contains 30,000 hectares. To find out how many acres are in this watershed, multiply 30,000 times 2.471. Following a 1-percent increase in urban land, how many more hectares (and acres) are now in urban land? Is a 1-percent increase of land a large amount of land? Why or why not?

Reflection Section



-  What national trends in land cover change were discovered for the drinking water watersheds?
-  Based on what you learned in this article, would you say that future threats to drinking water quality are equal across the United States? Why or why not? Provide reasons for your answer.

Did You Know?



The average U.S. household uses about 94,000 gallons of water each year. That amount is about 257 gallons used per household each day, or about 11 gallons each hour. In 2010, the U.S. Census Bureau estimated that an average U.S. household has 2.58 people. Based on this information, do you think your household uses more or less than 94,000 gallons of water every year?

Discussion

The scientists found that drinking water watersheds are mostly covered with natural vegetation. In some areas of the United States, however, watersheds contain a high percentage of urban land. Twenty percent of the Nation's drinking water watersheds have less than 50 percent natural vegetation. In addition, 8 percent of the Nation's drinking water watersheds contain at least 20 percent urban land. Over time, drinking water watersheds are losing natural vegetation and are becoming more urbanized. These trends indicate that many surface sources of drinking water may become more exposed to pollutants.

This study shows the importance of taking a regional and national look at U.S. drinking water supply. U.S. population increases will put more land use demands on drinking water watersheds. As more land becomes urbanized, drinking water source protection will likely become more difficult unless the percentage of protected lands increases as well.

Reflection Section



-  The scientists discovered that 8 percent of the Nation's drinking water watersheds contain at least 20 percent urban land. Do you think these more urbanized watersheds are mostly found in the Eastern United States or the Western United States? Why?
-  Based on this article, do you think that drinking water sources will face more challenges from pollution in the future? Why?

Adapted from Wickham, J.D.; Wade, T.G.; Riitters, K.H. 2011. An environmental assessment of United States drinking water watersheds. *Landscape Ecology*. 26: 605–616. http://www.srs.fs.usda.gov/pubs/ja/2011/ja_2011_wickham_001.pdf.

Glossary

amendment (ə **men**(d) mənt): A change in wording or meaning especially in a law, bill, or motion.

conservation (kän(t) sər vā shən): The care and protection of natural resources such as forests and water.

database (dā tə bās): A collection of related data organized for convenient access, generally in a computer.

degrade (di grād): To make the quality of something worse.

efficient (i fi shənt): Bringing about the result wanted with the least amount of time, waste, or materials.

groundwater (graünd wā tər): Water that sinks into the soil and is stored in aquifers.

hydrologic (hī drā lə jik): Relating to the properties, distribution, and circulation of water on and below Earth's surface and in the atmosphere.

indirect (in dī **rekt**): (1) Not straightforward and open; (2) Not directly aimed at.

median (mē dē ən): A value in an ordered set of values below and above which is an equal number of values or which is the arithmetic mean of the two middle whole values if there is not one middle whole number.

pesticide (pes tə sīd): A substance that is used to kill animals or insects that damage plants or crops.

regulate (re gyə lāt): (1) To control according to a system; (2) To bring under control of law or some authority.

wastewater (wāst wā tər): (1) Water that has been used; (2) Sewage.

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.



How does this scene relate to this article?



Time Needed

One class period

Materials

(for each student or group of students)

- Three paint roller pans
- One shovel
- 3/4 cup liquid kitchen oil, such as canola oil
- 2 gallons of water in plastic jugs
- One garden sprinkler can
- Blue or red food coloring

The questions you will answer in this FACTivity are: Which land cover surface best protects water quality and why?

Methods

Identify an area of thick grass near the edge of a grassy area. Ask an adult if the area you have chosen is a good location. Using the shovel, dig up an area of grass the size of one-half of the paint roller pan, including 1/2 to 1 inch of the soil underneath. Brush off the loose soil and place the grass into one of the paint roller pans. The roots of the grass should be holding the soil together. Make sure that the area of grass that you remove is away from the main lawn area.

Identify an area of bare soil. Bare soil is dirt with little or no vegetation. Dig up a shovelful of bare soil and place it into the second paint roller pan, to about 1-inch deep. If it is not possible to find the grass or bare soil in your schoolyard, your teacher will bring them to class. Leave the third paint roller pan empty. Line up the three paint roller pans so that you can easily compare them (**figure 15**).

During your experiment, use the graphic organizer in the next section to answer the

following questions. What do think each of the paint pans represents? (Hint: Think about the different land covers studied in the research you just read.) What do the water and oil represent? (The answers are given after the graphic organizer.) Based on your reading of this article, what do you predict will happen when oil is added and water is poured across each of the paint roller pans? Write your prediction in the form of a complete sentence in the graphic organizer.

Pour 1/4 cup of oil over the contents of each pan. Wait 5 minutes.

Add food coloring to the water. Mix the water and food coloring together until it makes a bright color. Add the water to the garden sprinkler can. Using the sprinkler can, pour an equal amount of water over each of the three paint pans. As the water drains into the bottom of each pan, observe the drained water in each of the pans. What differences do you see between the water in each pan? What has happened to the water in each case? What do you think is the reason for the water's appearance in each of the pans?

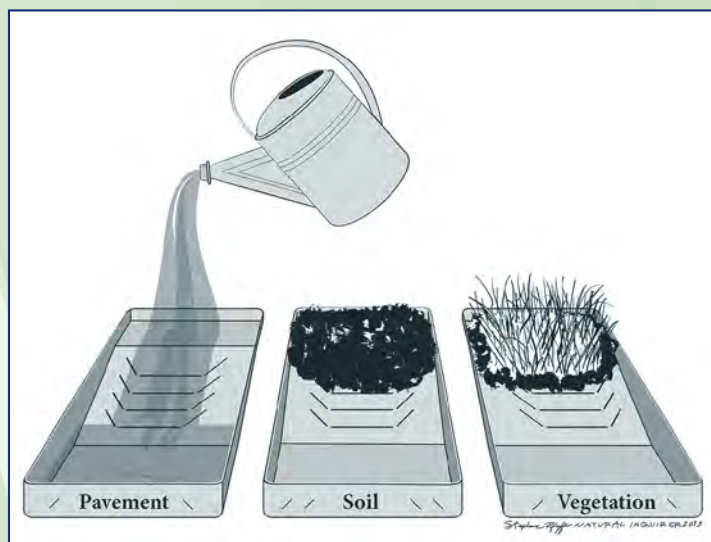


Figure 15. How to set up the paint roller pans. Illustration by Stephanie Pfeiffer.

Graphic Organizer

Note: Write using complete sentences, proper grammar, and appropriate punctuation.

The grass represents:	
The soil represents:	
The bare aluminum represents:	
Write your predictions about how the water will look after oil is added and the water drains into each pan.	Bare aluminum: Grass: Soil:
Describe your observations of the water in each pan.	Bare aluminum: Grass: Soil:
Explain why you think the water looks like it does in each pan.	Bare aluminum: Grass: Soil:
How does this experiment relate to the research you read about in the article?	
Based on what you learned, what are your conclusions about land cover and water quality?	

In this FACTivity, each paint roller pan represents a different watershed land cover. The grass represents a watershed with vegetation. The soil represents a watershed with agricultural land. The bare aluminum represents an urban watershed with pavement, such as roads and

parking lots. The oil represents pollution coming from cars, industry, and agriculture. The water represents rain.

Now answer the question posed at the beginning of this FACTivity: Which land cover surface best protects water quality and why? Share your answer with your class.

FACTivity Extension

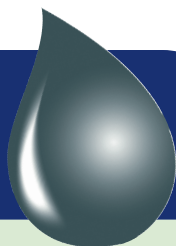


To better understand how water treatment plants clean water, do the U.S. Environmental Protection Agency water filtration activity found at http://www.epa.gov/ogwdw/kids/flash/flash_filtration.html.

If you are a trained Project Learning Tree educator, you may use “Water Wonders” as an additional resource.



Safe Drinking Water Hotline



The Safe Drinking Water Hotline provides information about drinking water and groundwater programs authorized under the Safe Drinking Water Act.

800–426–4791

<http://water.epa.gov/drink/hotline/>

Web Resources

U.S. Environmental Protection Agency: Learn About Water

<http://www2.epa.gov/learn-issues/learn-about-water>

U.S. Environmental Protection Agency: Surf Your Watershed

<http://cfpub.epa.gov/surf/locate/index.cfm>

U.S. Environmental Protection Agency Video: After the storm: The impact of storm water runoff on drinking water supply

<http://water.epa.gov/action/weatherchannel/index.cfm>

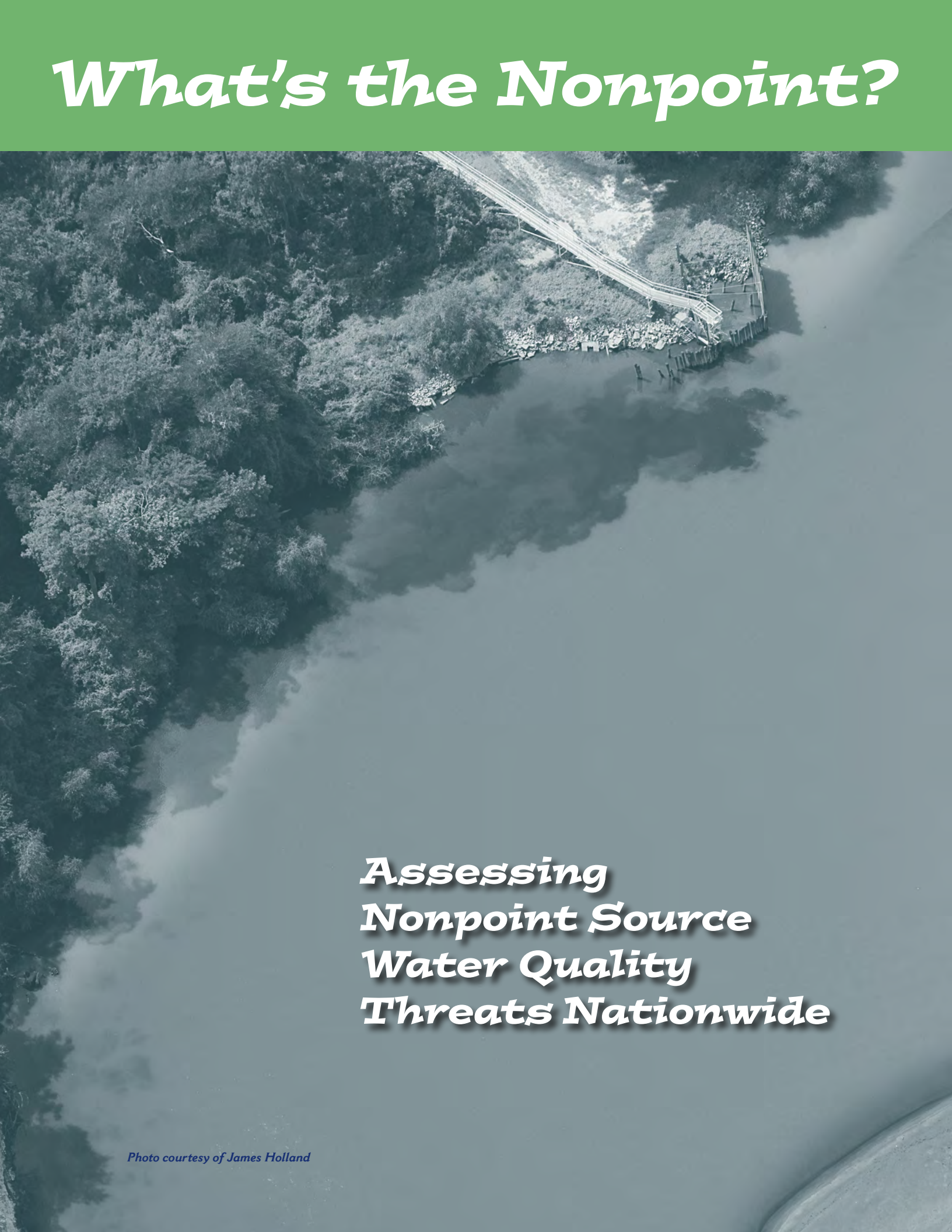
U.S. Environmental Protection Agency Water: Educator Resources

http://water.epa.gov/learn/resources/nationswaters_index.cfm

U.S. Environmental Protection Agency Water: Educator Resources: What Can I Do?

<http://water.epa.gov/learn/resources/projects.cfm#projects>

What's the Nonpoint?

An aerial photograph of a river. On the left, a dense forest covers the bank. A bridge or overpass structure crosses the river, with a road leading to it. The water is calm, reflecting the sky and the surrounding landscape. The text is overlaid on the bottom right of the image.

Assessing Nonpoint Source Water Quality Threats Nationwide

Photo courtesy of James Holland

Meet the Scientists



◀ **Dr. Thomas Brown, Economist:** My favorite science experience happened before I was a scientist. I was a Peace Corps (kòr) volunteer in rural Paraguay, in the heart of South America. I had grown up in the **suburbs**. When I arrived in Paraguay, therefore, I didn't know much about rural life and the natural resources that are so important to people who live off the land. In Paraguay, I learned first-hand about water supply and water quality. I also learned how essential it is that our water resources be protected. My experience in Paraguay pointed me in the direction that, several decades later, I am still following. Now, I study how our success as a society depends on the availability and quality of our water resources.



▶ **Ms. Pamela Froemke, Computer Specialist:** Being constantly exposed to the great outdoors when I was young led me to love and appreciate the natural world. I always felt the best when I was outside. So, my favorite science experience is just what I'm doing now. I work with scientists to provide information that helps to protect our natural resources. I feel like I contribute to society and make a difference by helping to protect our water and other natural resources.



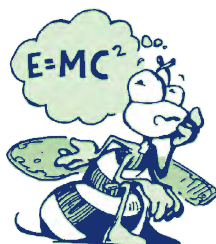
What Kinds of Scientists Did This Research?

computer specialist: Computer specialists provide help and advice to people and organizations using computer software or equipment.

economist: This scientist studies economics. Economics is a social science that addresses the production, distribution, and use of goods and services. Goods and services include purchased items and services, such as clothes and car repair. Goods and services also include those that are difficult if not impossible to buy and sell, including for example, clean water, clean air, and pollination.

Thinking About Science

When scientists want to figure out the total impact of a number of unlike **variables** on another variable, they need a standard way to



measure the variables. In this research, for example, the scientists wanted to know how a combination of variables might impact the level of water pollution risk in an area. These variables had different units of measurement. A unit of measurement is a standardized quantity of a physical property, such as inches, meters, degrees Celsius, etc. Different units of measurement cannot be added together. As an example, consider how we measure percentage of cloud cover and air temperature. Adding the percentage of cloud cover to the air temperature produces a senseless number.

In this research, the scientists divided the range of measurement for each variable into five equal categories. Each category represented 20 percent of the entire range of values. A category representing an equal percentage of the whole is called a percentile. Then, the scientists assigned a number from 1 to 5 for each measured value. A value in the lowest 20 percent of the range, for example, was given a score of 1. A measurement in the highest 20 percent of the range was given a score of 5 (**figure 1**). This process **standardized** the relative value of each variable so that the values could be compared and summed.

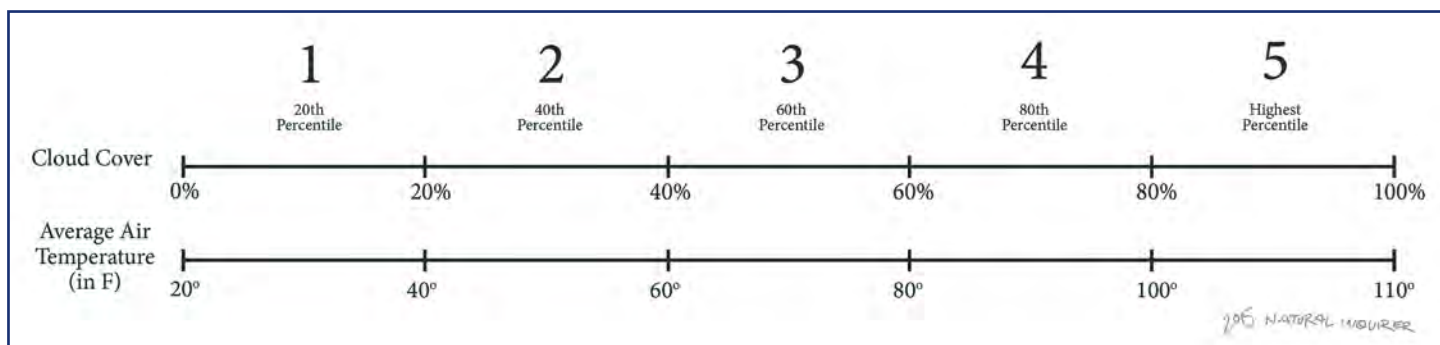


Figure 1. The units of measurement for percentage of cloud cover and air temperature are not comparable. Placing each value within a percentile enables scientists to compare and sum measurements. Illustration by Stephanie Pfeiffer.

Glossary words are **bold** and are defined on page 35.

Thinking About the Environment

Congress passed the Federal Water Pollution Control Act in 1972. Since the act's passage, water pollution coming from point sources has been reduced. Point sources of pollution are those that directly release pollution into a water source and may include factories and wastewater treatment plants. This reduction was possible because it is easy to identify point sources of pollution (**figure 2**).

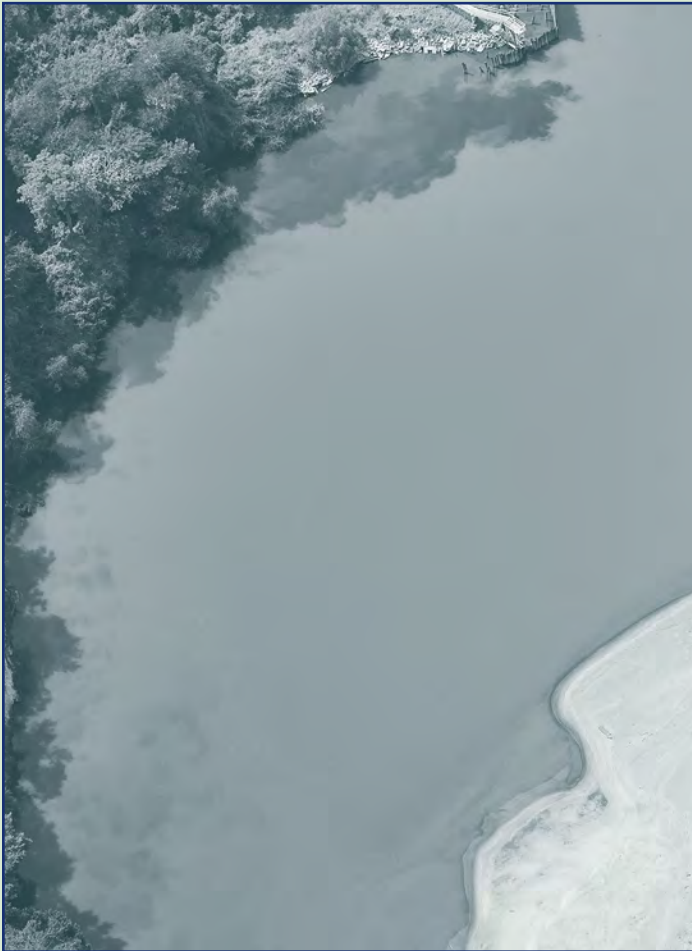


Figure 2. Although point sources of water pollution have been reduced, they have not been completely removed. This photo, taken in 2012, shows point source pollution of the Altamaha (ól tə mə hä) River in Georgia. The pipe coming from an unseen factory is the source of the dark **effluent**. Photo courtesy of James Holland.

Nonpoint sources of pollution, in contrast, are not easily identified or controlled. These sources are not easily identified or controlled because nonpoint sources of pollution include things like farms, roadways, and urban and suburban communities (**figure 3**).

The scientists in this study were interested in better understanding the risk of water pollution from nonpoint sources across the entire United States.



Figure 3. This highway is a nonpoint source of water pollution. The pollution from cars and trucks is spread out over the entire highway, rather than coming from a few points. Photo courtesy of Babs McDonald.

Introduction

Nonpoint source water pollution still remains a problem in the United States, even decades following the passage of the Federal Water Pollution Control Act of 1972. Nonpoint source water pollution comes from large areas or landscapes. These areas include roadways, farms, and urban and suburban communities. Scientists know that nonpoint sources of pollution exist. It is difficult, however, to identify and control such **diffuse** sources of pollution.

The scientists in this study were interested in how the threat from nonpoint sources of water pollution varies in watersheds across the United States (**figures 4 and 5**).

What Is the Federal Water Pollution Control Act of 1972?

The Federal Water Pollution Control Act is the primary Federal law in the United States governing water pollution. The Federal Water Pollution Control Act is commonly referred to as the Clean Water Act. The act's objective is to restore and maintain the chemical, physical, and biological health of the Nation's waters. Restoring and maintaining water quality is accomplished by limiting point and nonpoint pollution sources, by improving publicly owned wastewater treatment plants, and by maintaining the health of wetlands and watersheds.



Figure 4. A watershed is an area of land where all the water on it or under it drains to the same place. Illustration by Stephanie Pfeiffer.

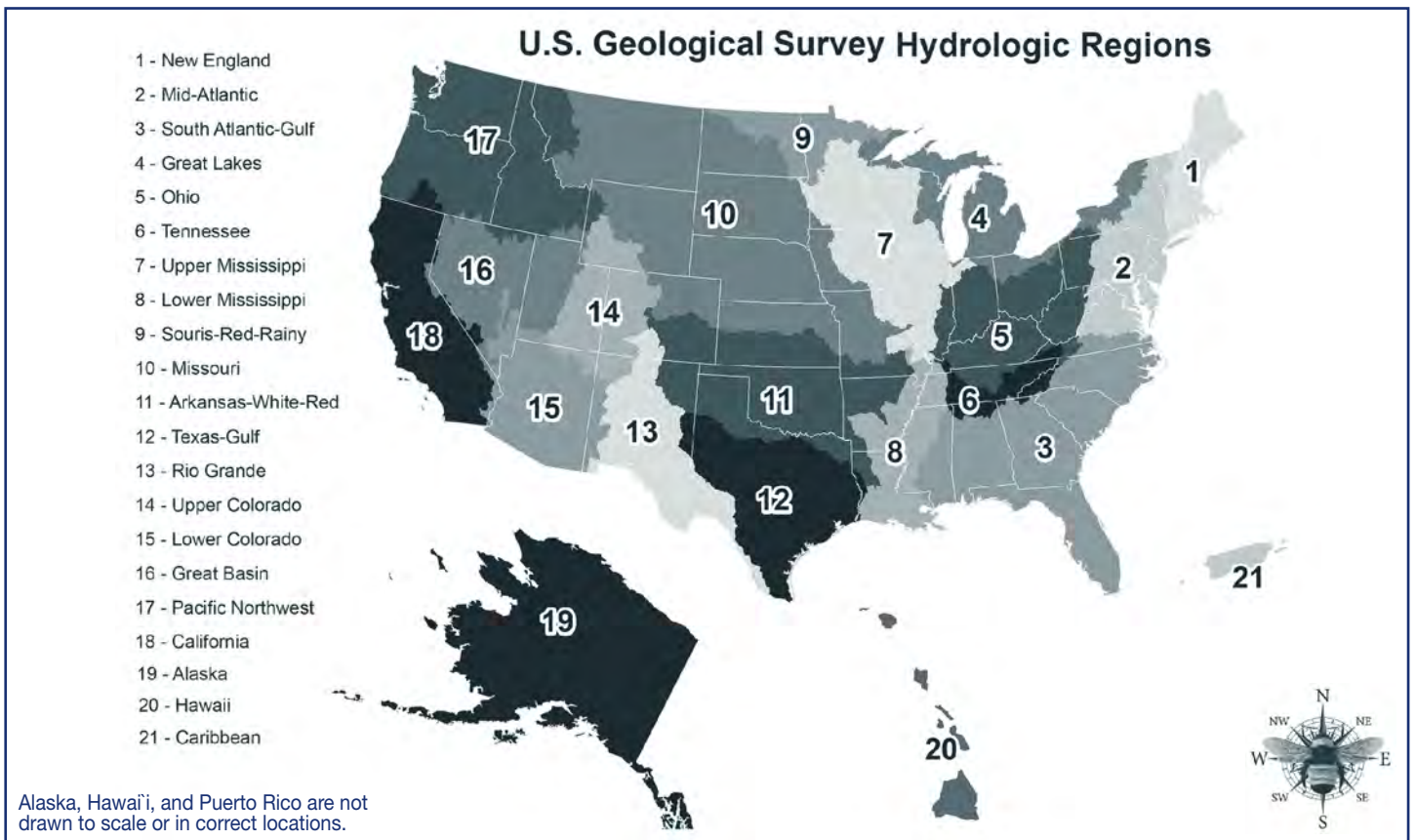


Figure 5. The scientists began with 18 watersheds identified by the U.S. Geological Survey. The scientists studied watersheds only in the 48 **contiguous** States. Those large watersheds each contain many smaller watersheds (**figure 6**). The scientists studied 15,272 watersheds contained within the 18 watersheds. Map by Lindsay Gnann.

With information based on regions of the country, scientists and managers will have a better idea what and where are the greatest threats to U.S. water quality.

Reflection Section



Why might understanding the nonpoint source water pollution threat by U.S. watershed region be helpful to those trying to better understand water pollution?

In the years since passage of the Clean Water Act of 1972, one type of threat to water quality has not been adequately addressed. Explain in your own words why it is difficult to identify and address nonpoint source pollution.

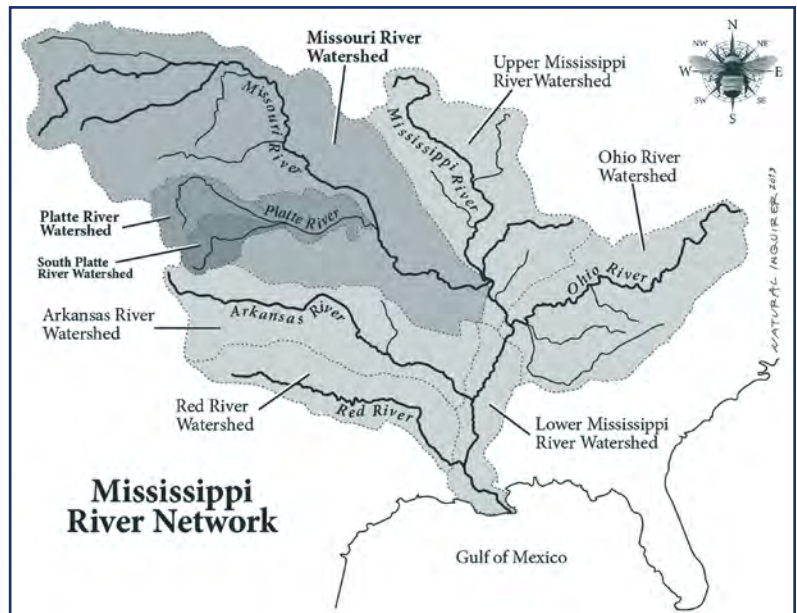


Figure 6. Each large watershed contains many smaller, nested watersheds. Illustration by Stephanie Pfeiffer.

Methods

The scientists studied three problems affecting water quality. These problems were sediment, nutrients, and toxic chemicals (**figure 7**). Then, scientists considered each of these problems and some of their contributing factors (**figure 8**).

Problem	Description
Sediment	Sediment contains soil particles carried along in streams and rivers. Some particles settle to the bottom of streams, reservoirs, lakes, canals, and pipes. Some particles move with the current. All rivers naturally receive and carry sediment. Too much erosion, however, can cause too much sediment to enter waterways. Too much sediment decreases water clarity and may carry attached nutrients, toxic chemicals, and other pollutants. Too much sediment reduces drinking water quality and makes water more expensive to treat.
Nutrients	Nutrients found in water are primarily nitrogen and phosphorus. These nutrients are essential for aquatic plant life. If too much nitrogen and phosphorus are found in waterways, however, they begin to destroy water quality. Too much nutrient content causes too much algae growth and reduces water clarity. Too much nutrient content also reduces the amount of oxygen in the water, which fish and other organisms need to live.
Toxic chemicals	These chemicals cause damage to plants and animals. These toxic chemicals include heavy metals such as mercury, lead, cadmium, and arsenic. Toxic chemicals may be contained in pesticides and herbicides , industrial chemicals, medical chemicals, and some acids. Mining and abandoned mines are often sources of toxic chemicals.

Figure 7. The three problems of sediment, nutrients, and toxic chemicals are responsible for 60 percent of water quality problems in U.S. rivers and streams.

Contributing Factor	Measurement	Problem		
		Sediments	Nutrients	Toxics
Housing density	Housing units per square kilometer in year 2000	X	X	X
Road density	Meters of road and railroad per square kilometer of watershed land	X		X
Agriculture	Percent of watershed area in agricultural land cover	X	X	X
Livestock grazing	Livestock animals per square kilometer in year 2007	X	X	
Confined animal feeding	Livestock animals per square kilometer in year 2007		X	X
Mining land cover	Percentage of watershed in mining land cover	X		
Potentially toxic mines	Total number of active and inactive mine sites potentially yielding toxics per 1,000 square kilometers of watershed			X
Potentially damaging wildfire	Percentage of area with a high risk of losing key ecosystem components, such as trees and other vegetation, in a wildfire	X		
Atmospheric deposition	Average yearly deposition in kilograms per hectare of nitrates and sulfates in wet atmospheric deposition (acid rain) in years 2000 through 2006		X	X

Figure 8. Each water quality problem was associated with a number of contributing factors. In some instances, the same factor contributed to more than one problem. The scientists measured the contributing factors in all 15,272 watersheds.

How Do You Compare the Metric System With the U.S. Imperial System?

This chart will help you understand how the metric system compares with the U.S. imperial system. Scientists take and report their measurements using the metric system.

Metric System	Multiplied by	U.S. Imperial System
Meters	1.094	= Yards
Kilometers	0.6214	= Miles
Kilograms	2.205	= Pounds
Square kilometers	0.3861	= Square miles

The scientists used existing data to represent each contributing factor. These data had been collected and recorded by other scientists. For example, the U.S. Census Bureau collects information about the number of housing units per square mile for census regions. The Census Bureau posts this information on its Web site. When necessary, the scientists changed these and other data

from the U.S. imperial system to the metric system. You can see, however, that these contributing factors did not have the same measured value (see figure 8).

The scientists changed the contributing factor measurements to a common unit of value for each watershed. For each contributing factor in figure 8, the scientists divided the range of value into five equal categories, with each category representing 20 percent of the range. (See “Thinking About Science” for more information.) The scientists assigned a number from 1 to 5 for each measurement, depending into which of the 5 percentiles the measure fell. This number gave the scientists a common measure for all contributing factors. In this way, the scientists were able to compare and combine the contributing factors with one another.

The scientists calculated a single score for all the contributing factors in the 15,272

watersheds. This single score enabled the scientists to identify the water pollution risk level, based on all the contributing factors, for each of the 15,272 watersheds.

Reflection Section



- What are the basic sources of the three water quality problems? (Hint: Look at the contributing factors in figure 8.)
- Observe the different measured values used for the different contributing factors in figure 8. As you can see, these different measured values could not be added together. Think about converting each of these measures to 1 of 5 percentiles. What is lost when this kind of standardization process is used? (Hint: Review figure 1 in “Thinking About Science” on page 27.)

Findings

The scientists created a map showing the threat to water quality for each contributing factor in the 15,272 watersheds across the United States. They also combined all the contributing factors and created a map showing the overall threat to water quality for the 15,272 watersheds in the 48 contiguous States (figure 9).

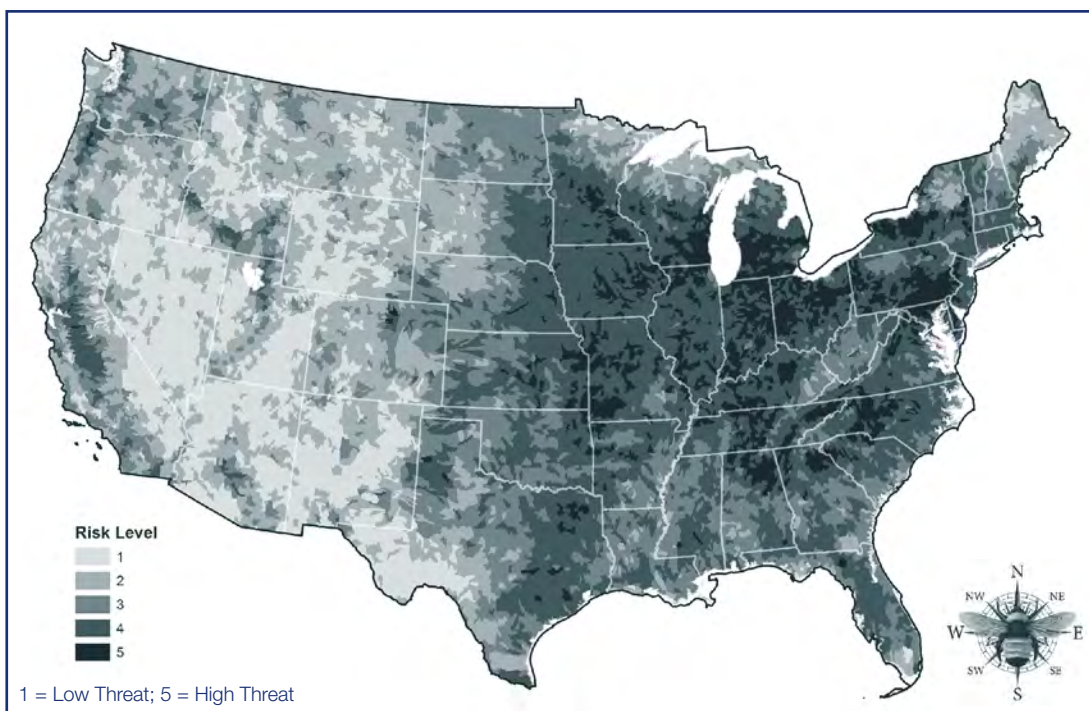


Figure 9. The overall threat to water quality across 15,272 watersheds in the 48 contiguous States in the United States. Map by Pam Froemke.

The scientists observed that water quality threats are greater in the Eastern United States than in the Western United States. The East, however, does contain some low-threat areas. These eastern low-threat areas include Michigan's Upper Peninsula, Minnesota's northern lake country, northern Maine, and the Florida Everglades. (Locate these areas in figure 9 or on another United States map.)

The West contains some high-threat areas. Most of the West, however, has a low water-quality threat. Western areas with high threat include large agricultural areas, urban areas, and places with a combination of urban and agricultural land. (Locate and identify one western urban area in figure 9.) The scientists observed that the United States' water-quality threat level is roughly divided at the 100th meridian.

Reflection Section



- ❖ Look closely at figure 9 and locate the area where you live. What is the nonpoint source water pollution threat level for your area? How does the threat level compare with other areas? Based on what you have read in this article and other things you know about your area, explain why the threat level is where it is.
- ❖ Observe the locations of the Eastern United States' low-threat areas. Name one difference between the Florida Everglades and the other locations.
- ❖ What is similar about all these eastern low-threat areas, including the Florida Everglades?

What Is the 100th Meridian?

The 100th meridian is an imaginary line with a longitude of 100° west. Imaginary lines are drawn between the north and south poles of Earth to indicate longitude (**figure 10**). Longitude is measured from 0 to 180° east and 0 to 180° west of the prime meridian. The prime meridian runs through Greenwich (**grə nich**), United Kingdom.

In the United States, the 100th meridian passes through North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Roughly half of the country lies east of the 100th meridian and half lies west. The 100th meridian has traditionally been considered the dividing line between the moist eastern half of the United States and the dry western half. The 100th meridian is also the rough dividing line between the more populated Eastern United States and less populated Western United States.

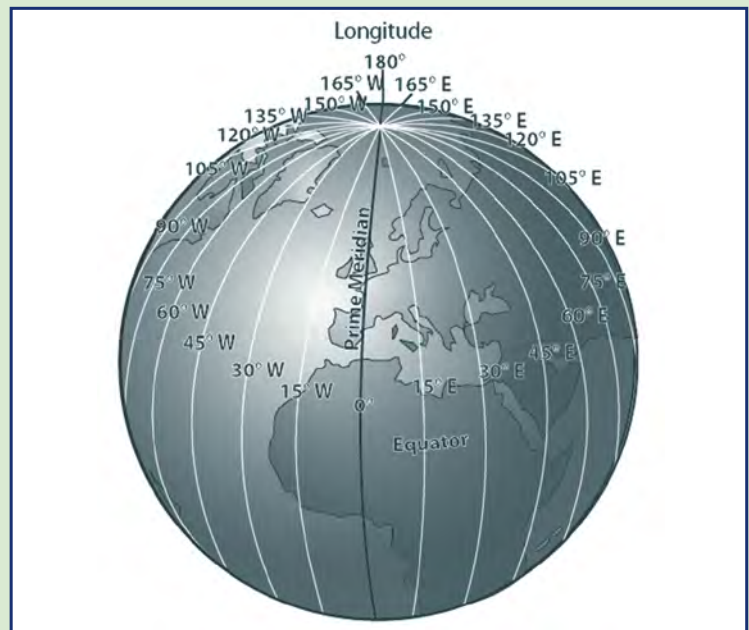


Figure 10. Longitude consists of imaginary lines and provides a way to identify exact locations east and west across the planet. Longitude is measured from the Prime Meridian, located in the United Kingdom. The Prime Meridian has a longitude of 0. Illustration by Samantha Bond.

Discussion

The scientists noted the importance of the division at the 100th meridian. When colonists settled the United States, the wetter, gentler **topography** of the Eastern United States was more supportive of human **habitation** and livestock grazing than other parts of the United States. Over time, a larger population led to greater demand for electricity and other resources, and to increased acid rain. These demands for natural resources, as well as urban growth and changing land uses, created more nonpoint source threats to water quality in the Eastern United States.

The much steeper and drier Western United States was less supportive of human habitation. Fewer people, along with less water and steeper topography, created an opportunity to protect large areas of western land. These protected areas include national forests, national parks, wildlife refuges, and other Federal and State-owned

lands (**figure 11**). Steep topography, limited water, and large areas of protected land further limited population growth. Lower human population density resulted in fewer demands on natural resources and therefore in lower nonpoint source water pollution threats in the West.

The threat of nonpoint source water pollution is expected to rise if human population continues to rise. The human need for agriculture, housing, roads, and livestock feeding and grazing raises the importance of addressing nonpoint source water pollution threats. The Clean Water Act recognized that both point source and nonpoint source pollution are threats to water quality. The act, however, only requires the control of point source pollution. The scientists noted that progress on controlling nonpoint source pollution will require more effort and energy, and may even include more direction from Congress.

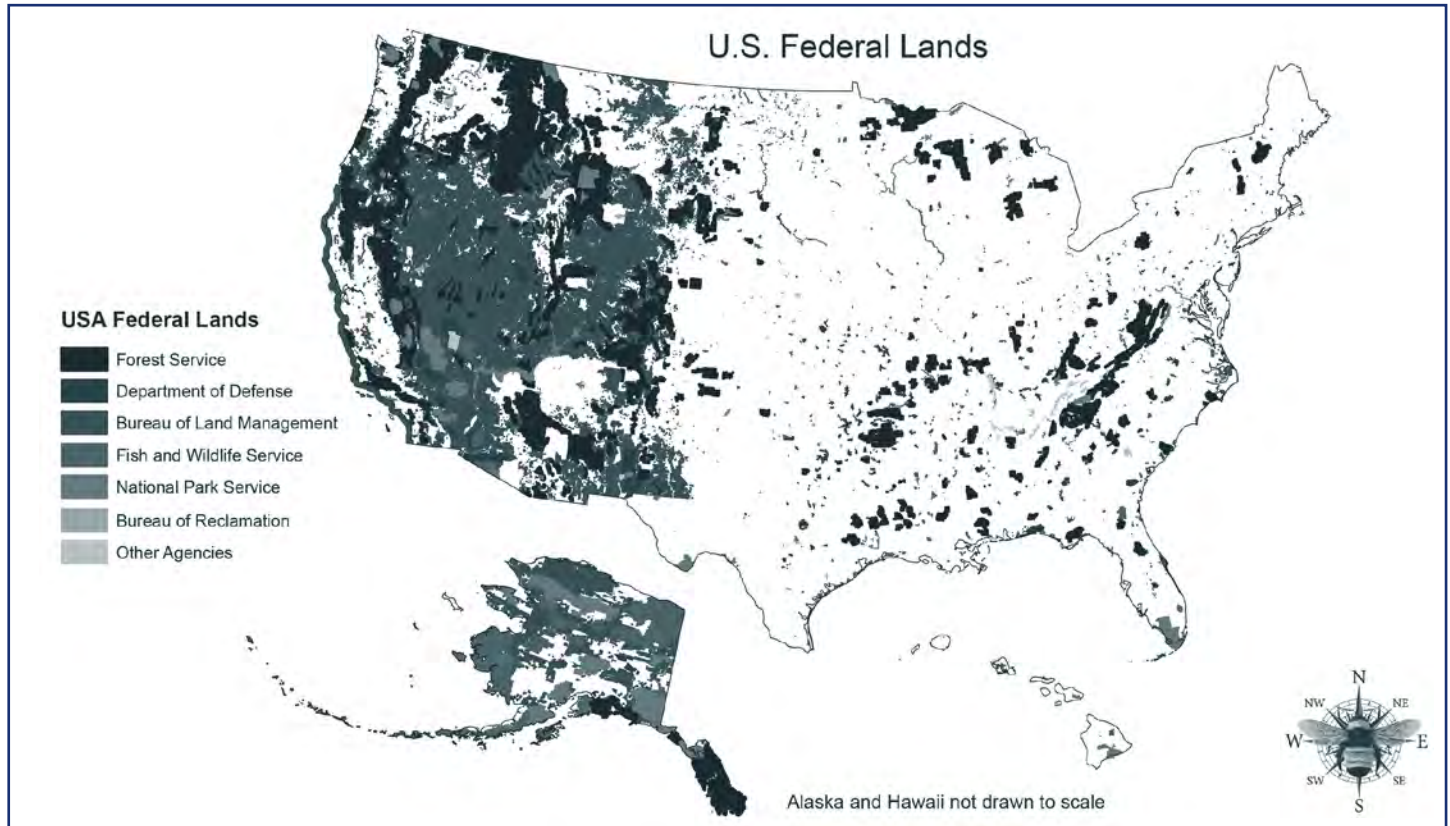


Figure 11. Federal lands, found mostly in the Western United States, are in a natural condition with limited human development. Map by Lindsay Gnaan.

Reflection Section



🍁 Federal and State lands help to protect water resources because they limit human development. Name two other natural resources that are usually protected by Federal and State lands.

🍁 Think about the Clean Water Act. If population continues to rise as expected, what actions might help protect Americans from a reduction in water quality?

Glossary

aquatic (ə kwä tik): (1) Living or found in, on, or near water; (2) of or relating to the animals or plants that live in, on, or near water.

contiguous (kən ti gyü wəs): Used to describe things that touch each other or are immediately next to each other.

density (den(t) sə tē): The average number of individuals or units per space unit; for example, a housing density of 10 houses per acre.

deposition (de pə zi shən): The action of depositing something (such as sand, snow, or mud) on a surface or area, especially over a period of time.

diffuse (di fyüs): Spread out over a large space; not concentrated in one area.

effluent (ə flū ənt): Liquid that is released as waste.

emission (ē mi shən): Something discharged or sent out.

erosion (i rō zhən): The process or state of wearing or washing away.

habitation (ha bə tā shən): Living in a place.

herbicide (hər bə sīd): A substance that destroys plants or prevents plant growth.

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

pesticide (pes tə sīd): A substance that is used to kill animals or insects that damage plants or crops.

pollutant (pə lü tənt): (1) A substance that makes land, water, air, etc., dirty and not safe or suitable to use; (2) Something that causes pollution.

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

standardize (stan dər dīz): To change (things) so that they are similar.

suburb (sə bərb): A town or other area where people live in houses near a larger city.

topography (tə pä grə fē): Physical features that make up an area and include mountains, valleys, plains, and bodies of water.

variable (ver ē ə bəl): Something that is able or apt to vary.

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.



Time Needed

One class period

Materials

- Graph provided in the FACTivity
- Blank paper for calculations
- Pencil

The questions you will answer in this FACTivity are: How do standardized units of measurement help scientists to answer questions? What are the advantages of using percentiles to standardize measurements? What are the disadvantages of using percentiles to standardize measurements?

Methods

Use figure 13 on page 40 and the graphic organizer (figure 12) on page 37 to answer the questions at the beginning of this FACTivity.

Look closely at figure 13. Notice the percentiles in the top bar. Then look at the next two bars.

The second bar shows the average number of clear days in each State over a year's period. The third bar shows the average percent of each State's surface waters (lakes, rivers, streams, and reservoirs) that contain clean water. The average number next to each State represents the alphabetical order of the State. The average number of clear days a year in Alabama (99), for example, is shown on the line at "99" with a "1." Review figure 1 on page 27 to help you understand figure 13.

If you do not understand figure 13, ask your teacher for help. It is important that you understand figure 13 to do the remainder of the FACTivity.

Pretend that you are a scientist interested in answering this question: What are the five least and five most desirable States for water-based outdoor recreation? Water-based outdoor recreation includes activities like swimming, boating, fishing, water skiing, and paddle boarding. You have determined that a combination of 4 variables will enable you to identify these 10 States.

The 4 variables are:

- The number of clear (cloudless) days in a year
- The average yearly air temperature in degrees Fahrenheit
- The percent of the State's area that has clean surface water
- The percent of the State's surface waters (lakes, rivers, streams, and reservoirs) with reported pollution problems

Most desirable States for water-based outdoor recreation will have more clear days, a higher average air temperature, a larger percent of their area with clean water, and a lower percent of surface waters with reported pollution problems.

To determine the five least and five most desirable States for water-based outdoor recreation, you need to sum the values for the 4 variables listed above. The units of measurement for these 4 variables are not the same. To sum the values, you will need to standardize the units of measurement. If you need more explanation, reread "Thinking About Science" on page 27.

In figure 13, the number of clear days and the percent of the State's area with clean water have already been standardized using the method described in figure 1 on page 27.

Using the two blank portions of the graphic organizer, plot the value for each State for the remaining two variables. You will find the variables in figure 13 on page 40. Write the number representing each State above the area on figure 13 that shows the State's value. For example, for the average annual air temperature for Alabama, find the place on figure 13 that shows 63 degrees, and write a "1" above it. For Idaho, find the place on figure 13 that shows 44 for the average annual air temperature, and write a "12" above it.

After you have plotted all 100 values, take a ruler and draw lines from each percentile mark in the top bar through all 4 graphs.

Using figure 13 on page 40, write the score from 1 to 5 on the graphic organizer below for each State for each variable.

Then, sum the four values for each State and write the value in the right-hand column. Locate the States with the lowest four values and the States with the highest four values. Write these State names at the bottom of the graphic organizer on page 39.

What do you notice about the positions of the data points on each bar? From what you know of the United States, do the 10 States' rankings make sense, based on the standardized data? Why or why not?

Now answer the questions posed at the beginning of this FACTivity.

State	Percent of Surface Water With Problems	Average Yearly Air Temperature in Degrees Fahrenheit	Standardized Percentile Score (1 to 5)				Total State Score
			Percent of Surface Water With Problems	Average Yearly Air Temperature	Number of Clear Days In a Year	Percent of State With Clean Surface Water	
1. Alabama	14	63					
2. Alaska	Not Available	27					
3. Arizona	1	60					
4. Arkansas	4	60					
5. California	15	59					
6. Colorado	3	45					
7. Connecticut	30	49					
8. Delaware	49	55					
9. Florida	18	71					
10. Georgia	12	64					
11. Hawai'i	5	70					
12. Idaho	8	44					
13. Illinois	7	52					
14. Indiana	14	52					
15. Iowa	6	48					
16. Kansas	12	54					

State	Percent of Surface Water With Problems	Average Yearly Air Temperature in Degrees Fahrenheit	Standardized Percentile Score (1 to 5)				Total State Score
			Percent of Surface Water With Problems	Average Yearly Air Temperature	Number of Clear Days In a Year	Percent of State With Clean Surface Water	
17. Kentucky	10	56					
18. Louisiana	22	66					
19. Maine	9	41					
20. Maryland	26	54					
21. Massachusetts	18	48					
22. Michigan	7	44					
23. Minnesota	3	41					
24. Mississippi	71	63					
25. Missouri	4	55					
26. Montana	11	43					
27. Nebraska	5	49					
28. Nevada	3	50					
29. New Hampshire	17	44					
30. New Jersey	42	53					
31. New Mexico	3	53					
32. New York	8	45					
33. North Carolina	18	59					
34. North Dakota	8	40					
35. Ohio	14	51					
36. Oklahoma	10	60					
37. Oregon	13	48					
38. Pennsylvania	15	49					
39. Rhode Island	21	50					
40. South Carolina	63	62					
41. South Dakota	3	45					
42. Tennessee	22	58					
43. Texas	5	65					
44. Utah	4	49					
45. Vermont	15	43					

State	Percent of Surface Water With Problems	Average Yearly Air Temperature in Degrees Fahrenheit	Standardized Percentile Score (1 to 5)				Total State Score
			Percent of Surface Water With Problems	Average Yearly Air Temperature	Number of Clear Days In a Year	Percent of State With Clean Surface Water	
46. Virginia	13	55					
47. Washington	3	48					
48. West Virginia	14	52					
49. Wisconsin	5	43					
50. Wyoming	2	42					
The Five Most Desirable States for Water-Based Outdoor Recreation			The Five Least Desirable States for Water-Based Outdoor Recreation				

Figure 12. State values and standardized scores with associated number.

Draw a brochure for one of the most desirable States using the information from the chart. In your brochure design, be sure to clearly illustrate why the State is considered one of the most desirable for water-based outdoor recreation.

Web Resources

U.S. Environmental Protection Agency: Water Is Worth It
<http://water.epa.gov/action/cleanwater40/>

Tennessee Valley Authority: Kids' Guide to Protecting Water
<http://www.tvakids.com/environment/cleanwater.htm>

Happy Birthday Clean Water Act! Wisconsin Environmental Education for Kids (EEK!)
<http://dnr.wi.gov/org/caer/ce/eeek/earth/cleanWaterActBirthday.htm>

U.S. Environmental Protection Agency: Nonpoint Source Pollution
<http://water.epa.gov/polwaste/nps/>

If you are a trained Project Learning Tree educator, you may use "Pollution Search" and "Watch on Wetlands" as additional resources.



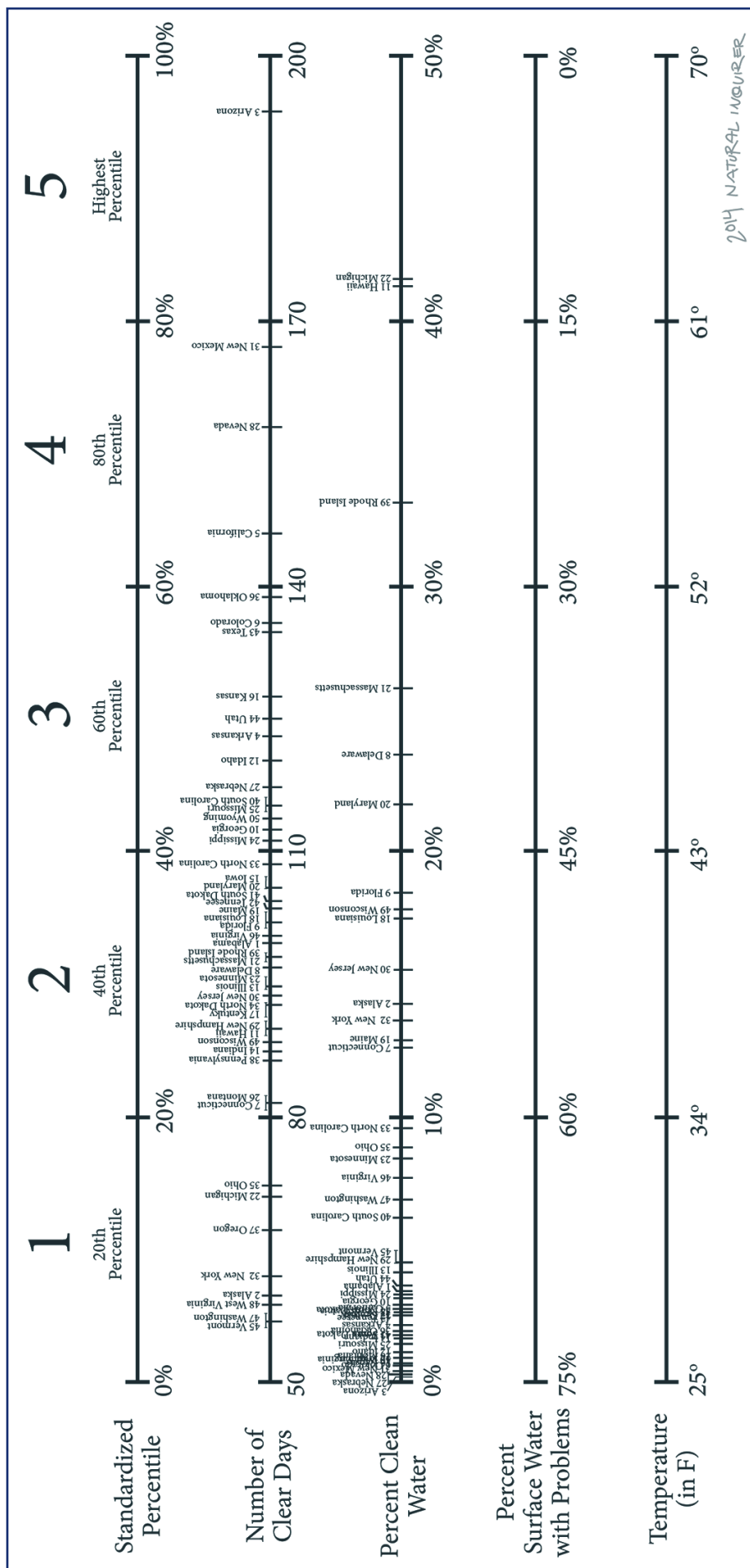


Figure 13. Graph of five variables for determining the most and least desirable States for water-based outdoor recreation.

The following States are listed in the above graph, in "Percent Clean Water," from 0 to 10 percent:

Alabama, Arizona, Arkansas, California, Colorado, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, West Virginia, and Wyoming.

Thirty-six States are listed in this first percentile. What does this number of States tell you about the percentage of clean surface water in the United States?

Hint: Use a magnifying glass to make it easier to read the State names.

Caribbean Cruise:

Examining the Amount and Quality of Organic Matter Over Time From Two Caribbean Watersheds

Photo courtesy of Tamara Heartsill Scalley

Meet the Scientists

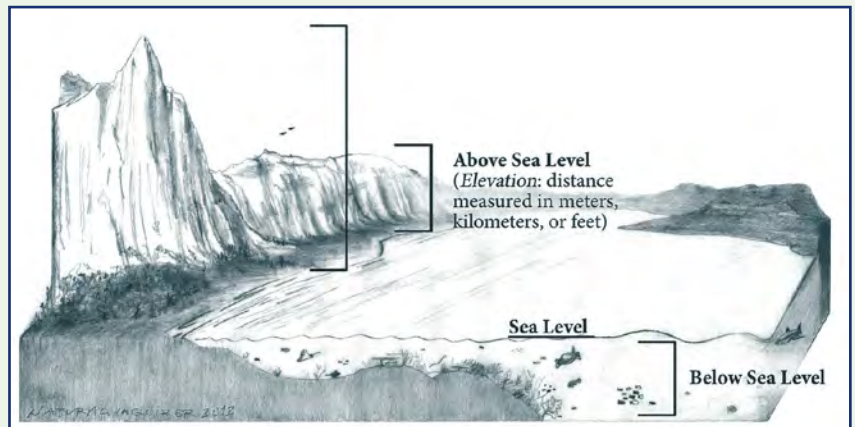


◀ **Dr. Tamara Heartsill Scalley, Ecologist:** One of my favorite experiences was sampling for aquatic **fauna** in the headwater streams at the highest elevations of the Luquillo (lū kē ō) Experimental Forest. The Elfin Cloud Forests have many small streams. Every surface is dripping wet, covered in all kinds of **bryophytes**, and the air is cool and humid. These tiny streams have small pools where the modified minnow traps that we used for sampling barely fit. The streams were full of life—with very high densities of filter feeder shrimp such as *Atya lanipes*.

These streams were the headwaters where streams first emerge from the ground at the highest elevation possible in the forest (**figure 1**). It was a pleasant surprise, because

we did not expect many shrimp to be in those pools at the top of the mountain where the river system begins. These shrimp are diadromous (dī a drə mās). Diadromous means that they came up the mountain by swimming upstream from the coast, where they were in the ocean saltwater. The shrimp swim and crawl to the highest elevation possible in this mountain stream system.

Figure 1. Observe the change in elevation. Illustration by Stephanie Pfeiffer.

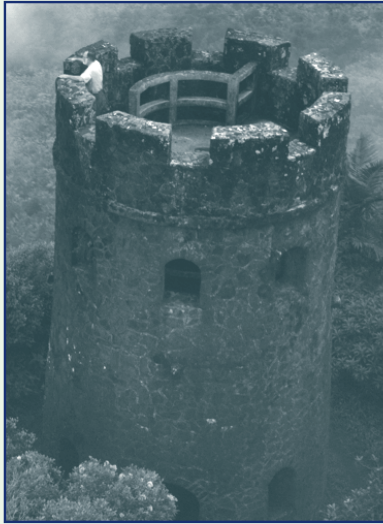


◀ **Mr. Samuel Moya, Biologist:** My favorite science experience is installing new scientific equipment and sensors on experimental sites. New sensors allow me to see more accurate results using graphics and **statistical** methods.

Meet the Scientists

► **Dr. Ariel Lugo**, Tropical Ecologist: My favorite science experience is interacting with other scientists and debating about science.

In this photo, Dr. Lugo is on Mount Britton Tower. Mount Britton Tower is an observation tower located at high elevation in the middle of the El Yunque (**yūn kā**) National Forest. Cloud cover usually **obscures** the view from the tower. The tower is named after Nathaniel Lord Britton (botanist) and his wife, Elizabeth G. Knight Britton (bryologist). The Brittons spent time doing research in Puerto Rico in the early 1900s. A botanist studies plants.



A bryologist is a type of botanist who studies plants like moss, liverworts, and hornworts (**figure 2**). Through the New York Botanical Gardens and the New York Academy of Sciences, the Brittons published the *Scientific Survey of Puerto Rico* in the 1920s.



Figure 2. Moss is growing in the forest. Photo courtesy of Jessica Nickelsen.

Glossary words are **bold** and are defined on page 54.

What Kinds of Scientists Did This Research?

biologist: This scientist studies living organisms and living systems.

ecologist: This scientist studies the relationships of living things with each other and the nonliving environment.

tropical ecologist: This scientist studies the relationships of living things with each other and the nonliving environment in tropical regions. Tropical regions are areas located between the Tropic of Cancer and the Tropic of Capricorn (**figure 3**).

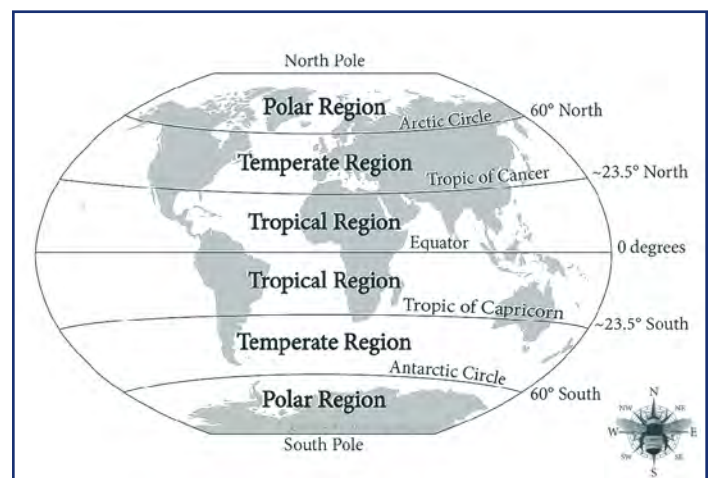
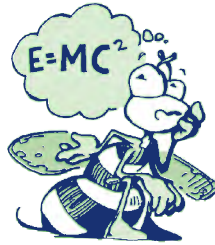


Figure 3. Tropical regions are areas located between the Tropic of Cancer and the Tropic of Capricorn. Illustration by Stephanie Pfeiffer.

Thinking About Science

Sometimes it is useful for scientists to study something over a long period of time. The Forest Service created 81 experimental forests and ranges with this idea in mind (**figure 4**). The Forest Service started setting up these experimental areas in 1908. Most of the experimental areas are at least 50 years old. These areas are useful for scientists because they provide scientists with the opportunity to observe and conduct experiments in an area over a long period of time.

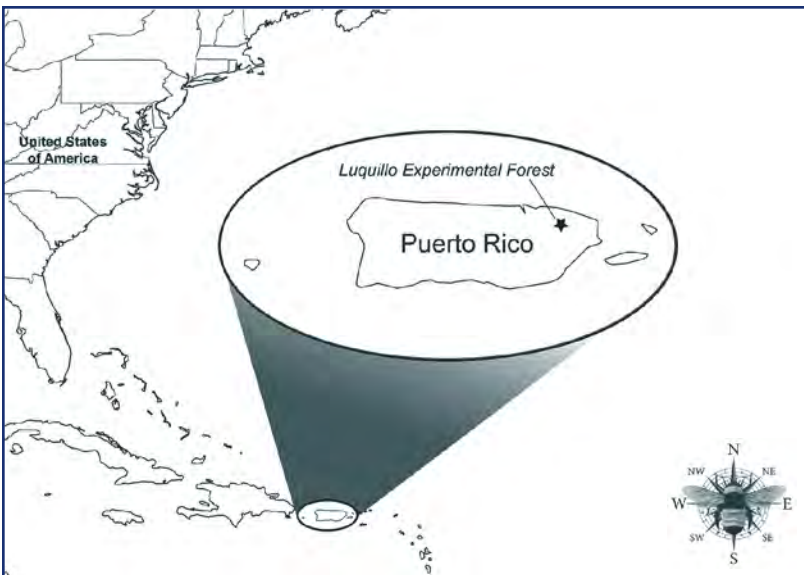
When scientists are able to gather information over several years, they can gain a better idea of what is happening in the area. For example,



think about a time in school when a student does not give his or her best effort with schoolwork. Then the student has several years in which he or she gives his or her best effort. If the student were given a choice to be evaluated over the short time period when they didn't give their best effort or the longer time period, the student would want to be judged on the schoolwork done over the longer period of time. The longer time period would provide better information about the student. Similarly, scientists gain a deeper understanding of what is happening when they can review several years of data. Scientists are also able to identify **trends** in the data this way. In this article, you will learn about an experimental forest located in Puerto Rico (**figure 5**).



Figure 4. Experimental forests and ranges can be found throughout the United States. Find the one closest to where you live. Map by Carey Burda.



Number Crunches



The first experimental forest was Fort Valley Experimental Forest in Arizona. It was established in 1908. How many years old is the experimental forest today? How many decades old is the experimental forest?

Figure 5. Puerto Rico is a territory of the United States located in the northeast Caribbean Sea. Map by Carey Burda.

Thinking About the Environment



A watershed is the area that drains to a common waterway, such as a stream, lake, estuary, wetland, aquifer, or even the ocean (**figure 6**). Understanding the activities that occur within watersheds and the location of the watershed is important. The activities and location can affect the watershed's water quality.

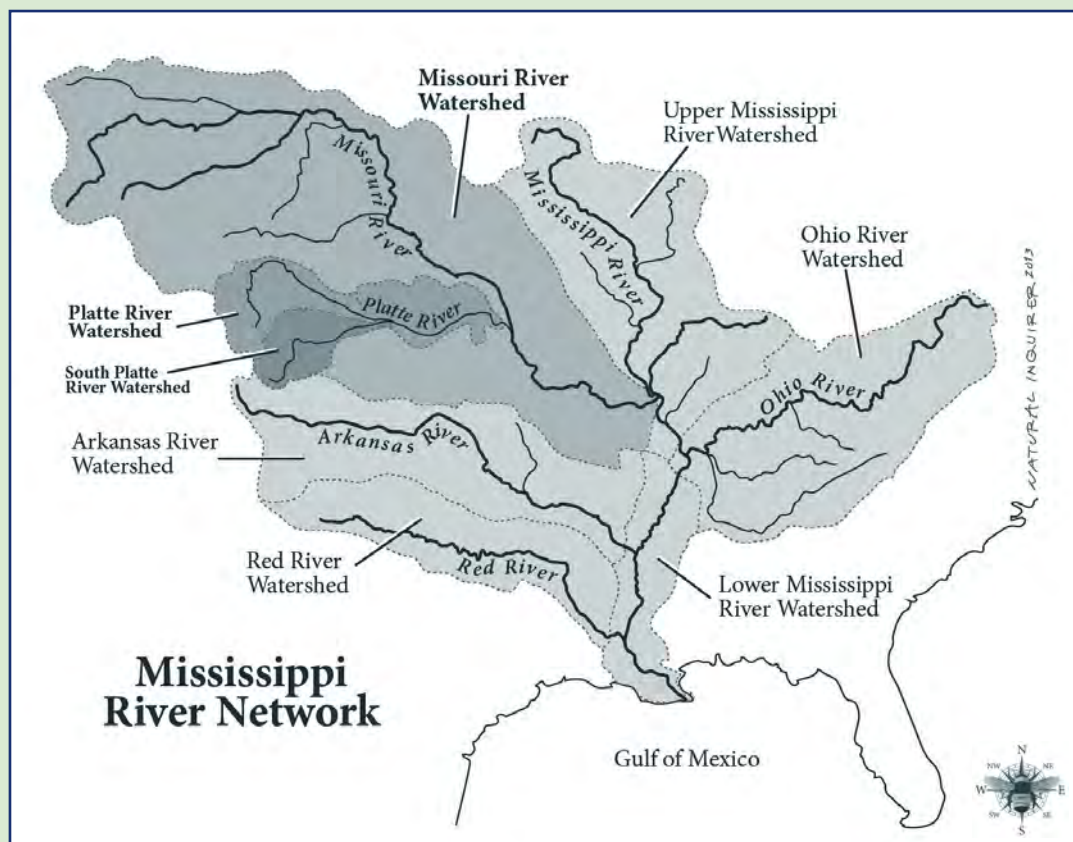


Figure 6. A watershed is the area that drains to a common waterway, such as a stream, lake, estuary, wetland, aquifer, or even the ocean. Illustration by Stephanie Pfeiffer.

In this research, scientists studied two watersheds in Puerto Rico. The watersheds are located in tropical forests. Tropical forests are unique because they are located near the Equator (**figure 7**). These forests have a high degree of **biodiversity** and are characterized by a lack of a winter and the occurrence of only two seasons: a wet season and a dry season. In particular, the **drainage** areas for the watersheds the scientists studied are located in a tabonuco (tä bə **nü** kō) forest. This type of forest has tall trees and very little light reaches the forest floor. The tabonuco tree (*Dacryodes excelsa*) **dominates** the tabonuco forest. The tabonuco tree can grow up to 100 feet tall (**figures 8a and 8b**).



Figure 7. The Equator is an invisible line around the middle of planet Earth. It is located at zero degrees latitude. The Equator divides the planet into the Northern and Southern Hemispheres. Illustration by Stephanie Pfeiffer.

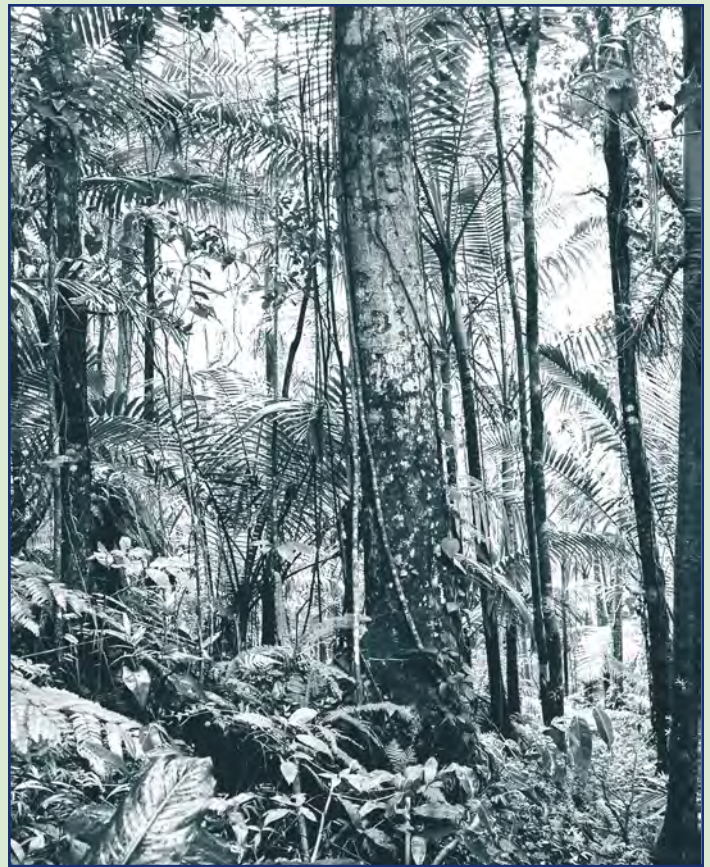


Figure 8a. The tabonuco tree can grow up to 100 feet tall. In Puerto Rico, the tabonuco tree is found mostly in lower elevations of mountainous areas. Photo courtesy of Jerry Bauer.



Figure 8b. The tabonuco tree oozes sap. Photo courtesy of Jerry Bauer.

Number Crunch



How tall can the tabonuco tree grow in meters? (Hint: 1 foot = 0.3048 meters.)

Introduction

The scientists chose to study two of the Bisley Experimental Watersheds in the Luquillo Experimental Forest (**figure 9**). Luquillo Experimental Forest shares its boundaries with El Yunque (ū(ng) kā) National Forest. Because the watersheds are located within the Luquillo Experimental Forest, the scientists could observe and record how things changed over a long period of time. For this research, the scientists studied particulate **organic** matter (POM).

POM consists of small pieces of twigs, leaves, soil, and other items found in the water (**figure 10**). POM measurements are important for several reasons. For example, POM is a source of food and energy for many animals. POM keeps some environmental pollutants out of the water by binding heavy metals and **pesticides**. POM also serves other roles in an **ecosystem** such as being an important part of the food web. POM is a part of the **decomposition** process of the food web (**figure 11**).

In this research, the scientists examined the amount and types of a particular type of POM called **coarse particulate organic matter** (CPOM). CPOM is the pieces of organic

material that falls into or is carried into the river. CPOM is generally greater than 1 millimeter (mm) in size. Examples of CPOM are leaves, sticks, and other pieces of plant material. Because CPOM is an important component of an ecosystem and food webs, the scientists wanted to figure out how the amount and quality of CPOM changed over a period of time.

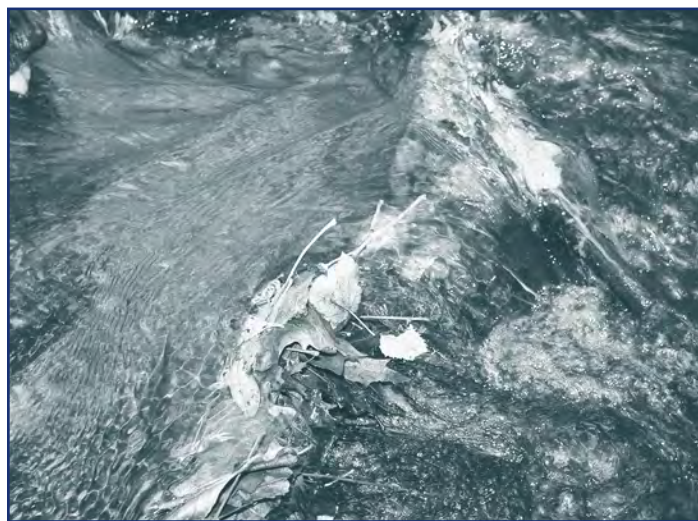


Figure 10. Particulate organic matter (POM) is an important component of an ecosystem and the food web. Photo courtesy of Babs McDonald.

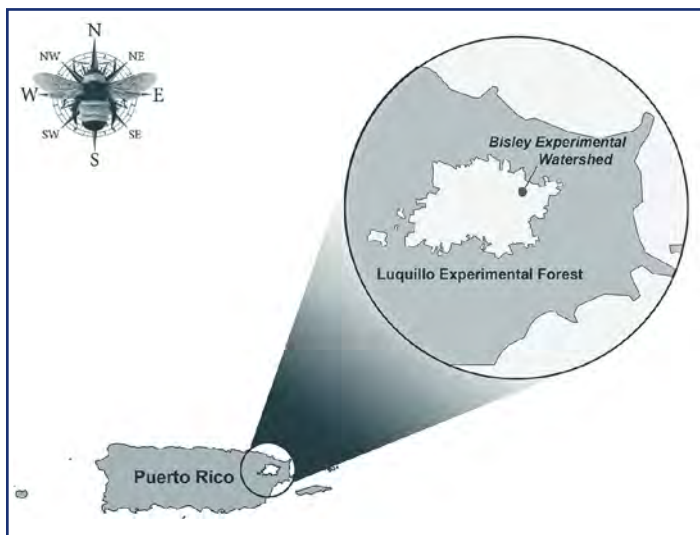


Figure 9. Bisley Experimental Watersheds are located in the Luquillo Experimental Forest. Map by Carey Burda.

Reflection Section



- ❧ In your own words, what is the question the scientists wanted to answer in this study?
- ❧ The scientists studied two watersheds in the experimental forest. What is one reason the scientists wanted to study two watersheds instead of only one watershed?

Number Crunch

- ❧ CPOM is generally greater than 1 mm in size. Is 1 mm smaller or larger than 1 inch? How do you know?

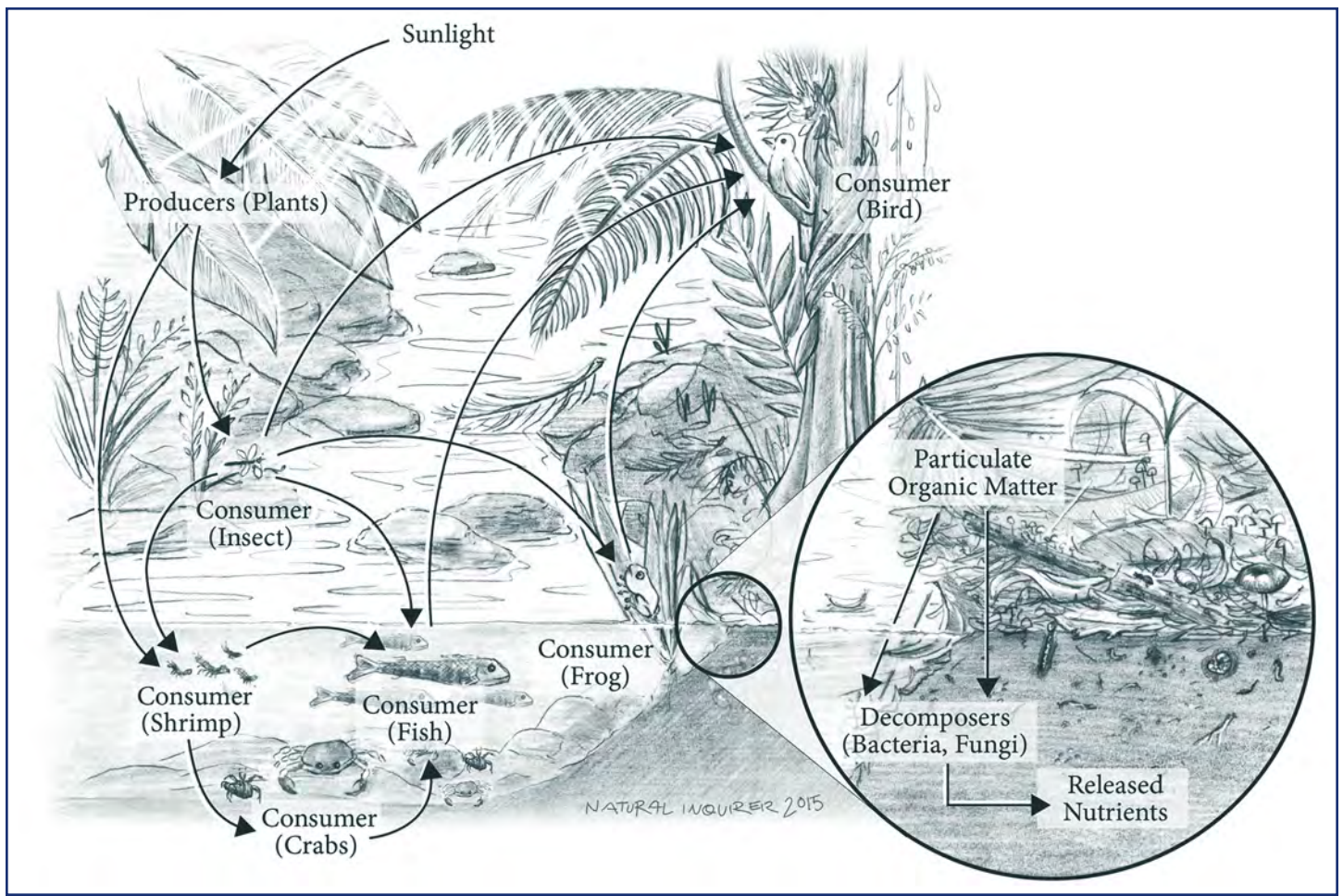


Figure 11. Particulate organic matter (POM) is part of the decomposition process of the food web. Illustration by Stephanie Pfeiffer.

Methods

The scientists collected data from the two watersheds from 1987 to 2005. The scientists collected mean annual rainfall, size of watershed area, stream channel length, as well as dates of hurricanes and other natural disturbances, such as drought (**figure 12**).

The scientists wanted to know how much CPOM was being **exported** from the watersheds. After CPOM is in the water, it undergoes some amount of decomposition. The amount that actually leaves the watershed is the amount that is exported. From 1987 to 2005, scientists collected CPOM that was trapped in metal mesh traps that they placed in the streams.

The scientists collected CPOM every other Tuesday and following large storms. The metal

mesh traps were placed across the stream channels (**figure 13**). Scientists tested several mesh traps and sizes from 1987 to 1989. These test traps broke during periods of high water flow. Since 1989, however, the traps the scientists designed did not break. These traps recorded accurate measurements of CPOM by collecting all the CPOM going into the trap.

The scientists also completed chemical **analysis** on some of the samples to see what kinds of elements were in the CPOM. Elements are important to both living and nonliving things. For example, approximately 96 percent of the human body is made up of four elements: carbon, oxygen, hydrogen, and nitrogen. In this study, the scientists measured elements such as carbon, nitrogen, phosphorus, potassium, and calcium in the CPOM.

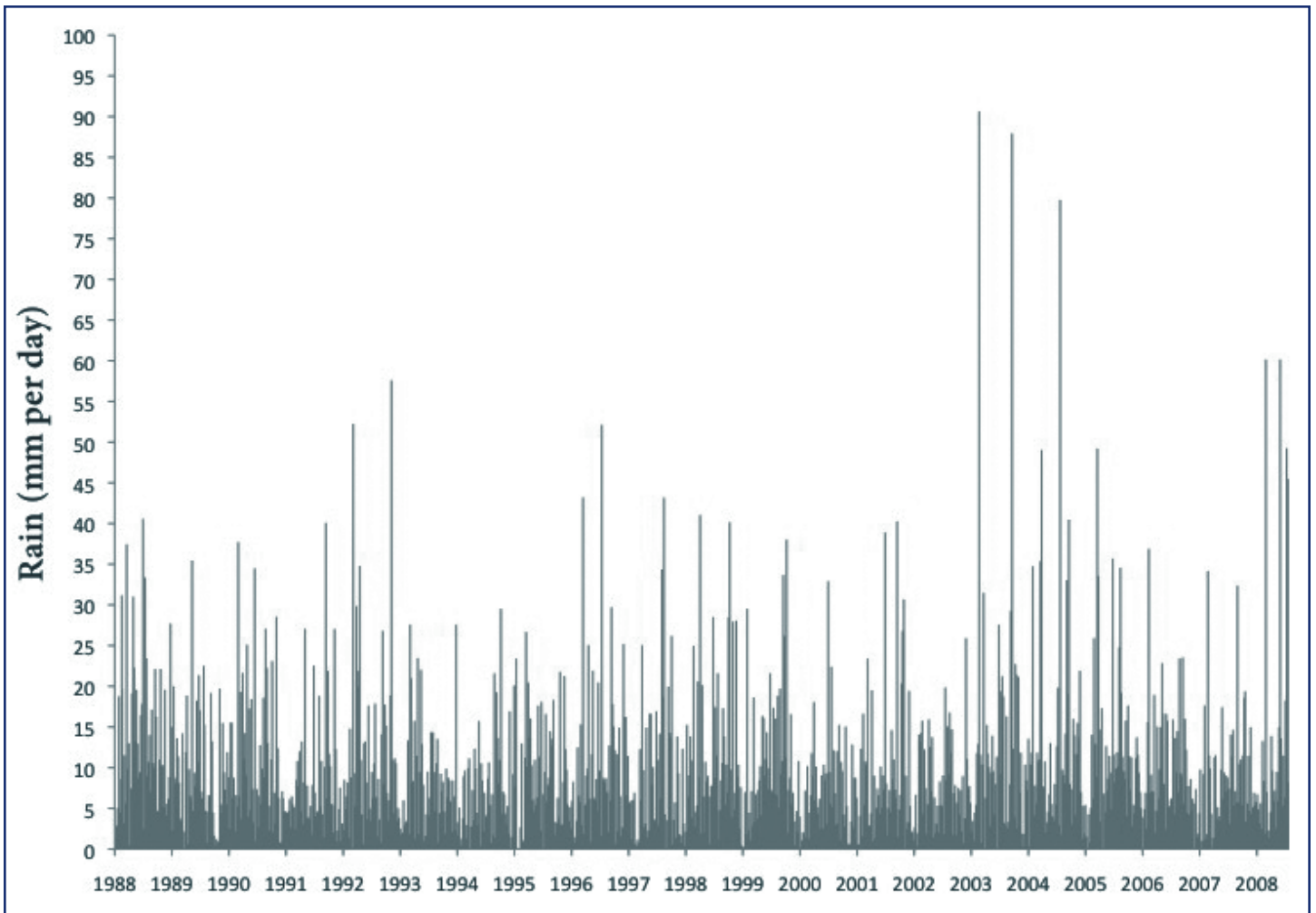


Figure 12. A lot of data change over time. In this graph, you can see what happened to the mean annual rainfall at the study site between 1988 and 2008. Illustration by Stephanie Pfeiffer.



Figure 13. Mesh traps were placed across the stream channels to collect coarse particulate organic matter (CPOM). Photo courtesy of Tamara Heartsill Scalley.

The Periodic Table and Symbols

The periodic table (figure 14) is a table that arranges the chemical elements by atomic number. Each element has a letter or several letters that identify it in a simpler way and is called a symbol. For example, the symbol for carbon is C and the symbol

for oxygen is O. Look at the periodic table and find the symbols for the elements the scientist studied: nitrogen, phosphorus, potassium, calcium, aluminum, magnesium, iron, and manganese.

1 H Hydrogen												2 He Helium					
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton

Figure 14. This table is a shortened form of the periodic table of elements. For a full table, search the Internet for “periodic element table” or look for it in your science book. The complete periodic table contains 118 elements.

Reflection Section



- ✿ The scientists collected CPOM after large storms. Why do you think these collections were a good idea?
- ✿ The scientists had to test several different types of metal mesh traps to collect the CPOM until they found a design that worked. Think of a time that you have tried to make something or do something and it didn't work. What did you do? What are some characteristics that you think are important for scientists to have in order to overcome obstacles? (Hint: Take a look at some of the *Natural Inquirer* scientist cards at <http://www.naturalinquirer.org/scientists-v-92.html>. Look at the back of the cards and read about important scientist characteristics. See if you think any of those characteristics apply to this situation.)

Findings

During the 18-year study period, the scientists found several things. The highest CPOM export through the watershed occurred before and during Hurricane Hugo. The scientists found that other tropical storms and hurricanes after Hurricane Hugo did not create as much CPOM export as during the time of Hurricane Hugo.

Relatively high exports of CPOM were recorded from 1995 to 2000 (figure 15). The greatest export of leaves (which are part of CPOM) occurred during April, May, and September. These months have the most intense rain showers and the greatest number of plants with falling leaves. During this time, the leaves

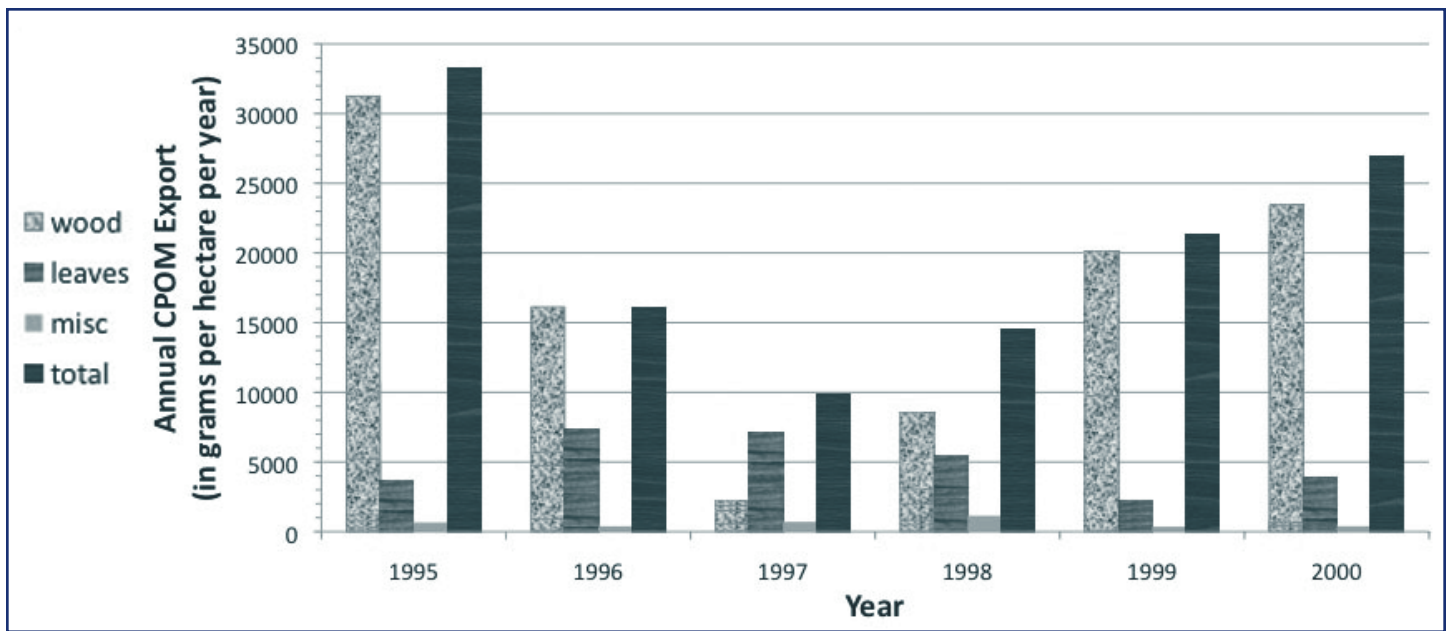


Figure 15. Scientists measured coarse particulate organic matter (CPOM) exports from 1995 to 2000. What do you notice about CPOM export during this time? Graph by Stephanie Pfeiffer.

are mostly falling because of storms, wind, and rain, and they are still green when they fall. Therefore, these leaves have different nutrients and different chemical composition than leaves that fall in the dry season from natural aging.

Low CPOM export occurred during 1990–1991, 1993–1994, and 2000–2002. The lowest amounts of CPOM export were during times of drought. The months of December, January, and February also show low CPOM exports.

Watershed 1 had higher values of potassium than watershed 2. Watershed 2 had higher levels of calcium, magnesium, aluminum, and iron. The scientists found no difference between the two watersheds for levels of nitrogen, phosphorus, and manganese. The scientists thought that the types of leaves and the amount of **decay** that the leaves had undergone may have affected the elements they found in the watersheds.

Reflection Section



- CPOM export was lowest during times of drought. Think about the stream and the surrounding environment during these times. Brainstorm some ideas as to why you think CPOM export could have been low. You may want to research one of your ideas to see what you can find out about it.
- December, January, and February had low CPOM export. Why do you think this low level may have occurred?

Hurricane Hugo

Hurricane Hugo (figure 16), which made landfall in September 1989, created some of the highest stormtide heights that had ever been recorded on the east coast of the United States. Hugo was a category 5 hurricane in the Atlantic Ocean and then became a category 4 storm that went through the Caribbean. Hurricane Hugo had maximum sustained winds of 135 to 140 miles per hour. During that time, Hugo was the strongest storm to hit the United States within a 20-year period, and it created approximately \$7 billion (\$7,000,000,000) in damage (figure 17). To learn more, visit <http://www.weather.gov/chs/HurricaneHugo-Sep1989>.

The Saffir-Simpson Hurricane Wind Scale is a 1-to-5 rating based on a hurricane's sustained wind speed (figure 18). The National Oceanic and Atmospheric Administration explains that "this scale estimates potential property damage. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. Category 1 and 2 storms are still dangerous, however, and require preventative measures."

Figure 17. Pre- and post-Hugo photos at Folly Beach, South Carolina. Photos courtesy of National Oceanic and Atmospheric Administration.



Figure 16. Hurricane Hugo. Photo courtesy of National Oceanic and Atmospheric Administration.



Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74–95 mph 64–82 kt 119–153 km/h	Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding, and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96–110 mph 83–95 kt 154–177 km/h	Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (major)	111–129 mph 96–112 kt 178–208 km/h	Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130–156 mph 113–136 kt 209–251 km/h	Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher 137 kt or higher 252 km/h or higher	Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

mph = miles per hour. kt = knots. km/h = kilometers per hour.

Figure 18. The Saffir-Simpson Hurricane Wind scale. Courtesy of the National Oceanic and Atmospheric Administration.

Discussion

The export of CPOM generally followed a seasonal pattern that was a combination of the monthly rainfall pattern and seasonal patterns for leaves falling from plants and trees. The scientists found that one of the greatest events of CPOM export was during Hurricane Hugo. The scientists also found that tropical storms and hurricanes after Hurricane Hugo did not create as much CPOM as during the time of Hurricane Hugo.

The scientists believe that this finding has to do with the fact that, during Hurricane Hugo, the forest was more mature. A more mature forest means that it is an older forest with larger trees and more growth. After Hurricane Hugo came through, parts of the forest were destroyed and fewer large trees remained. When tropical storms or other hurricanes came through the area after Hurricane Hugo, less

organic material was available to fall and export into the streams. Therefore, the **frequency** and intensity of hurricanes and tropical storms, along with the age of the forest, had a measurable effect on the export of CPOM through the watersheds.

Reflection Section



- ✿ In your own words, what did the scientists learn from their study?
- ✿ Why are natural disasters and other large weather events important to study? What information can they provide for the future management of the natural systems?

Glossary

analysis (ə nā lə səs): A careful study of something to learn about its parts, what they do, and how they are related to each other.

biodiversity (bī ō də vər sə tē): The existence of many different kinds of plants and animals in an environment.

bryophyte (brī ə fīt): Any of a division (Bryophyta) of nonflowering plants comprising the mosses, liverworts, and hornworts.

coarse particulate organic matter (CPOM) (kōrs pār ti kyə lət ōr gā nīk mā tər): CPOM is the pieces of organic material that falls into or is carried into a river. CPOM is generally greater than 1 millimeter (mm) in size. Examples of CPOM are leaves, sticks, and other pieces of plant material.

decay (di kā): To break down, rot, or undergo decomposition.

decomposition (dē kəm pə zi shən): The slow destruction of something (such as dead plants and the bodies of dead animals) by natural processes, chemicals, etc.

dominate (dā mə nāt): To have a prominent place or position.

drainage (drā nij): (1) The act or process of draining something; (2) The act or process of removing water or liquid from a place or thing.

ecosystem (ē kō sis təm): Community of plants and animal species interacting with one another and with the nonliving environment.

export (ek spōrt): To carry away.

fauna (fä nə): All the animals that live in a particular area, time period, or environment.

frequency (frē kwən(t) sē): The number of times that something happens during a particular period.

obscure (äb skyūr): Not clearly seen or easily distinguished.

organic (ōr gā nīk): Of, relating to, or obtained from living things.

pesticide (pes tə sīd): A substance that is used to kill animals or insects that eat plants or crops.

statistical (stə tis ti kəl): Based on statistics, a branch of mathematics that deals with analyzing and interpreting data.

sustain (sə stān): Continuing for an extended period.

trend (trend): A general direction of change.

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.

Adapted from Heartsill Scalley, T.; Scatena, F.N.; Moya, S.; Lugo, A.E. 2012. Long-term dynamics of organic matter and elements exported as coarse particulates from two Caribbean montane watersheds. *Journal of Tropical Ecology*. 28: 127–139. <http://www.treeseearch.fs.fed.us/pubs/41610>.



Time Needed

One class period

Materials

(for each student or group of students)

- Pencil
- Graph paper
- "Caribbean Cruise" article in this *Natural Inquirer* edition

The question you will answer in this FACTivity is: What can you learn from data about gage height and streamflow for a stream for an extended period of time?

Methods

In the article you just read, the scientists examined a variety of different types of data from the Bisley Experimental Watersheds

in the Luquillo Experimental Forest. The table of data provided in the following table is from the Rio Sabana in Luquillo Experimental Forest and El Yunque National Forest. The data have been collected for 33 years. The gage height is the height of the water above zero on the water gage. A water gage is an instrument used to find the depth or quantity of water or to indicate its surface height. Streamflow is the water released from a stream. Streamflow is measured in cubic feet per second. Examine the data in table 1. On the graph paper provided (on page 123), create a graph for either the gage height data or the streamflow data (**figure 19**).

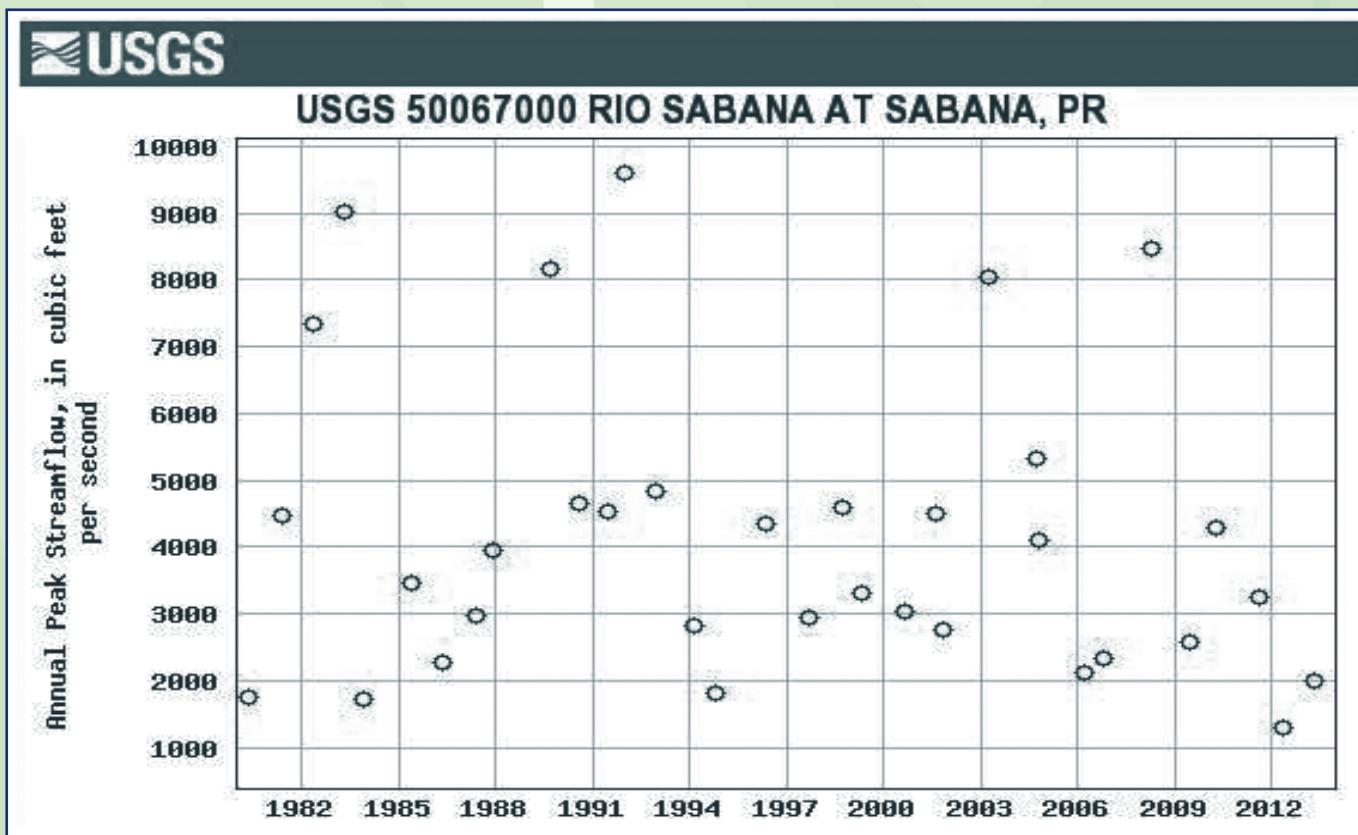


Figure 19. A sample graph of the peak streamflow data from Rio Sabana. Graph courtesy of the U.S. Geological Survey.

Year	Date	Gage Height (feet)	Streamflow (cubic feet per second)
1980	May 22, 1980	12.55	1,760
1981	May 19, 1981	15.77	4,480
1982	May 10, 1982	18.17	7,340
1983	Apr. 21, 1983	19.35	9,010
1984	Dec. 02, 1983	12.50	1,730
1985	May 17, 1985	14.73	3,470
1986	May 13, 1986	13.27	2,260
1987	May 25, 1987	14.16	2,970
1988	Nov. 27, 1987	15.23	3,940
1989	Sep. 18, 1989	18.77	8,170
1990	Aug. 13, 1990	16.08	4,660
1991	Jun. 30, 1991	15.80	4,520
1992	Jan. 05, 1992	19.74	9,600
1993	Dec. 29, 1992	16.11	4,840
1994	Feb. 19, 1994	14.00	2,830
1995	Nov. 07, 1994	12.62	1,810
1996	May 13, 1996	15.64	4,350
1997	Sep. 26, 1997	14.15	2,960
1998	Sep. 21, 1998	15.86	4,580
1999	May 08, 1999	14.56	3,310
2000	Aug. 23, 2000	14.24	3,030
2001	Aug. 22, 2001	15.79	4,500
2002	Nov. 09, 2001	13.91	2,760
2003	Apr. 17, 2003	18.69	8,050
2004	Sep. 15, 2004	16.55	5,330
2005	Oct. 29, 2004	15.41	4,120
2006	Apr. 05, 2006	13.07	2,120
2007	Oct. 20, 2006	13.35	2,320
2008	Apr. 27, 2008	18.99	8,480
2009	Jun. 12, 2009	13.67	2,570
2010	Apr. 13, 2010	15.58	4,290
2011	Aug. 22, 2011	14.50	3,260
2012	May 10, 2012	11.82	1,300
2013	May 10, 2013	12.89	1,990

Table 1. Gage height and streamflow data from Rio Sabana in Puerto Rico. Data courtesy of U.S. Geological Survey.

After you have created the graph, compare the data over the 33-year time period.

- Circle any points that seem to be very high or very low.
- Name at least two things from the data that seem important. Why do you think the data from these two times may be important? What do you think the data from these times may indicate?
- How did creating a graph from the data help you to analyze and understand the data?
- Share and discuss your results with your classmates. Did they notice similar points in the data? How were your graphs and analysis of the graphs similar and different?

Natural Inquirer Connections

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

- “Leaf Me Alone” in the Tropical Forest edition of *Natural Inquirer*.
- “Don’t Litter the Stream” in the Hawai‘i-Pacific Islands edition of *Natural Inquirer*.
- “I’ll Huff and I’ll Puff and I’ll Blow Your Trees Down!” in the Tropical Forest edition of *Natural Inquirer*.
- “Swimming Upstream Without a Ladder” in the Tropical Forest edition of *Natural Inquirer*.

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

What’s in a Word?

One of the many questions that people have asked from time to time is the spelling of the word “streamgage” versus spelling it with a “u” as in “streamgauge.” Page 50 of the U.S. Geological Survey report, *A History of the Water Resources Branch, U.S. Geological Survey: Volume I, From Predecessor Surveys to June 30, 1919* (<http://on.doi.gov/USGSWaterHistory>) includes a reference giving credit to the change in spelling to F.H. Newell around 1892. The author wrote:

At about this time, F.H. Newell adopted the spelling “gage” instead of “gauge.” As he informed the writer, “gage” was the Saxon spelling before the “u” was inserted as a result of Norman influence on the language.

Ever since then, the U.S. Geological Survey has spelled the word without the “u.”

Web Resources

International Institute of Tropical Forestry
<http://www.fs.usda.gov/iitf/>

U.S. Geological Survey Water Data for Rio Sabana
http://waterdata.usgs.gov/nwis/inventory/?site_no=50067000&agency_cd=USGS

A Distance Learning Adventure: America’s Rainforests—Caribbean National Forest/Luquillo Experimental Forest
http://rainforests.pwnet.org/americas_rainforests/caribbean.php

El Yunque National Forest
<http://www.fs.usda.gov/elyunque>

Luquillo Long-Term Ecological Research Program
<http://luq.lternet.edu/>

Tabonuco Trees
http://www.na.fs.fed.us/pubs/silvics_manual/volume_2/dacryodes/excelsa.htm

University of California Museum of Paleontology: Tropical Forests
<http://www.ucmp.berkeley.edu/exhibits/biomes/forests.php#tropical>

History of Fort Valley Experimental Forest
<http://www.foresthistory.org/ASPNET/Places/ResearchSites/FortValley.aspx>

Sediment-al Journey:

Measuring Metal Concentrations in Soils Beside Urban Waterways



Photo courtesy of K. T. Belt

Meet the Scientists



◀ **Dr. Daniel Bain**, Hydrologist: My favorite science experiences generally involve one of three things: (1) finding a clear pattern from data I have collected, (2) working in an urban stream or soil pit and having a local resident come up and ask a question or share an insightful observation about the area, and (3) contributing technical data to challenges created by interactions between humans and natural systems within neighborhoods.

▶ **Mr. Ian Yesilonis**, Soil Scientist: Did you know more living individual organisms are in a tablespoon of soil than people are on Earth? Usually people don't know a lot about soil, and without it, our lives on Earth would be very different. Soil is important to our daily health and holds the evolving history of our planet. Soils do a lot of things, like provide footing for

plants to grow, homes for worms and insects, and filtration for water.

I enjoy playing in, learning from, and unlocking the mystery of soils. My favorite science experience is when I am out in a field, with a soil corer in hand; ready to discover something new about soil. Often, I feel like a detective, investigating the soil structure below the surface to search for the unique story it has to tell. To figure out the story, I first survey the area and look at the landscape for markers like hills; I look at the rocks to see what they are made of; I look at the plants, the streams, and the rivers. All of these first insights give me an idea of how the soil developed and how it interacts with the current environment.

Next, I get out my **auger**, dig out a soil sample from the Earth, and lay the samples down **systematically** to create a soil profile on a ground cloth. Then, I feel the soil, look at its color, and shape, and sometimes I even smell it. Combined, this information can tell me a lot about the soil. Using the soil profile, I can identify (1) if erosion took place hundreds of years ago, (2) if the area has been farmed or plowed, (3) how quickly water may or may not move through it, (4) if worms or mammals have made it their habitat, and (5) if the soil is old or young. For me, the best experience is going out into the field with my auger, on a nice sunny day, prepared to uncover the secrets of the soil.



◀ **Dr. Richard Pouyat**, Urban Ecosystem Ecologist: For me, science is most exciting when I have made a new discovery! If you practice science long enough, you too will make a discovery. One of my first scientific discoveries was when I found an **invasive species** of earthworm living in a forested park in New York City—a worm species from Asia! How did it get there? Why was this worm species not noticed before? Was it changing the soil? The species was probably brought to the United States with **exotic** plants and has had a dramatic effect on **nutrient cycling**.

Nobel-prize winner and Hungarian scientist Albert Szent-Gyorgyi (aul bərt sent gərj ē) once said, "Discovery is seeing what everybody else has seen and thinking what nobody else has thought." Using his definition, every discovery you make is your own!



Did You Know?

Dr. Pouyat found an earthworm that was an invasive species from Asia that was living in New York City parks. He was interested how it affected the environment. The same earthworm species was found hundreds of miles away in Georgia. Scientists in Georgia conducted research to find out how this invasive species affected the ability of native earthworms to survive.

To learn more about these earthworms, read the *Natural Inquirer* Monograph "Worming Their Way In." It can be found online at <http://www.naturalinquirer.org/all-issues.html>.

What Kinds of Scientists Did This Research?

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

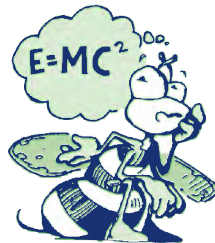
soil scientist: This scientist studies soils as one of Earth's natural resources.

urban ecosystem ecologist: This scientist studies the interactions of people and other organisms with each other and with nonliving parts of urban environments.

Thinking About Science

In 1980, the National Science Foundation created a network of research locations to study how ecosystems change over a long period of time. This network is called the Long Term Ecological Research (LTER) Network.

The United States has 26 of these areas, which includes one in Puerto Rico and two in Antarctica. The research being done at these locations is unusual because it focuses on changes that are happening over a long period of time. From a scientific perspective,



long-term research provides information that is impossible to discover in any other way.

One of these research locations is the Baltimore Ecosystem Study. Scientists working with the Baltimore Ecosystem Study seek to understand **metropolitan** Baltimore as an ecological system. The Baltimore Ecosystem Study involves scientists from the biological, physical, and **social sciences**. The LTER network enables a variety of scientists to work together. By working as a team, these different scientists can provide a much more complete picture of what is happening over time and why it is happening.

What Is the National Science Foundation?

The National Science Foundation (NSF) is an independent Federal agency created by Congress in 1950. The NSF provides funding for scientific research. This research promotes scientific progress; advances national prosperity, health, and welfare; and aids in national defense. For more information, visit <http://www.nsf.gov>.



Glossary words are **bold** and are defined on page 70.

One goal of the Baltimore Ecosystem Study is to understand how urban and suburban ecosystems change over a long period of time. In this study, you will learn what scientists are

discovering about changes in the **riparian** areas that drain into Baltimore's Middle Branch of the Patapsco River. This body of water is also known as Baltimore Harbor (**figures 1 and 2**).

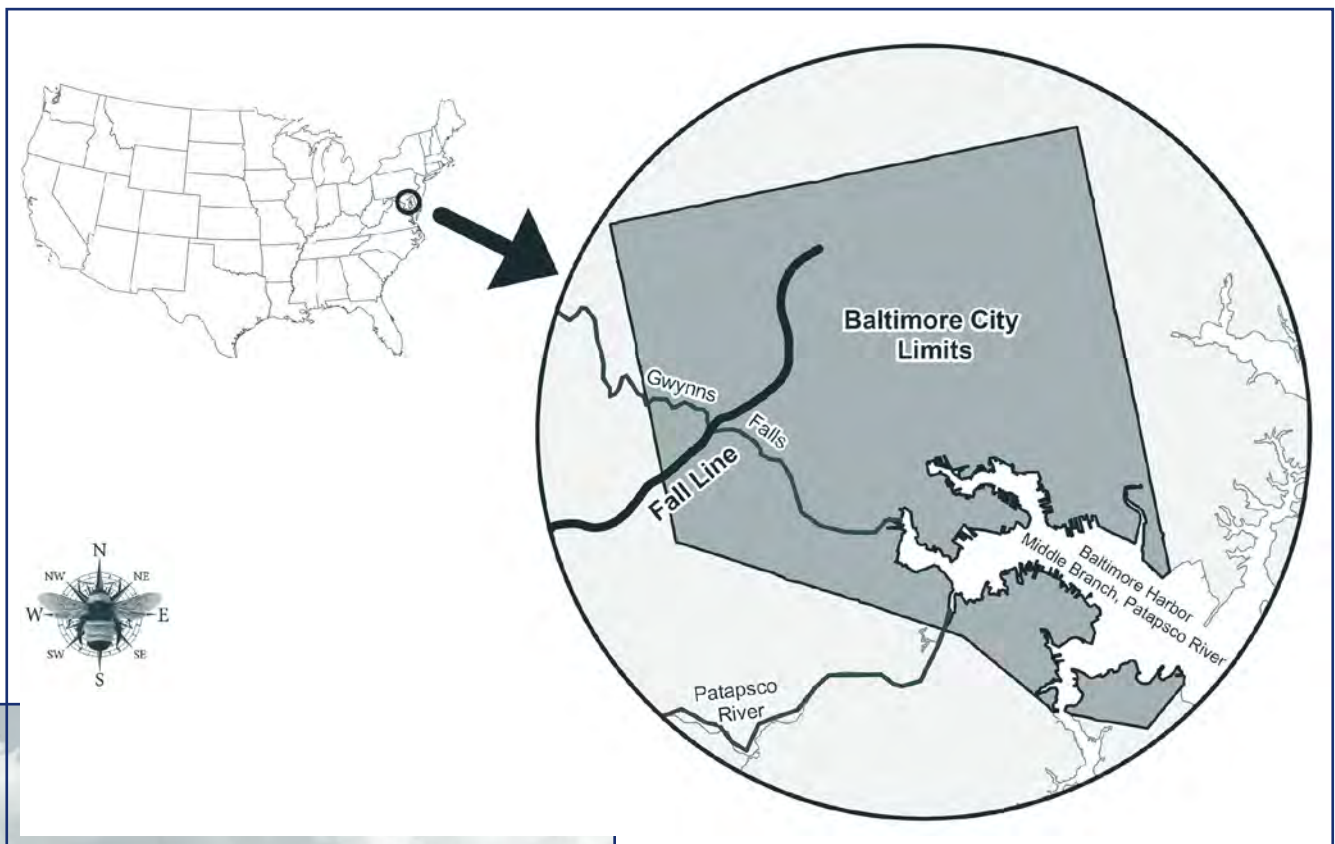


Figure 1. Baltimore is a large city in Maryland. Locate Baltimore Harbor on this map. Map by Lindsay Gnann.



Figure 2. People enjoy water sports in Baltimore Harbor. Photo courtesy of K.T. Belt.

Thinking About the Environment

Riparian areas are **transition** areas between waterways and land (**figures 3 and 4**). Riparian areas are ecologically important. They provide habitat for wildlife species and for plant species that grow in wet areas. When streams flow into rivers, the streams carry **sediment** into the rivers. Sediment is created by soil **erosion**. Soil erosion is caused by heavy rainfall from both



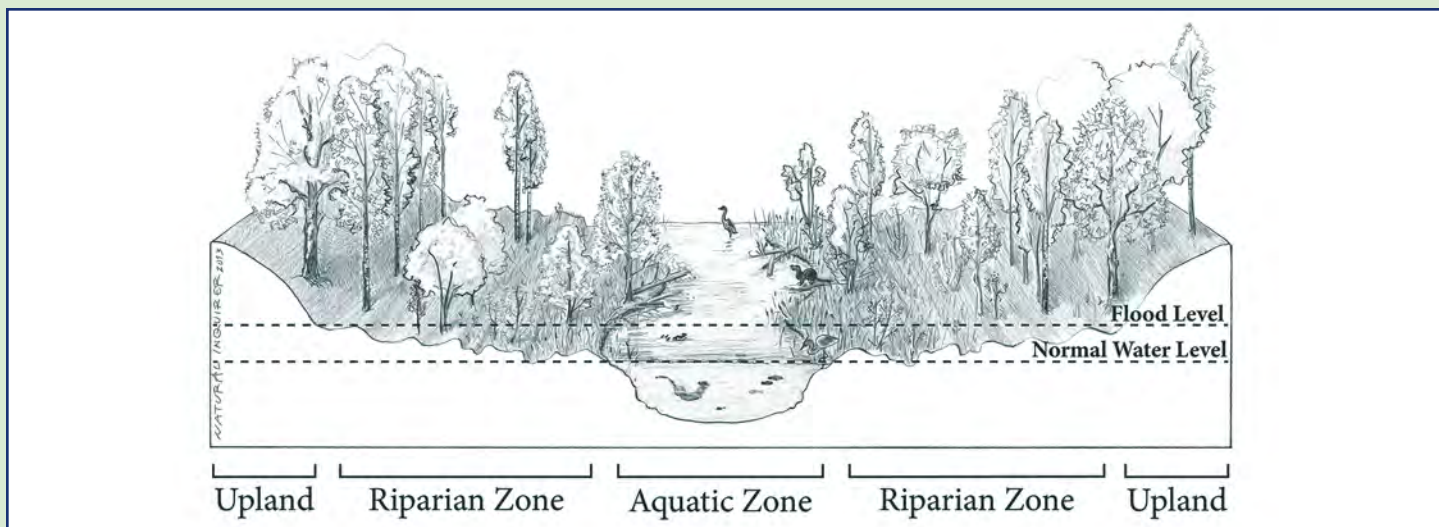


Figure 3. Riparian areas are found along waterways. When water levels are high, these areas may become flooded. When riparian areas are flooded, sediment being carried by the waterways is deposited onto the riparian area. Illustration by Stephanie Pfeiffer.

the lands through which streams and rivers flow and the riverbanks of the waterways themselves. Riparian areas protect waterways from too much soil erosion and **sedimentation**, and they protect upland areas from flooding.

Urban areas have a large amount of impervious (im **pər** vē əs) surface area. Concrete and asphalt are examples of impervious surfaces. Water cannot drain through impervious surfaces. Following rainfall or snowfall in urban areas, impervious surfaces cause rainfall or melted snow to enter waterways more quickly than it does in nonurban areas. Managers often take

action to slow the rate of runoff into waterways and to protect streambanks from erosion (**figure 5**).

In this study, the scientists wanted to learn about changes in urban riparian areas in **metropolitan** Baltimore. The scientists studied the sediment that is deposited onto riparian areas during high streamflows. They wondered about the sediment's **chemical** content, including trace chemicals like lead and plant nutrients like calcium. The scientists wanted to discover what the sediment's chemical content indicates about urban **land use**.



Figure 4. This riparian area is located in metropolitan Baltimore. Photo courtesy of K.T. Belt.



Figure 5. Rocks may be placed along urban streambanks or riverbanks to protect waterways from soil erosion. This photo is of Silver Creek in Illinois. Photo courtesy of ENCAP, Inc., <http://www.encapinc.net>.

Introduction

Most urban areas include places that contain chemicals from automobile and truck emissions, industrial processes, and urban development. Two chemicals found **abundantly** in urban areas are calcium and lead. Calcium is abundant in urban areas because concrete contains calcium (**figure 6**). Lead is released to urban areas by industrial processes, from oil-based fuels, battery acid, and vehicle exhaust fumes, among other sources. Chemicals that bind to soil particles, such as calcium and lead, can be washed into waterways during periods of high rainfall (**figure 7**). Waterways carry this sediment downstream. When flooding occurs, the sediment is deposited on the riparian areas along the waterways (see “Thinking About the Environment”).

The scientists in this study wanted to answer the following questions: What is the chemical content of riparian sediment samples across an urban-suburban **gradient**? What does the chemical content tell us about urban land use?



Figure 6. Concrete is abundant in urban areas. Concrete is used for sidewalks and for building and bridge foundations. Photo courtesy of K.T. Belt.



Figure 7. Storm drains may carry chemicals from urban areas into waterways. Photo courtesy of Babs McDonald.

Reflection Section



- ❖ Concrete is used for many building projects, including bridges, sidewalks, and buildings. Concrete is made from calcium. What part of your body contains calcium? Does this body part need to be strong? Why or why not?
- ❖ Based on what you have read so far, would you expect to find more calcium and lead in riparian sediment closer to or farther away from the city center? Why?

What Is the Urban-Rural Gradient?

Urban areas are not uniformly developed. City centers are areas with large buildings and a lot of people. Industrial sites are often found near city centers. In general, the farther away an area is from the city center, the less developed it is. Suburban areas are areas away from a city that have more homes and

open space. Beyond suburban areas are small towns and rural areas. These areas have fewer people, more farms, and more forests. This change from urban city center to suburban land use, and then to rural areas, is called the urban-rural gradient (**figure 8**).



Figure 8. Urban areas have a lot of large buildings, roads, and people. Suburban areas have homes, shopping centers, and more open space. Rural areas are primarily open space. Photos courtesy of Babs McDonald.

Methods

The scientists studied riparian areas within the Gwynns Falls watershed (**figures 9 and 10**). Many scientists involved with the Baltimore Ecosystem Study are studying this watershed. During the study period, the headwaters of the Gwynns Falls watershed were less urban than the waterways downstream. This watershed, therefore, followed an urban-suburban gradient. The Gwynns Falls watershed does not include rural lands.

Another feature of the Gwynns Falls watershed is that it straddles a fall line (**figure 11**). This geographic feature is important, because it indicates a change in the types of underlying rock.

The scientists collected 26 soil samples from Gwynns Falls watershed riparian areas (**figures 12 and 13**).



Figure 9. A watershed includes an area that drains to a common waterway, such as a stream, lake, estuary, wetland, aquifer, or even the ocean. The headwaters of a watershed is the area where water enters the watershed. Illustration by Stephanie Pfeiffer.

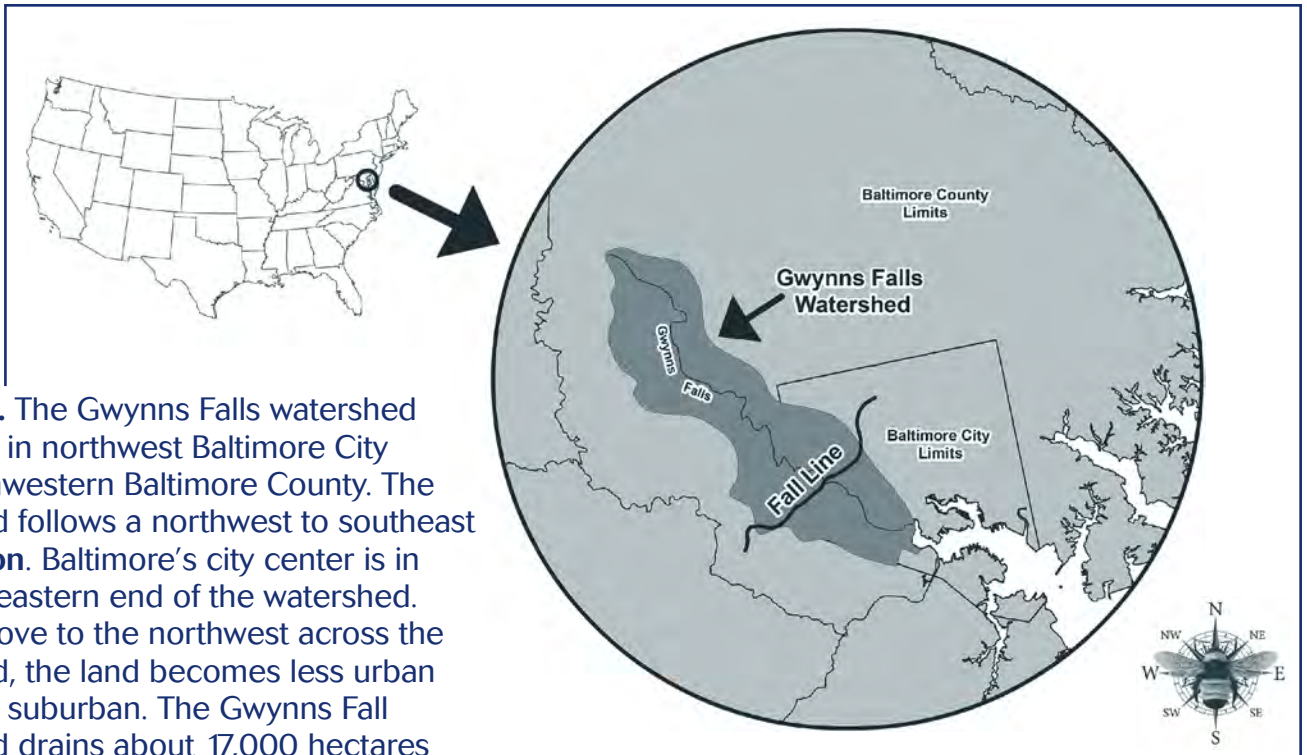


Figure 10. The Gwynns Falls watershed is located in northwest Baltimore City and southwestern Baltimore County. The watershed follows a northwest to southeast **orientation**. Baltimore's city center is in the southeastern end of the watershed. As you move to the northwest across the watershed, the land becomes less urban and more suburban. The Gwynns Fall watershed drains about 17,000 hectares of land. Map by Lindsay Gnaan.

Number Crunches

- 🍁 How many acres is 17,000 hectares? Multiply the number of hectares by 2.47 to find out.
- 🍁 How many square kilometers is 17,000 hectares? Divide 17,000 by 100 to find out.

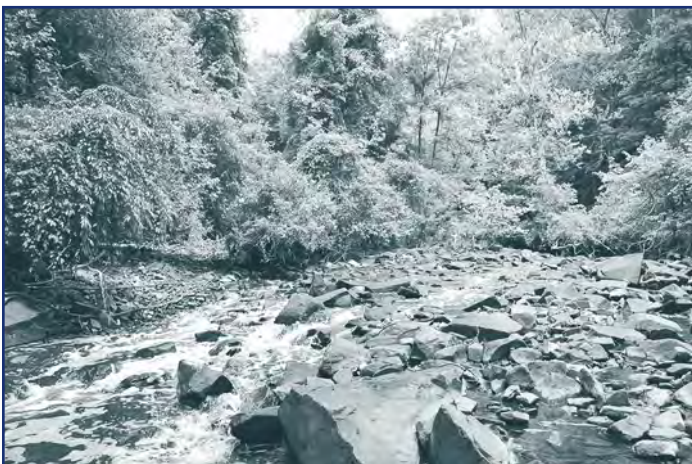


Figure 11. The Gwynns Falls watershed straddles a fall line. A fall line is not really a line but an area where rolling hills meet the flatter Coastal Plain. Photo courtesy of K.T. Belt.

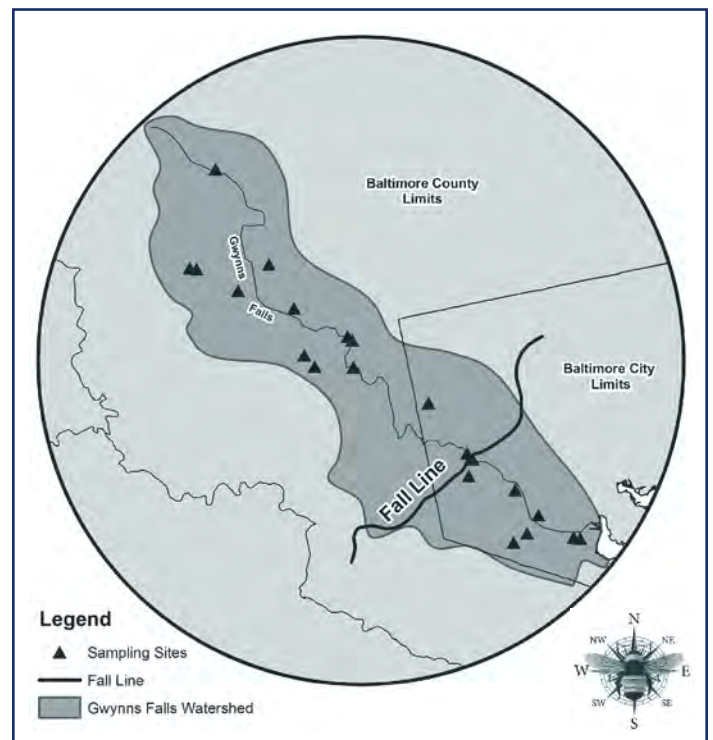


Figure 12. The scientists took soil samples from areas near Gwynns Falls waterways. Each triangle on this map represents one of the areas from which a soil sample was taken. Why do you think some of the triangles are not close to the Gwynns Falls River? (Hint: What is missing on this map?) Map by Lindsay Gnaan.

Each sample was taken 10 meters from the water's edge. The soil samples were taken between 0 and 15 centimeters from the soil surface. The scientists analyzed these samples for chemical content (**figures 14 and 15**).



Figure 13. Scientists take a soil sample in a suburban area. Photo courtesy of Dr. Richard Pouyat.



Figure 14. Scientists examine soil samples in the laboratory. Photo courtesy of Dr. Richard Pouyat.



Figure 15. The scientists used a Perkins-Elmer ELAN 6000 ICP-MS to analyze the sediment samples. This equipment enabled the scientists to identify a wide variety of chemical concentrations in the sediment samples. Photo courtesy of Dr. Daniel Bain and the University of Pittsburgh.

What Is a Fall Line?

A fall line is the place where an upland region of rolling hills ends and the flatter Coastal Plain begins. The upland region of rolling hills is called the Piedmont. The underlying rock of the Piedmont is harder and the underlying rock of the Coastal Plain is softer. Waterfalls, or a series of rapids, mark the fall lines. On the U.S. east coast, the Atlantic Seaboard Fall Line is 900 miles (1,400 kilometers) long. This fall line stretches from Massachusetts to Alabama. Is the Gwynns Falls watershed a part of the Atlantic Seaboard Fall Line? How do you know? If you do not know, look at a map that includes the Eastern United States.

Number Crunches

- How many feet are equal to 10 meters?
Multiply 10 by 3.28 to find out.
- How many inches are equal to 15 centimeters?
Multiply 15 by .3937 to find out.

Reflection Section

- Observe figure 12. Why did the scientists take samples across the entire watershed, from northwest to southeast?
- Why did the scientists take every sample 10 meters from the water's edge?



Findings

The underlying rock structure changes at a fall line. The chemical nature of naturally occurring sediment, therefore, is usually different above and below fall lines. This difference is because the underlying rock above and below the fall line contains different chemicals. These chemicals are washed into the water and deposited onto riparian areas. When analyzing soil samples, scientists expect to see a change in the types of naturally occurring chemicals found in sediment above and below a fall line.

The scientists found that the level of calcium and lead in the soil samples increased as soil samples were pulled near increasingly urbanized land. The level of calcium did not change suddenly at the fall line, as it would have if it was occurring naturally. Instead, the scientists found an increase in calcium across the entire watershed from the northwest to the southeast (**figures 16 and 17**).

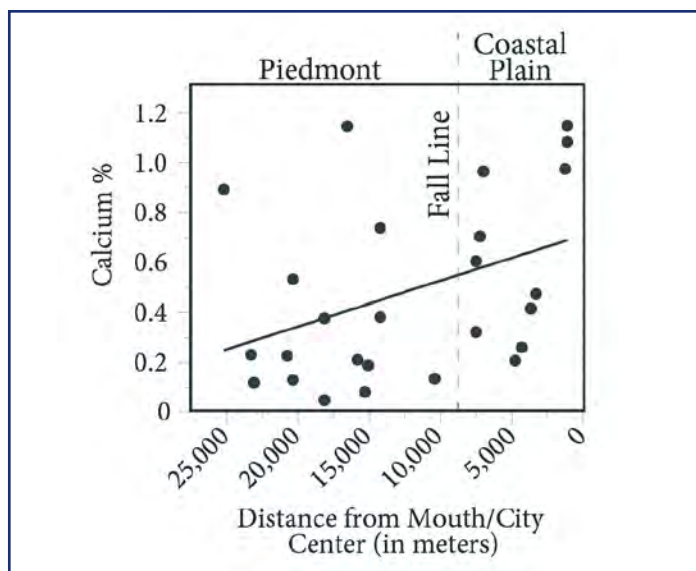


Figure 16. The percent of calcium found in the sediment samples was greater in areas closer to the city center. Each dot on this scatter plot represents a sampling site. When data are displayed in a scatter plot, scientists calculate an equation that shows a straight line. This straight line is mathematically determined to minimize the sum of the distances between the points and the line.

This line is called the line of best fit. A line of best fit shows the general trend of the data. A line of best fit may pass through some points, just one point, or all the points on a scatter plot. It is possible, but not likely, that a line of best fit will not pass through any of the points. Does the line of best fit in this figure pass through any of the points? Explain in your own words what the line of best fit in this scatter plot is showing about the calcium content across the urban-suburban gradient. Illustration by Stephanie Pfeiffer.

The scientists also tested the sediment samples for copper and zinc. These trace chemicals are often found in urban areas. Trace chemicals are chemicals found in small quantities. The scientists found that these chemical amounts also increased across the watershed's urban-suburban gradient from the northwest to the southeast (**figure 18**).



Figure 17. Urban concrete could be a source of the increased calcium measured in riparian sediment samples. Photo courtesy of K.T. Belt.

The scientists discovered something surprising about the amount of trace chemicals in the sediment. At four of the sampling sites, the amounts of trace chemicals were two to three times higher than those found at the other sampling sites. When comparing the sampling sites with maps of the watershed, the scientists observed something interesting. They observed that areas close to three of these four sampling sites were land areas created by adding fill dirt to existing low-lying land areas (**figure 19**). The scientists discovered that where these fill areas were created, high amounts of trace minerals were deposited onto nearby riparian areas.

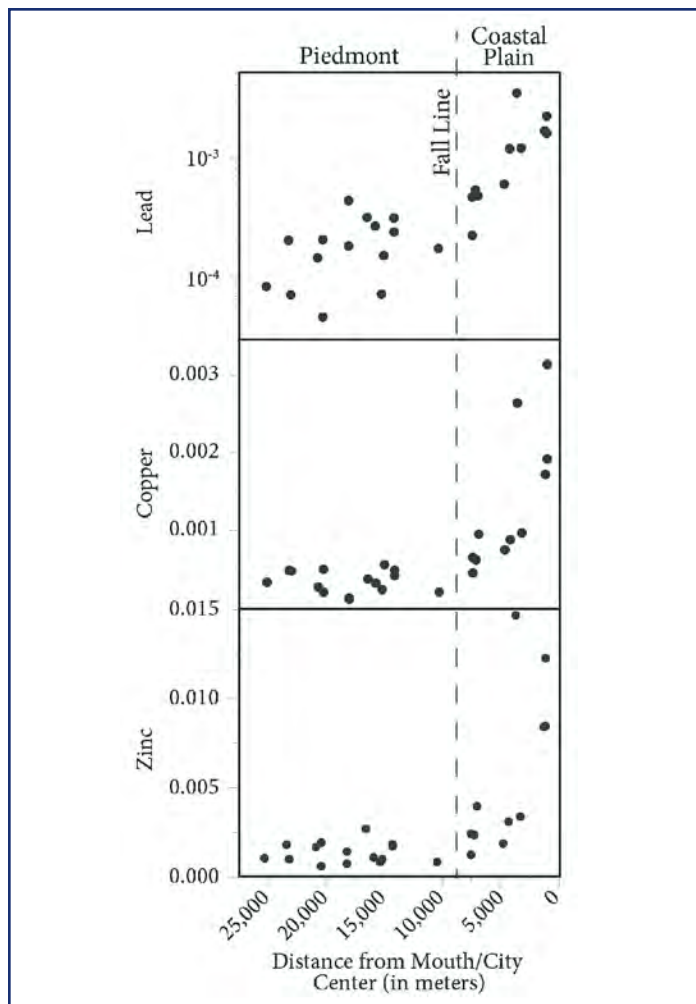


Figure 18. The increase in concentration of the trace metals lead, copper, and zinc shows a strong relationship with the most urbanized areas of Baltimore. Compare this scatterplot with the map of Gwynns Falls watershed (**figure 12**). Illustration by Stephanie Pfeiffer.



Figure 19. Fill dirt is sometimes used to create land areas that are suitable for development. Look carefully at this photo. Why might high rates of soil erosion be associated with fill dirt? Photo courtesy of Babs McDonald.

Reflection Section



Scientists prefer to use measurements to describe conditions. For example, rather than describing a day as hot, a scientist would prefer to report that the temperature is 94 °F (34 °C). Based on this study's results, what measure might one day be used to describe the amount of an area's urbanization? What is one advantage of using this measure?

The scientists found a relationship between higher levels of trace chemicals in riparian sediment and nearby artificially created land areas. If that same relationship is found in other studies, what might you conclude about one consequence of using fill dirt to create new areas of land?

Elements and Symbols in the Periodic Table

Symbols of elements (chemicals) are written by capitalizing the first letter. Symbols are derived from names of the elements, name of the discoverer, place of discovery, or other characteristic.

In this research, the following elements, or chemicals, were studied:

Element	Symbol
Calcium	Ca
Lead	Pb
Copper	Cu
Zinc	Zn

To examine a portion of the periodic table of elements, see page 50 in the "Caribbean Cruise" article of this *Natural Inquirer* journal.

Discussion

The scientists identified three important potential streamflow processes within urban watersheds. First, urban streams deposit sediment onto riparian areas. This sediment may contain chemicals found in roadways, industrial areas, and other developed areas. Second, the flooding of urban riparian areas during heavy rains may cause roadway, industrial, and development-related trace chemicals to enter waterways. Third, the process of creating new land areas from fill dirt placed in low-lying wet areas may introduce trace chemicals directly into waterways.

The scientists noted that little is known about the effects of increased chemical sediment deposited on riparian areas. Because urban riparian areas appear to have greater percentages of urban-related chemicals, this area deserves more scientific research.

Reflection Section



Do you agree with the scientists that more research is needed about urban-related chemical sediment deposits? Why or why not?

Baltimore is just one urban area among thousands of urban areas across the globe. If the findings of this study were true for all urban areas with nearby waters, what long-term change might you expect to find in these waters, such as rivers, lakes, and coastal bays around the world? What impact would this change have on global health? (Hint: Reread the first sentence of the last paragraph in the "Discussion" section).

Glossary

abundantly (ə **bun** dənt lē): Marked by great plenty.

auger (ò gər): A sharp tool that is used for making holes.

chemical (kē mi kəl): A substance, such as an element or compound.

erosion (i rō zhən): The process or state of wearing or washing away.

exotic (ig ză tik): Strange, different, or foreign.

gradient (grā dē ənt): An ordering of something according to a value. In this article, the urban-rural gradient is an ordering of landscapes according to the number of buildings and population size.

invasive species (in vā siv spē shēz): Any plant, animal, or organism that is not native to the ecosystem it is in, and is likely to cause harm to the environment, the economy, or human health.

land use (land yūs): How people are using the land.

metropolitan (me trə pā lə tən): Of, or relating to, a large city and the surrounding cities and towns.

nutrient cycling (nü trē ənt sik lɪŋ): The uptake, use, release, and storage of nutrients by plants and their environments.

open space (ō pən spās): Undeveloped land that is accessible to the public.

orientation (òr ē ən tā shən): Position or direction relative to other points or directions.

riparian (rə per ē ən): Areas along streams and rivers.

sediment (se də mən): Soil particles carried along in streams and rivers, some of which may settle to the bottom.

sedimentation (se də mən tā shən): The natural process in which material (such as soil, stones, and sand) is carried to the bottom of a body of water.

social sciences (sō shəl sī ən(t)s is): Particular areas of study that relate to human behavior and society.

systematically (sis tə mā tik lē): Marked by thoroughness or regularity, or according to a system.

transition (tran si shən): The act or process of passing from one condition, form, or place to another.

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.

What's in a Name?

The title, "Sediment-al Journey," was taken from a popular song called "Sentimental Journey." This song was written by Les Brown and sung by Doris Day in the mid-1940s.

Adapted from Bain, D.J., Yesilonis, I.D., and Pouyat, R.V. 2012. Metal concentrations in urban riparian sediments along an urbanization gradient, *Biogeochemistry*, 107: 67–79. <http://www.treesearch.fs.fed.us/pubs/40667>.



Time Needed

One class period

Materials (for each student or group of students)

- Table on page 72
- Four blank pieces of graph paper (page 123)
- Pencils
- Rulers

The question you will answer in this FACTivity is: What is the relationship between the level of chemicals in a city's soils and level of the same chemicals in the city's riparian areas?

Methods

Examine the table on page 72. This table contains actual data provided to you by the scientists in this study. The table presents the median and mean (average) levels of chemicals found in the Gwynns Falls watershed's riparian areas. The table also presents the median and mean level of chemicals in Baltimore city soils.

You will construct bar graphs based on the data in table 1 to help you understand the data. You can use the graph paper on page 123 to help you construct your bar graphs. You will have to understand the difference between the mean, or average, and the median. The mean is the value of all the values summed and divided by the number of values. The median is the middle value in a list of values, ordered from the smallest value to the largest value.

Your teacher may hold a class discussion about what these two values represent. Both values are summary values, intended to give you a feel for the entire list of values. The average, however, is sensitive to values that may be very different from most of the other values. The median, on

the other hand, is not influenced by values that are very different from most of the other values.

- First, construct a bar graph for the mean value of the chemicals expressed as a percentage of a volume. Include both the Gwynns Falls Riparian Sediments and the Baltimore City Soils. Label the x-axis and y-axis.
- Next, construct a bar graph for the mean value of the chemicals expressed in ppm. Include both the Gwynns Falls Riparian Sediments and the Baltimore City Soils. Label the x-axis and y-axis.

How Much Is 1 PPM?

1 part per million (ppm) is roughly equal to:

1 inch in 16 miles
1 second in 11.5 days
1 minute in 2 years

- Now, observe your two bar graphs showing mean values. What do you notice about the amount of chemicals in Baltimore City Soils compared with the amount of chemicals in the riparian areas? What explanations do you have for your results?
- Now, construct a bar graph for the median value of the chemicals expressed as a percentage of a volume. Include both the Gwynns Falls Riparian Sediments and the Baltimore City Soils. Label the x-axis and y-axis.
- Next, construct a bar graph for the median value of the chemicals expressed in ppm. Include both the Gwynns Falls Riparian Sediments and the Baltimore City Soils. Label the x-axis and y-axis.

Blank graph paper is located on page 123.

- Now, observe your two bar graphs showing median values. What do you notice about the amount of chemicals in Baltimore city soils compared with the amount of chemicals in the riparian areas? What explanations do you have for your results? How do the two pairs of graphs compare? Did each statistical measure (mean and median) lead you to the same explanations?

What do you conclude about using different statistical measures? Your teacher will lead a class discussion about your class explanations and the effect of using different statistical measures to represent and summarize data.

Chemical	Symbol	Gwynns Falls Riparian Sediments		Baltimore City Soils		Unit of Measurement (ppm = parts per million)
		Median	Mean	Median	Mean	
Aluminum	Al	1.9	1.8	1.4	1.4	%
Calcium	Ca	0.29	0.46	0.025	0.043	%
Copper	Cu	20	30	35	45	ppm
Iron	Fe	2.2	2.0	2.2	2.3	%
Magnesium	Mg	0.39	0.39	0.22	0.27	%
Manganese	Mn	450	440	420	470	ppm
Lead	Pb	35	76	89	231	ppm
Zinc	Zn	63	120	81	141	ppm
Cadmium	Cd	54	170	89	106	ppm
Cobalt	Co	11	12	12	15	ppm
Chromium	Cr	32	31	38	72	ppm
Potassium	K	0.12	0.14	0.076	0.090	%
Molybdenum	Mo	35	97	300	500	ppm
Sodium	Na	150	150	96	120	ppm
Nickel	Ni	26	40	18	27	ppm
Phosphorus	P	300	330	460	530	ppm
Titanium	Ti	110	110	197	282	ppm
Vanadium	V	31	33	31	37	ppm

Table 1. Chemicals Measured in Gwynns Falls Watershed Riparian Areas and Baltimore City Soils. Parts per million, or ppm, is a measure of how concentrated the chemical is in water. Percentage is a measure of the percent of a particular volume of liquid that contains the chemical.

Natural Inquirer Connections

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

- “Green Means Clean” on page 7 of this edition of *Natural Inquirer*. The FACTivity demonstrates the difference between runoff in vegetated, agricultural, and paved areas. You can modify this FACTivity by eliminating the agricultural option and assuming that the oil represents chemicals in the water.
- “Food for the Soil” *Natural Inquirer* monograph. The FACTivity simulates how water flows onto streambanks during a flood and deposits materials on the streambanks.

These resources can be found at: <http://www.naturalinquirer.org/all-issues.html>.

If you are a trained Project Learning Tree educator, you may use “Water Wonders,” “Field, Forest, and Stream,” and “Soil Stories” as additional resources.



Web Resources

The U.S. Geological Survey (USGS) Water Science School: Runoff

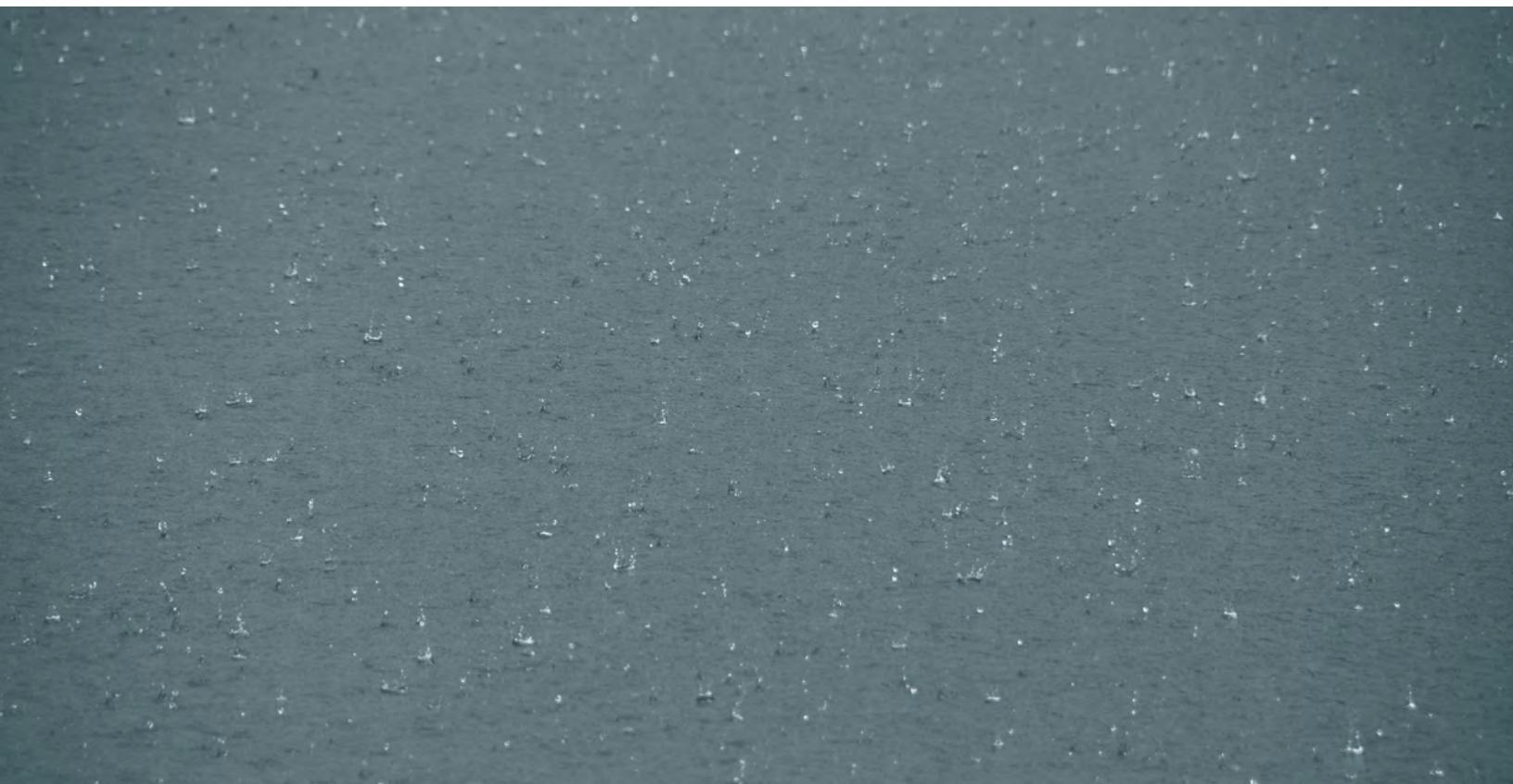
<http://water.usgs.gov/edu/runoff.html>

The U.S. Geological Survey (USGS) Water Science School: Sediment

<http://water.usgs.gov/edu/sediment.html>

When It Rains It Runs Off: Runoff in Urbanized Areas in Arizona

<http://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1542.pdf>



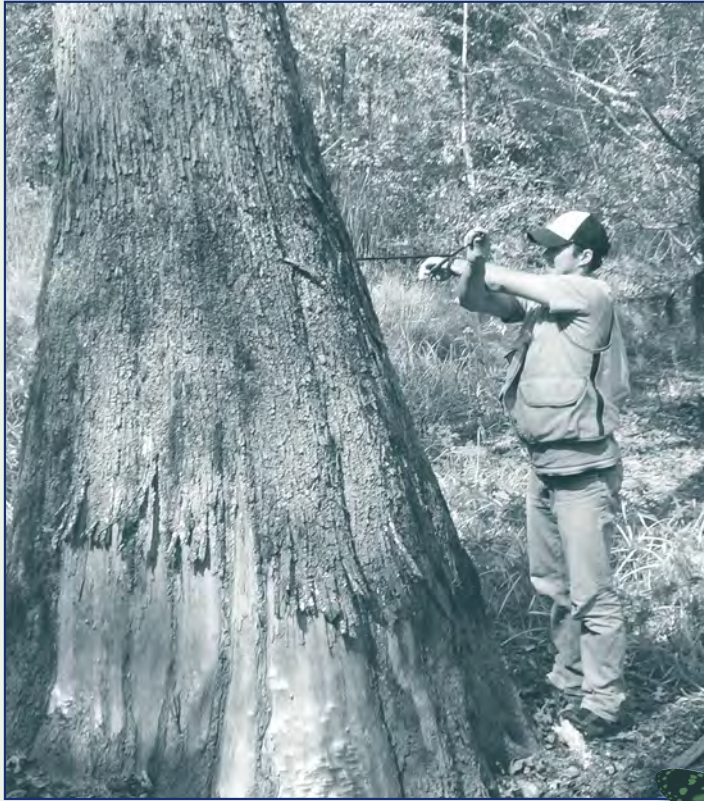
How does this scene relate to what you learned in this article?

Mussel Mania!

***How Streamflow Affects
Freshwater Mussels
Over Long Time Periods***

Photo courtesy of Dr. Andrew Rypel

Meet the Scientists



◀ **Dr. Andrew Rypel**, Applied Aquatic Ecologist: My favorite science experience is finding something totally unexpected that other people can't believe, but also can't argue with, because the data are so clear!

In this photo, I am using an increment (in krə mən) borer to take a tree core. For more information on tree coring, see the sidebar on page 82.



▶ **Dr. Wendell Haag**, Fisheries Biologist: When I was a kid, I loved to roam the fields, woods, creeks, and even my backyard, catching salamanders and crayfish and looking at plants and birds. In high school, I was lucky to have some great biology teachers who told me that I might actually be able to make a living doing these things. Now I think I have the best job in the world because I get to work with cool creatures every day, learn about how they live, and maybe even help to protect them.

Another great part of my job is working with other people who love animals and plants. People can be so generous and helpful when they're doing something they love. That tells me they must be pretty happy, and I know that being a biologist certainly makes me happy.



Glossary words are **bold** and are defined on page 85.

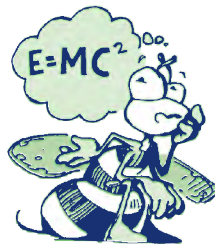
What Kinds of Scientists Did This Research?

applied aquatic ecologist: This scientist studies the effects of man-made change on aquatic ecosystems.

fisheries biologist: This scientist studies fish and other aquatic organisms living in the wild, including what they eat, their habitat, and how they interact with their environment.

Thinking About Science

When scientists identify a problem they must sometimes find new methods to study the problem. Sometimes scientists come up with a new method based on some other method they know about or have used before. One new field of study is called **sclerochronology** (skler ə krə nə lə jē). This new field of study is based on **dendrochronology**.



What's in a Word?

Large words can be broken down into smaller words. Breaking larger words into smaller words helps to illustrate how the words were created and to understand why they are used. Sclerochronology is the study of chemical and physical changes in the gradual increase in hard tissue of organisms. Break down the word “sclerochronology:”

sclero: hard, hardened, or hardening

chronos: time

logos: science

By piecing these smaller words together, you can see that the word sclerochronology comes from the science of how things harden over time, such as shells and bones.

Dendrochronology is a field of study in which scientists learn about trees by studying the tree's growth rings (**figure 1**). The field of sclerochronology similarly enables scientists to learn about any organism that leaves growth rings in hard tissues like bones or shells. Some scientists examine fish scales and mussel shells to learn more about the animal (**figure 2**). The growth rings in mussel shells can provide information about how fast the animal grew, how old it is, and how growth changes with changes in climate.



Figure 1. A tree's growth rings can show times of fire, drought, and other events that the tree experienced. The rings also tell the age of the tree. Photo courtesy of Jessica Nickelsen.



Figure 2. A mussel has a hard exterior shell, and the animal deposits a ring of hard tissue each winter when its growth slows. Photo courtesy of Dr. Andrew Rypel.

Thinking About the Environment

Bottomland hardwood forests are unique **ecosystems** (figure 3). These ecosystems have a lot of **diversity** and are highly **endangered**.



Bottomland hardwood forests are river swamps. These forests are found along rivers and streams and typically include large **floodplains**. The way in which water moves and flows through these rivers and forests has an effect on the entire ecosystem. Hydrology is the study of how water moves and flows. Changes to the hydrology of the rivers and streams may cause problems for the entire ecosystem.



Figure 3. Bottomland hardwood forests are river swamps. These forests are found along rivers and streams and typically include large floodplains. Photo courtesy of the U.S. Fish and Wildlife Service.

In earlier studies, scientists learned that periods of flooding are important to this ecosystem. One reason these periods of flooding are important is because **carbon** deposits from the land, in the form of leaves and other **organic matter**, are transferred into the river during these periods. Carbon is important for the plants and animals in and along the river. The scientists in this study wondered if flooding provides other benefits for this ecosystem.

One way to study flooding is to look at the amount of water in a stream or river at different

times. The amount of water and the **velocity**, or speed, of water in a stream or river is called streamflow (**figures 4a, 4b, and 4c**). You will learn more about streamflow in the “Introduction” section. The scientists were particularly interested in how freshwater mussels responded to changes in streamflow.

(4a)



(4b)



Figures 4a and 4b. Note the differences between the two illustrations. Which illustration has a high streamflow? How do you know? Illustrations by Stephanie Pfeiffer.



Figure 4c. This river currently has a low streamflow. Photo courtesy of Dr. Wendell Haag.

Introduction

An ecosystem is a community of plant and animal species interacting with one another and the nonliving environment. Ecosystems may change over time. Ecosystem changes are recorded in unique ways. For example, a tree's growth rings show scientists which years of the tree's life included drought and fire. Similarly, the shell of a mussel can show scientists the age and growth rate of the animal. In this study, the scientists wanted to use information from the mussels' shells to help them better understand the environment in which the mussels lived.

The scientists in this study were interested in studying mussels in bottomland hardwood forest ecosystems. Streamflow is an important factor in bottomland hardwood forest ecosystems. Streamflow is the volume of water flowing through a stream at any particular place. The scientists wanted to figure out how streamflow affected mussels and plants near and in the rivers in these ecosystems. The scientists also wanted to compare streamflow with cypress trees along the river to see if streamflow affected mussels and trees the same way (**figure 5**).

North America has the highest diversity of freshwater mussels in the world (**figure 6**). Mussels are **mollusks**. They have two shells that are joined by a ligament (**figure 7**). Mussels have two small **siphons** used to draw in and expel water. This siphoning action helps to filter water of bacteria, algae, and other small particles, and it makes this material available to



Figure 5. Bald cypress trees are found in bottomland hardwood forests because they are able to survive in areas that are seasonally flooded or that are covered in water a majority of the time. These bald cypress trees are found in Okefenokee National Wildlife Refuge. Photo courtesy of Babs McDonald.

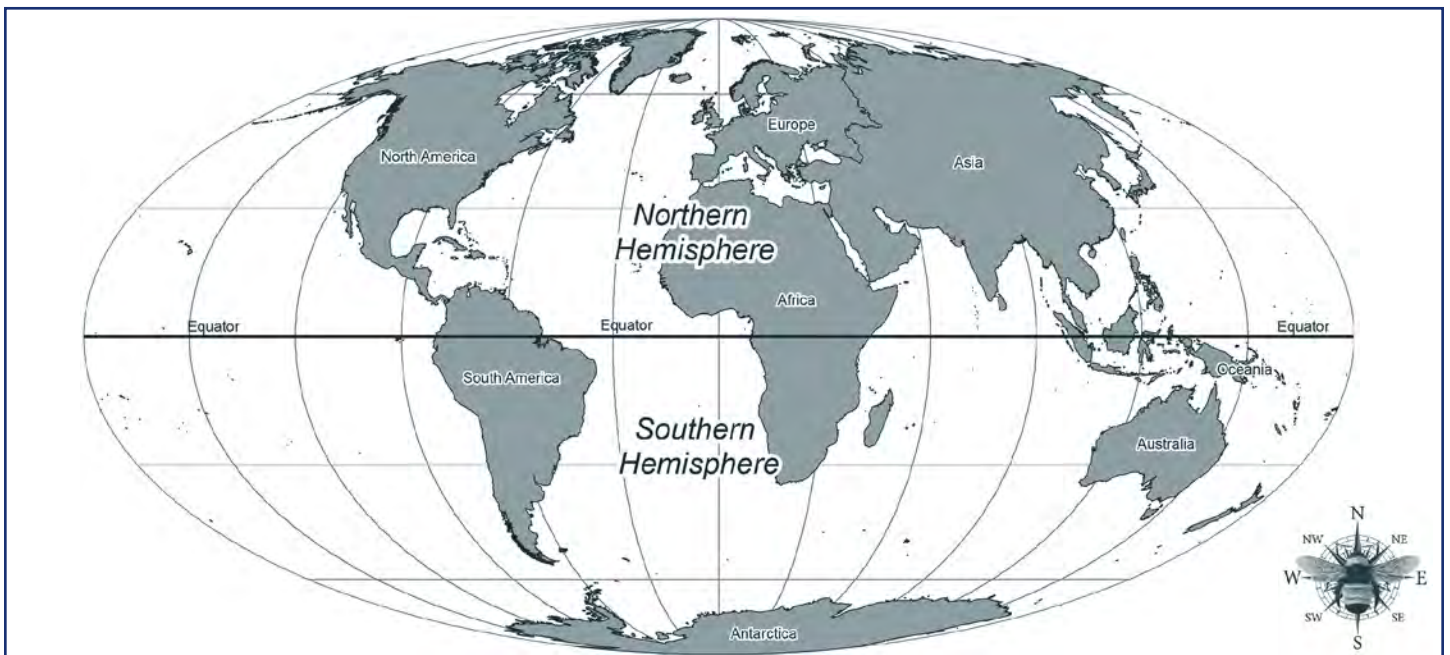


Figure 6. North America is located in the Northern Hemisphere. Map by Carey Burda.

other organisms that live on the bottom. Mussels, therefore, help improve water quality.

The outer shell of a living mussel is a home to some organisms. Mussels are also a source of food for many animals. Some animals that eat mussels are muskrats, raccoons, otters, turtles, and fish (**figure 8**). In addition, the empty shells become homes for animals after the mussels are no longer living.

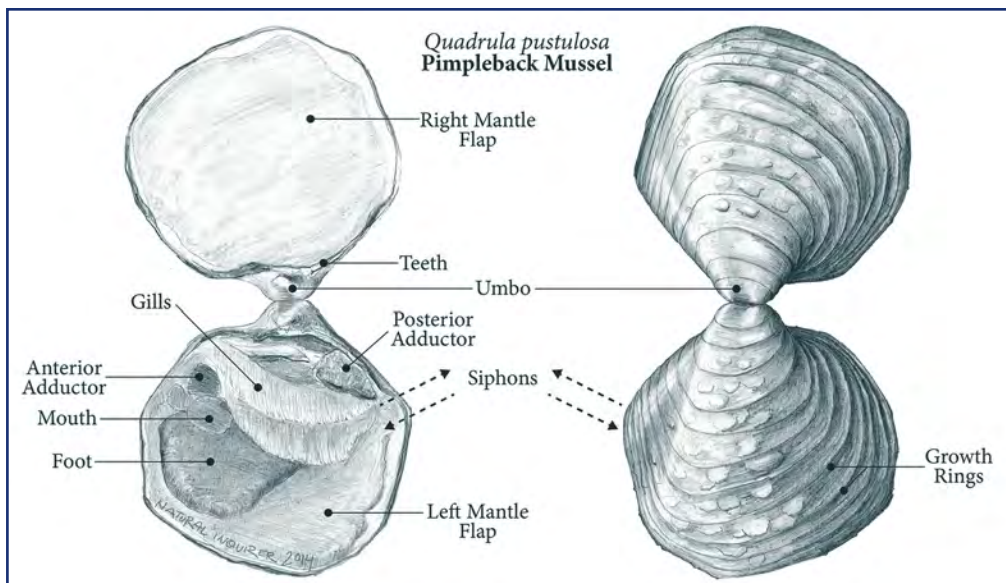


Figure 7. A mussel has many interesting features, such as a foot, a mouth, and teeth that help lock the shell together. Illustration by Stephanie Pfeiffer.



Figure 8. Raccoons and other animals use mussels as a source of food. Photo courtesy of Babs McDonald.

Mussels are very sensitive to changes in rivers or lakes, and this sensitivity makes them good indicators of the health of aquatic ecosystems. Mussels are also interesting because they have a unique reproductive cycle (see sidebar on page 80). Due to the importance of mussels in the ecosystem, the scientists wanted to know how streamflow in the bottomland hardwood forest ecosystems affected the mussels. The scientists wanted to know specifically how streamflow affected mussel growth.

Reflection Section

- State in your own words and in the form of questions what the scientists wanted to learn.
- Mussels are important to the ecosystem. Name three ways mussels are important and why each function is important to the ecosystem.



Why Is the Mussel Reproductive Cycle Important?

Male mussels release sperm into the water, and the current carries the sperm to female mussels. After the eggs are fertilized, they hatch into tiny **larvae** inside the female's gills. The females then release the larvae into the water where they must attach to a fish. The larvae are parasites that need nutrition from a fish to grow into young mussels. Different mussel species need different kinds of fish. The female mussel must somehow make sure her larvae find the right kind of fish.

Mussels have different ways of attracting fish depending on what kind of fish their larvae need. For example, mussels whose larvae need big predators like bass have large lures that look like minnows. In this case, lures are something that attracts a fish. Other mussels whose larvae need smaller fishes have tiny lures that look like insects or snails. When a fish tries to attack the lure, the larvae attach to the fish and remain for several weeks. After they have developed into young mussels, they

drop off, leaving the fish unharmed. Due to this interesting reproductive cycle, healthy mussel communities are dependent on a healthy and diverse fish community (**figure 9**).

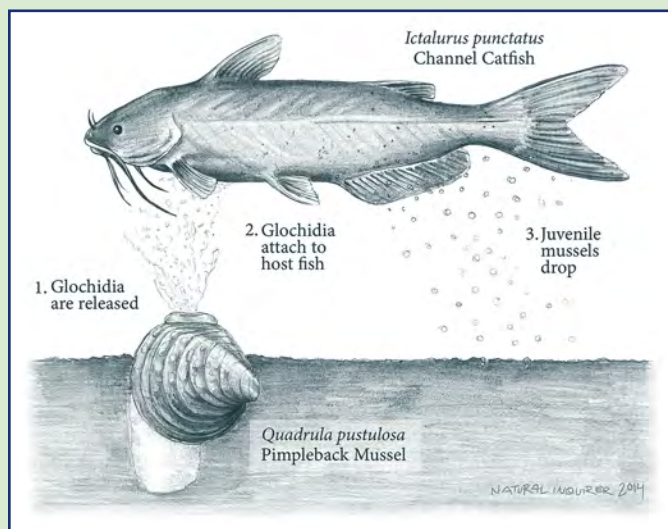


Figure 9. A simplified version of mussel reproduction illustrates some of the interesting features of the reproductive cycle. Illustration by Stephanie Pfeiffer.

Methods

The scientists studied 13 mussel species. The scientists collected the mussels from Alabama, Arkansas, and Mississippi (**figure 10**). They collected mussels from two sites in Alabama on the Sipsey River, one site on the St. Francis River in Arkansas, and one site on the Little Tallahatchie River in Mississippi (**figure 11**).

The rivers that the scientists collected from were different from each other in several important ways. Some of the rivers were regulated and some were unregulated. A regulated river is a river whose water is

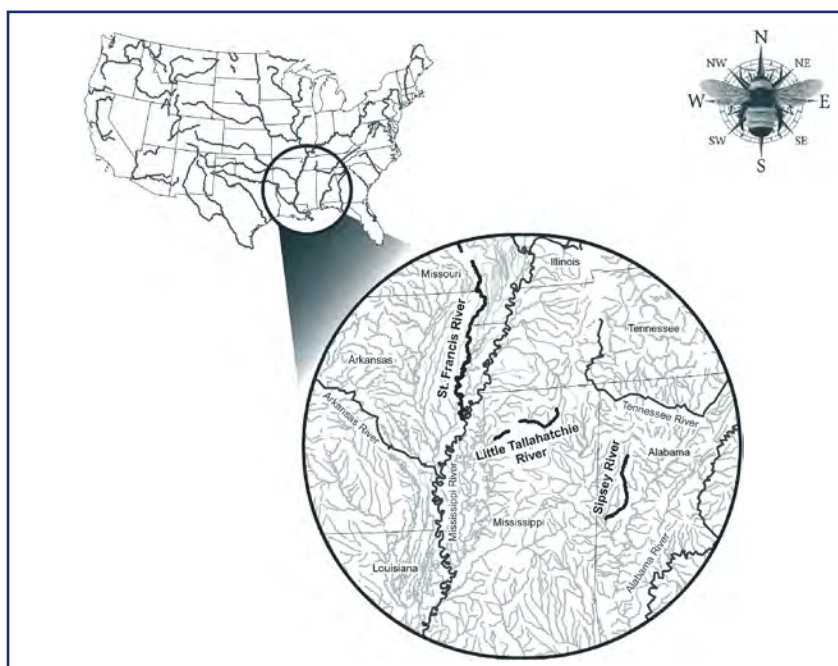


Figure 10. The mussels were collected in three States: Alabama, Arkansas, and Mississippi. Map by Lindsay Gnann.

controlled by dams or other water storage methods (**figure 12a**). An unregulated river does not have any dams or other water storage methods (**figure 12b**). Unregulated rivers are free flowing.

Streamflow can be different for regulated and unregulated rivers. For example, a dam can be opened to release more water, which causes higher streamflow, or it can be closed, reducing the amount of water in the river. Changes in streamflow at certain times of year can have negative impacts on aquatic organisms.



Figure 11. The Sipsey River in Alabama goes through part of the Sipsey Wilderness, and 61 miles of the river have been designated Wild and Scenic. For more information, visit <http://www.wilderness.net>. Photo courtesy of Dr. Andrew Rypel.

The scientists wanted to see if the difference between regulated and unregulated streams affected the mussels (**figure 13**).



Figure 12a. This river is regulated by a dam. Illustration by Stephanie Pfeiffer.



Figure 12b. This river is unregulated. Illustration by Stephanie Pfeiffer.

Name of River	Regulated or Unregulated	Description of River
Sipsey River	Unregulated	The watershed is mostly forested. Water quality is high, and the river has one of the most complete aquatic communities in this region.
St. Francis River	Mostly Unregulated	This river was mostly unregulated at the study site and has a high diversity of mussels; however, much of the watershed is affected by large-scale agriculture and water diversion projects.
Little Tallahatchie River	Regulated	The study site was just below a major storage reservoir , and another small dam is downstream of the study site.

Figure 13. The description of each river includes whether it is regulated or unregulated.

In order to understand how streamflow affected the mussels, the scientists had to collect a variety of **data**. The scientists used microscopes to examine thin sections of mussel shells (**figures 14 and 15**). The scientists took pictures of these shell sections with a digital



Figure 14. Ms. Cram, a Forest Service scientist, uses a microscope to study very small things. Ms. Cram is studying different types of fungi with this microscope. Look at the “Meet the Scientists” section on page 75. You will see Dr. Haag is using a microscope to study mussel shells. Photo courtesy of Jessica Nickelsen.



Figure 15. This thin piece of mussel shell provides the scientists with a lot of information. For example, the number of rings in the shell tells how old the mussel is, and the width of a particular ring tells how fast the mussel grew in that year. Photo courtesy of Dr. Andrew Rypel.

camera, which allowed them to measure how fast the mussels grew in different years. They also took cores from cypress trees to measure how fast the trees grew.

The scientists gathered streamflow data for each of the rivers they studied. The scientists were able to obtain streamflow data for each day over several decades from data collected by the U.S. Geological Survey and other government agencies. They put all of this information into a computer program to help them analyze the data.

What Is Tree Coring?

Obtaining a tree core is a way of getting information about a tree without cutting it down. Scientists, like the one pictured, use a tool called an increment borer to obtain the core.

The core looks like a long pencil with rings. Tree cores help scientists learn the age of the tree and how it grew over time.

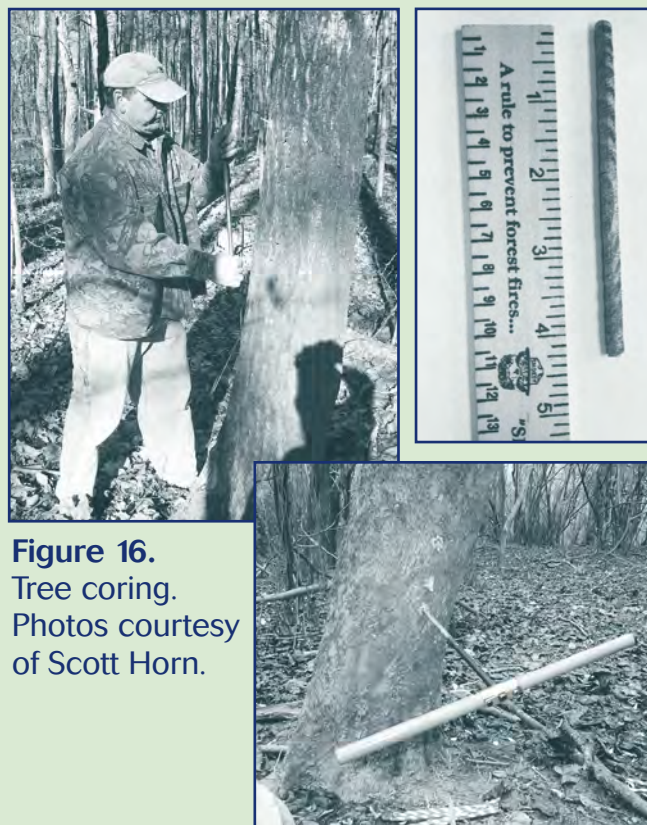


Figure 16. Tree coring. Photos courtesy of Scott Horn.

Reflection Section



- ✦ The scientists collected data from three different rivers. Do you think it is a good idea to collect data from different areas? Why or why not?
- ✦ The scientists included a description of each river in the study (see figure 13). Why do you think this information is useful?

Findings

In the unregulated Sipsey River, mussels grew faster during times of low streamflow and slower during times of high streamflow (**figure 17**). Some mussel species in the St. Francis River also

showed this relationship. The strongest and most consistent trend in the St. Francis River was a strong, positive relationship between mussel growth and **hydrologic** reversals.

A hydrologic reversal is when the river changes from a rising river to a falling river or from a falling river to a rising river. A greater number of reversals can mean that the water falling on the land winds up in the river and flows downstream very quickly. This rapid movement of water often happens in an **agricultural** landscape like the St. Francis River because much of the forest is gone. In a forested landscape like the Sipsey River, the water is absorbed by the forest and enters the river more slowly. This absorption of water influences things like the frequency and severity of floods.

River Name, Mussel Species Name, and Common Name	Low Streamflow	High Streamflow	Number of Hydrologic Reversals
Sipsey River Mussels			
<i>Elliptio arca</i> (Alabama spike)	+	–	No change
<i>Elliptio crassidens</i> (Elephant ear)	+	–	No change
<i>Fusconaia cerina</i> (Gulf pigtoe)	+	–	No change
<i>Fusconaia ebena</i> (Ebonyshell)	+	–	No change
<i>Lampsilis ornata</i> (Southern pocketbook)	+	–	No change
<i>Pleurobema decisum</i> (Southern clubshell)	+	–	No change
<i>Quadrula asperata</i> (Alabama orb)	+	–	No change
<i>Quadrula verrucosa</i> (Pistolgrip)	No change	No change	No change
<i>Obovaria unicolor</i> (Alabama hickorynut)	+	–	No change
St. Francis River Mussels			
<i>Lampsilis teres</i> (Yellow sandshell)	No change	No change	A change
<i>Potamilus purpuratus</i> (Bleufer)	No change	–	A change
<i>Quadrula quadrula</i> (Mapleleaf)	No change	No change	A change
Little Tallahatchie River Mussels			
<i>Quadrula pustulosa</i> (Pimpleback)	No change	No change	No change

Figure 17. Mussel growth each year compared with low and high streamflow and number of hydrologic reversals. A plus sign means that growth was faster and a minus sign means growth was slower. What do you notice about the periods of low streamflow and high streamflow? You can see from the figure that mussels have very colorful names!

Unlike in the other rivers, mussel growth in the regulated Little Tallahatchie River was not significantly related to any streamflow measurements. This finding suggests that regulation of streamflow can disrupt the normal cycles of mussel growth found in unregulated streams. Interestingly, cypress trees behaved exactly the opposite from mussels. Cypress trees grew faster in high-streamflow years but slower in low-streamflow years.

Reflection Section



-  How does mussel growth change in times of high and low streamflow? How do you know based on the data in figure 17?
-  What did the scientists find out about the relationship between regulated and unregulated rivers and mussel growth? (Hint: Review figures 13 and 17.)
-  Read the descriptions of the rivers in figure 13. Do you think any of these river characteristics could influence mussel growth? What do you think the scientists might suggest as the next steps to take after this research?

Discussion

The scientists found that in unregulated streams, mussels showed higher growth in low-streamflow conditions. Low-streamflow conditions enable the growth of microbes and algae in the water, which make up much of an adult mussel's diet. During periods of high streamflow, mussel growth slows.

The scientists think that the mussels' growth pattern may be a result of several factors. One factor is that during times of high streamflow, mussels may require more energy to maintain their position in the riverbed. Another factor

is that high streamflow might make it more difficult for mussels to process their food. This difficulty is because the water is **turbid** and carries a lot of sediment that mussels must separate from edible material like algae and microbes. Finally, high water may dilute the food particles that mussels need to grow. The scientists would need to conduct additional studies to find out exactly why mussel growth is related to streamflow.

Even though the mussels experience lower growth during high streamflows, higher streamflows are needed periodically. Higher streamflows help keep the mussel habitat in good condition by removing fine **sediment** from the streambed. For some species of mussel, too much fine sediment may impact growth, feeding, and survival of young mussels. The different response of cypress trees also shows that a wide range of streamflows is necessary for the best growth for different organisms in the ecosystem.

The scientists found no relationship between streamflow and mussel growth in regulated streams. This finding suggests that dams or other forms of regulation disrupt the normal cycles of mussel growth. The scientists said that the potential relationships found between mussels and streamflow should be studied in other landscapes and rivers. This additional research is necessary so that the scientists will know if these relationships occur in many different places or only in the rivers they studied.

Reflection Section



-  Do you think it is important to study the impact of streamflow on mussels? Why or why not?
-  What are the advantages and disadvantages of dams on our rivers? Discuss with your classmates.

Glossary

agricultural (ə gri kəl ch(ə) rəl): Of, relating to, or used in farming or agriculture.

aquatic (ə kwä tik): (1) Living or found in, on, or near water; (2) of or relating to the animals or plants that live in, on, or near water.

carbon (kär bən): A chemical element that forms diamonds and coal and that is found in petroleum and in all living plants and animals.

data (dā tə): (1) Factual information used as a basis for reasoning, discussion, or calculation; (2) Facts or figures studied to make a conclusion.

dendrochronology (den drō krə nä lä jē): The science of dating events and variations in an environment in former periods by the study of growth rings in trees and aged wood.

diversion (də vər zhən): The act of changing the direction or use of something.

diversity (də vər sə tē): A measure of the differences between the types and numbers of living things in a natural area.

drought (draut): A period of dry weather with little or no rain.

ecosystem (ē kə sis təm): Community of plant and animal species interacting with one another and with the nonliving environment.

endangered (in dān jər ed): Being in danger or peril.

floodplain (fləd plān): Flat land area next to a stream or river.

hydrologic (hī drə lä jik): Of or relating to the science dealing with the properties, distribution, and circulation of water on and below Earth's surface and in the atmosphere.

larvae (lär vē): Wormlike feeding form that hatches from the egg of some animals.

mollusks (mä ləks): Any one of a large group of animals (such as snails and clams) that have a soft body without a backbone and that usually live in a shell.

organic matter (ör ga nik ma tər): Substance which breaks down naturally and which comes from either plants or animals.

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

sclerochronology (skler ə krə nä lä jē): The study of chemical and physical changes in the gradual increase in hard tissue of organisms.

sediment (se də mən): Soil particles carried along in streams and rivers, some of which may settle to the bottom.

siphon (sī fən): Tube-like organ in animals and especially mollusks or arthropods used for drawing in or ejecting fluids.

turbid (tər bəd): Not clear; foul or muddy.

velocity (vē lä sə tē): Speed of movement.

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 for watershed is taken directly from the U.S. Environmental Protection Agency (<http://www.epa.gov>).

Adapted from Rypel, A.L.; Haag, W.R.; Findlay, R.H. 2009. Pervasive hydrologic effects on freshwater mussels and riparian trees in southeastern floodplain ecosystems. *Wetlands*. 29(2): 497–504. <http://www.treesearch.fs.fed.us/pubs/33529>.



Time Needed

One class period

Materials (Materials for each student or group of students)

- Three graphs on pages 86 and 87.
- Pencils

In this article, you learned about freshwater mussels and how they respond to streamflow. In this FACTivity, you will be the scientist and analyze real-time streamflow data from the three rivers that the scientists in this study studied.

The question you will answer in this FACTivity is: How do the three graphs of data from the rivers studied by the scientists compare with each other?

Look at the three graphs provided (figures 18, 19, and 20). Each graph represents the streamflow for each river during the same 8-day period. What is similar and different between the graphs? Look back at the findings about mussel growth and streamflow. Now, look at the three graphs. In which river or rivers do you think the mussels may grow the best during the 8-day period? Why? Do you think an 8-day period provides enough information about the streamflow in a river? Why or why not?

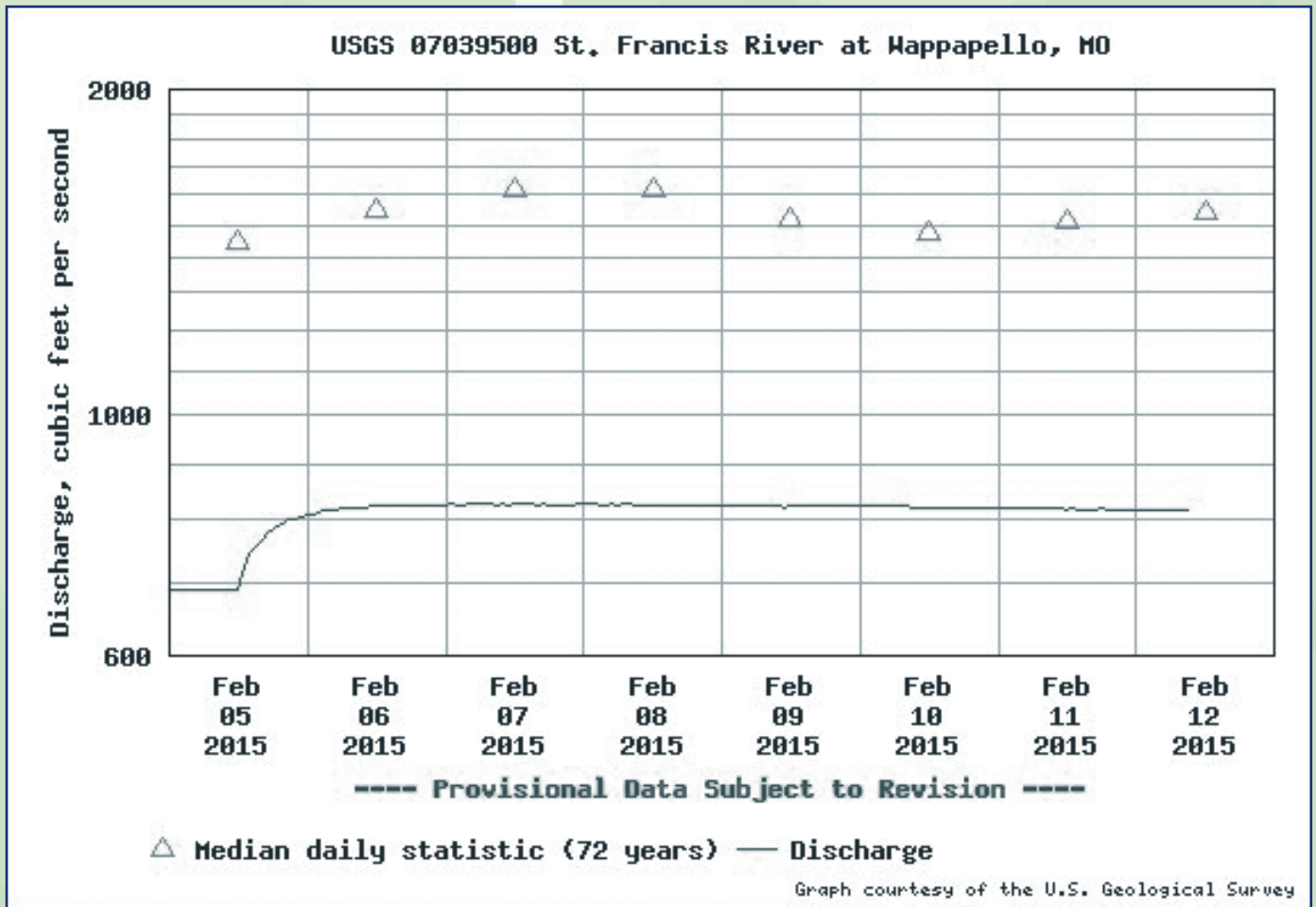


Figure 18. Graph of stream discharge for the St. Francis River at Wappapello, MO. Graph courtesy of the U.S. Geological Survey.

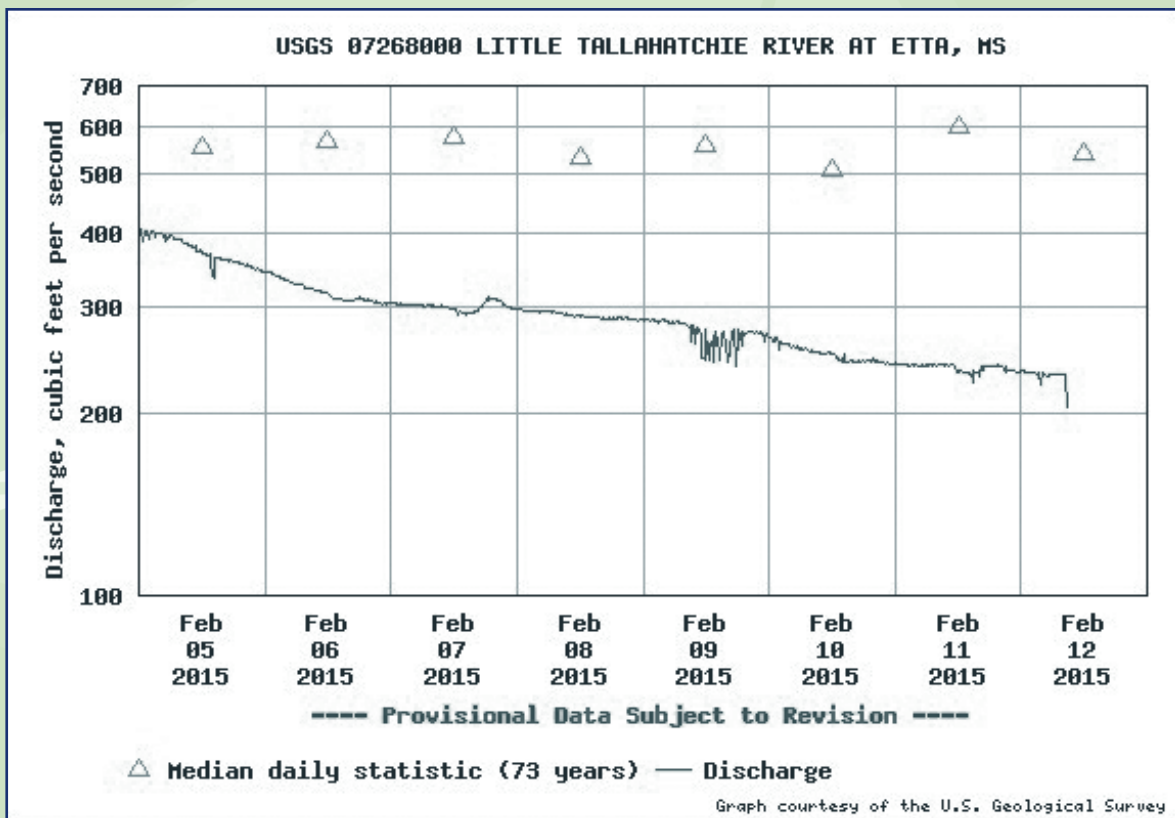


Figure 19. Graph of stream discharge for the Little Tallahatchie River at Etta, MS. Graph courtesy of the U.S. Geological Survey.

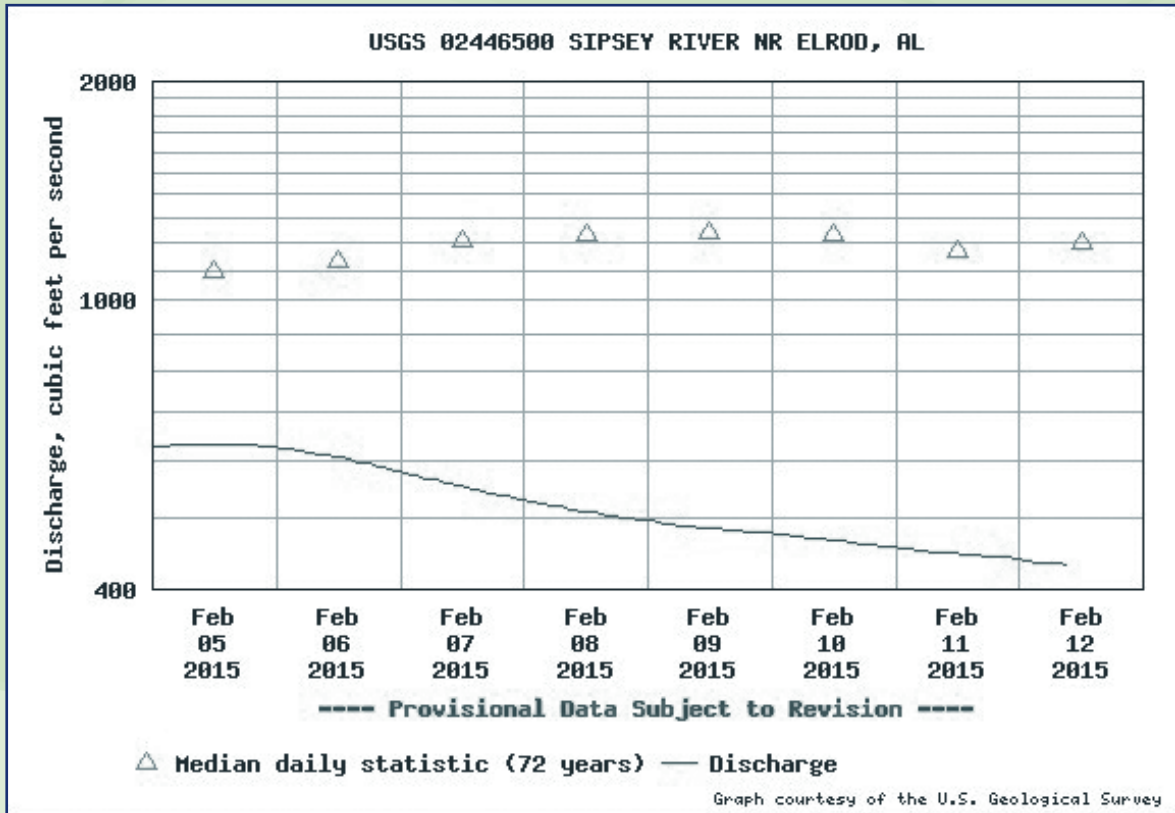


Figure 20. Graph of stream discharge for the Sipsey River near Elrod, AL. Graph courtesy of the U.S. Geological Survey.

Alternate FACtivity



First, you will need access to a computer to visit <http://waterdata.usgs.gov/nwis/rt>. This Web site is the U.S. Geological Survey's Web site for daily streamflow conditions across the United States (**figure 21**).

The three rivers that the scientists studied were the St. Francis, the Little Tallahatchie, and the Sipsey. Each of these rivers has a streamflow gage in it that records daily streamflow as well as other data.

1. Use the dropdown menu in the upper right hand corner to select a State. For each river, you will need to select the State. For example, for the St. Francis River, you would select Missouri (see bulleted list that follows).
2. After the Missouri Current Water Data page is displayed, then click on "Statewide Streamflow Table."
3. After the "Statewide Streamflow Table" is displayed, select the specific locations provided in the following list.
 - St. Francis at Wappapello, Missouri is 07039500

- Little Tallahatchie at Etta, Mississippi is 07268000
 - Sipsey River at Erod, Alabama is 02446500
4. Compare the data between the three rivers during different time periods and seasons. You might want to create graphs or charts to help you make your comparisons. What similarities and differences do you notice?
 5. Now, go back to the main page and click on your State. Explore some of the rivers around where you live. How do the data from these rivers compare to the three rivers in the study?
 6. Share what you found with your classmates. If you have time, create a poster about a river in your area. These posters can be hung up in the classroom or in the school to help others learn about streams and rivers in your area.

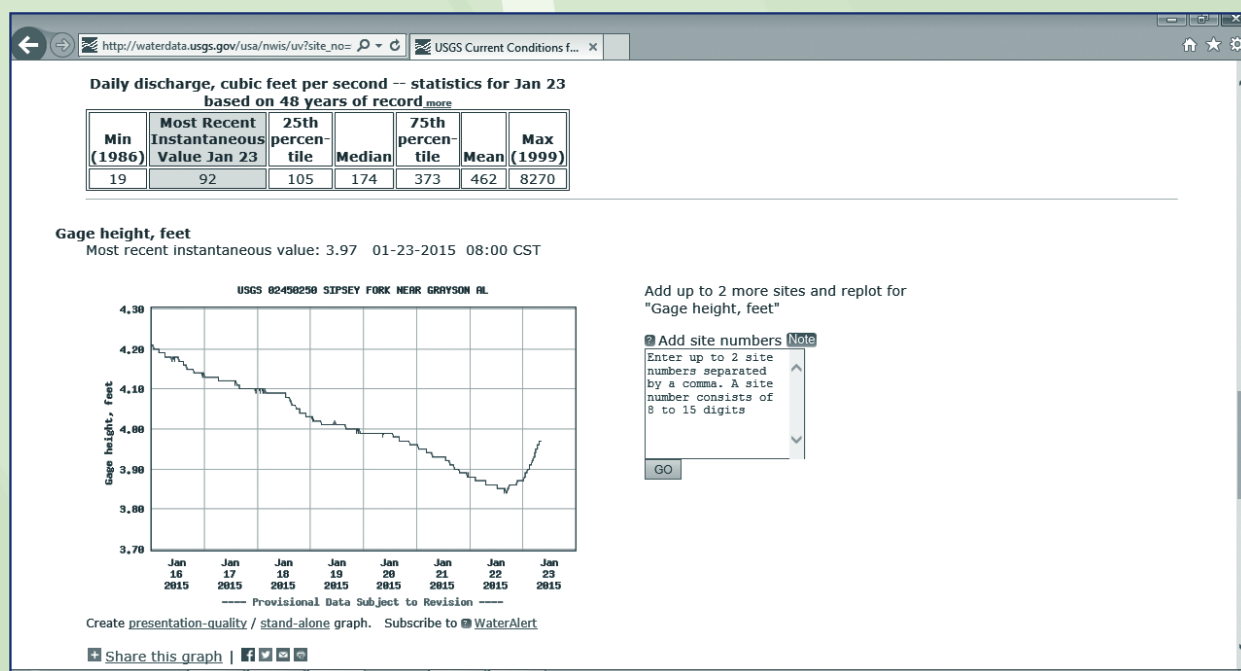


Figure 21. The U.S. Geological Survey Web site for daily streamflow conditions provides information about streams and rivers across the United States.

What's in a Word?

One of the many questions that people have asked from time to time is the spelling of the word “streamgage” versus spelling it with a “u” as in “streamgauge.” Page 50 of the U.S. Geological Survey report, *A History of the Water Resources Branch, U.S. Geological Survey: Volume I, From Predecessor Surveys to June 30, 1919* (<http://on.doi.gov/USGSWaterHistory>) includes a reference giving credit to the change in spelling to F.H. Newell around 1892. The author wrote:

At about this time, F.H. Newell adopted the spelling “gage” instead of “gauge.” As he informed the writer, “gage” was the Saxon spelling before the “u” was inserted as a result of Norman influence on the language.

Ever since then, the U.S. Geological Survey has spelled the word without the “u.”

Natural Inquirer Connections

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

- For more on turbidity, sediment, and pollution in water, read “What’s the Nonpoint?” on page 25 or “Sedimental Journey” on page 58 in this *Natural Inquirer* edition.
- To learn about another impact of regulated streams, see the sidebar on page 100 of “Timed Travel” in this *Natural Inquirer* edition.
- For more on the connectivity of stream habitats, read “Swimming Upstream Without a Ladder” in the Tropical edition of *Natural Inquirer*.

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

Web Resources

U.S. Geological Survey Water Data
<http://waterdata.usgs.gov/nwis/rt>

Bottomland Hardwood Forests
<http://water.epa.gov/type/wetlands/bottomland.cfm>

Fun With Freshwater Mussels!
<http://www.uvm.edu/~pass/tignor/mussels/>

America’s Mussels: Silent Sentinels
<http://www.fws.gov/midwest/endangered/clams/mussels.html>

Florida Museum of Natural History: Sclerochronology
<http://www.flmnh.ufl.edu/envarch/sclerochronology.htm>

Freshwater Mussel YouTube Video from Virginia Department of Game and Inland Fisheries
<https://www.youtube.com/watch?v=URHTrAAkpr0>

Timed Travel:

Measuring the Relationship Between Stream Temperature and the Development of Salmon



Meet the Scientists



◀ **Dr. E. Ashley Steel**, Statistician and Quantitative Ecologist: I have so many favorite science experiences! One cool science experience was when I was standing right in the middle of the Snoqualmie (snō kwōl mē) River. I was thinking about how my 35 water temperature loggers were recording data all across the Snoqualmie River watershed at that very second!

▶ **Ms. Abby Tillotson**, Fisheries Biologist: My favorite science experience so far has been participating in salmon surveys on the Yakima (yak ə ma) River near Cle Elum, Washington. We spent a few days floating the river on rafts, counting redds (salmon egg nests), and pulling over to the bank to count and measure salmon that died after spawning (laying eggs). This photo is of me holding a brown trout on the Sprague River in southeast Oregon.



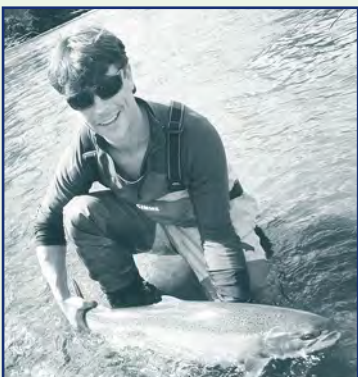
◀ **Dr. Donald Larsen**, Fisheries Biologist: My favorite science experience was rowing a raft down the Yakima River in Washington State. I was collecting data on spring Chinook salmon on a beautiful fall day and thinking...I can't believe I get paid to do this.

▶ **Ms. Aimee Fullerton**, Fisheries Biologist: It is tough to choose my favorite science experience. I'd have to say that it was watching nonnative fish use different habitats in the dark in a lab experiment. We marked fish with fluorescent paint and used a black light so the fish couldn't see us observing them. This process was the subject of my Master of Science research in the late 1990s. You can earn a Master of Science degree after earning your Bachelor's degree in college.

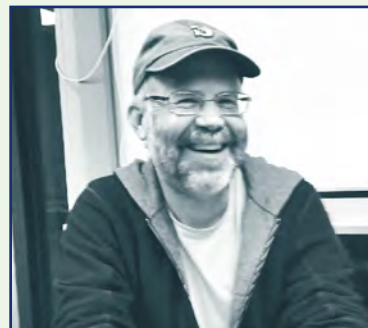


▼ **Mr. Keith Denton**, Fisheries Biologist: My favorite science experience was capturing 40-pound Chinook salmon in the newly

restored Elwha River. The Elwha River is in Olympic National Park in Washington State. I was measuring the impact of large-scale dam removal on salmon recovery.



▶ **Dr. Brian Beckman**, Fisheries Biologist: I enjoy mentoring young scientists, helping them to develop useful and interesting questions and to form thorough and accurate answers. The curiosity and enthusiasm of these bright young people are amazing and I'm fortunate to be able to work with them.



What Kinds of Scientists Did This Research?

fisheries biologist: This scientist studies fish and how the environment and other outside forces affect fish throughout their life cycle.

statistician: This scientist uses statistical methods to collect and analyze data and help solve real-world problems in business, engineering, the sciences, or other fields. Statistical methods include the collection, analysis, interpretation, presentation, and organization of data.

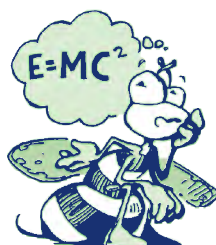
quantitative ecologist: This scientist applies statistical methods and mathematics to problems in ecology. Ecology is the study of the interactions of living things with each other and with the nonliving environment.

Thinking About Science

Part of a scientist's job is to develop, establish, or improve methods of collecting, analyzing, organizing, or presenting data.

Some scientists are particularly interested in helping to improve scientific methods. In this research, the scientists thought that a different method of collecting data might improve scientists' understanding of fish development.

Have you ever thought of a better way to do something? Before you knew for sure that it was better, you would have to try your new way and compare it with an existing way. That is exactly what the scientists did in this research.



Thinking About the Environment

Over many years, decades, and thousands of years, organisms adapt to different factors in their physical

environment. Temperature is one of the environmental factors to which organisms adapt. Many organisms live part, or all, of their lives in water. Water temperature, therefore, is a **variable** that affects the life cycle of many of Earth's organisms.

In this research, the scientists studied the relationship of water temperature to the time it took Chinook salmon eggs to hatch and develop as young fish. The scientists also studied how water temperature affected the rate at which the fish developed. Water temperature can change over time as a result of global climate change, dams, irrigation, and changing **land use**. The scientists in this study, therefore, wanted to understand how **variation** in water temperature can affect the development of young Chinook salmon (**figure 1**).

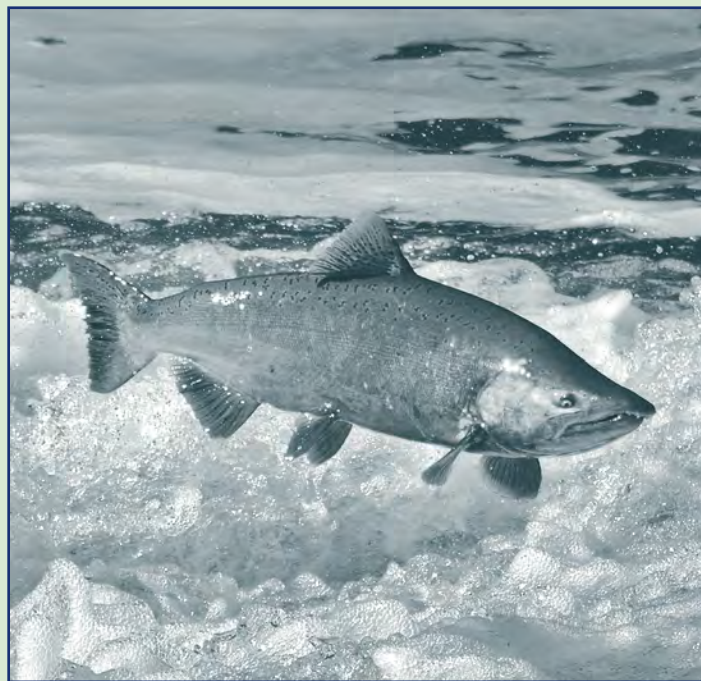


Figure 1. An adult Chinook salmon leaps out of the water. Photo courtesy of <http://iStockphoto.com>.

Glossary words are **bold** and are defined on page 101.

How Are Salmon Important to the Ecosystem?

Salmon play an important role in their ecosystem. You probably know that salmon provide food for bears. Did you also know that salmon provide food for the soil? Salmon die after they lay their eggs, or spawn. During high water flows, the dead salmon are washed onto riverbanks. As the dead salmon decay, they provide important nutrients to the riverbank soils. To learn more about how salmon help riverbank soils in Alaska, read the *Natural Inquirer* monograph, "Food for the Soil," <http://www.naturalinquirer.org/Food-for-the-Soil-i-37.html>.

Introduction

Water temperature helps **regulate aquatic** ecosystems. Aquatic scientists, therefore, often measure water temperature. Scientists usually record daily water temperature by calculating the **mean** or average temperature over a 24-hour period. Scientists also calculate degree days. Degree days describe the total temperature units (TU) delivered. One degree day Celsius is equal to a temperature of 1 °Celsius (C) for 1 day. Temperature units describe the amount of energy or heat available to the fish. You will learn about temperature units and degree days in this article.

Aquatic organisms spend their lives in, on, or near water. For many aquatic organisms, life-cycle phases are tied to water temperature. Salmon eggs, for example, generally hatch when a certain number of degree days, or temperature units, have been **accumulated**. Scientists have figured out how many temperature units are required for Chinook salmon eggs to hatch and for young salmon to grow and **emerge** as young fish (**figure 2**). Scientists have focused their

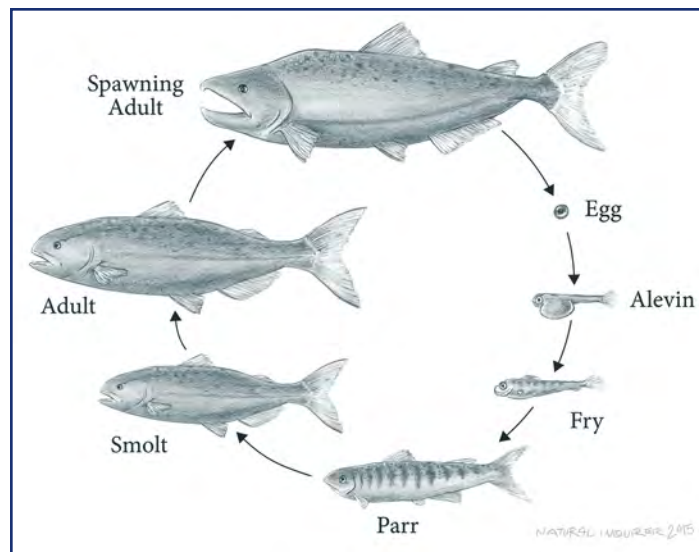


Figure 2. The Chinook salmon life cycle. Illustration by Stephanie Pfeiffer.

attention on total temperature units. Until now, they have not given a lot of attention to how those temperature units are delivered. Does it make a difference, for example, if the temperature is 3 °C one day and then 7 °C the next, or if it is just a stable 5 °C every day? Over a month, the same number of temperature units would be delivered but they would be delivered in different ways.

The scientists in this study knew that stream and river water temperature varies in at least two ways. First, the temperature varies across each 24-hour period. Second, water temperature varies within and across seasons. The scientists knew that recent human actions were altering the patterns of water temperature where Chinook salmon laid their eggs. Dams, land-use changes, irrigation, and climate change can cause altered water temperatures (**figures 3, 4, 5, and 6**).

The scientists suspected that fish might respond to more than just total temperature units. They thought that it might matter whether the water temperature was stable or variable. Just knowing the number of total temperature units delivered does not enable scientists to understand how temperature variations affect the life cycle of Chinook salmon. The scientists asked this question: Do daily and

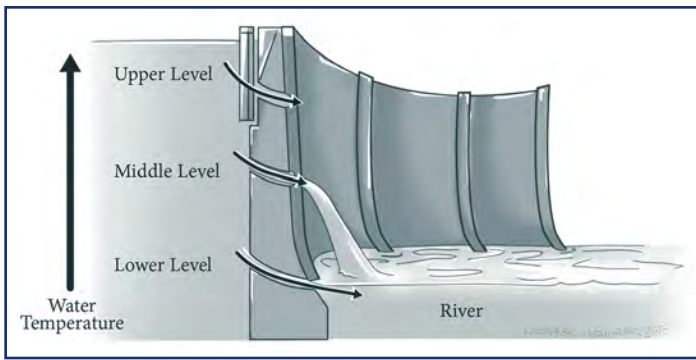


Figure 3. Dams can affect the water temperature, depending on the depth at which water is released downstream. Typically, surface water is warm and deep water is cold. When unnaturally warm or cold water is released, the change in water temperature can disrupt fish **habitat**. Illustration by Stephanie Pfeiffer.



Figure 4. When vegetation near waterways is disturbed, less plant cover can open waterways to more sunlight and result in higher water temperatures. Photo courtesy of Babs McDonald.



Figure 5. Irrigation withdraws water from waterways. This disturbance can cause water temperature changes. Irrigation usually causes the water temperature to rise. Photo courtesy of Babs McDonald.

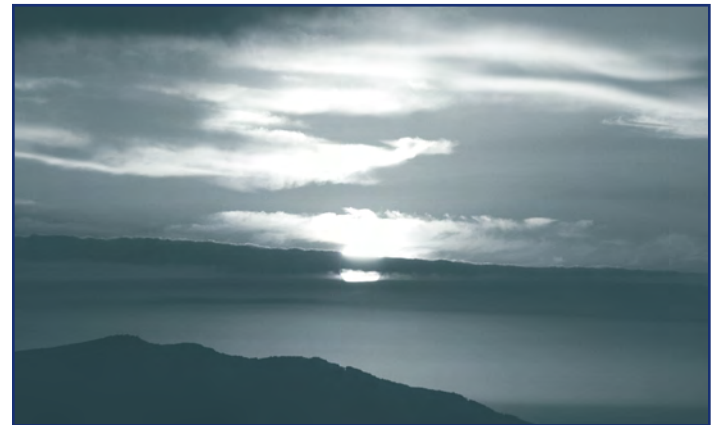


Figure 6. Climate change can cause water temperature to change over time. The same factors that cause air temperature to rise can cause water temperature to rise as well. Photo courtesy of Babs McDonald.

seasonal water-temperature variations affect the development of salmon eggs and alevins (**a lə vənz**), or young salmon, before they become free-swimming **fry**?

To answer their question, the scientists did something new. The scientists observed Chinook salmon development in fish that were exposed to different water-temperature patterns. The scientists altered water temperature experimentally to explore how water temperature variability affects Chinook salmon development.

Reflection Section



- 🍁 Why does stream or river water temperature vary across a 24-hour period?
- 🍁 Imagine that you are going camping over the weekend. You will be sleeping in a tent. The average daily air temperature across 24 hours will be 45 °F (7.2 °C). Do you think it would be more helpful for you to know how the air temperature will vary across the 24-hour period? Why or why not?

Methods

The scientists collected adult Chinook salmon near the Roza Dam on the Yakima River in June and July 2009 and took them to a hatchery (**figures 7 and 8**). The salmon spawned (laid eggs) while in the hatchery, and the scientists collected the fertilized eggs (**figure 9**). The scientists put 150 eggs into each of 64 chambers (**figure 10**). These chambers were set up so that the eggs would hatch and the alevins could develop into fry (**figures 11 and 12**).



Figure 7. The Yakima River, named for the native Yakama people, has numerous dams and irrigation canals. The Yakima River is a source of water for the dry agricultural region of central Washington State. Photo courtesy of <http://www.iStockphoto.com>.

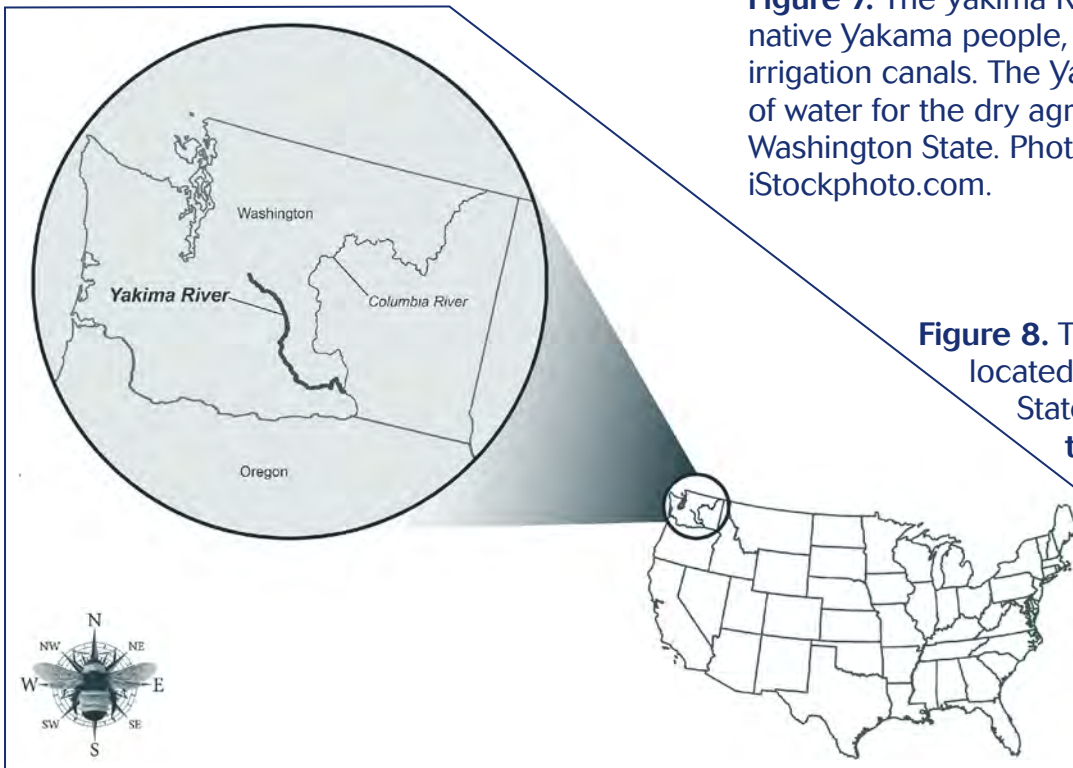


Figure 8. The Yakima River is located in central Washington State. The Yakima River is a **tributary** of the Columbia River and is 214 miles (344 kilometers) long. Map by Carey Burda.



Figure 9. Fish hatcheries are large indoor or outdoor facilities where fish eggs are hatched and young fish are allowed to develop. Photo courtesy of Babs McDonald.

Number Crunch



How many alevins were observed overall?



Figure 10. The chambers were made with plastic pipe. Each chamber enabled the eggs to hatch and the alevins to develop into fry. The scientists were able to catch, measure, and count the young fry as they emerged from the chamber. Photo courtesy of Dr. E. Ashley Steel and illustration by Stephanie Pfeiffer.

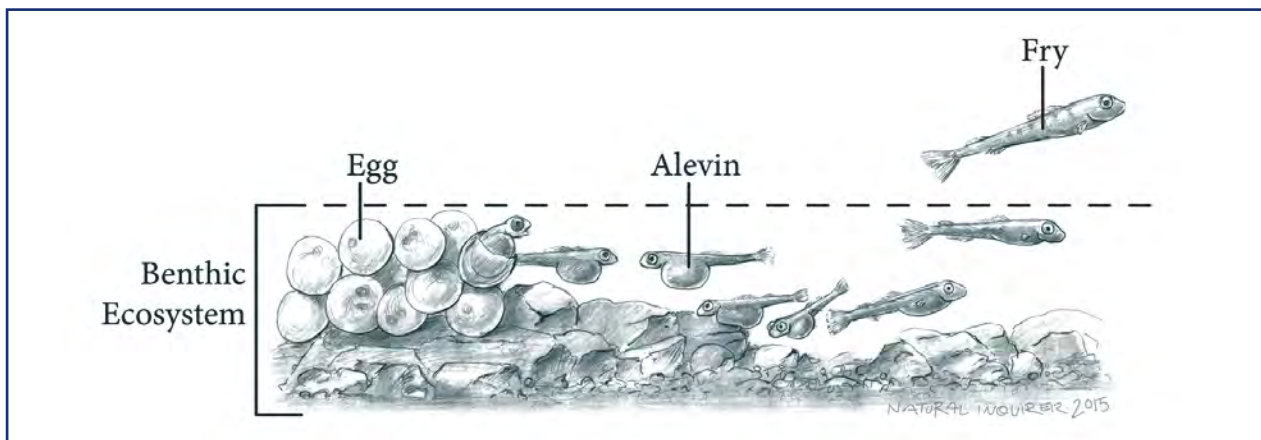
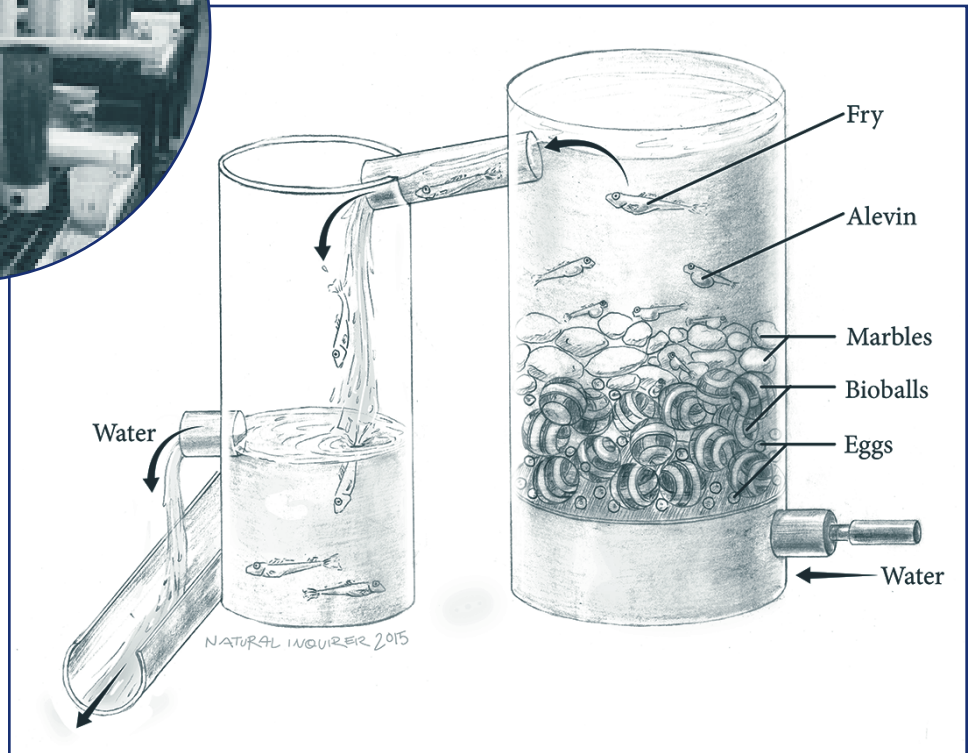


Figure 11. Chinook salmon lay eggs in the gravel beds of a river. After hatching, the alevins, or young salmon, live among the gravel on the river's bottom. While alevins are developing, they exist on a yolk sac. As they develop, they slowly absorb the yolk sac. When the yolk sac is gone, the alevins become free-swimming fry and they leave the graveled river bottom. Illustration by Stephanie Pfeiffer.

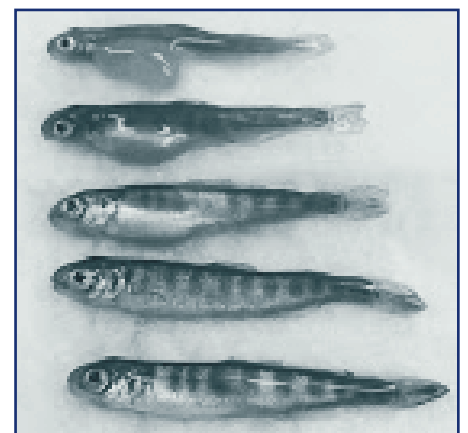


Figure 12. When an alevin's yolk sac has been absorbed, it becomes a free-swimming fry. Photo courtesy of Abby Tillotson.

The scientists controlled the water temperature in the chambers using very large aquarium heaters. They created eight different patterns of water temperature (**figure 13**). The different water-temperature patterns were meant to **simulate** stable temperatures, daily

variation in water temperature, seasonal variation in water temperature, and daily plus seasonal variation in temperature. In two cases, the scientists also simulated completely unnatural patterns just to see if the fish would respond.

A: Water temperature stable at 5 °C	B: Water temperature varied daily from 5 to 10 °C	C: Water temperature varied seasonally by reducing 1 °C per week, then warmed 1 °C per week	D: Daily variation plus seasonal variation (combination of B and C)
E: Extreme seasonal variation by flip flopping 5 °C one week, then 10 °C the next week	F: Extreme daily variation by changing the temperature from 5 to 10 °C twice daily	G: Water temperature stable at 10 °C	H: 10 °C with daily variation as high as 13 °C

Figure 13. The eight different water-temperature patterns.

Number Crunch

-  The scientists divided the temperature treatments equally across all 64 chambers. How many chambers received each of the eight treatments?

The scientists recorded the water temperature every hour. The temperature patterns were designed so that the chambers with variable temperatures delivered about the same total temperature units every day as those with stable temperatures.

Number Crunches

-  Temperature units (TUs) are usually thought of as degree days, the total amount of temperature delivered in one day. To design the temperature patterns, the scientists calculated TU every hour and then added the 24 hourly measurements together to determine the total temperature units delivered in 1 day.
-  Calculate the TUs delivered in 1 day for a stable pattern of 10 °C: $(10/24 + 10/24 + 10/24 + 10/24...)$ (Include all 24 hours TUs of $10/24$). What are the total TUs for the day? Note that for a stable water temperature, the TUs for 1 day is equal to the water temperature.
-  Try calculating TUs for a temperature pattern that goes up and down every hour:
 - If the water temperature fluctuated between 9 °C for 1 hour and 11 °C for the next hour, and this pattern repeated across 24 hours: $(9/24 + 11/24...)$ (include all 24 of TUs in your calculations), what would be the total TUs for the day?
-  Now calculate the TUs for this temperature pattern:
 - If the water temperature was 5 °C for 6 hours, 10 °C for 10 hours, and 7 °C for 8 hours, what would be the total TUs for the day?

At 11:00 a.m. every day, the total temperature units (TUs) for the past 24 hours were recorded for each chamber and the scientists checked to see if any fish had emerged. The scientists noted the day when most of the fish, 125 of the 150 alevins, emerged as fry. At that point, the scientists calculated the total TUs that had accumulated in each chamber over all the days that the alevins had been developing in that chamber.

The scientists designed temperature patterns that delivered about the same daily total TUs but had different kinds of **variability**. By using these patterns, the scientists measured the impact of variation in water temperature on the development of Chinook salmon. Note that everything else was held constant in the experiment. Any differences between the TUs that had been delivered when most of the fry

emerged, therefore, were likely related to the variability in the water-temperature patterns.

The scientists collected a **sample** of fry as they emerged from each chamber. The scientists weighed, measured, and determined the fry's overall condition.

Now, answer the Reflection Section questions on this page.

Findings

The water-temperature patterns influenced when fry emerged. Eggs and alevins exposed to the most stable water temperature (5 °C and 10 °C) had accumulated a mean of 1,160 (5 °C) and 1,153 (10 °C) TUs by the time most of the fry had emerged. Recall that the scientists used eight chambers for each of the eight temperature patterns. Therefore, the scientists calculated mean accumulated TUs for each of the eight patterns. The scientists expected these numbers to be similar. They expected this similarity because they knew that Chinook salmon eggs require a certain number of TUs to be ready to emerge.

The fry living in the chambers in which the water temperature varied by 5 to 10 °C once per day emerged after accumulating fewer TUs than when the water temperature was held stable (**figure 14**). The scientists

Reflection Section



Explain in your own words how the experiment was controlled so that any observed differences in fry emergence and condition would most likely be related to water-temperature patterns.

What were the scientists trying to discover in this experiment?

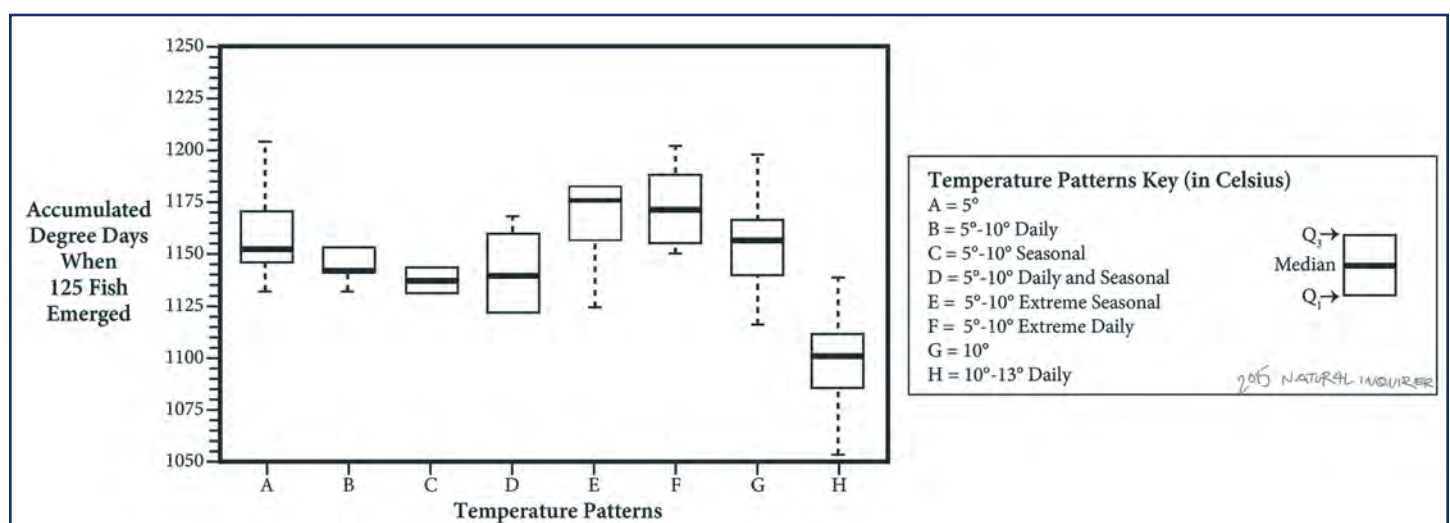


Figure 14. The emergence of Chinook salmon fry based on accumulated temperature units for eight water-temperature patterns. Illustration by Stephanie Pfeiffer.

discovered something different for the alevins exposed to water-temperature patterns with extreme daily or extreme seasonal variations. These alevins needed to accumulate more TUs than when the water-temperature was held stable for most of the fish to emerge as fry.

The scientists also discovered that fish exposed to the warmer patterns of water temperature emerged less fully developed than other fish. These fish were four times more likely to still have a visible yolk sac upon emergence.

Reflection Section



- Based on the scientists' results, what would you conclude about the relationship between water-temperature variability and Chinook salmon development?
- Look at figure 14. What do you notice about fry emergence from this figure?

How Does a Box Plot Show Interquartile Range?

Figure 14 is a box plot. Box plots are one way to display interquartile range. Calculating an interquartile range helps scientists to understand the variation in their data. To find an interquartile range, the data must be listed in rank order, from the lowest value to the highest value. The middle value (the median) is identified. Then, the middle value of the bottom half and the middle value of the top half is identified. After this step is

complete, the data have been divided into four parts or quartiles, called Q1, Q2, Q3, and Q4. Q2 is the median. The interquartile range is the value of Q3-Q1.

In figure 14, the middle bar in each box is the median. The bottom of the box is Q1 and the top of the box is Q3. The entire box for each temperature pattern represents the interquartile range.

Discussion

When scientists consider fish development based only on accumulated temperature units, they may be missing an important influence on fish development. This research shows that the timing of Chinook salmon development is dependent upon more than total accumulated temperature units. It matters how those total temperature units are delivered. Daily and seasonal water-temperature variability have an impact on how many temperature units are required for most of the fish to emerge.

The scientists estimate that variability in water temperature may affect fry emergence by as much as 1 week. Fish, like most wildlife

species, have adapted to the availability of food sources in time. Emerging a few days early or late may cause fry to miss important food resources. If human changes to water-temperature patterns affect when fish emerge, fish might emerge at a time with fewer food resources. The possible lack of food resources could affect Chinook salmon survival.

Understanding the relationship between fry emergence and water variability is important now because humans are changing water-temperature patterns. Building dams, changing land cover, irrigating, and changing the global climate may have important impacts on the life cycle of Chinook salmon.

Reflection Section



🍁 If you were teaching young scientists how to study fish emergence, what would you teach about considering water-temperature variability?

🍁 Do you think the results of this research are convincing? Why or why not?

Adapted from Steel, E.A.; Tillotson, A.; Larsen, D.A.; Fullerton, A.H.; Denton, K.P.; Beckman, B.R. 2012. Beyond the mean: The role of variability in predicting ecological effects of stream temperature on salmon. *Ecosphere*. 3(11): 104. <http://dx.doi.org/10.1890/ES12-00255.1>. http://www.fs.fed.us/pnw/pubs/journals/pnw_2014_steel001.pdf.

Why Was the Elwha Dam Removed?

In 2014, the National Park Service completed the removal of two large dams on the Elwha River in Olympic National Park, Washington State (**figure 15**). For 100 years, the dams blocked all but the last 5 miles of the river. This blockage created reservoirs (large lakes) where a river once was, and

stopped natural sediment flow and salmon migration. The dams had dramatically changed the Elwha River ecosystem. Removal of the dams has reopened more than 70 miles of important salmon spawning habitat, restored natural sediment flow, and begun the restoration of the Elwha River ecosystem.

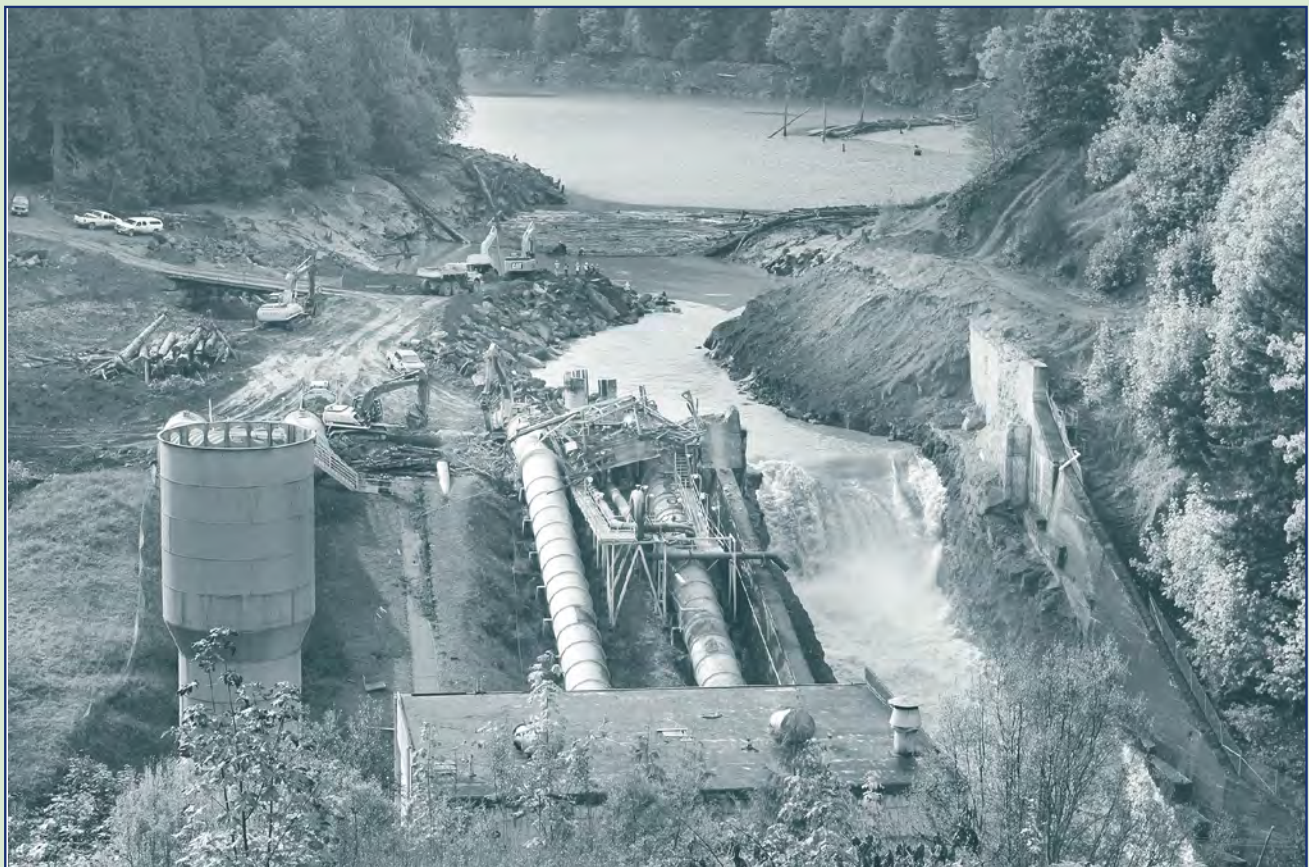


Figure 15. The Elwha Dam in the midst of its removal. Photo courtesy of the National Park Service.

Glossary

accumulate (ə kyü m(y)e lāt): To increase gradually in amount as time passes.

aquatic (ə kwä tik): (1) Living or found in, on, or near water; (2) of or relating to the animals or plants that live in, on, or near water.

emerge (i mərj): To become known or visible.

fry (fri): Recently hatched or juvenile fishes.

habitat (hə bə tat): The place or environment where a plant or animal naturally or normally lives and grows.

land use (land yūs): How people are using the land.

mean (mēn): The average of a set of values.

migratory (mī grə tōr ē): Having a characteristic of moving from one place to another on a periodic basis.

regulate (re gyə lāt): To set or adjust the amount, degree, or rate of something.

sample (sam pəl): A small subset group, representative of the entire group.

sediment (se də mən): Soil particles carried along in streams and rivers, some of which may settle to the bottom.

simulate (sim yə lāt): To create the appearance or effect of something for purposes of evaluation.

tributary (tri byə ter ē): A stream that flows into a larger stream or river or into a lake.

variable (ver ē ə bəl): Subject to changes.

variability (ver ē ə bi-lə tē): The degree to which something is variable.

variation (ver ē ā shən): A change in the form, position, condition, or amount of something.

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>).

FACTivity



Time Needed

- One class period for graphing data or 3 to 4 weeks for downloading and graphing data
- 3 to 4 weeks for observation involving 5 to 10 minutes per day
- One class period for analysis, reporting, and discussion

Materials (for each small group)

- Observational tools appropriate for the event, such as binoculars or butterfly nets
- Graph paper and pencil
- Copy of the log sheet on page 103

- Daily access to a computer with Internet access (optional) or your teacher will provide daily data (from a Web site)

The question you will answer in this FACTivity is: How do air temperature patterns relate to a yearly natural event?

Your teacher will divide your class into groups. Your group will select an event to study. Identify a natural event that is at least partly dependent upon the air temperature for its occurrence. Your group may select an event from the following list, or identify a yearly natural event of your own:

1. The emergence of a particular species of leaves.
2. The emergence of a particular species of flowers.
3. The first sighting of butterflies.
4. The first sighting of a particular **migratory** bird species.
5. The first occurrence of the developmental stage of an amphibian species.
6. The first leaf color change in the fall.
7. The first frost.
8. The first snowfall.

Identify a yearly natural event that you expect to occur in your area within the next 3 to 4 weeks.

As a group, write down exactly what you will be looking for in the event. For example, you might write: "We are looking for the first sign of autumn color change in the maple tree in the front school yard, beside the front stairs. Color change means any change on any part of a leaf on that tree, from green to red, yellow, orange, or brown."

After you have identified and described your event, look at the science log sheet on page 103. Your group will need three to four copies of the log sheet.

You will either access <http://www.weather.noaa.gov> every day to record hourly temperatures, or your teacher will provide this information to you.

As an alternative, you may record your own hourly temperatures using an outdoor thermometer. If you choose this method, you may have to fill in nighttime temperatures and weekend temperatures from <http://www.weather.noaa.gov>.

Observe daily, watching for your event to happen. When your event happens, record the date. At this point, you may stop recording the hourly temperature.

Using your completed log sheet, calculate the average daytime temperature and average nighttime temperature for each week. For this FACTivity, daytime temperatures

Project BudBurst™

Timing is everything!

Plants are all around us. Changes in emergence of plants each year can tell scientists about changes in climate. Contribute your observations of plants at home, at school, or at local parks with Project BudBurst (<http://www.budburst.org>), a citizen science project that allows you to become the scientist. Use the QR (Quick Response) code to start collecting data for science.



include those from 9:00 a.m. until 8:00 p.m. Nighttime temperatures include those from 9:00 p.m. until 8:00 a.m.

Make a graph of the two daily temperature averages across the weeks leading up to your event. (See **figure 16** for an example.) You may need to make three or four graphs, one for each week. Blank graph paper is located on page 123.

Your group will analyze your graphs as you think about your event. What patterns do you see in the air temperature in the weeks and days leading up to your event? How could these patterns affect the timing of your event? Write your observations and analysis, using complete sentences. Report your results to the class. Your teacher will hold a class discussion about the patterns you noticed in your data. Compare and contrast between different events.

To find hourly temperatures, visit <http://www.weather.noaa.gov>. Select your State and then select your location. Select the location that is nearest to you.

This Web site displays hourly weather data for the past 3 days. Record the hourly temperatures using the log sheet. On Monday, record air temperature from over the weekend.

Group Members: _____

Event: _____

Log of Hourly Temperatures by Week

Week of _____

	Sun	Mon	Tue	Wed	Thurs	Fri	Sat
	Degrees Fahrenheit						
12 am							
1 am							
2 am							
3 am							
4 am							
5 am							
6 am							
7 am							
8 am							
9 am							
10 am							
11 am							
12 pm							
1 pm							
2 pm							
3 pm							
4 pm							
5 pm							
6 pm							
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8 pm							
9 pm							
10 pm							
11 pm							



FACTivity Extension

As a class, compare and contrast this FACTivity with the salmon research in the article.

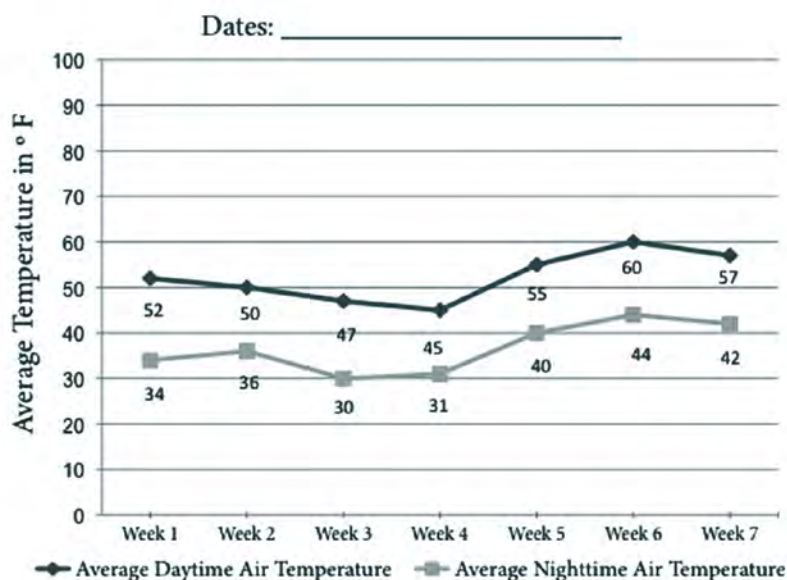


Figure 16. An example of a graph showing air temperatures over time. Illustration by Stephanie Pfeiffer.

What's in a Name?

Time travel is the concept of moving either forward or backward in time. In this article, the emergence of young fish from an earlier developmental stage was timed, in a way, by using a value called temperature units.

Web Resources

National Oceanic and Atmospheric Administration, Chinook Salmon

<http://www.nmfs.noaa.gov/pr/species/fish/chinooksalmon.htm>

National Park Service, Elwha River Restoration

<http://www.nps.gov/olym/naturescience/elwha-ecosystem-restoration.htm>

National Oceanic and Atmospheric Administration, Fisheries: Elwha Restoration

<https://www.youtube.com/watch?v=TP9z5S5oivo>

Project Budburst/National Geographic Growing Degree Days Tool

http://budburst.org/documents/871408/1044448/FS_Unit_3.pdf/5b4c635f-2d09-4055-a881-35a174d0085d

Project Budburst

<http://www.budburst.org>

USA National Phenology Network

<https://www.usanpn.org/>

Natural Inquirer Connections

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

- For more on the impact of dams, read “Mussel Mania” on page 74 of this edition of *Natural Inquirer*.
- For more information on salmon and their ecosystems, read “Food for the Soil” in the *Natural Inquirer* monograph.

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

Under Where?

Underground Water and Its Contribution to Streams

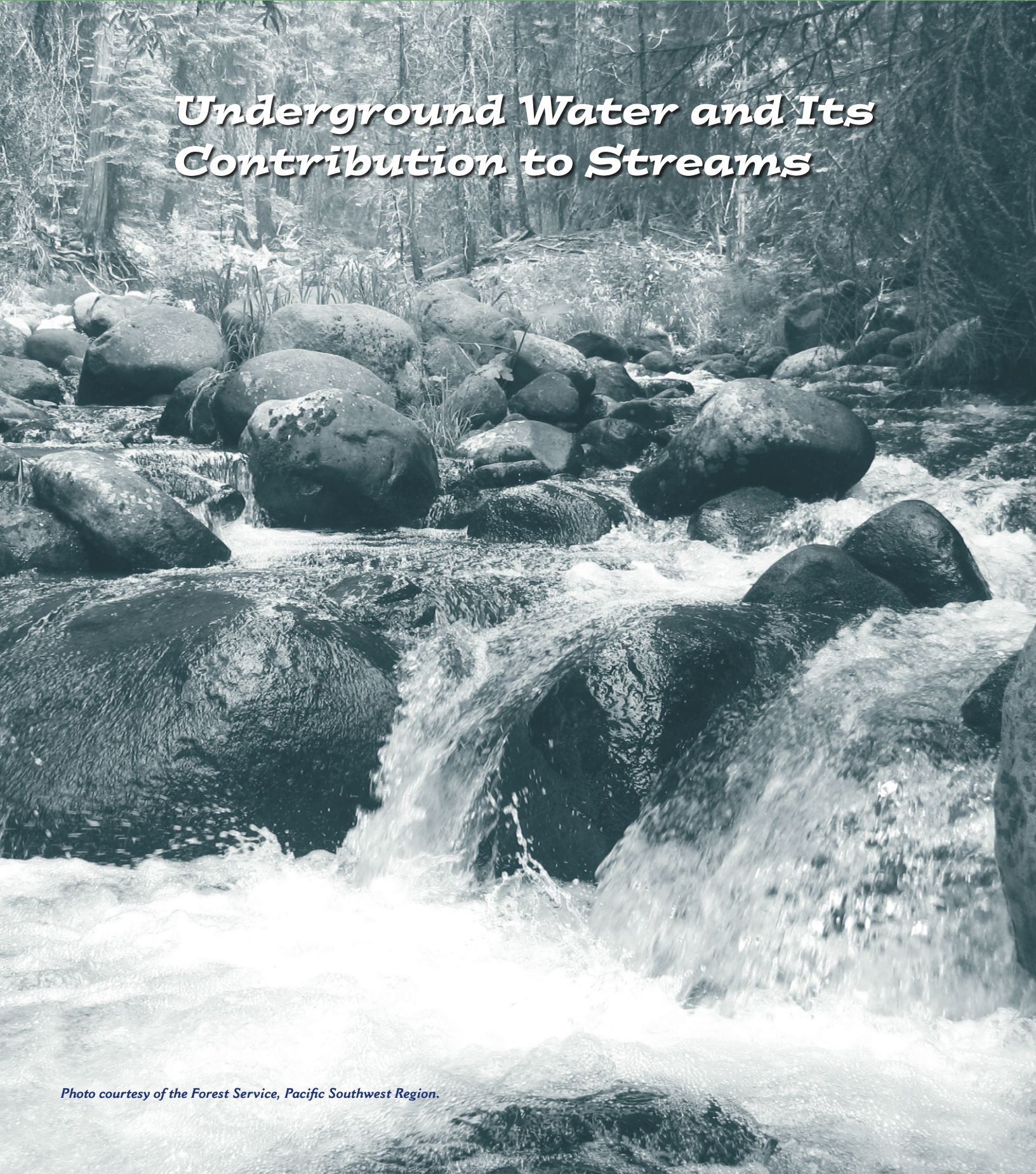


Photo courtesy of the Forest Service, Pacific Southwest Region.

Meet the Scientists



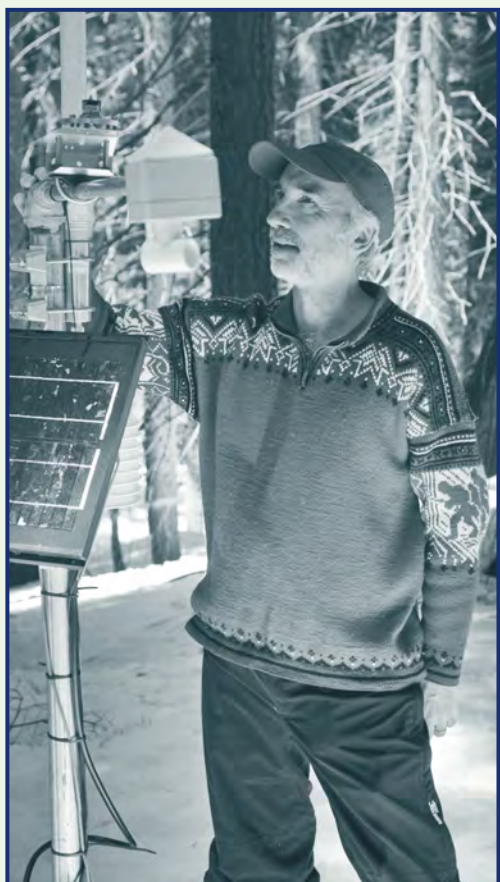
▲ **Dr. Fengjing Liu**, Hydrologist: My favorite science experience is doing research to understand how water and **contaminants** move and how they are linked within a **watershed**.

► **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?

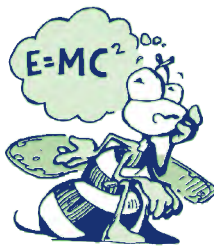
ecologist: This scientist studies the relationship of living things with their living and nonliving environment.

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.

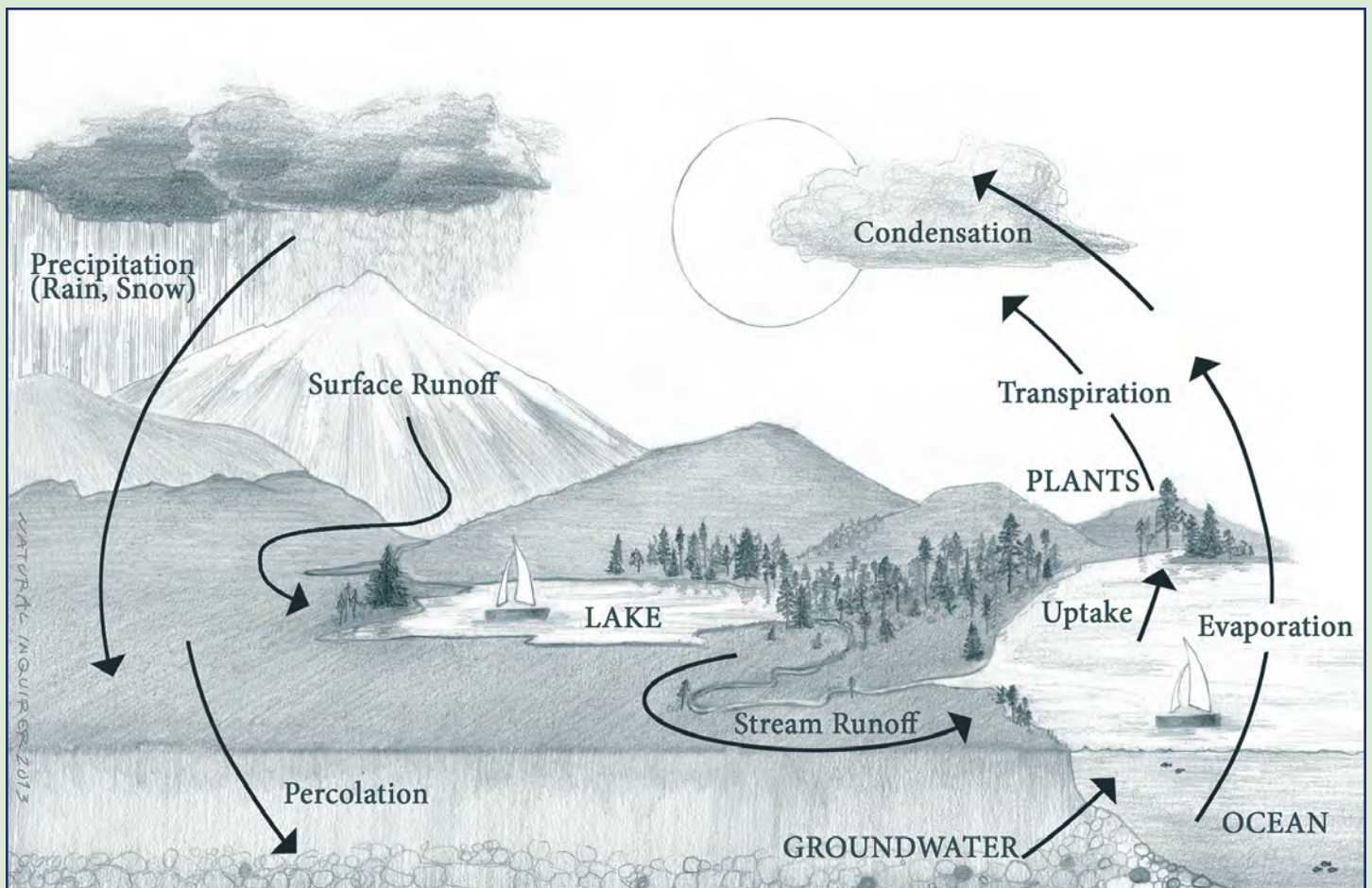


Figure 1. The water cycle. Illustration by Stephanie Pfeiffer.

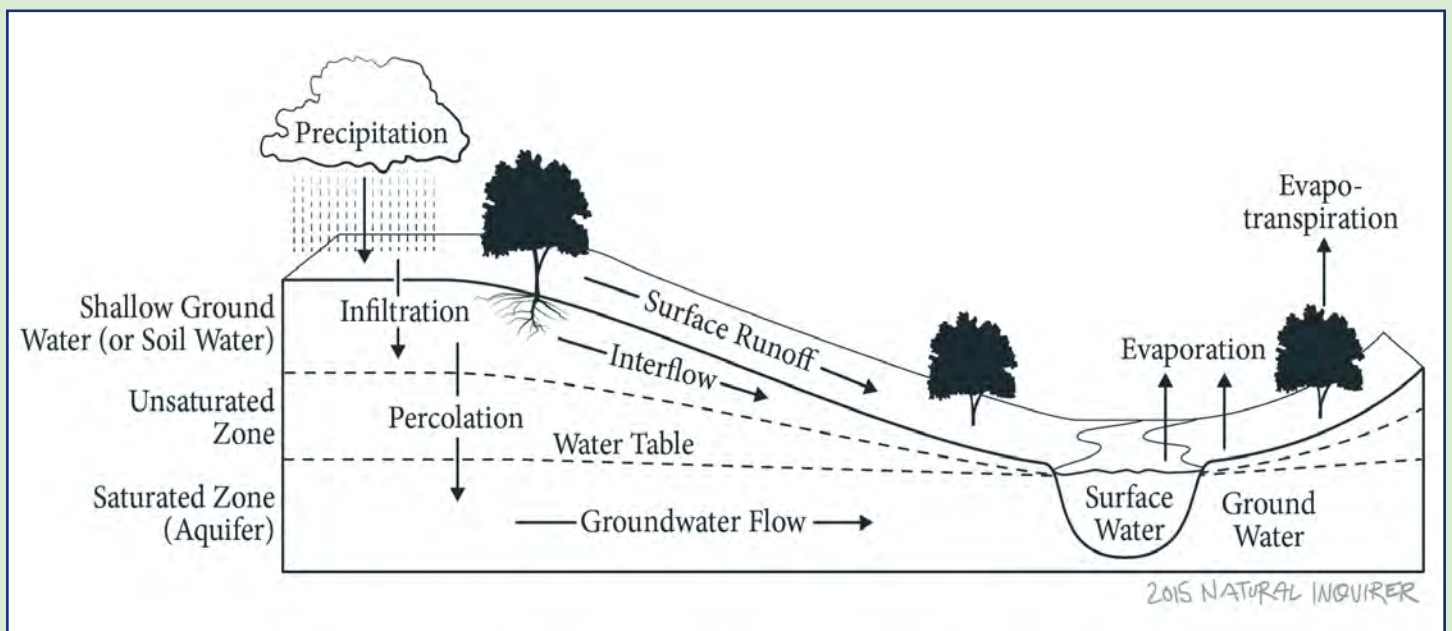


Figure 2. Water moves underground as part of the water cycle. Notice that some water stays near the soil surface. This shallow groundwater, or soil water, may be a few feet deep or up to 20 feet deep below the soil surface. Deeper underground water is called deep groundwater or just groundwater. Illustration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

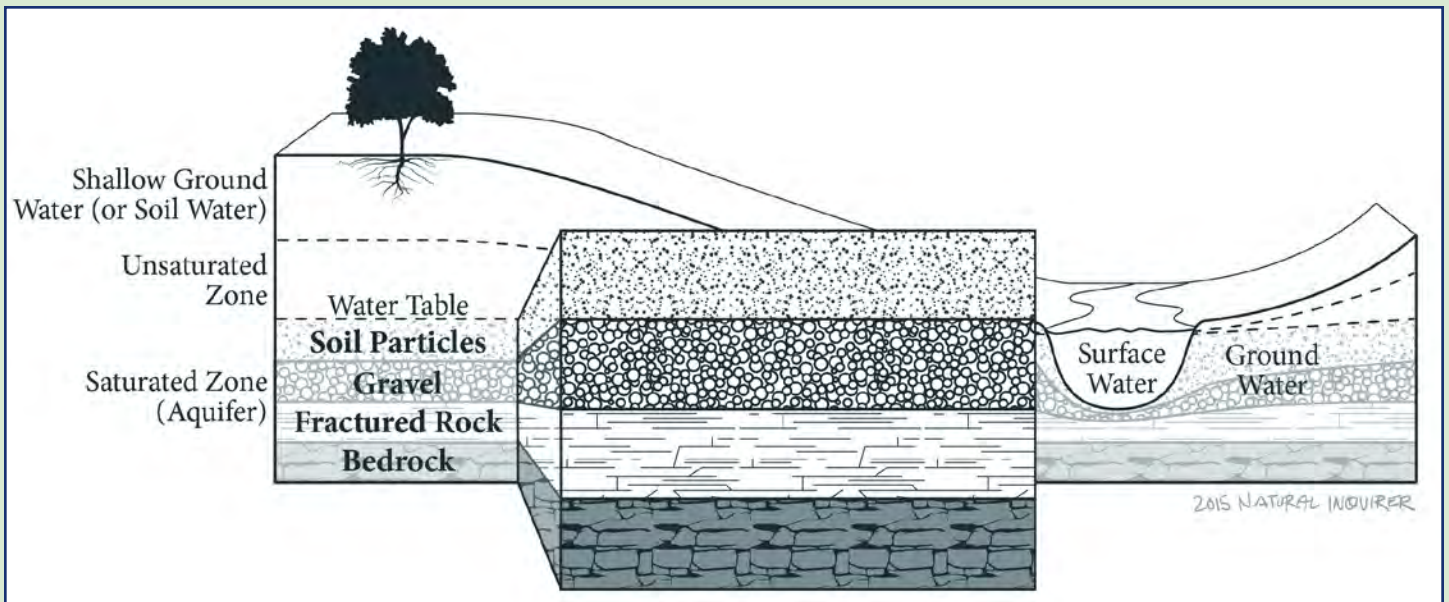


Figure 3. Groundwater fills the spaces between soil particles and fractured rock underground. Notice that below the water table, all openings between soil particles and rocks are full of groundwater. Above the water table, some water, held by molecular attraction, may surround particles and rocks. Illustration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

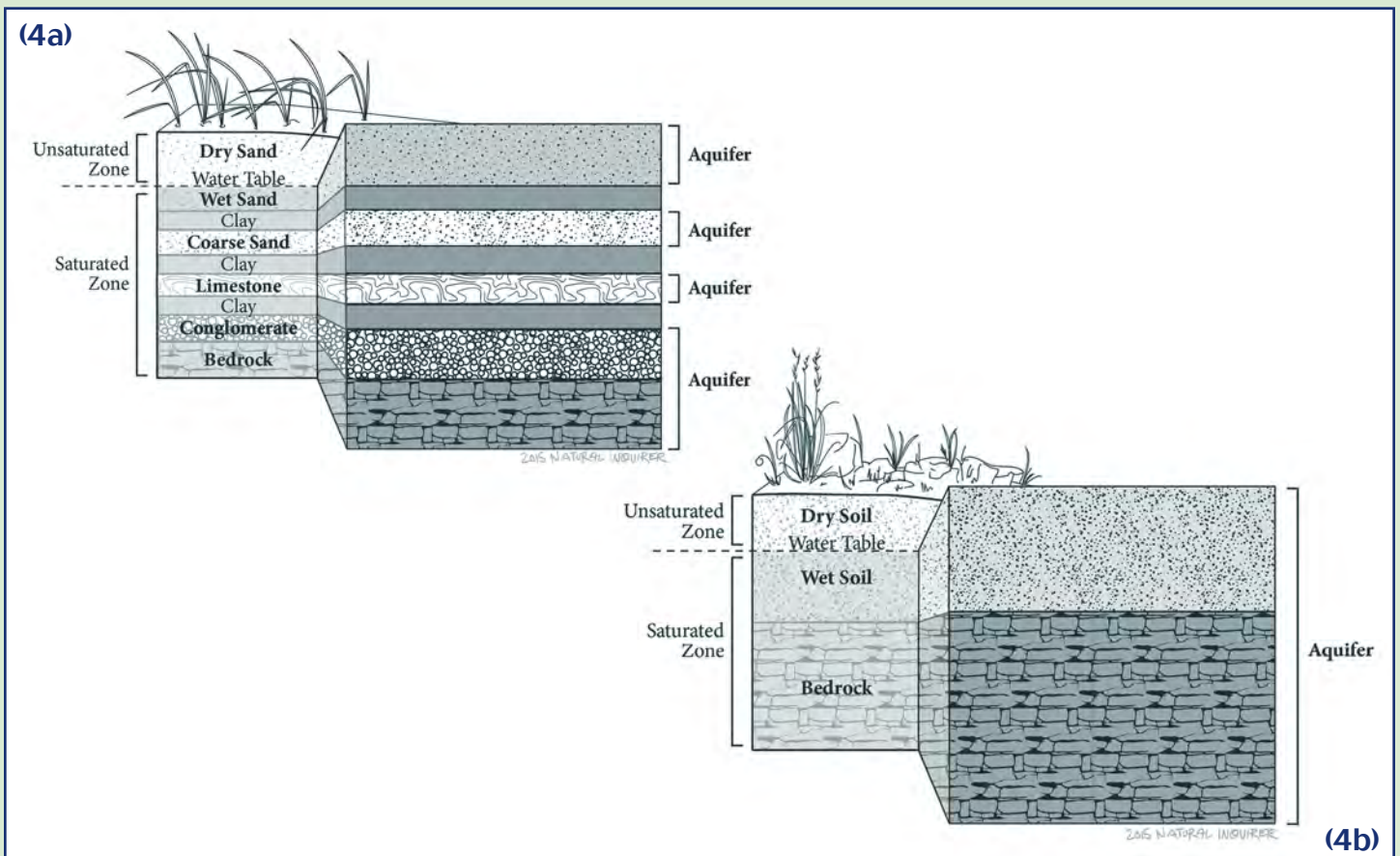


Figure 4a and 4b. Aquifers are natural underground water storage areas. Coastal aquifers (4a) are different than aquifers found in hilly or mountainous areas (4b). Illustrations by Stephanie Pfeiffer.

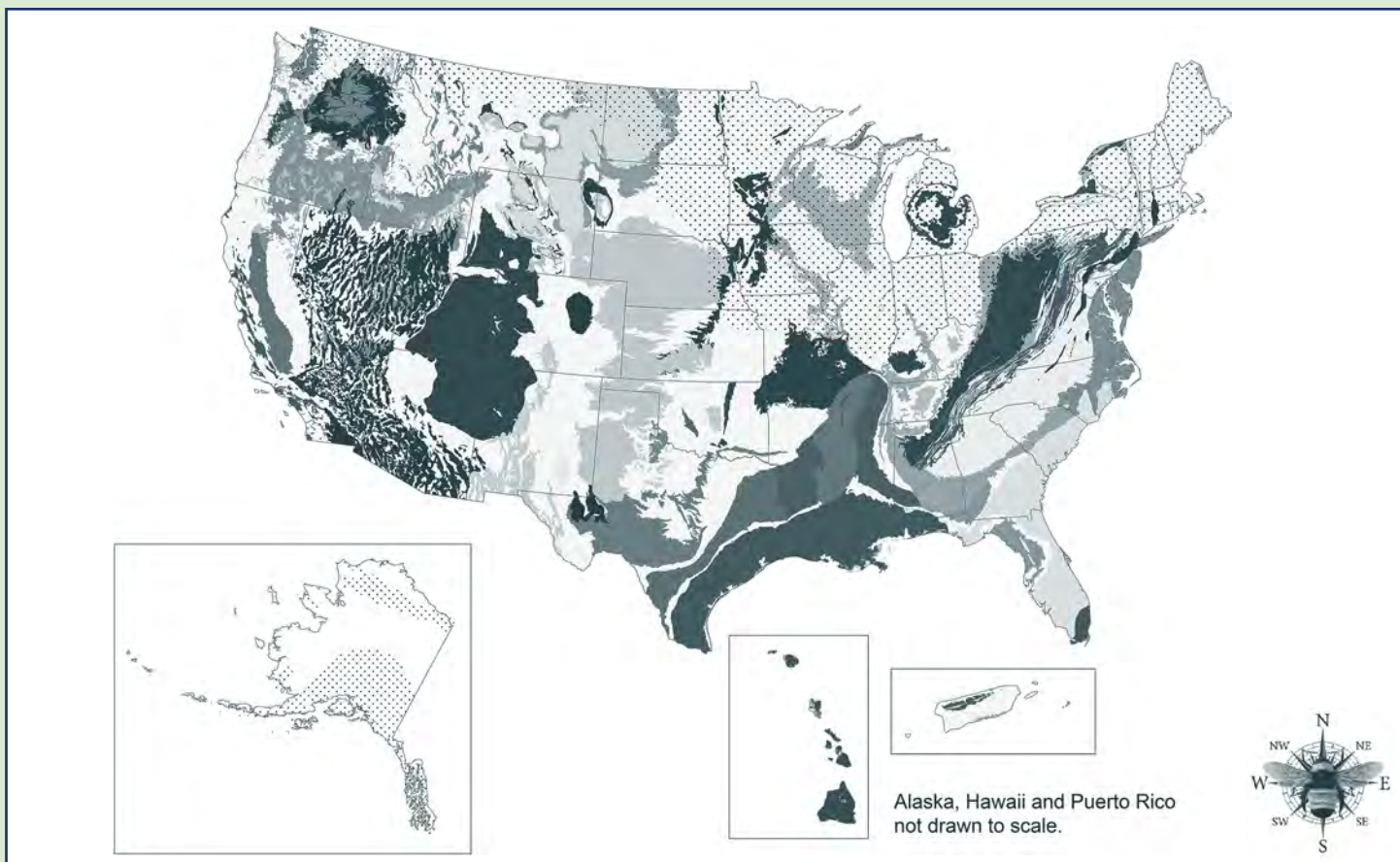


Figure 5. Groundwater provides water to underground aquifers or water storage areas. This water provision is called recharge. Most of the United States contains underground aquifers. This map shows the primary aquifers in the United States. Although the areas in white show no aquifers, these areas may 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.

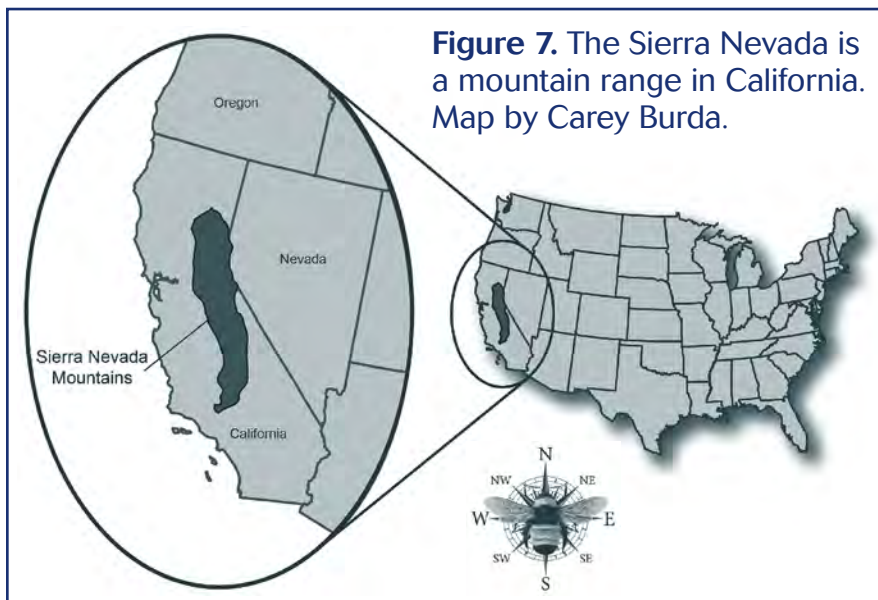


Figure 7. The Sierra Nevada is a mountain range in California. Map by Carey Burda.

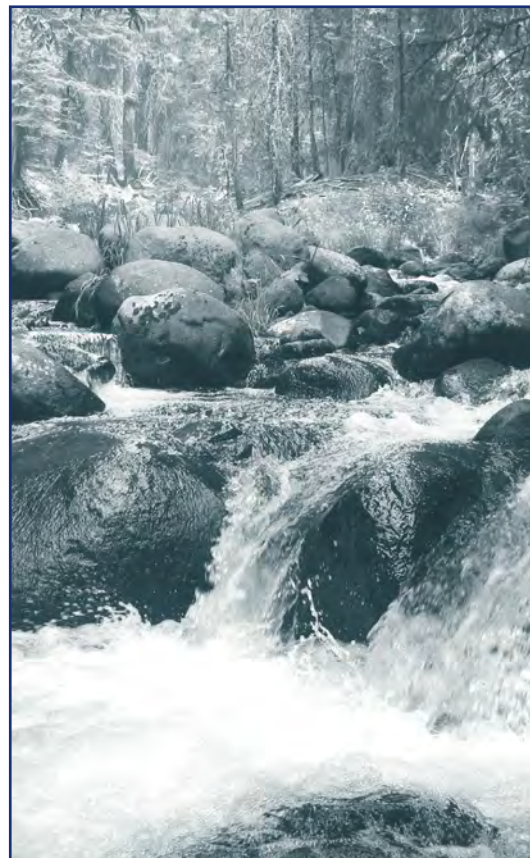


Figure 8. The Sierra Nevada has steep, forested slopes and clear mountain streams. Photo courtesy of the Forest Service, Region 5.

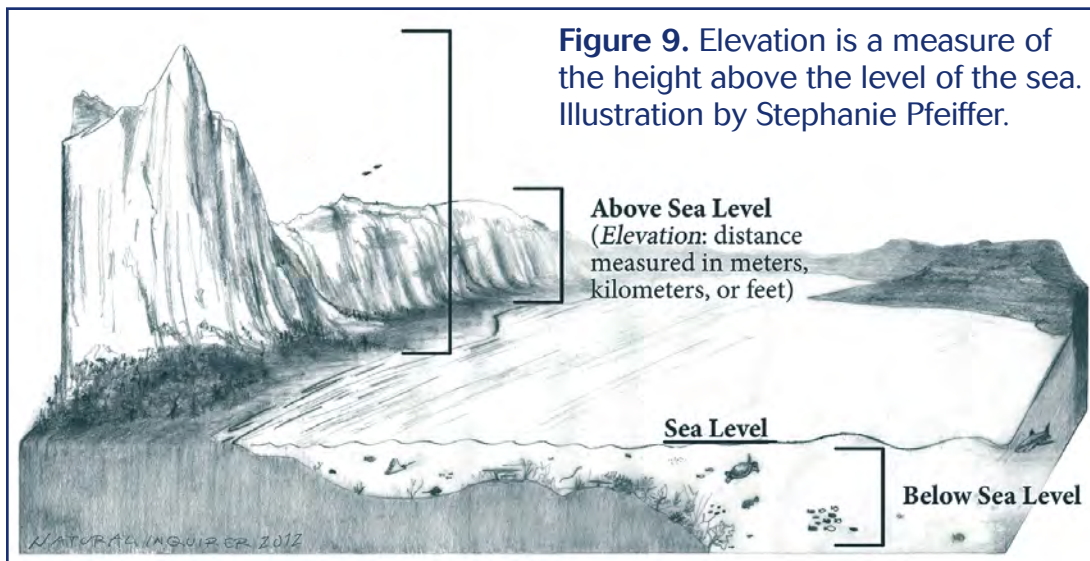


Figure 9. Elevation is a measure of the height above the level of the sea. Illustration by Stephanie Pfeiffer.

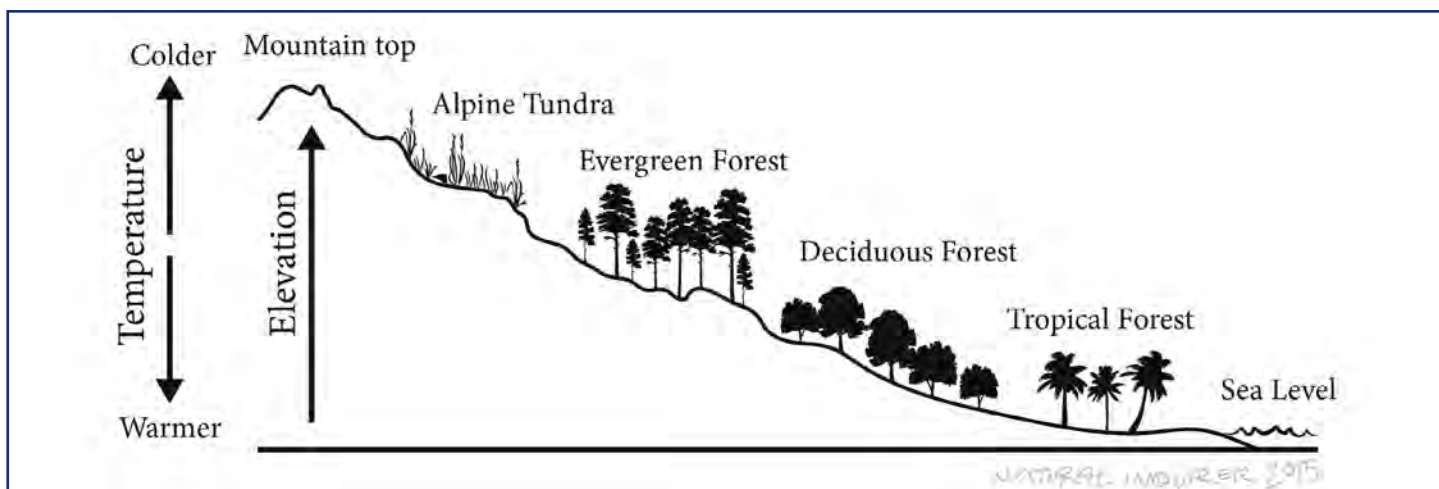


Figure 10. As elevation increases, an area’s climate gets cooler and snow may fall often in the winter months. Illustration by Stephanie Pfeiffer.

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.



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

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.

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**).

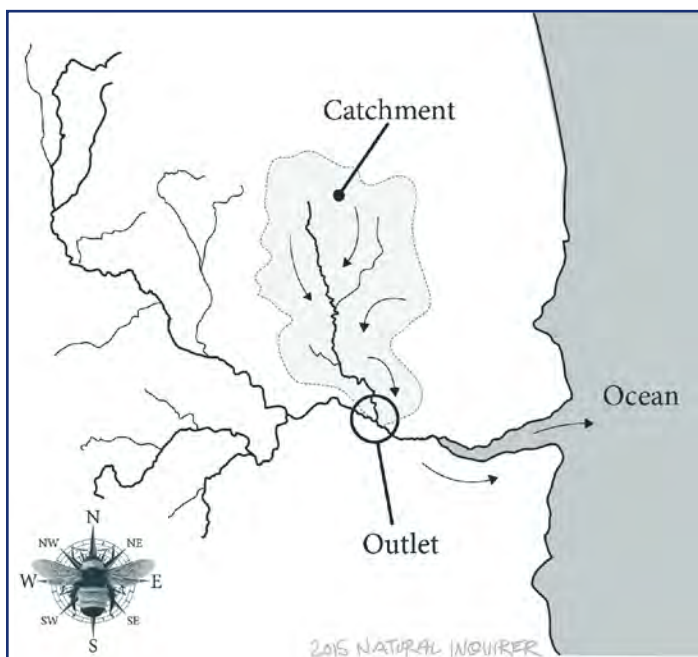


Figure 12. All streamwater flowed to one stream outlet in each catchment. Illustration by Stephanie Pfeiffer.



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.

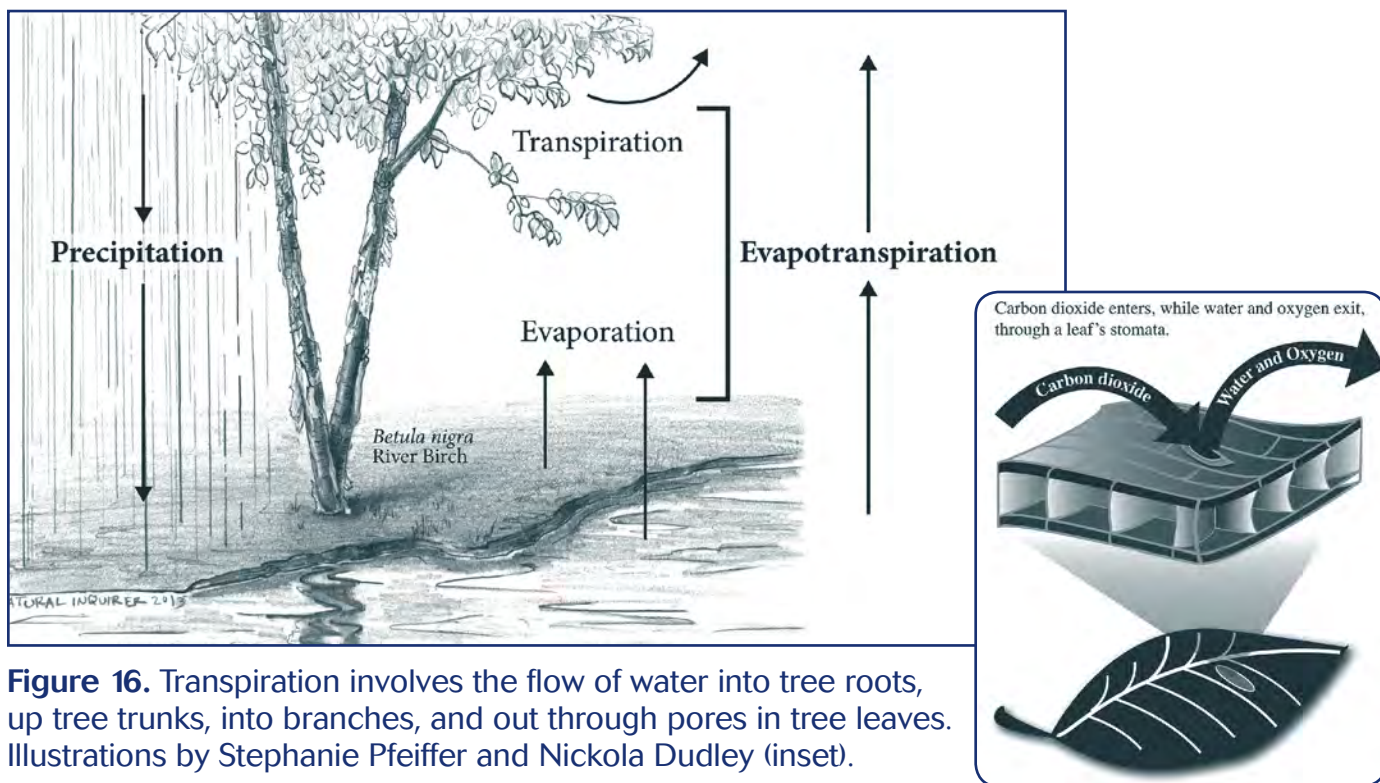


Figure 16. Transpiration involves the flow of water into tree roots, up tree trunks, into branches, and out through pores in tree leaves. Illustrations by Stephanie Pfeiffer and Nickola Dudley (inset).

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 mən): A small, steep watershed.

contaminant (kən tā mə nən): 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 (graünd 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 òf): 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?



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.

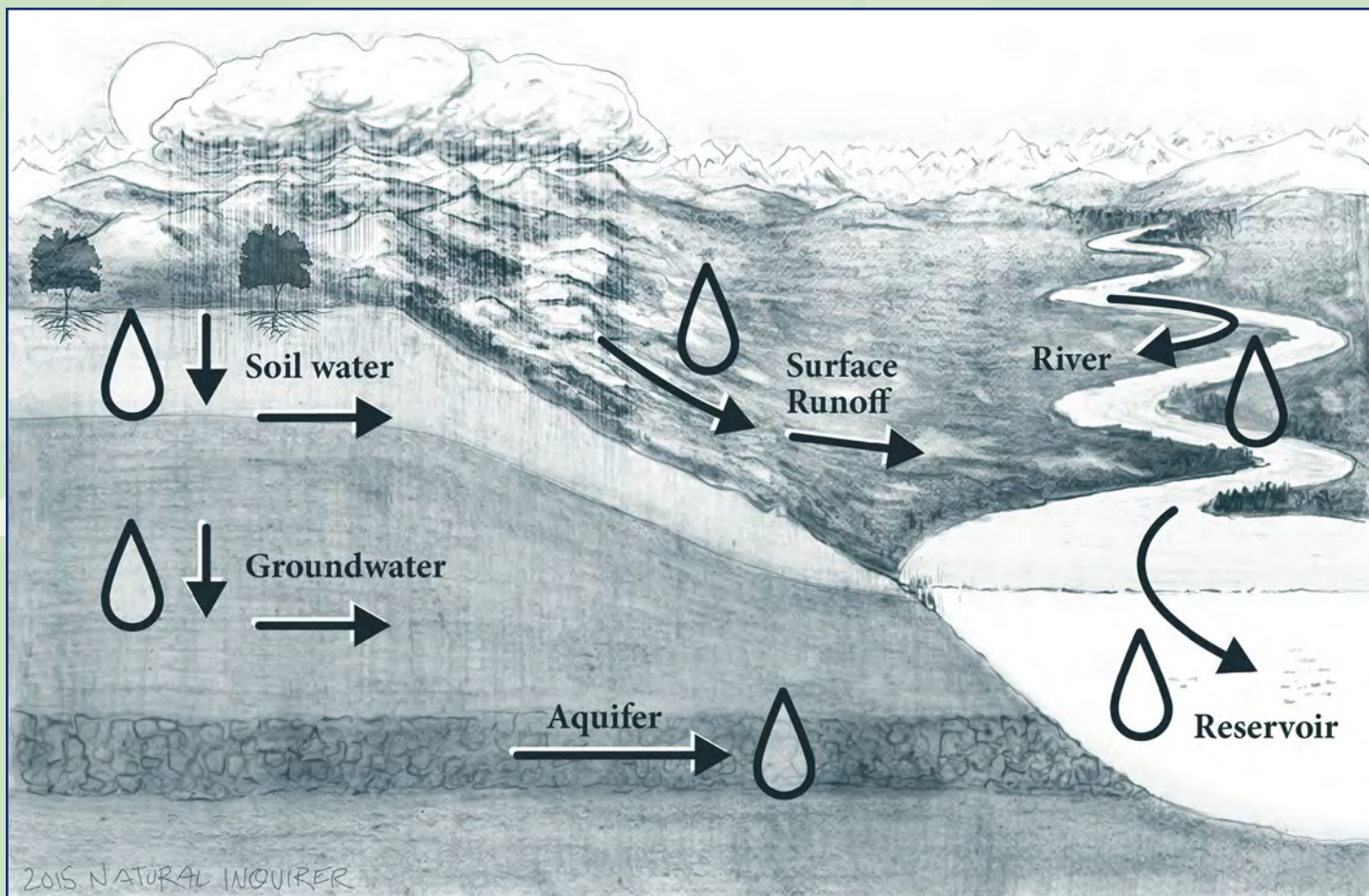


Figure 17. Water drops appear in many places throughout the water cycle. Illustration by Stephanie Pfeiffer.

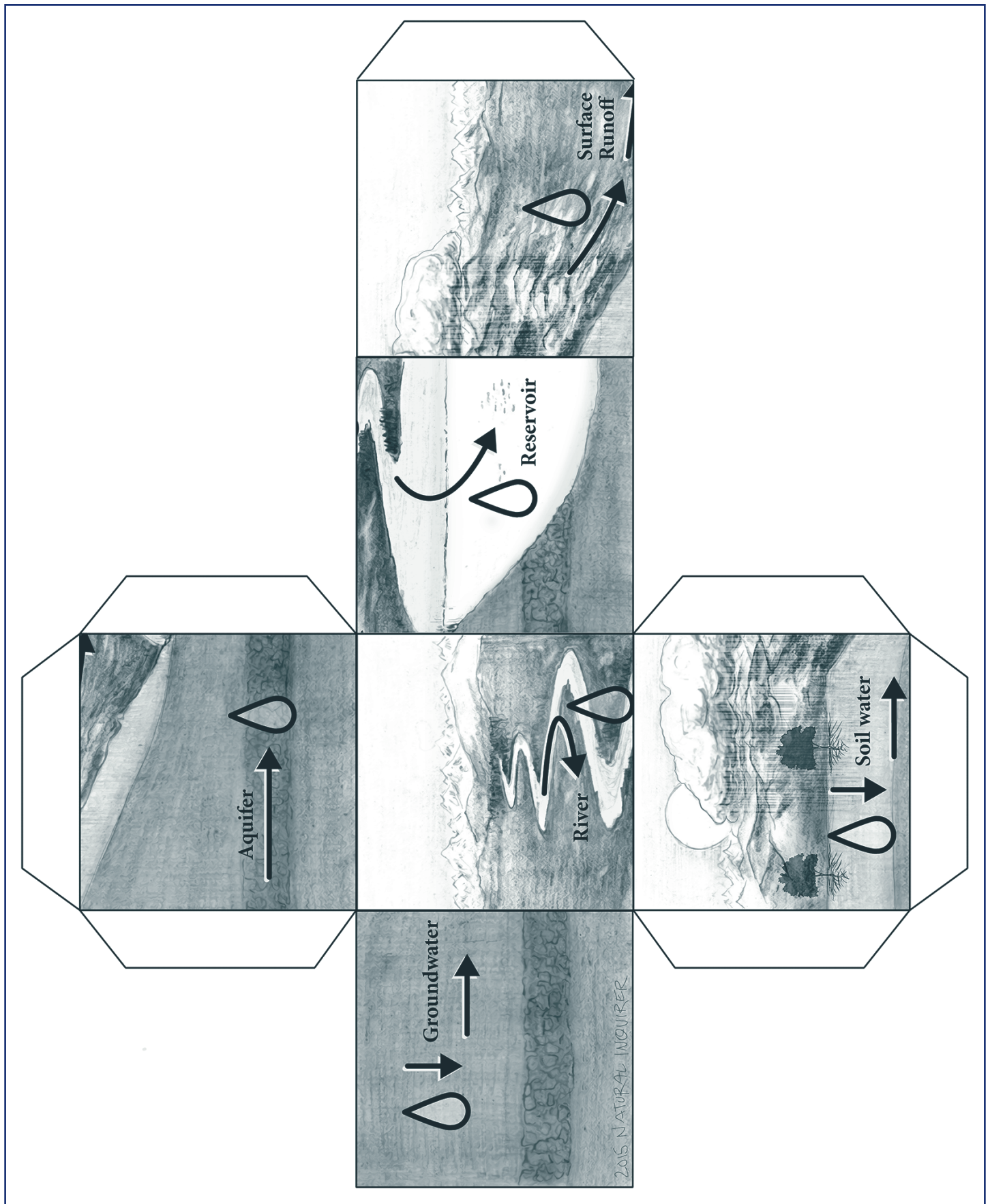
Each student pair will roll the cube. (All student pairs may take turns rolling the same cube.) Each pair will work with whatever portion of the illustration lands on top. Identify the location of the water drop.

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.



Alternate FACTivity



Time Needed

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

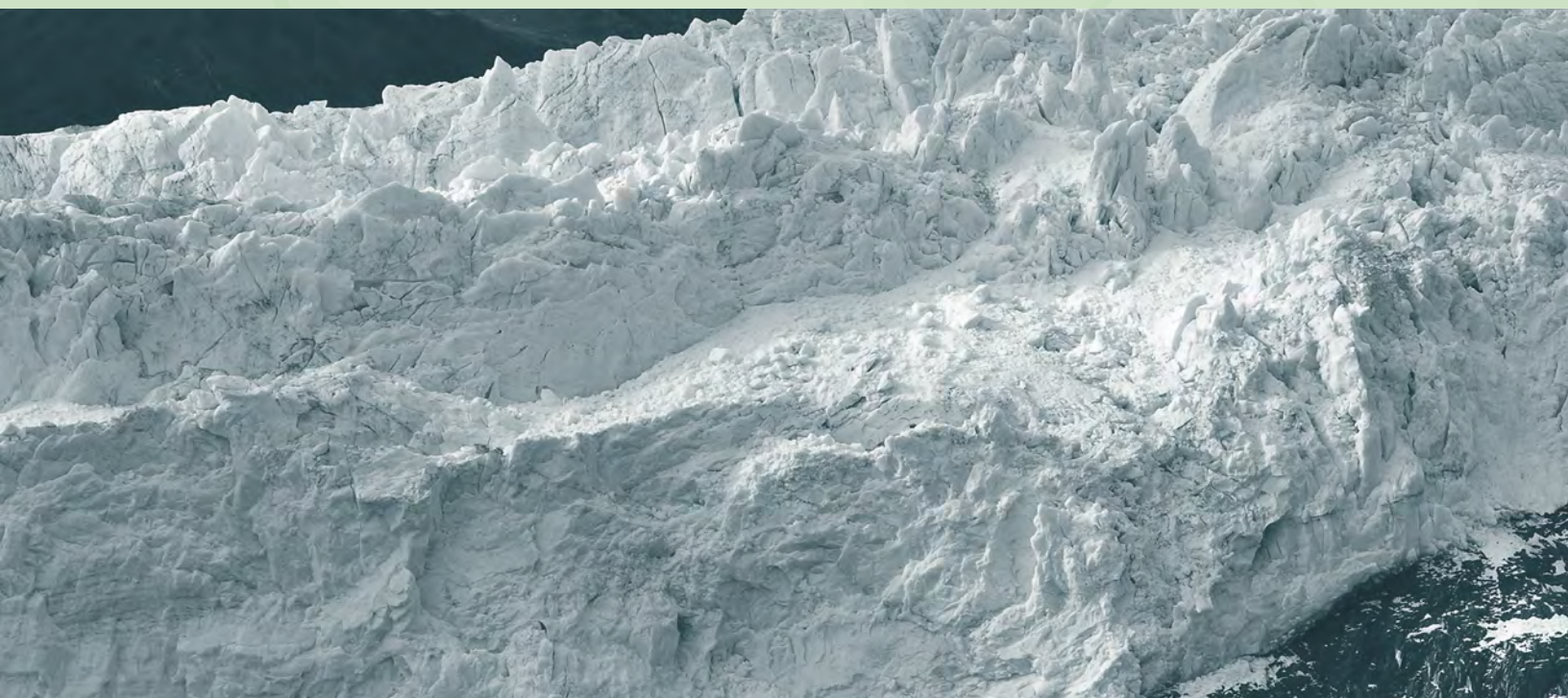
Materials

- 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>

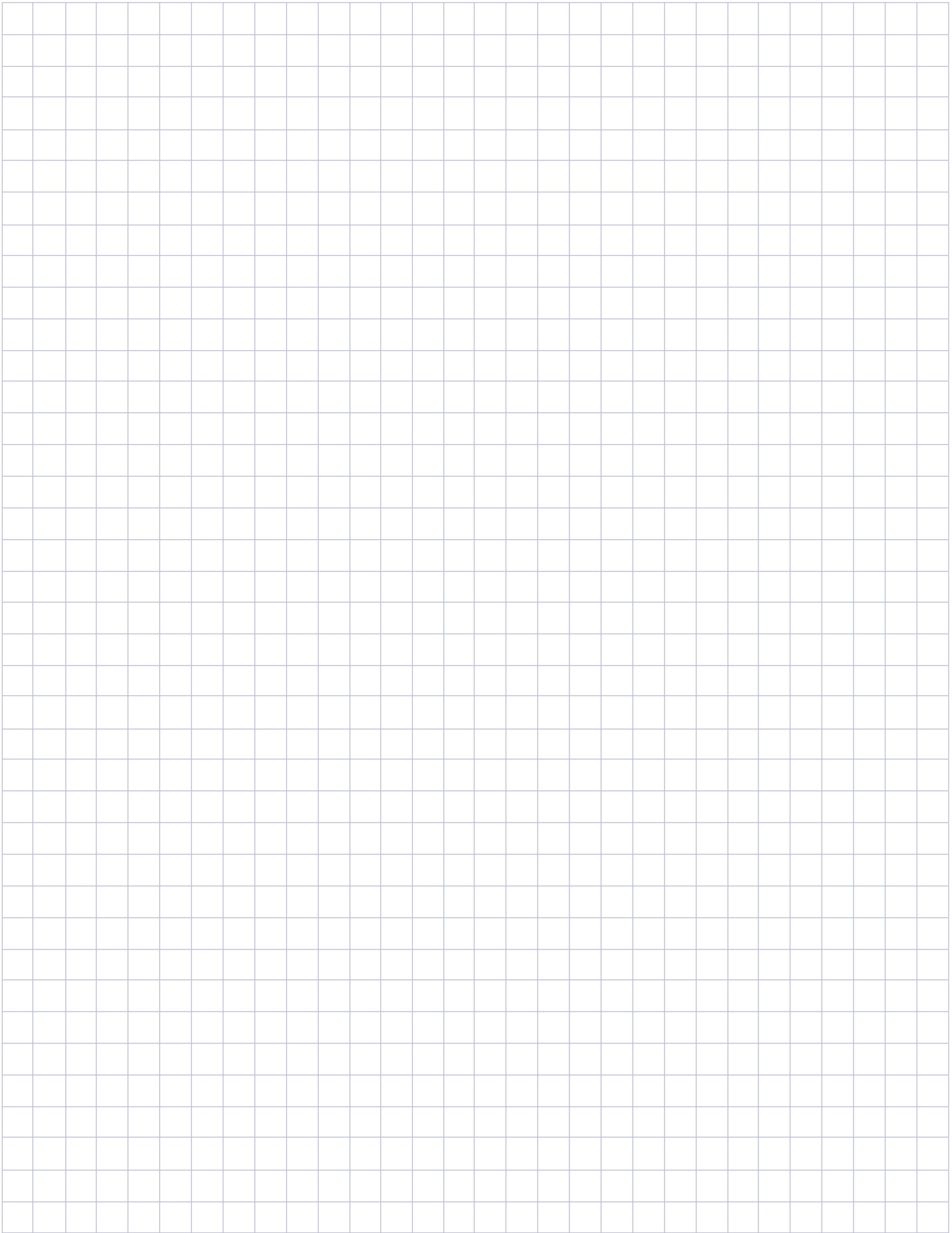
U.S. Geological Survey: Water Basics
<http://water.usgs.gov/edu/mwater.html>

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/

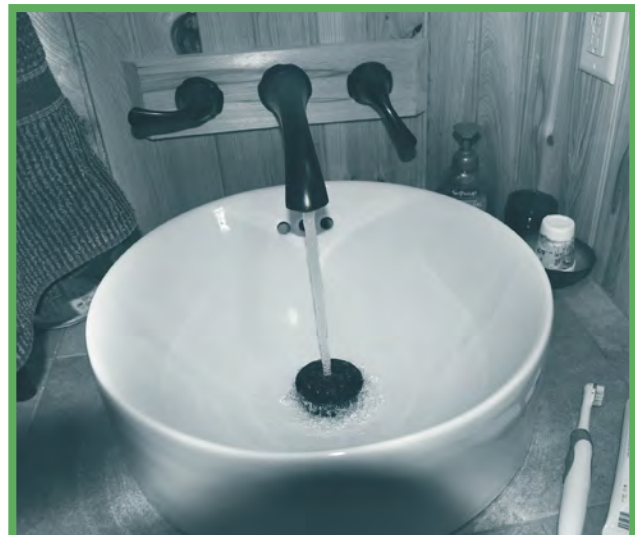
If you are a trained Project Learning Tree educator, you may use “Rain Reasons” and “Water Wonders” as additional resources.

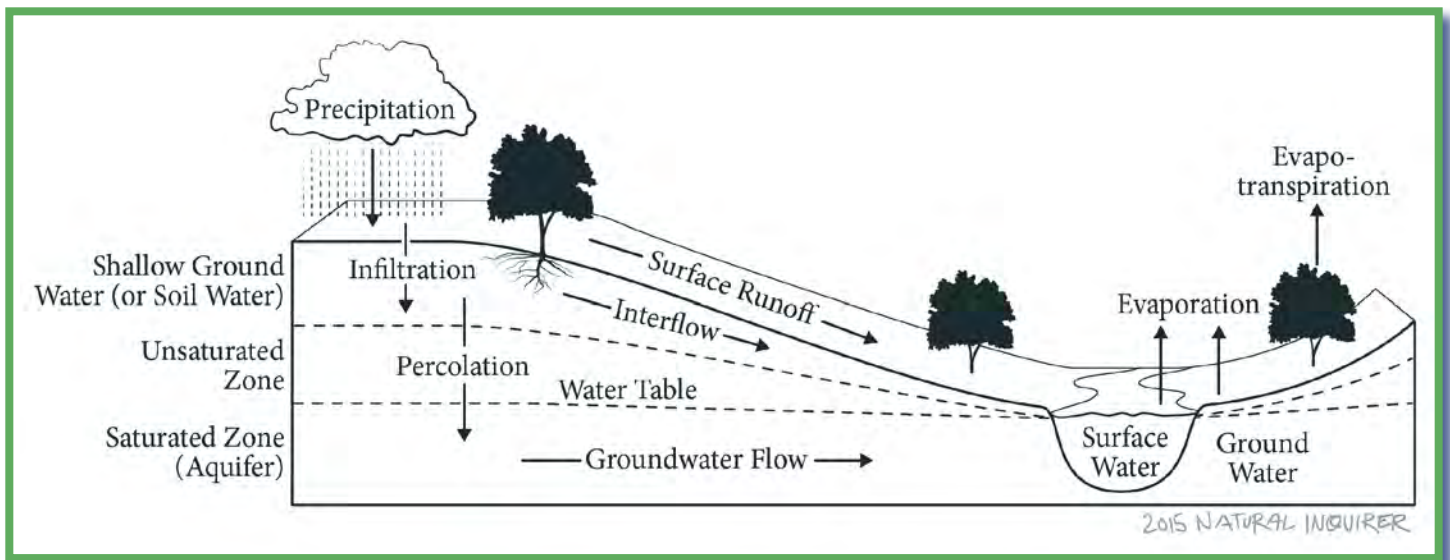




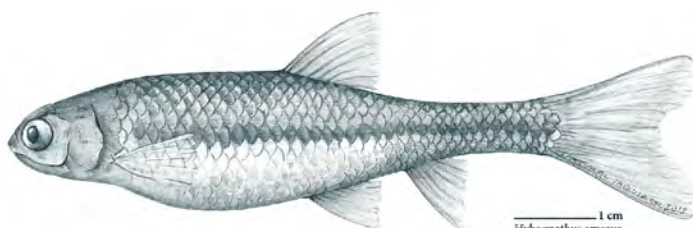
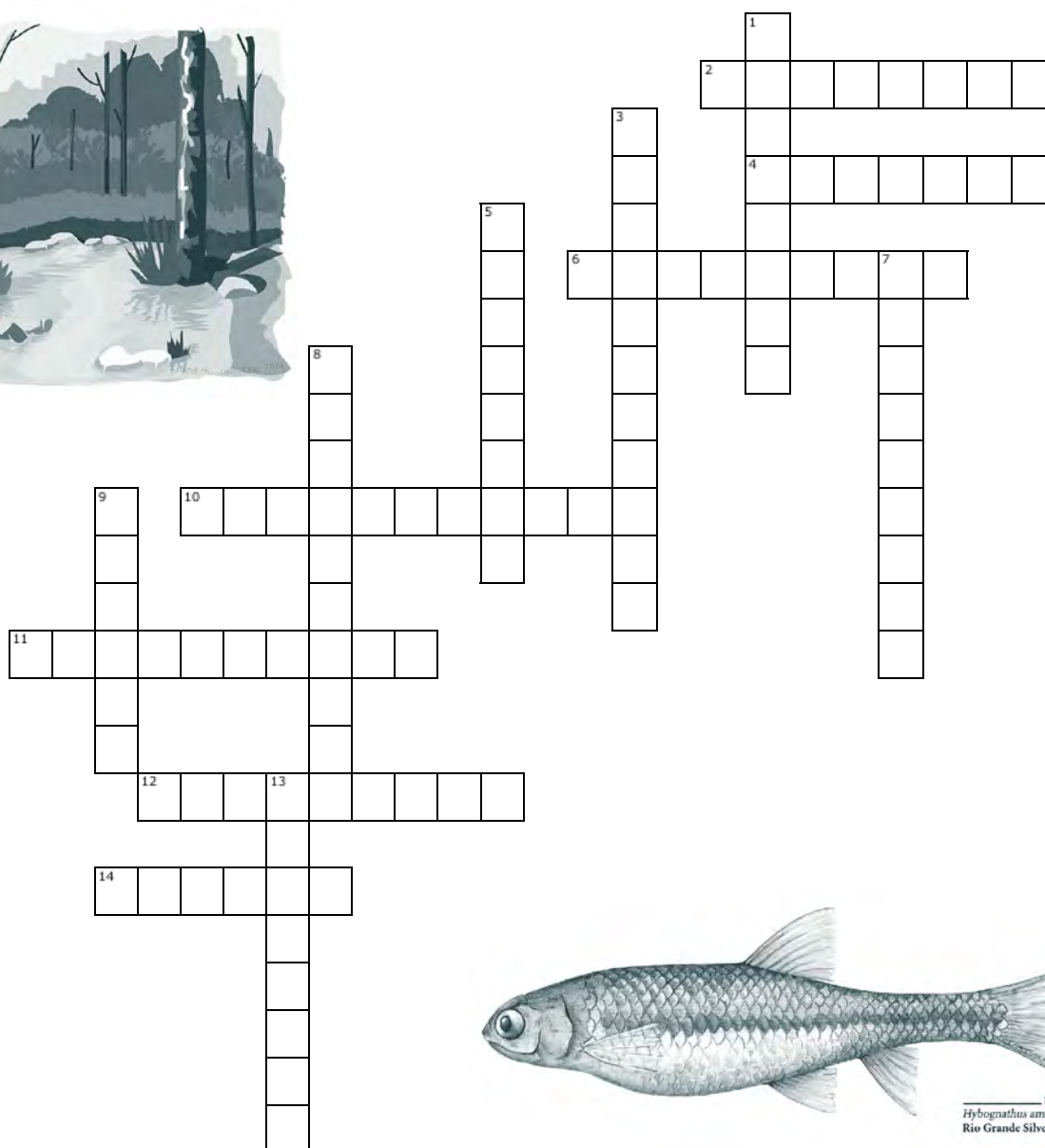
Freshwater eyeChallenge

Explain what each of these photos represents. You may write your explanation or hold a class discussion. If you write your explanation, use complete sentences, proper spelling and grammar, and appropriate punctuation.





Freshwater Crossword



1 cm
Hybognathus amarus
Rio Grande Silvery Minnow

Across

2. To set or adjust the amount, degree, or rate of something.
4. Of, relating to, or obtained from living things.
6. A measure of the cloudiness or muddiness of a water body.
10. Something that makes a place or a substance no longer suitable for use.
11. Flat land area next to a stream or river.
12. The area that drains to a common waterway, such as a stream, lake, estuary, wetland, aquifer, or even the ocean.
14. The portion of rain or snow that flows over land and into streams.

Down

1. Speed of movement.
3. Water that sinks into the soil and is stored in aquifers.
5. An ordering of something according to a value.
7. A stream that flows into a larger stream or river or into a lake.
8. (1) Water that has been used; (2) Sewage.
9. To carry away.
13. Liquid that is released as waste.



National Education Standards

A generic Common Core State Standards alignment, as well as alignment to the Next Generation Standards for these *Natural Inquirer* articles can be found on the “Education Standards” page under “Educational Resources” at the *Natural Inquirer* Web site, <http://www.naturalinquirer.org>.

Which National Science Education Standards Can These Articles Address?

	Green Means Clean	What's the Nonpoint?	Caribbean Cruise	Sediment-al Journey	Mussel Mania	Timed Travel	Under Where?
Science as Inquiry							
Abilities Necessary To Do Scientific Inquiry							
Understandings About Scientific Inquiry							
Physical Science							
Properties and Changes of Properties in Matter							
Motions and Forces							
Transfer of Energy							
Life Science							
Regulation and Behavior							
Populations and Ecosystems							
Diversity and Adaptations of Organisms							
Structure and Function in Living Systems							
Earth Science							
Structure of Earth System							
Science in Personal and Social Perspectives							
Risks and Benefits							
Science and Technology in Society							
Abilities of Technological Design							
Understandings about Science and Technology							
Personal Health							
Populations, Resources, and Environments							
History and Nature of Science							
Science as a Human Endeavor							
Nature of Science							
History of Science							

Which National Curriculum Standards for Social Studies Can These Articles Address?

	Green Means Clean	What's the Nonpoint?	Caribbean Cruise	Sediment-al Journey	Mussel Mania	Timed Travel	Under Where?
Culture and Cultural Diversity							
Time, Continuity, and Change							
People, Places, and Environments							
Power, Authority, and Governance							
Science, Technology, and Society							
Global Connections							
Individuals, Groups, and Institutions							
Civic Ideals and Practices							
Production, Distribution, and Consumption							
Individual Development, and Identity							



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What Is the Forest Service?



The Forest Service is part of the United States Department of Agriculture (USDA). The Forest Service is made up of thousands of people who care for the Nation's forest land. The Forest Service manages 154 national forests and 20 national grasslands. These are large areas of trees, streams, and grasslands. National forests are similar in some ways to national parks. Both are public lands, meaning they are owned by the public and managed for the public's use and benefit. Both national forests and national parks provide clean water, homes for the animals that live in the wild, and places for people to do fun things in the outdoors. National forests also provide resources for people to use, such as trees for lumber, minerals, and plants used for medicines. Some people in the Forest Service are scientists whose work is presented in the journal. Forest Service scientists work to solve problems and provide new information about natural resources so that we can make sure our natural environment is healthy, now and into the future.

<http://www.fs.fed.us>.

What Is the Cradle of Forestry in America Interpretive Association?



The Cradle of Forestry in America Interpretive Association is a 501(c)(3) nonprofit organization based in Pisgah Forest, North Carolina. The interpretive association strives to help people better understand ecology through recreation and education opportunities. Their projects include the following:

- Campground and recreation area management
- Educational programs and services, including *Natural Inquirer*, *Investi-gator*, *Natural Inquirer* Reader Series, *NSI: Nature Science Investigator*, scientist cards, and *Leaf Prints* (formerly *Nature-Oriented Parenting*)
- Sales of forest-related gifts and educational materials
- Workshops, newsletters, and publications
- Partnership with the Forest Service to provide programming at the Cradle of Forestry Historic Site

<http://www.cfaia.org>

What Is FreshWaterLIVE?



The "FreshWaterLIVE: A Distance Learning Adventure" (<http://www.freshwaterlive.org>) brings the mysteries of freshwater to classrooms grades 4 to 8 through FREE webcasts, webinars, and online resources about the origins, travels, and perils of water from green forests and grasslands to household faucets. Check out previous LIVE programs at <http://www.FSNatureLIVE.org> and register your class to participate in the 2015–2016 FreshWaterLIVE adventure.



Web Site Resources

Natural Inquirer
<http://www.naturalinquirer.org>

Forest Service Conservation Education
<http://www.fs.usda.gov/conservationeducation>

FreshWaterLIVE
<http://www.freshwaterlive.org>

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