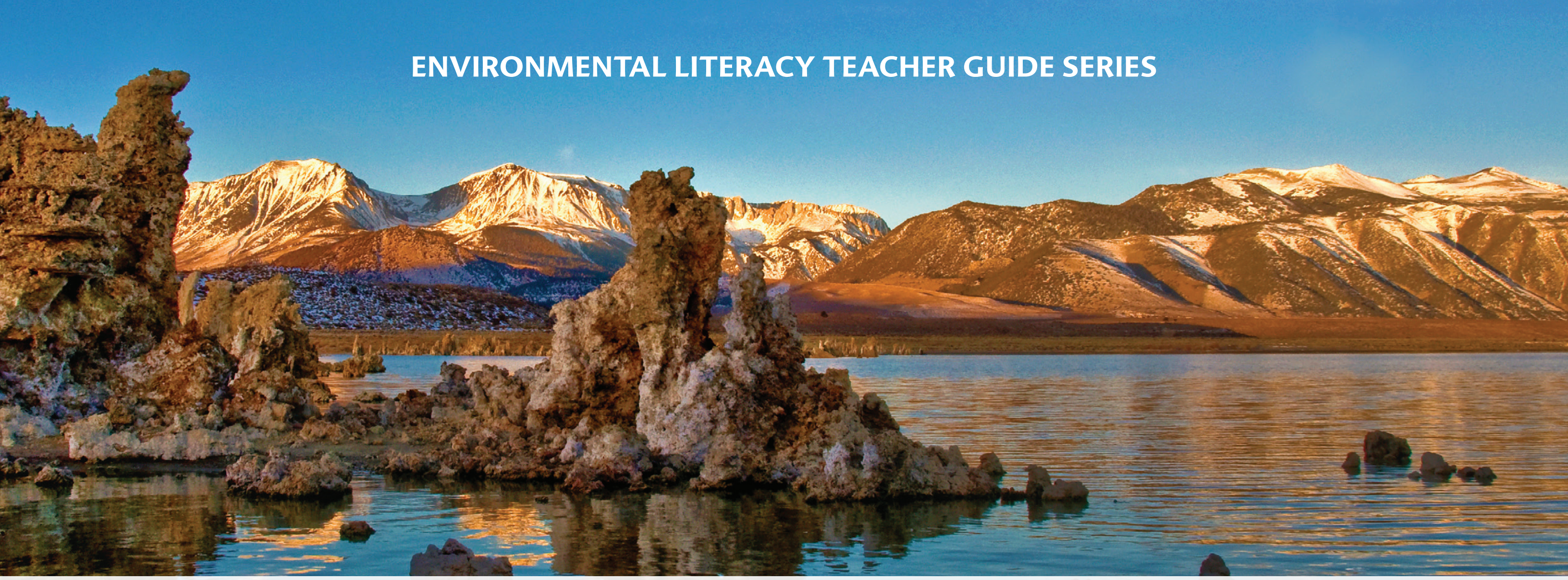
ENVIRONMENTAL LITERACY TEACHER GUIDE SERIES



Earth's Freshwater

A Guide for Teaching Freshwater in Grades 3 to 8

NATIONAL GEOGRAPHIC
education

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Acknowledgements

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California Education and the Environment Initiative

California has always been a leader in environmental education and conservation, including the existence of environmental content in its academic standards.

To increase California's impact on environmental education, Assembly Bill 1548 was passed into law in 2003 mandating the creation of a K–12 curriculum charged with incorporating more environmental education into the state's required academic content standards in Science and History/Social Science. The bipartisan law was supported by various state and nonprofit groups, and marked the – beginning of the landmark Education and the Environment Initiative (EEI). The law helped solidify California's leadership role in improving national and international environmental education.

EEI Principles and Model Curriculum

With an emphasis on students' relationship with the environment, EEI aims to increase environmental literacy in a format familiar to California teachers. Critical environmental issues, such as climate change, freshwater, ocean, energy, and other topics, are addressed in the law.

"This nation-leading initiative will educate our next generation of workers in environmental preservation and protection and will help catapult California's growing green economy."

Former Governor Schwarzenegger

ENVIRONMENTAL PRINCIPLES AND CONCEPTS

1. People depend on natural systems.
2. People influence natural systems.
3. Natural systems change in ways that benefit people, and they can influence.
4. There are no permanent or impermeable boundaries that prevent matter from flowing between systems.
5. Decisions affecting resources and natural systems are complex and involve many factors.

Creation of this unprecedented curriculum began in 2004 with the development of the California Environmental Principles and Concepts (EP&C), which clearly highlight the relationship between humans and the environment. In addition to the Environmental Principles and Concepts, EEI also developed a Model Curriculum that was comprised of weeklong units for K–12 teachers to use in their own classrooms. Development of the Model Curriculum began in 2005, with a focus on aligning the unit content to California's academic standards. From 2006–2009, the California EPA worked with partners, such as the California Department of Education, to create a curriculum that would be comprehensive and innovative, while continuing to teach academic content standards for Science and History/ Social Science. More than 200 teachers and 600 students in 19 school districts across the state piloted the Model Curriculum units in 2007–2008 in order to test that the materials would be easily implemented in the classroom. Even more teachers and content experts independently reviewed the materials, making certain that the units fit with established classroom and assessment practices and would not burden teachers who would be using the curriculum. At the end, EEI developed 85 curriculum units spanning grades K–12, which were approved by the State Board of Education in Spring 2010.

The EEI Model Curriculum is poised to reshape how the environment is taught and presented to California's students. The California/Environmental Protection Agency (Cal/EPA), in partnership with the Department of Education, will be reaching out to inform teachers about how the curriculum can be used independently from, in conjunction with, or integrated into current instructional materials. The EEI curriculum will be made available electronically to school districts and teachers, free of charge, which will greatly increase the number of teachers who can easily access the materials. Find out more about the EP&C's and the EEI Model Curriculum at http://www.calepa.ca.gov/education/eei/.

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.a-e	Structures for Survival in a Healthy Ecosystem Living Things in Changing Environments
Grade 4	4.2.a-c 4.3.a-b	Plants: The Ultimate Energy Resource The Flow of Energy Through Ecosystems Life and Death with Decomposers
Grade 5		
Grade 6	6.5.a-e	Energy: Pass It On! Playing the Same Role
Grade 7	7.3.a 7.3.e	Shaping Natural Systems Through Evolution Responding to Environmental Change
Grade 8		

Each teacher guide chapter includes a table that aligns the content in the chapter to California state science and social studies academic standards, and to the EEI Model Curriculum.

Connecting EEI to the Teacher Guide Series

The hope of the EEI is to provide cutting-edge environmental content to students, while supporting them in achieving academic content standards. Given the environmental topics addressed by the units, professional development is needed so teachers feel confident and effective in delivering this content in their classrooms. Whether using the EEI Model Curriculum or other educational materials about the environment, teachers will need additional preparation to feel comfortable with teaching about the latest environmental issues.

The Environmental Literacy Teacher Guide Series responds to this need, providing both content background for teachers on these environmental issues, as well as providing information about concepts that likely will be challenging for students to learn. The Environmental Literacy Teacher Guide Series includes Climate Change, Ocean, Freshwater, and Energy guides. Each teacher guide is intended to prepare upper elementary and middle school teachers for instruction in these content areas.

The content and educational components of the teacher guides are aligned to both California Standards, and the units in the EEI Model Curriculum, allowing teachers to use specific chapters as resource when teaching those standards and units. While the goal of the teacher guide is not to prepare teachers for using a specific EEI unit, it is hoped that the information provided by the guide helps teachers feel more confident and prepared to teach about these topics in the classroom and to anticipate what their students will know and struggle with as they learn the EEI units or similar environmental curriculum.

Why Is Freshwater Education Important?

Most people have heard Earth referred to as "the water planet." With that name comes the rightful image of a world with plentiful water. In photographs taken from space, we can see that Earth has more water than land. It is unexpected and somewhat inconceivable that less than 3 percent of Earth's water is freshwater. According to the U.S. Geological Survey, most of that 3 percent is inaccessible. More than 68 percent of the freshwater on Earth is found in ice caps and glaciers and little more than 30 percent is found in ground water. Only about 0.3 percent of our freshwater is found in the surface water of lakes, rivers, and swamps. Of all the water on Earth, more than 99 percent of Earth's water is unusable by humans and many other living things! It seems extraordinary that freshwater that supports terrestrial as well as aquatic life on Earth is actually so scarce. With this stunning realization comes a recognition that we have to utilize this resource very wisely. An important first step is to educate ourselves and future generations of citizens. We can make better consumer, voter, and community-member choices when we are informed about how we use resources, the ramifications of misuse, and solutions and actions to prevent freshwater issues.

It seems extraordinary that the water that supports all life on Earth is actually so scarce.

Given its tiny proportion on Earth, and the tremendous diversity of plants and animals dependent upon it for survival, freshwater is a vital global issue. We see pictures on the news and hear conversations in our community groups and at dinner tables. There is often so much information, it's sometimes difficult to know which sources to believe. In 2008, a nationwide panel of earth science educators, researchers, and community-policy members, supported by the National Science Foundation, addressed the need for a coherent set of guiding principles around earth science education. In an effort to offer current and accurate scientific understanding, which is so critical to the promotion of good stewardship and sound policies, the partners formulated a set of "Big Ideas" for Earth Science Literacy (http://www.earthscienceliteracy.org/), of which freshwater played a central part. These principles can be one source of information for choosing the key water concepts that should be taught to students.

Yet even given these guiding principles, few resources are provided to educators in order to better understand these issues and plan for instruction. Many teachers and many states and local agencies have recognized the need for resources on environmental topics. Teachers have struggled to develop units on their own to help address the issues, while states have looked to rectify it through legislation. With the passage of Assembly Bill 1548 in 2003, commonly referred to as the Education and the Environment Initiative (EEI), the state of California is working toward

bridging the gap between real-world and theoretical learning, connecting the concepts students are learning to their environment. This initiative calls for mastery of standards and curricula on environmental topics, through the use of EEI curriculum or comparable curriculum on environmental topics. The EEI units include many content connections to freshwater, and California is a state with many special-water needs and water issues. The importance of an educated population cannot be overstated. EEI is another resource that California educators can use to help guide instruction on freshwater.

Teaching science offers the opportunity to explore our world as scientists do. We can ask open-ended questions and formulate tentative hypotheses without any pressure to know the "right" answer. Our ideas will ultimately be based on the observations we make, having analyzed the data we've collected and organized. In studying "real-world" issues in our environment, we are presented with problems with relevance to many students. The problems of freshwater scarcity and **pollution** are not hypothetical. Teaching freshwater is a great opportunity to integrate science and social studies curricula, as well as connecting school learning with real-world experiences that students have each day.

Understanding the tiny proportion of Earth's freshwater in relation to its importance raises many questions. How is it possible that such a small amount of freshwater exists on Earth? How can such a small amount of freshwater sustain a wide diversity of terrestrial, as well as freshwater plants and animals? What can we do to preserve this precious resource? How can we protect the **water quality**? What human interventions have created increased burdens on freshwater systems? Can we still mitigate the adverse effects of our previous interventions and help protect our freshwater resources today? Students will likely wonder about these questions, and need support from teachers to begin developing their ideas and answering them.

Students can be part of the solution, but they need help from teachers.

This guide was developed to support teachers in teaching topics with real-world context, and provide them with the background to feel competent and comfortable when teaching about freshwater. It provides a solid introduction to freshwater in an accessible and reader-friendly manner. In addition to general information about freshwater, the guide includes numerous education features, such as teaching tips and student thinking, that help to connect the content to classroom practice.

The teacher guide describes our current understanding of water cycling and freshwater issues that affect natural and human communities. Chapter 1 explores biodiversity in freshwater systems and threats to that diversity. Chapter 2 reviews the traditional water-cycle processes, and common student ideas about the water cycle. This chapter also introduces the idea of an **urban water cycle.** In Chapter 3, we turn our attention to human alterations to the water cycle through the use of **dams** and **canal** systems, as well as **groundwater** pumping. Chapter 4 takes a closer look at water quality and water pollution and treatment. Chapters 5 and 6 explore impacts of misuse of fresh water on both natural and human communities. Chapter 5 focuses on environmental impacts that affect humans and wildlife, while Chapter 6 discusses social issues that arise around water rights and conflict. Chapter 7 revisits these issues looking at various solutions for conservation and actions that individuals can take in their daily lives. It is hoped that these chapters will supply not only information and resources for teachers, but also a greater sense of confidence and ease in communicating the concepts to students.

Teacher Guide Tour

Environmental Content

Environmental science includes a wealth of content that teachers may not learn as part of their professional preparation. Content pages provide teachers with an opportunity to learn this content alongside information about how students think about these topics. The content pages also reconsider fundamental science concepts in the context of environmental issues. Interesting and new concepts are in bold and defined in the accompanying glossary.

Standards Table

Chapters are aligned to California state science and social studies standards, as well as aligned to the Education and Environment Initiative (EEI) model curriculum units.

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.a/b 3.3.c/d 3.1.1 3.5.3	Structures of Survival in a Healthy Ecosystem Living Things in Changing Environments The Geography of Where We Live California's Economy—Natural Choices
Grade 4	4.2.b 4.3.a-b 4.1.3-5	The Flow of Energy Through Ecosystems Reflections of Where We Live
Grade 5	5.3.d	Our Water: Sources and Uses
Grade 6	6.5.c-e	Energy: Pass It On! Playing the Same Role
Grade 7	7.3.a 7.3.e	Shaping Natural Systems through Evolution Responding to Environmental Change
Grade 8		

ecosystems! In the United States, 37 percent of fish species, 67 percent of mussels, 51 percent of crayfish, and 40 percent of amphibians have become threatened or **extinct** (Revenga & Mock, 2000). This may sadden your students, but there are things they can do to personally address the situation once they know more about freshwater systems and consequences of human actions on these systems.

Even though freshwater found on Earth's surface is a tiny percent of total water, it exists in a variety of different systems, creating diverse habitats. The variations are usually determined by local topography. Rainwater falling near a river's **headwaters** (i.e., the source) flows downhill due to gravity through a **watershed.** A watershed is a region where all water drains into the same river systems. The topography of the land (i.e., mountains, ridges, gullies, and so on) contains the moving water in small streams. As these small streams flow downward, they meet other small streams and contribute to larger streams, which in turn meet others and form rivers. Rivers and streams can also be fed by groundwater that, similar to surface water, flows due to gravity. Areas with more gently sloping geographical profiles hold the moving surface water for longer periods than areas with steep profiles. These slower moving areas often develop into a variety of wetlands, which can include marshes, sloughs, bogs, or seasonal pools known as **vernal pools.** Sometimes, there is no outlet for the rainwater, but rather a contained recess in the landform. Water then accumulates and forms either a pond or lake depending on the amount of water retained. Some water will infiltrate into the ground and become groundwater, while some will remain at the surface. In high altitudes, such as alpine regions, and high latitudes, such as polar regions, freshwater can also be frozen into snowpack that regularly melts during the year, or glaciers that can last for centuries. Water in a watershed generally flows from high elevations in the watershed to low elevations, which is often the ocean.

CHAPTER OVERVIEW

Despite the fact that two-thirds of Earth is covered in water, very little of that water is freshwater available for human consumption or for sustaining the lives of freshwater organisms. Accessible freshwater is found in rivers, ponds, and lakes, as well as underground.

Human activity has affected the biodiversity of freshwater ecosystems. Freshwater ecosystems in rivers are threatened when people start to change the water flow or block the movement of organisms through their normal habitats. Farmland covers areas of land that were once wetland and areas of land that once were home to ecosystems living in vernal pools. One consequence of these human actions is increased numbers of endangered freshwater species.

In this chapter, we explore the biodiversity of freshwater ecosystems and some of the impacts humans have on the organisms in these ecosystems.

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Case Study **California Vernal Pools**

Vernal pools in California bloom in the spring, displaying brilliant yellow colors that dot the landscape.

When walking in an open field, it would be very easy to overlook a vernal pool. As the name suggests, a vernal pool is a seasonal body of water that is usually at its peak volume in the spring. It is formed when a shallow land depression with poor drainage is filled by water from winter rain. In the spring, the water remains long enough for plants to grow. While timing of rainy seasons differ in other areas, these special ponds are still known as vernal pools. Many of the plants and animals that thrive in vernal pools are so well adapted to this short growth season that they are found nowhere else. When walking in a field during the summer or autumn, you may not realize you are in a highly fragile and threatened ecosystem.

Vernal pools are found in areas where the underlying soils are relatively **impermeable.** This can occur with soils derived from volcanic flows. The foothills of the northern Sierras (Butte County) and the Peninsular Ranges in western Riverside County are two places where these types of soils are found. This lack of drainage is also found in terraces along the Central Valley.

Although they have short active seasons, vernal pools are actually vibrant ecosystems. Some plants found in vernal pools have air-filled stems for floating, while others have adapted floating leaves. Small crustaceans and amphibians are also found here. As the water begins to evaporate, plants set seed, forming concentric rings of showy blossoms. During the dry months, amphibians dig deep into the mud and enter a dormant phase. Vernal pools are a source of rest and nourishment for migratory birds. The vernal pools of the Central Valley form part of the **Pacific Flyway** between Alaska and South America. Nesting sites for a number of overwintering local resident populations are also found here.

Vernal pools are among the most severely threatened wetland environments. More than 90 percent of vernal pool habitats in California have been lost. Agricultural or urban development, off-road vehicle activity, and brush clearing for fire prevention have taken their toll. Most of the remaining sites have little legal protection, but the Endangered Species Act (about a third of the plants found in vernal pools are endangered), the California Environmental Quality Act, and the Migratory Bird Treaty Act (reaffirmed in 2001 by the federal Department of Transportation) are all legal provisions that can be called upon to help save these habitats. Acquisition of these ecosystems by park departments or nonprofit conservation organizations is another way they can be protected.

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Case Study

Case Studies offer an in-depth look at how concepts play out in particular locations or situations. Case studies provide real-life examples of how issues affect both natural and human communities today.

In the Classroom **Freshwater Biodiversity Studies**

When scientists study freshwater ecosystems, they often use probes and tests to collect data for a variety of **chemical parameters** (e.g., nutrients, pH, alkalinity, and so on.). They also examine physical properties such as **turbidity** (cloudiness or haziness of a fluid), evidence of erosion, depth, and flow rate. A variety of techniques are used to study freshwater biological communities. Plankton nets can catch and concentrate plankton, which are then studied under a microscope. Using techniques such as **quadrats** (squares, often one meter, used to isolate a sample in the field) and **transect lines** (a path along which one counts and records occurrences of the phenomena of study), scientists can approximate the density of species within a body of water and its banks. Physical, chemical, and biological studies can give important information about water health, indicating, for example, if there is a nutrient imbalance or oxygen depletion. Healthy ecosystems support biodiversity.

Leaf-Pack Activities. The leaf-pack activity increases awareness of the amazing array of life that we often overlook because of its small size. By investigating the undersides and spaces between the leaves found in a local stream, a multitude of insects and microorganisms are revealed. Additionally, students can place their own leaf packs within a streambed, pond, or other aquatic habitat to see what organisms make the pack home. Explore more at http://www.stroudcenter.org/lpn/.

Stream Study. Investigate a local stream or pond. Observe the **clarity** and temperature of water (pH, if possible), number and type of plants adjacent to and in the water (leaves, branches also), number and type of animals adjacent to and in the water (collect a water sample in a jar and investigate with magnifying lens or microscope). Also, look for evidence of humans, such as litter or change in flow of the stream. Although this works well as a one-time experience, it is more powerful if students have the opportunity to revisit the same site during the year to observe changes in the natural cycle. Find out more about your local water prior to your investigation at http://water.usgs.gov/education.html and http://water.epa.gov/type/location/regions.cfm.

Water Quality. Investigate and compare images of healthy versus polluted water using a local, state, or national freshwater location. Then experiment using three samples of the same type of plant in similar containers and given the same amounts of water, but alter the water chemistry slightly. Add lemon-lime soda (acid) to one container, diluted dish soap (alkaline, with phosphates) to another, and keep the third as a control by using distilled water. Observe the plants for a week and compare results. Check out additional ideas at http://www.projectwet.org/.

Report on Endangered Species. Have your students conduct research (individually or in groups) on freshwater species in peril. For example, have students investigate local dams and potential threatened populations or other local threatened populations. Ask students to think about human impacts that have threatened these species and actions they can take to reduce the threat. Explore your local endangered species at http://www.earthsendangered.com/index_s.asp or http://www.fws.gov/endangered/.

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In the Classroom

In the Classroom features iconic or helpful classroom activities, as well as ideas for teaching topics. Details are provided to use the activity in the classroom, including materials lists and directions, as well as interesting discussion questions to ask your students. When possible, additional online resources are connected to the classroom activities.

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

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

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

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

Plants give off water through transpiration.

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

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

Teaching Tip

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

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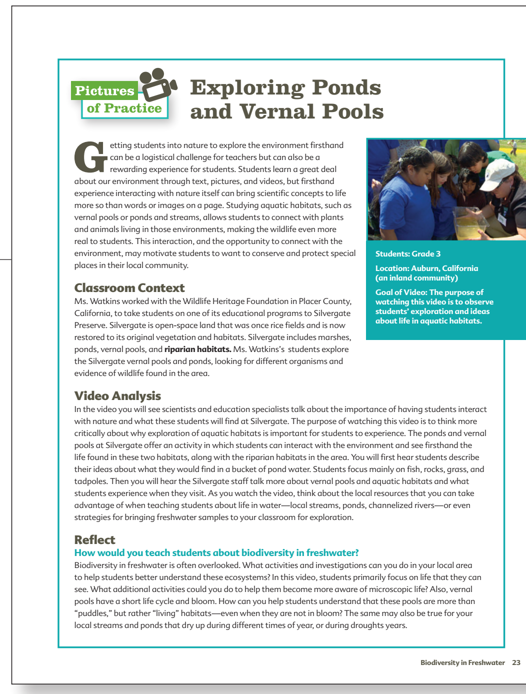
Teaching Tip

Throughout the content pages, **Teaching Tips** connect the content to classroom practice. Teaching Tips suggest practical activities and resources to consider when teaching about a particular topic. When available, Teaching Tips direct teachers to additional online resources.

Pictures of Practice

Classroom video is a valuable resource for reflecting on practice. **Pictures of Practice** are videos, about two to five minutes in length, focusing on student ideas. The purpose of these videos is to capture everyday classroom life, and to provide real-life examples of how students learn and think about these topics. The focus of the videos is on student participation and ideas, as opposed to the teacher and instructional style. Reading the video activity prior to watching the video will help prepare you to get the most out of the videos.



Pictures of Practice

Exploring Ponds and Vernal Pools

Getting students into nature to explore the environment firsthand can be a logistical challenge for teachers but can also be a rewarding experience for students. Students learn a great deal about our environment through text, pictures, and videos, but firsthand experience interacting with nature itself can bring scientific concepts to life more so than words or images on a page. Studying aquatic habitats, such as vernal pools or ponds and streams, allows students to connect with plants and animals living in those environments, making the wildlife even more real to students. This interaction, and the opportunity to connect with the environment, may motivate students to want to conserve and protect special places in their local community.

Students: Grade 3
Location: Auburn, California (an inland community)
Goal of Video: The purpose of watching this video is to observe students' exploration and ideas about life in aquatic habitats.

Classroom Context

Ms. Watkins worked with the Wildlife Heritage Foundation in Placer County, California, to take students on one of its educational programs to Silvergate Preserve. Silvergate is open-space land that was once rice fields and is now restored to its original vegetation and habitats. Silvergate includes marshes, ponds, vernal pools, and **riparian habitats.** Ms. Watkins's students explore the Silvergate vernal pools and ponds, looking for different organisms and evidence of wildlife found in the area.

Video Analysis

In the video you will see scientists and education specialists talk about the importance of having students interact with nature and what these students will find at Silvergate. The purpose of watching this video is to think more critically about why exploration of aquatic habitats is important for students to experience. The ponds and vernal pools at Silvergate offer an activity in which students can interact with the environment and see firsthand the life found in these two habitats, along with the riparian habitats in the area. You will first hear students describe their ideas about what they would find in a bucket of pond water. Students focus mainly on fish, rocks, grass, and tadpoles. Then you will hear the Silvergate staff talk more about vernal pools and aquatic habitats and what students experience when they visit. As you watch the video, think about the local resources that you can take advantage of when teaching students about life in water—local streams, ponds, channelized rivers—or even strategies for bringing freshwater samples to your classroom for exploration.

Reflect

How would you teach students about biodiversity in freshwater?

Biodiversity in freshwater is often overlooked. What activities and investigations can you do in your local area to help students better understand these ecosystems? In this video, students primarily focus on life that they can see. What additional activities could you do to help them become more aware of microscopic life? Also, vernal pools have a short life cycle and bloom. How can you help students understand that these pools are more than "puddles," but rather "living" habitats—even when they are not in bloom? The same may also be true for your local streams and ponds that dry up during different times of year, or during droughts years.

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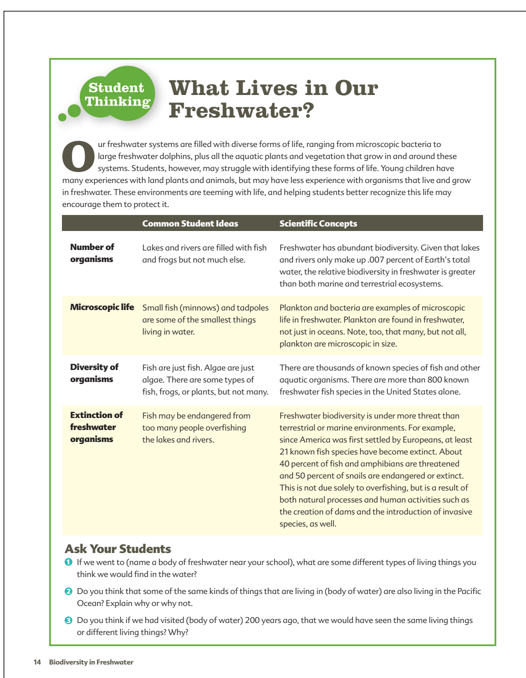

Student Thinking

What Lives in Our Freshwater?

Our freshwater systems are filled with diverse forms of life, ranging from microscopic bacteria to large freshwater dolphins, plus all the aquatic plants and vegetation that grow in and around these systems. Students, however, may struggle with identifying these forms of life. Young children have many experiences with land plants and animals, but may have less experience with organisms that live and grow in freshwater. These environments are teeming with life, and helping students better recognize this life may encourage them to protect it.

	Common Student Ideas	Scientific Concepts
Number of organisms	Lakes and rivers are filled with fish and frogs but not much else.	Freshwater has abundant biodiversity. Given that lakes and rivers only make up .007 percent of Earth's total water, the relative biodiversity in freshwater is greater than both marine and terrestrial ecosystems.
Microscopic life	Small fish (minnows) and tadpoles are some of the smallest things living in water.	Plankton and bacteria are examples of microscopic life in freshwater. Plankton are found in freshwater, not just in oceans. Note, too, that many, but not all, plankton are microscopic in size.
Diversity of organisms	Fish are just fish. Algae are just algae. There are some types of fish, frogs, or plants, but not many.	There are thousands of known species of fish and other aquatic organisms. There are more than 800 known freshwater fish species in the United States alone.
Extinction of freshwater organisms	Fish may be endangered from too many people overfishing the lakes and rivers.	Freshwater biodiversity is under more threat than terrestrial or marine environments. For example, since America was first settled by Europeans, at least 21 known fish species have become extinct. About 40 percent of fish and amphibians are threatened and 50 percent of snails are endangered or extinct. This is not due solely to overfishing, but is a result of both natural processes and human activities such as the creation of dams and the introduction of invasive species, as well.

Ask Your Students

1. If we went to (name a body of freshwater near your school), what are some different types of living things you think we would find in the water?
2. Do you think that some of the same kinds of things that are living in (body of water) are also living in the Pacific Ocean? Explain why or why not.
3. Do you think if we had visited (body of water) 200 years ago, that we would have seen the same living things or different living things? Why?

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Student Thinking

The purpose of **Student Thinking** features is to help you prepare for the challenges students may face as they learn about these topics. Common student ideas are compared alongside scientific concepts or are situated in real-life classroom scenarios. Provided quotes come from real students. Suggestions for questions to ask your students are also provided. Accessing student ideas through formative assessment is a great way to learn about your students' knowledge and pique your students' interest in learning more about a topic. Students love to share what they know! You can use what you learn to help guide your teaching. You may find that you need to provide experiences for the students that help them confront their existing ideas and begin to develop more scientific conceptions.

1 Biodiversity in Freshwater

by Marcia S. Matz

All living things are greatly dependent on water for survival. For example, to support the diet of an average American, by growing crops and raising animals, 1,320 gallons of water are needed per day (*National Geographic* 2010). Despite this need, less than one percent of Earth's water is available to support the people and numerous other species that rely on freshwater.

Students may know, just from looking at a globe, that water covers most of Earth's surface. It is unlikely that they will understand that very little of the water they see is available for people to drink. Freshwater is classified as water with less than .05 percent **dissolved** salts (GF 2010). Accessible freshwater in the forms of rivers, lakes, ponds, and wetlands make up less than one percent of all the water on Earth (USGS, 2010). When fresh water that is trapped in glaciers, icebergs, and groundwater is included in the total amount of freshwater, it still comprises less than 3 percent of Earth's water (USGS 2010). Other water on Earth is found as salt water in our ocean. Groundwater is accessible for use through wells and groundwater pumping. Although surface freshwater and groundwater accounts for only a tiny amount of Earth's water, it plays a vital role in the habitability of Earth.

While there are significant concerns about the small amount of freshwater available to people, we are not the only organisms that rely on it for survival. Freshwater ecosystems are actually home to a remarkably large proportion of wildlife, including about 12 percent of all animals and 40 percent of fish species. Because these ecosystems host such a wide variety of fish, amphibians, mollusks, crustaceans, and insects, they are excellent habitats for large numbers of resident and migratory birds as well. Freshwater ecosystems are also home to a wide variety of plants, which in turn, support both animal and human populations by providing food and shelter. These ecosystems are, however, imperiled. They have extinction rates as much as 15 times greater than marine

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.a/b 3.3.c/d 3.1.1 3.5.3	Structures of Survival in a Healthy Ecosystem Living Things in Changing Environments The Geography of Where We Live California's Economy—Natural Choices
Grade 4	4.2.b 4.3.a-b 4.1.3-5	The Flow of Energy Through Ecosystems Reflections of Where We Live
Grade 5	5.3.d	Our Water: Sources and Uses
Grade 6	6.5.c-e	Energy: Pass It On! Playing the Same Role
Grade 7	7.3.a 7.3.e	Shaping Natural Systems through Evolution Responding to Environmental Change
Grade 8		

ecosystems! In the United States, 37 percent of fish species, 67 percent of mussels, 51 percent of crayfish, and 40 percent of amphibians have become threatened or **extinct** (Revenga & Mock, 2000). This may sadden your students, but there are things they can do to personally address the situation once they know more about freshwater systems and consequences of human actions on these systems.

Even though freshwater found on Earth's surface is a tiny percent of total water, it exists in a variety of different systems, creating diverse habitats. The variations are usually determined by local topography. Rainwater falling near a river's **headwaters** (i.e., the source) flows downhill due to gravity through a **watershed.** A watershed is a region where all water drains into the same river systems. The topography of the land (i.e., mountains, ridges, gullies, and so on) contains the moving water in small streams. As these small streams flow downward, they meet other small streams and contribute to larger streams, which in turn meet others and form rivers. Rivers and streams can also be fed by groundwater that, similar to surface water, flows due to gravity. Areas with more gently sloping geographical profiles hold the moving surface water for longer periods than areas with steep profiles. These slower moving areas often develop into a variety of wetlands, which can include marshes, sloughs, bogs, or seasonal pools known as **vernal pools.** Sometimes, there is no outlet for the rainwater, but rather a contained recess in the landform. Water then accumulates and forms either a pond or lake depending on the amount of water retained. Some water will infiltrate into the ground and become groundwater, while some will remain at the surface. In high altitudes, such as alpine regions, and high latitudes, such as polar regions, freshwater can also be frozen into snowpack that regularly melts during the year, or glaciers that can last for centuries. Water in a watershed generally flows from high elevations in the watershed to low elevations, which is often the ocean.

CHAPTER OVERVIEW

Despite the fact that two-thirds of Earth is covered in water, very little of that water is freshwater available for human consumption or for sustaining the lives of freshwater organisms. Accessible freshwater is found in rivers, ponds, and lakes, as well as underground.

Human activity has affected the biodiversity of freshwater ecosystems. Freshwater ecosystems in rivers are threatened when people start to change the water flow or block the movement of organisms through their normal habitats. Farmland covers areas of land that were once wetland and areas of land that once were home to ecosystems living in vernal pools. One consequence of these human actions is increased numbers of endangered freshwater species.

In this chapter, we explore the biodiversity of freshwater ecosystems and some of the impacts humans have on the organisms in these ecosystems.


Rapids form as the Yukon River flows from its source in British Columbia, Canada, through Alaska.

Although all of these water systems are freshwater, they each support a distinctive and wide diversity of wildlife. As your students learn more about each particular habitat, the reasons for their uniqueness will become more apparent. Student understanding of the variety of habitats and wildlife will deepen. They will see that each habitat contributes to the intricate web of life on Earth.

Freshwater Habitats

Rivers. Rivers can be looked at as open systems, which means they are affected by outside factors. They are free flowing from their headwaters and throughout the entire watershed as they travel downstream. Your students might not be aware of the tremendous diversity of life in microhabitats along the journey downstream. They may think that all rivers and all parts of rivers contain the same types of living things. However, there are many factors that influence diversity of living things in rivers. For example, steepness of slope impacts the speed of the water flow and thus the size of particles such as pebbles and silt that are able to settle to the streambed. The force of quickly moving water can push large pebbles and even boulders. As the speed and force of the moving water decreases, the larger pebbles drop and the smaller ones travel further downstream. In its shallowest profile, the speed and force of the moving water are greatly reduced and it is here that the fine particles of silt settle, creating wetlands such as bogs and marshes. Areas just below small cascades have excellent aeration and the ability to flush waste, and so are ideal sites for salmon to lay their eggs, which they hide among the small pebbles. Shallow pools with calm waters are excellent habitats for small fish, crustaceans, turtles, amphibians, and mollusks, not to mention birds and small mammals. Raptors, as well as other predators like bears, can be seen hunting the fish found in rivers. Streamside vegetation also affects these microhabitats by offering cooler temperatures in their shade, protection within their root structures, and stabilized embankments. They also harbor an abundance of insects and microorganisms in their decomposing leaf pack. Each river contains minerals that have been dissolved from the land they flow through. Differences in the type and concentration of minerals also have an impact on the type of wildlife able to survive there.

Historically, humans have found benefits in settling alongside rivers. Your students will probably be aware of this from social studies, as they learn about how American pioneers often traveled and settled alongside rivers and other water systems. They may have learned about civilizations on other continents, such as the farming societies of Mesopotamia. Besides transportation (still used worldwide), humans utilized rivers for cleansing, irrigation of crops, and most recently as a source of hydroelectric power. Unless your students live in a rural area, they may be unaware that the diversion of river water for crop irrigation has depleted both the amount and quality of many rivers. Most will be stunned to learn that the freshwater diverted from rivers or pumped from **aquifers** for agricultural purposes accounts for about 70 percent of all global water use! Besides water quantity depletion and habitat loss, the fertilizers, pesticides, and industrial and residential wastes that make their way into water also seriously impact rivers and the wildlife dependent upon them. Humans, in turn, are impacted through exposure to waterborne illness and chemicals during swimming or eating crops or fish that are tainted. The building of dams that obstruct the continuous flow of rivers has also proven to have negative consequences to ecosystems, and humans as well, which will be discussed in further detail in Chapter 3. Bringing these issues to life can help your students better understand their local rivers, and how to sustain healthy river habitats for wildlife and humans alike.

Ponds and Lakes. Ponds and lakes can be thought of as closed systems.

Amphibians often require freshwater to reproduce, and spend their juvenile lives living and breathing in water.

They are generally located in low-lying areas (i.e., relative to the water flowing in), and often have no surface water **outflow.** When there is no exit for the water, wildlife such as fish, mollusks, crustaceans, most amphibians, and turtles must remain in that space. Due to lack of outflow, when incoming toxins or **invasive species** accumulate, it is difficult to expel them from the system, although sometimes toxins may leave the pond or lake and leech into groundwater, or may break down over time.

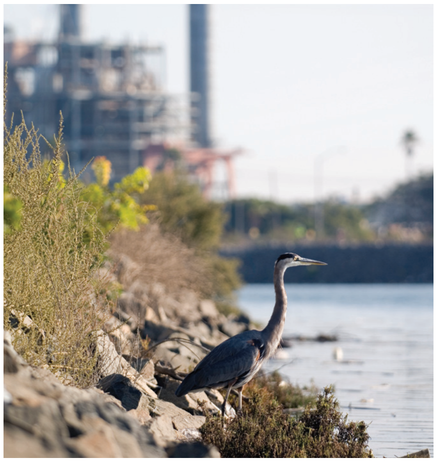
Students may wonder about the difference between ponds and lakes. However, there is no precise scientific definition to differentiate between the two. Ponds are generally shallow, and if small, can be seasonal by drying out during the summer months. Light will penetrate to the bottom, even at their deepest parts. Lakes are larger and deeper, and, because of this, are often sites for boating and water-skiing activities. Lakes are large enough for stratified layers of different temperatures to form.

Wetlands. Wetlands, as the name implies, refers to any land surface area that spends at least part of its existence submerged or predominantly wet. This umbrella term can include both fresh and saltwater bodies, including marshes and bogs, sloughs, and vernal pools. Wetlands are highly diverse and unique habitats that are amazingly rich in the diversity of species they support and the services they provide to the planet. They often harbor fish, amphibian, mollusk, and crustacean nurseries, and are common habitat for foraging bird species. Many wetlands support endangered species that are seen nowhere else. These wetland areas offer natural flood plains for rivers that expand rapidly after a storm, and, thus, safeguard neighboring communities. They also act as nature's filters, screening pollutants from the water that flows through—a tremendous and free service. Your students may know of a local wetland area but might consider it to be a wasteland rather than the invaluable asset it truly is. These areas are local treasures and need to be preserved. Unfortunately, the vast majority of California's wetlands have been lost to human encroachment and development. Similar development is happening around the United States and throughout the world. There are still some left, with concerned citizens replanting native species and advocating for wetland protection. Your students can take part in saving wetlands—locally or globally.

Teaching Tip

Many of your students may not have ever considered the issue of native versus non-native species. Native species are plants and animals well-adapted to the specific habitat in which they live. Non-native species are organisms that are introduced to a habitat, usually by people. Some non-native species may not be as well adapted to a habitat as the native species. For example, non-native plants, such as ornamentals, are not always as well-adapted, and they may require much more watering to maintain their beautiful flowers and large leaves. With water shortages in California, there is an effort in many communities to replant municipal and private gardens with native plants that are adapted to drier habitats. Some of your students may know about this from their own experiences in gardens or landscaping they have at home. Sometimes, the presence of non-native plants, or other non-native species, can be harmful to other organisms in the natural habitat. When this happens, they are referred to as "invasive species." Apart from needing more water than local plants, the presence of invasive species could harm the local habitat because invasives may not have a natural local predator. Some invasive species can easily outcompete the natives for food or water. Invasives can also have a negative impact on animals that depend on natives for food. Remind your students of the food web and what happens to the habitat when a species is lost. When a species is lost, the plants and animals that depend on that species are also compromised, and the balance within the habitat is compromised. Have your students investigate local invasive freshwater species (like the crayfish, Zebra mussel, or New Zealand mudsnail), and how their community is responding to those species. Learn more before you teach the topic at http://www.invasivespeciesinfo.gov/ and your local state department of wildlife and natural resources.

Industrialized development can be seen behind Los Cerritos Wetlands located close to Seal Beach, California.



Student Thinking

What Lives in Our Freshwater?

Our freshwater systems are filled with diverse forms of life, ranging from microscopic bacteria to large freshwater dolphins, plus all the aquatic plants and vegetation that grow in and around these systems. Students, however, may struggle with identifying these forms of life. Young children have many experiences with land plants and animals, but may have less experience with organisms that live and grow in freshwater. These environments are teeming with life, and helping students better recognize this life may encourage them to protect it.

	Common Student Ideas	Scientific Concepts
Number of organisms	Lakes and rivers are filled with fish and frogs but not much else.	Freshwater has abundant biodiversity. Given that lakes and rivers only make up .007 percent of Earth's total water, the relative biodiversity in freshwater is greater than both marine and terrestrial ecosystems.
Microscopic life	Small fish (minnows) and tadpoles are some of the smallest things living in water.	Plankton and bacteria are examples of microscopic life in freshwater. Plankton are found in freshwater, not just in oceans. Note, too, that many, but not all, plankton are microscopic in size.
Diversity of organisms	Fish are just fish. Algae are just algae. There are some types of fish, frogs, or plants, but not many.	There are thousands of known species of fish and other aquatic organisms. There are more than 800 known freshwater fish species in the United States alone.
Extinction of freshwater organisms	Fish may be endangered from too many people overfishing the lakes and rivers.	Freshwater biodiversity is under more threat than terrestrial or marine environments. For example, since America was first settled by Europeans, at least 21 known fish species have become extinct. About 40 percent of fish and amphibians are threatened and 50 percent of snails are endangered or extinct. This is not due solely to overfishing, but is a result of both natural processes and human activities such as the creation of dams and the introduction of invasive species, as well.

Ask Your Students

1. If we went to (name a body of freshwater near your school), what are some different types of living things you think we would find in the water?
2. Do you think that some of the same kinds of things that are living in (body of water) are also living in the Pacific Ocean? Explain why or why not.
3. Do you think if we had visited (body of water) 200 years ago, that we would have seen the same living things or different living things? Why?

Student Thinking

Life in a Bucket of Freshwater

A simple way to study life in a local stream with your students is by scooping the water from that stream into a bucket and bringing it back to your classroom. Depending on your local ecosystem, you may find small insects, possibly a frog or tadpole, or even small fish. You may also see a couple of different types of plants and algae. But much of the life in the bucket is actually microscopic, from different types of plankton to decomposing bacteria. Using microscopes, you can explore the microorganisms in the bucket.

Scenario

Your students have some experience with microscopes looking at premade slides of human and animal cells. You are just beginning your ecology unit and decide that you want your students to conduct an investigation of a local freshwater stream. Prior to conducting their study, you want to get a sense of their knowledge of the various organisms found in these systems. You ask your students to name living things they would find in a bucket of freshwater. Students share their predictions and you keep a running list on the front board. You suggest to your students that there may be living things in the bucket that are too small to see with your eyes. After asking for some suggestions on how to see really tiny organisms, the class decides to examine a bucket of life from a local stream by preparing slides using this water and looking at them under a microscope. After class, you look at the students' original predictions about life in the bucket. How would you revisit their original ideas after they have done the microscope activity?

Question

What living things would you find in a bucket of freshwater?

Scientific Answer

A sample of freshwater can contain thousands to millions of living things, most of which we cannot see with the naked eye.

Student Answers

Ronnie: In that bucket you can find little fishes and frogs.

April: In the bucket you would find rocks and seaweed.

Derek: You would find dirt or grass. Other things may have lived in it, like fish.

Laurie: Small fish, algae, worms.

What Would You Do?

1. What are additional activities you could do to revisit students' predictions and expand on their list of living things, based on their findings?
2. How can you help students make a connection between what they learned during the microscope activity and their upcoming ecology investigation?
3. What tools can students develop to help them continue to identify microscopic life?

Case Study

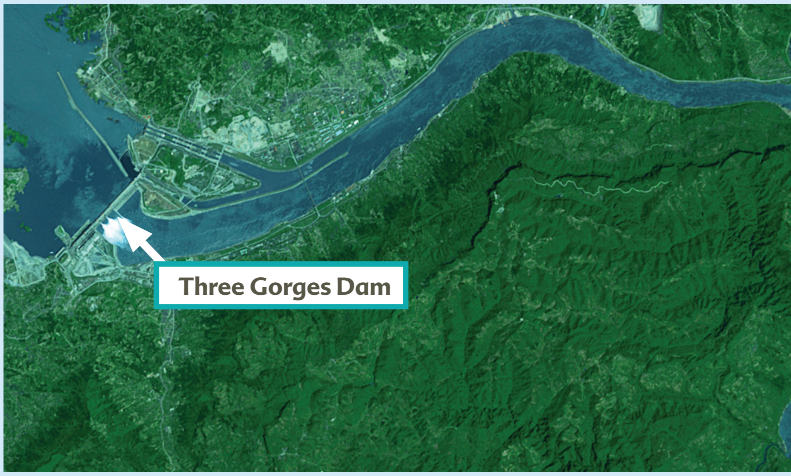
Trade-Offs of Dams and Salmon Populations

Humans have been building dams worldwide for generations. The advantages of generating clean energy and storing water for a variety of uses are considered to be valuable benefits of building dams. Some contend that dams are a means of flood control. With the increase in demand for electricity has come an increase in the number and size of dams being constructed. In recent years, however, a number of red flags regarding dam construction have arisen that warrant taking a closer look in order to weigh the pros and cons and make informed decisions about the future of dams.

Globally, many large dam projects are underway. The Three Gorges Dam project in China is one well-known example of a dam that presented problems to the region in which it was built. It took more than 10 years to complete the dam, which is more than 600 feet high and close to a mile-and-a-half wide. To construct the dam, more than a million people were relocated and more than 1,600 factories were submerged! Even though the dam generates 80,000 gigawatt/hour of clean energy for people each year, there was considerable environmental and political opposition internationally.

Some dams, however, receive a great deal of support from communities. The construction of three dams built to create the Diamond Valley Lake **reservoir** for southern California presented great benefits to both the community and local wildlife. In Hemet, California, 5,000 people were employed during the 1990s to construct the dams. It is estimated that energy produced by the dams will be able to supply the energy needs for up to 40,000 households. Two adjacent nature reserves were established to mitigate loss of habitat for several endangered or threatened species.

While the generation of electricity and water storage are benefits of dams, the issue of flood control has been contested in recent years. In the past, dams were thought to serve as catch basins for floods, and so would safeguard communities downstream. Dams can incorporate waters from small- to medium-sized floods; however, large floods are beyond their holding capacity unless they are empty. Dams are not kept empty, because this is at cross-purposes with both water storage and hydropower. With climate changes, larger storms are occurring more frequently that can overwhelm a dam. This puts downstream communities at greater risk for flooding.



The Three Gorges Dam controls the flow of freshwater in the Yangze River in China. In 2008 it began operation and was the largest electricity generation facility of any kind worldwide.

When dams are built, the continuous flow of a river is interrupted. This has potential impact on several fish species, including wild salmon and steelhead trout. Salmon are **anadromous** fish, which means that they live in both fresh and saltwater habitats for different phases of their life cycle. They spend their early lives in the shelter of a freshwater stream, migrate downstream to an open ocean to hunt, and then return to their home stream, managing to swim upstream to spawn the next generation. Because of this, salmon need river and stream habitats that are not obstructed by impassable dams. They also need upland **riparian** vegetation that shades, stabilizes, and shelters the developing fish. When these needs are met, they are able to reproduce successfully.

Worldwide there have been four main areas of concentration for salmon: Asian Far East, Atlantic

Europe, Eastern North America and Western North America. Currently the Asian, European, and Eastern North American populations are either seriously reduced or have disappeared. A number of reasons have been suggested, but dams appear to be a major cause. Dams make the return to home stream difficult. Dams also potentially alter the magnitude of river flow, decrease riparian shelter, and inhibit young salmon from swimming to sea. Given threats that dams pose to existing salmon populations, several places, especially on the Pacific Coast, have experimented with the installation of aquatic "ladders" that enable salmon to reach upstream areas.

Several types of interventions to maintain salmon populations have been tried. For example, many fish-and-wildlife departments assist salmon populations by extracting and transplanting salmon eggs in traditional spawning grounds. Another intervention, farm-raising salmon, has proven detrimental. In most cases, the introduction of aquatic farms adjacent to wild populations has actually precipitated dramatic declines in the wild salmon population (some estimate up to 50 percent). A variety of reasons for this decline have been suggested, including parasites spreading from the farmed to the wild salmon or farmed salmon leaping out of their enclosures and interbreeding with wild salmon, which weakens the robustness of the wild salmon. The introduction of farmed animals into the wild has also enabled false population counts that cannot accurately monitor what is happening to the wild salmon.

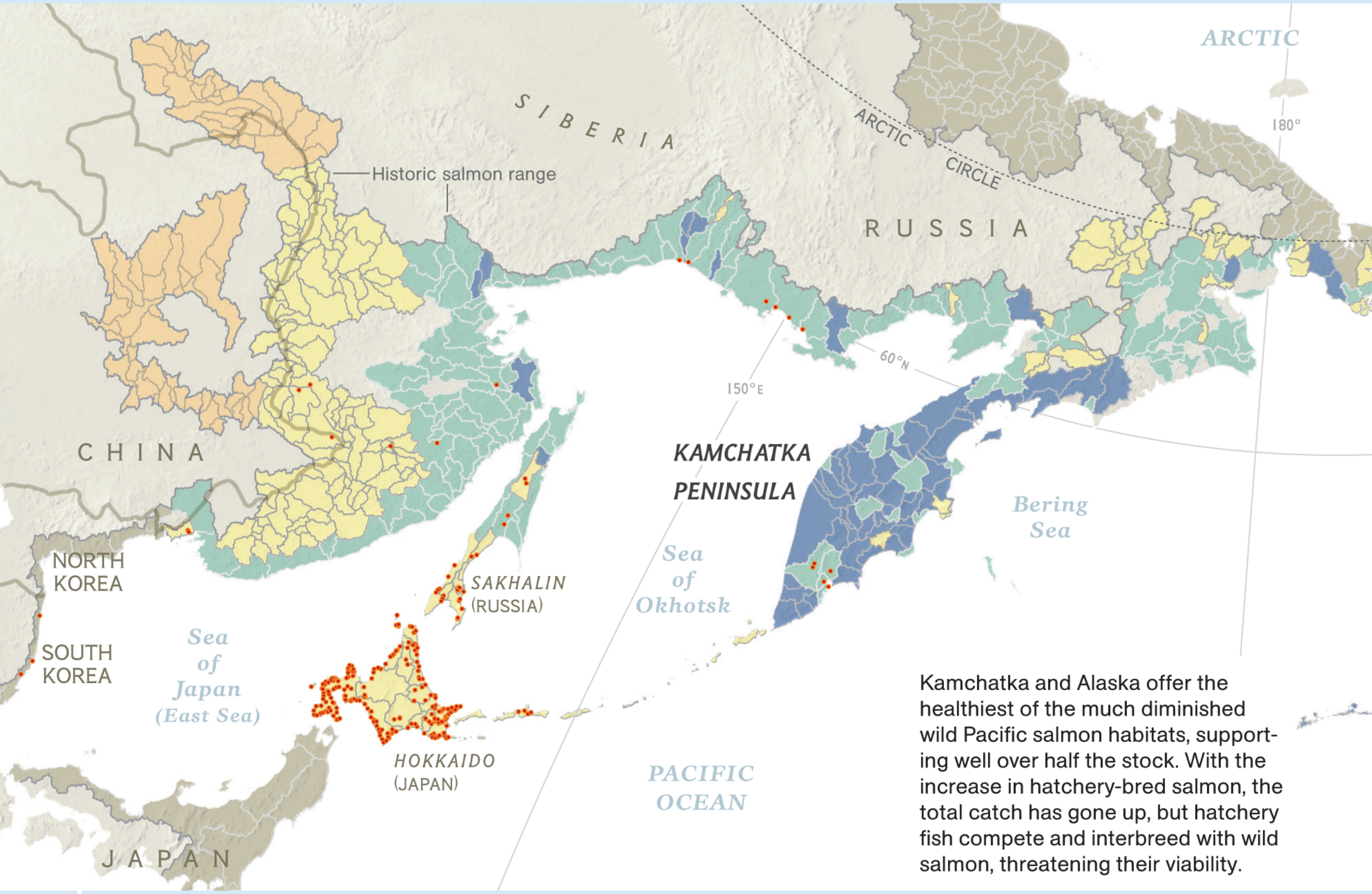
The increased mercury and PCB levels found in farmed salmon have caused another problem: more people are demanding wild fish! Recent research by the Environmental Defense Fund finds that there are now high levels of mercury and PCBs in wild salmon from California, Oregon, and Washington, as well as Atlantic salmon.

It is estimated that nearly 30 percent of the West's wild salmon and trout populations have been lost, and another third are endangered or threatened. Legislative efforts have been made in an effort to save

Salmon live in both fresh and salt water and migrate upstream when it is time to spawn. Spectators watch at Bonneville Dam on the Columbia River as this ritual occurs on a human-made aquatic fish ladder. Salmon typically swim upstream, navigating the natural rapids.

these animals and ecosystems. In America, Pacific Coast senators have been cosponsoring legislation to "protect the best by establishing Salmon Strongholds, or federally protected ecosystems protecting the wild salmon population" from California to Alaska since 2008. Similar legislation was proposed in Congress as the Pacific Salmon Stronghold Conservation Act in 2009 (S.817) and again in 2011 (S.1401), when in was passed out of committee to the Senate as a whole. The outcome of this legislation is still unclear; however, it is evident that that there is concern about safeguarding the future of wild salmon populations. In Canada, Ecojustice, a nonprofit organization, took a case against their federal government all the way to the Supreme Court over the government's lack of action to protect salmon habitats, and won. Concern and action are necessary now if the fate of the salmon in western North America is to be different from that of the other three global salmon populations.

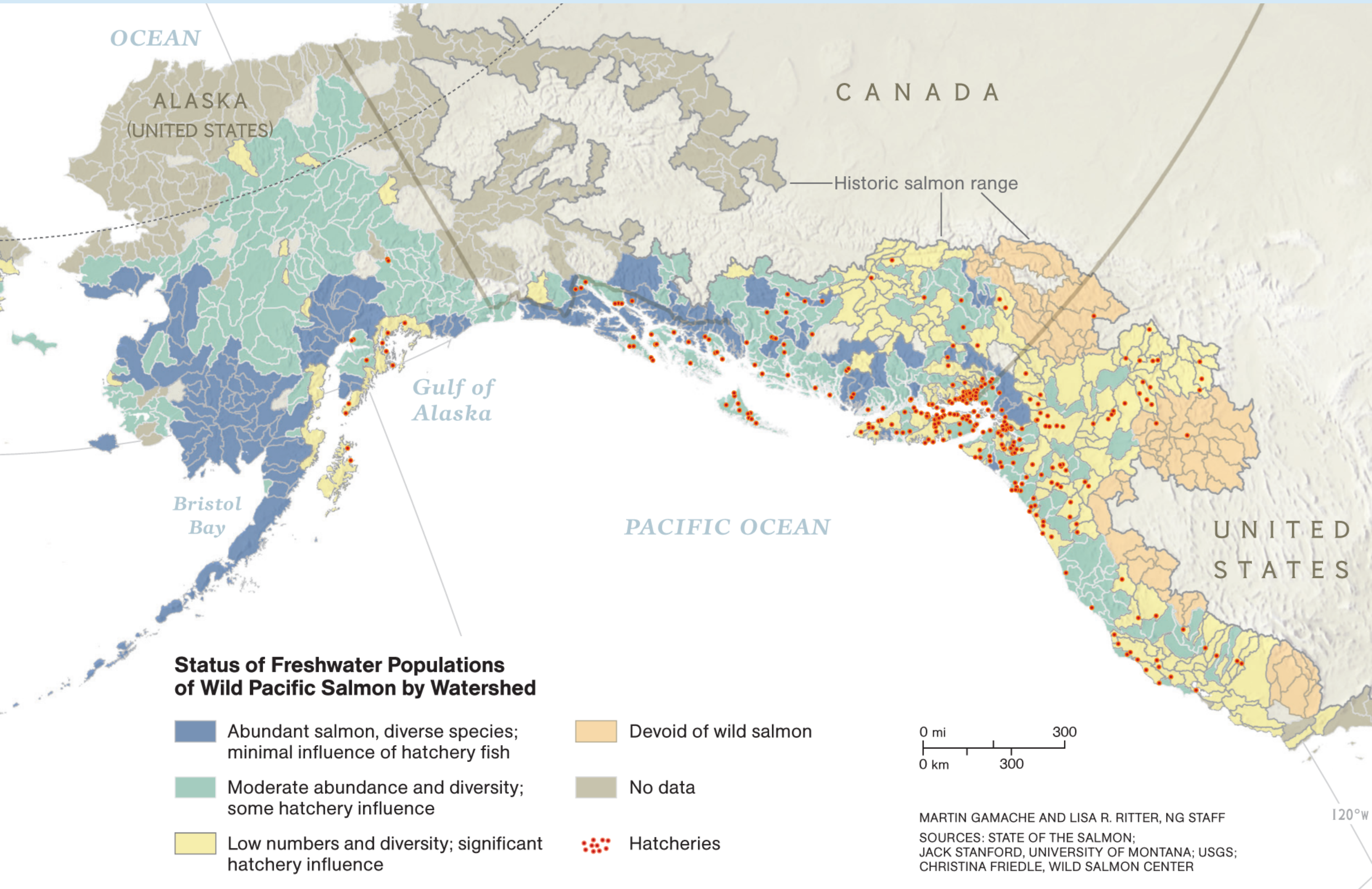
In the last few years, several watchdog organizations have actively advocated for the removal of old and deteriorating dams, and the restoration of free-flowing river systems. In California, a feasibility study was contracted to "look at various passage options over Englebright Dam which is a complete barrier to approximately 563 miles of historic salmonid habitat"



Kamchatka and Alaska offer the healthiest of the much diminished wild Pacific salmon habitats, supporting well over half the stock. With the increase in hatchery-bred salmon, the total catch has gone up, but hatchery fish compete and interbreed with wild salmon, threatening their viability.

along the Yuba River, according to National Oceanic and Atmospheric Administration (NOAA). Dams currently block salmon and steelhead trout from "95-98% of their historic spawning and rearing habitat." NOAA's National Marine Fisheries Service has the authority to review hydroelectric project licensing. In May 2010, an "Early Decommissioning Agreement with Pacific Gas and Electric to remove hydroelectric facilities on Kilarc and Cow Creeks" was announced. The decommissioning of these facilities along tributaries of the Sacramento River will restore access to salmon and steelhead that had been blocked for nearly a century. Two dams in California were removed in 2009: Camp Meeker Dam and Waterman Dam. The dam removals opened 3.4 miles of spawning habitat for Coho salmon and steelhead trout along Dutch Bill Creek, and 1.5 river miles of habitat along Waterman Creek, improving habitat for steelhead trout.

On another front, a network of grassroots organizations work locally. Across the state of California there is a mixture of concerned citizens including scientists and sports anglers who are advocating for the restoration of salmon habitat. Some activists talk to local groups, such as restaurant and market owners, civic organizations, and school groups, about actions they can take to better sustain the salmon and their ecosystems. These local organizations and groups are helping to ensure native California species don't become extinct because of human-made structures such as dams.



Teaching Tip

The Monterey Bay Aquarium has a downloadable “Seafood Watch” guide that advises consumers about how to make sustainable choices about what fish they should buy, and what species have been overfished and should be avoided. Many students will not know what fish are sustainable in their area and may have misconceptions about what “sustainable” means. To help illustrate sustainable seafood practices to your students, download your local “Seafood Watch” guide at http://www.montereybayaquarium.org/cr/cr_seafoodwatch/download.aspx and share it with your students. See also the ocean teacher guide in this series, Chapter 7 (page 71) for more information about sustainable seafood.

Case Study: Endangered Freshwater Species

When most of us think of dolphins, we think of them in the ocean. Surprisingly, there are a few species of dolphins that have adapted to life in freshwater—either entirely or partially. The freshwater dolphins are primarily found in Asia and South America in some of the busiest rivers (Yangtze, Amazon, Ganges, Mekong, and Indus). After a 2006 survey in Asia resulted in no sightings of the Yangtze river dolphin, there is some question about whether this species still exists. In addition, many of the other species of freshwater dolphins are threatened. There is increased concern about what is causing their demise and the possibilities of saving them. These dolphins are considered by many to be among the most endangered of all the world's **cetacean** species. Cetaceans are marine mammals including whales, dolphins, and porpoises. As with salmon and trout, when the flow of their river habitat is interrupted by dams, the freshwater dolphin populations become isolated, which weakens their robustness. These mammals have also been impacted by pollution, including noise pollution that accompanies increased human population **density** and development in their vicinity (e.g., mining, motor boats, and construction).

Because they live in rivers and hunt in murky waters where fish can hide, the river dolphins have a different anatomy than their marine relatives. They have elongated beaks that are able to probe into mud as well as roots. They also have longer necks that can rotate for hunting. Two of the groups (from the Ganges and the Yangtze), are essentially blind—depending instead on their highly developed sonar ability. River dolphins are also generally smaller than their marine cousins.

Amazon river dolphins, or pink dolphins, reside in the Rio Negro in Brazil

The river dolphins in Asia appear to be the most severely impacted by human activity. The Yangtze River has been impacted by the construction of dams as the need for electricity in the region is great. Yangtze River dolphins have not been sighted since a 2002 survey and are possibly extinct. The endangered Ganges River dolphins used to range through the Himalayan rivers and to the Bay of Bengal. The population has been fragmented into several groups isolated by dams along

Teaching Tip

This is a good opportunity to review the terms "threatened," "endangered," and "extinct" with your students. These are official designations of a continuum, depending on the number of individuals still living and the vulnerability of their habitat. Your students will probably know about extinctions from their studies of woolly mammoths and other species that perished during the Ice Age. Many students are also aware and concerned about the number of extinctions occurring today. When a species is endangered, it is on the verge of extinction. When it is threatened, it is one step away from endangerment. These classifications allow different interventions and protections, based on the insecurity of survival, as a result of the federal Endangered Species Act, which was enacted in 1973. International protections and regulations are in place as well. While the legal protections afforded by the Endangered Species Act are not always adhered to, they do allow legal action against those who don't honor the law. Check out your local endangered and threatened species at http://www.fws.gov/endangered/ and http://www.earthsendangered.com.

RIVER DOLPHINS

RIVER DOLPHINS: A CURIOUS CLAN

Four far-flung species are loosely grouped as river dolphins because of their shared habitat and body traits. Long beaks, short dorsal fins, and other adaptations to river life distinguish them from their marine cousins.

SOUTH AMERICA

Amazon dolphin *(Inia geoffrensis)* The largest of river dolphins, with an estimated population of at least 100,000, the *boto* ranges widely in the Amazon and Orinoco River systems.

Franciscana *(Pontoporia blainvillei)* Also known as the La Plata dolphin, it lives in coastal Atlantic waters and brackish estuaries. Its population may be about 70,000.

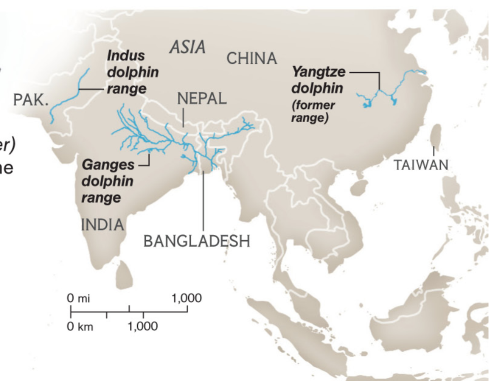
HIRAM HENRIQUEZ AND LISA R. RITTER, NG STAFF

SOURCES: AMERICAN CETACEAN SOCIETY; GILLIAN BRAULIK, WWF; TONY MARTIN, UNIVERSITY OF KENT; RANDALL REEVES, IUCN; EDUARDO R. SECCHI, UNIVERSIDADE FEDERAL DO RIO GRANDE

ASIA

Indus and Ganges dolphins *(Platanista gangetica)* Now classified as a single species, Pakistan's *bhulan* and the *susu* of India, Bangladesh, and Nepal are threatened: Only 3,000 to 4,000 remain.

Yangtze dolphin *(Lipotes vexillifer)* Development and fishing along the Yangtze River have all but wiped out the *baiji*. There have been no confirmed sightings since 2002.



the river. The World Wildlife Fund believes there may be fewer than 2,000 individuals remaining.

The freshwater dolphin species in South America are also facing harsh challenges, but there are some outspoken advocates. Locally called *boto,* these dolphins live in the Amazon and Orinoco river systems. The Franciscana or La Plata dolphin is generally smaller than the Amazon river dolphins and has a distinct advantage that helps its survival. It is adapted to live in both fresh and salt water, ranging through the La Plata River and along the nearby Atlantic coasts of Argentina, Uruguay, and Brazil. During the rainy season, water levels can rise more than 20 feet higher than water levels in the dry season. This allows infusion of nutrients from plants, which enriches the river habitat. With the clear-cutting of rain forests, however, this enrichment process has been severely diminished. Raising awareness among local and global populations is key to amassing help. Ecotourism is seen as a way of supporting the health of the entire ecosystem. The Bolivian River dolphin is now viewed as an important indicator of water quality in certain freshwater ecosystems. With local and international attention, there is hope to save these dolphins.

Case Study

California Vernal Pools

Vernal pools in California bloom in the spring, displaying brilliant yellow colors that dot the landscape.

When walking in an open field, it would be very easy to overlook a vernal pool. As the name suggests, a vernal pool is a seasonal body of water that is usually at its peak volume in the spring. It is formed when a shallow land depression with poor drainage is filled by water from winter rain. In the spring, the water remains long enough for plants to grow. While timing of rainy seasons differ in other areas, these special ponds are still known as vernal pools. Many of the plants and animals that thrive in vernal pools are so well adapted to this short growth season that they are found nowhere else. When walking in a field during the summer or autumn, you may not realize you are in a highly fragile and threatened ecosystem.

Vernal pools are found in areas where the underlying soils are relatively **impermeable.** This can occur with soils derived from volcanic flows. The foothills of the northern Sierras (Butte County) and the Peninsular Ranges in western Riverside County are two places where these types of soils are found. This lack of drainage is also found in terraces along the Central Valley.

Although they have short active seasons, vernal pools are actually vibrant ecosystems. Some plants found in vernal pools have air-filled stems for floating, while others have adapted floating leaves. Small crustaceans and amphibians are also found here. As the water begins to evaporate, plants set seed, forming concentric rings of showy blossoms. During the dry months, amphibians dig deep into the mud and enter a dormant phase. Vernal pools are a source of rest and nourishment for migratory birds. The vernal pools of the Central Valley form part of the **Pacific Flyway** between Alaska and South America. Nesting sites for a number of overwintering local resident populations are also found here.

Vernal pools are among the most severely threatened wetland environments. More than 90 percent of vernal pool habitats in California have been lost. Agricultural or urban development, off-road vehicle activity, and brush clearing for fire prevention have taken their toll. Most of the remaining sites have little legal protection, but the Endangered Species Act (about a third of the plants found in vernal pools are endangered), the California Environmental Quality Act, and the Migratory Bird Treaty Act (reaffirmed in 2001 by the federal Department of Transportation) are all legal provisions that can be called upon to help save these habitats. Acquisition of these ecosystems by park departments or nonprofit conservation organizations is another way they can be protected.

Pictures of Practice

Exploring Ponds and Vernal Pools

Getting students into nature to explore the environment firsthand can be a logistical challenge for teachers but can also be a rewarding experience for students. Students learn a great deal about our environment through text, pictures, and videos, but firsthand experience interacting with nature itself can bring scientific concepts to life more so than words or images on a page. Studying aquatic habitats, such as vernal pools or ponds and streams, allows students to connect with plants and animals living in those environments, making the wildlife even more real to students. This interaction, and the opportunity to connect with the environment, may motivate students to want to conserve and protect special places in their local community.

Students: Grade 3

Location: Auburn, California (an inland community)

Goal of Video: The purpose of watching this video is to observe students' exploration and ideas about life in aquatic habitats.

Classroom Context

Ms. Watkins worked with the Wildlife Heritage Foundation in Placer County, California, to take students on one of its educational programs to Silvergate Preserve. Silvergate is open-space land that was once rice fields and is now restored to its original vegetation and habitats. Silvergate includes marshes, ponds, vernal pools, and **riparian habitats.** Ms. Watkins's students explore the Silvergate vernal pools and ponds, looking for different organisms and evidence of wildlife found in the area.

Video Analysis

In the video you will see scientists and education specialists talk about the importance of having students interact with nature and what these students will find at Silvergate. The purpose of watching this video is to think more critically about why exploration of aquatic habitats is important for students to experience. The ponds and vernal pools at Silvergate offer an activity in which students can interact with the environment and see firsthand the life found in these two habitats, along with the riparian habitats in the area. You will first hear students describe their ideas about what they would find in a bucket of pond water. Students focus mainly on fish, rocks, grass, and tadpoles. Then you will hear the Silvergate staff talk more about vernal pools and aquatic habitats and what students experience when they visit. As you watch the video, think about the local resources that you can take advantage of when teaching students about life in water—local streams, ponds, channelized rivers—or even strategies for bringing freshwater samples to your classroom for exploration.

Reflect

How would you teach students about biodiversity in freshwater?

Biodiversity in freshwater is often overlooked. What activities and investigations can you do in your local area to help students better understand these ecosystems? In this video, students primarily focus on life that they can see. What additional activities could you do to help them become more aware of microscopic life? Also, vernal pools have a short life cycle and bloom. How can you help students understand that these pools are more than "puddles," but rather "living" habitats—even when they are not in bloom? The same may also be true for your local streams and ponds that dry up during different times of year, or during droughts years.

In the Classroom: Freshwater Biodiversity Studies

When scientists study freshwater ecosystems, they often use probes and tests to collect data for a variety of **chemical parameters** (e.g., nutrients, pH, alkalinity, and so on.). They also examine physical properties such as **turbidity** (cloudiness or haziness of a fluid), evidence of erosion, depth, and flow rate. A variety of techniques are used to study freshwater biological communities. Plankton nets can catch and concentrate plankton, which are then studied under a microscope. Using techniques such as **quadrats** (squares, often one meter, used to isolate a sample in the field) and **transect lines** (a path along which one counts and records occurrences of the phenomena of study), scientists can approximate the density of species within a body of water and its banks. Physical, chemical, and biological studies can give important information about water health, indicating, for example, if there is a nutrient imbalance or oxygen depletion. Healthy ecosystems support biodiversity.

Leaf-Pack Activities. The leaf-pack activity increases awareness of the amazing array of life that we often overlook because of its small size. By investigating the undersides and spaces between the leaves found in a local stream, a multitude of insects and microorganisms are revealed. Additionally, students can place their own leaf packs within a streambed, pond, or other aquatic habitat to see what organisms make the pack home. Explore more at http://www.stroudcenter.org/lpn/.

Stream Study. Investigate a local stream or pond. Observe the **clarity** and temperature of water (pH, if possible), number and type of plants adjacent to and in the water (leaves, branches also), number and type of animals adjacent to and in the water (collect a water sample in a jar and investigate with magnifying lens or microscope). Also, look for evidence of humans, such as litter or change in flow of the stream. Although this works well as a one-time experience, it is more powerful if students have the opportunity to revisit the same site during the year to observe changes in the natural cycle. Find out more about your local water prior to your investigation at http://water.usgs.gov/education.html and http://water.epa.gov/type/location/regions.cfm.

Water Quality. Investigate and compare images of healthy versus polluted water using a local, state, or national freshwater location. Then experiment using three samples of the same type of plant in similar containers and given the same amounts of water, but alter the water chemistry slightly. Add lemon-lime soda (acid) to one container, diluted dish soap (alkaline, with phosphates) to another, and keep the third as a control by using distilled water. Observe the plants for a week and compare results. Check out additional ideas at http://www.projectwet.org/.

Report on Endangered Species. Have your students conduct research (individually or in groups) on freshwater species in peril. For example, have students investigate local dams and potential threatened populations or other local threatened populations. Ask students to think about human impacts that have threatened these species and actions they can take to reduce the threat. Explore your local endangered species at http://www.earthsendangered.com/index_s.asp or http://www.fws.gov/endangered/.

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Teaching Resources

American River's listing of endangered rivers by region: www.americanrivers.org

America's Mussels: Silent Sentinels: http://www.fws.gov/midwest/Endangered/clams/mussels.html

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

California's Fish and Game Department resources on local species: www.dfg.ca.gov

California Invasive Plant Council resources: www.cal-ipc.org

Federally-supported clearinghouse for invasive species: http://www.invasivespeciesinfo.gov/

Follow the Pacific Flyway in California State Parks: http://www.parks.ca.gov/pages/24317/files/followthepacificflyway.pdf

Fresh Water Dolphin Fact Sheet: http://www.whaletrackers.com/education/factsheet/factsheet-river-dolphins.html

National Geographic Society Dam Geoguide: http://www.nationalgeographic.com/geoguide/dams/

National Geographic Society Interactive: Amazing Dolphins: http://ngm.nationalgeographic.com/2009/06/dolphins/amazon-dolphins-interactive

Nature Conservancy lists of environmental issues and activities: www.nature.org

Pacific Flyway Map: http://www.pacificflyway.gov/Documents/Pacific_map.pdf

Salmon: frequently asked questions: http://www.nefsc.noaa.gov/faq/fishfaq2d.html

Vernal Pool Education Project: http://www.vernalpool.org/enet_1.htm

Vernal pool plant and animal life photo gallery: http://www.wildbynature.org/gallery/?album=1&gallery=2

Wildlife Heritage Foundation information: http://www.wildlifeheritage.org/

World Wildlife Foundation's threatened and endangered species: http://wwf.panda.org/

2 Water Cycle and Water Reservoirs

by Anica Miller-Rushing, Abraham Miller-Rushing, and Marcia S. Matz

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

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

The Water Cycle

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

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.e-f 3.1.1	Living Things in Changing Environments The Geography of Where We Live
Grade 4	4.5.c 4.1.4-5 4.4.7	Reflections of Where We Live
Grade 5	5.1.g 5.3.a-e 5.4.b	Earth's Water Changing States: Water, Natural Systems, and Human Communities Precipitation, People, and the Natural World
Grade 6	6.2.a-d	The Dynamic Nature of Rivers
Grade 7		
Grade 8	8.3.d-e 8.5.d 8.12.5	Industrialization, Urbanization, and the Conservation Movement

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

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

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

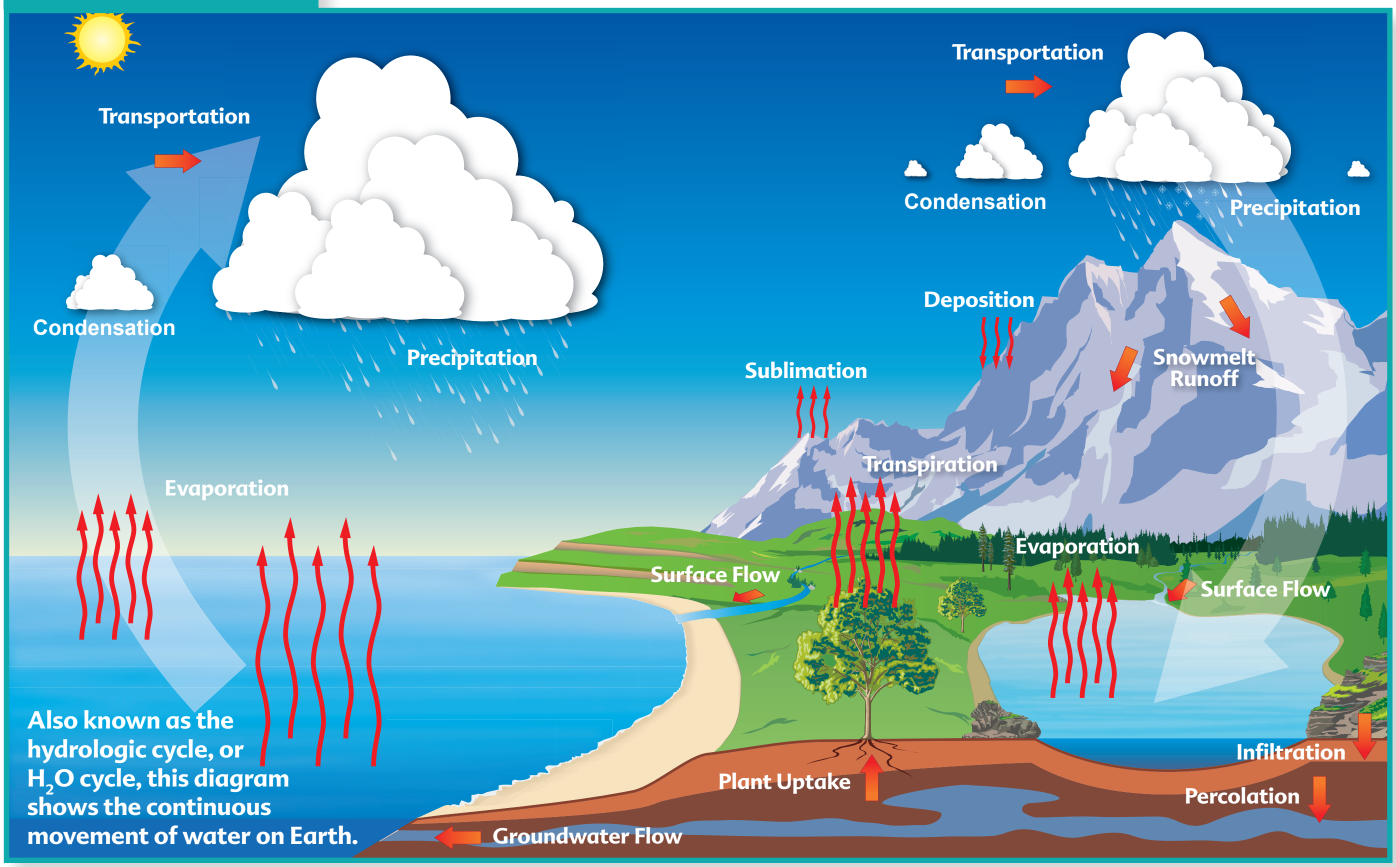
CHAPTER OVERVIEW

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

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

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

HYDROLOGIC CYCLE



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

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

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

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

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

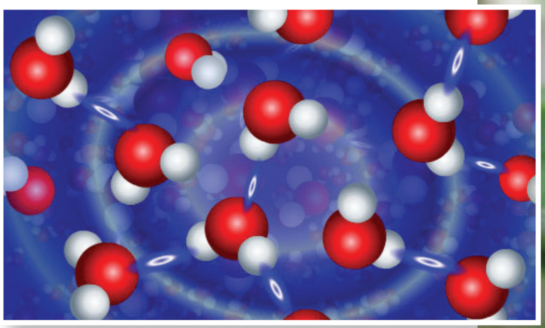
feature, usually a river or stream. For example, in central North America, the Arkansas River watershed consists of all the rivers, creeks, streams, and land surfaces that drain into the Arkansas River as it travels from Colorado to Arkansas, where it spills into the Mississippi River. Many watersheds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

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

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

Special Qualities of Water

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



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

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

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

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

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

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

Surface tension allows this insect to walk on water!

The States of Water

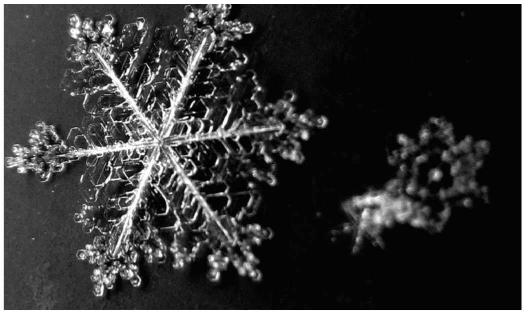
Water makes up 55–78 percent of the human body, is considered a universal solvent (meaning many substances dissolve in it), and is integral to life as we know it on Earth. It has specific temperatures at which it boils, freezes, and melts. The combination of these properties, plus the energy from the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

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

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

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

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



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

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

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

The Ways Water Moves

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

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

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

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

Teaching Tip

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

In the Classroom

Surface Tension

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

Materials

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

Directions

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

Discuss

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

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

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

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

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

Plants give off water through transpiration.

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

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

Teaching Tip

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

Student Thinking

Water-Cycle Processes

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

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

Ask Your Students

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

Pictures of Practice

Learning About Evaporation

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

Students: Grade 3

Location: Auburn, California (an inland community)

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

Classroom Context

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

Video Analysis

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

Reflect

How would you teach evaporation?

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

In the Classroom

Cloud in a Bottle

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

Materials

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

Directions

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

Discuss

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

Student Thinking

What Makes Up a Cloud?

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

Scenario

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

Question

What are clouds made of?

Scientific Answer

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

Student Answers

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

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

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

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

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

What Would You Do?

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

Representations of Science

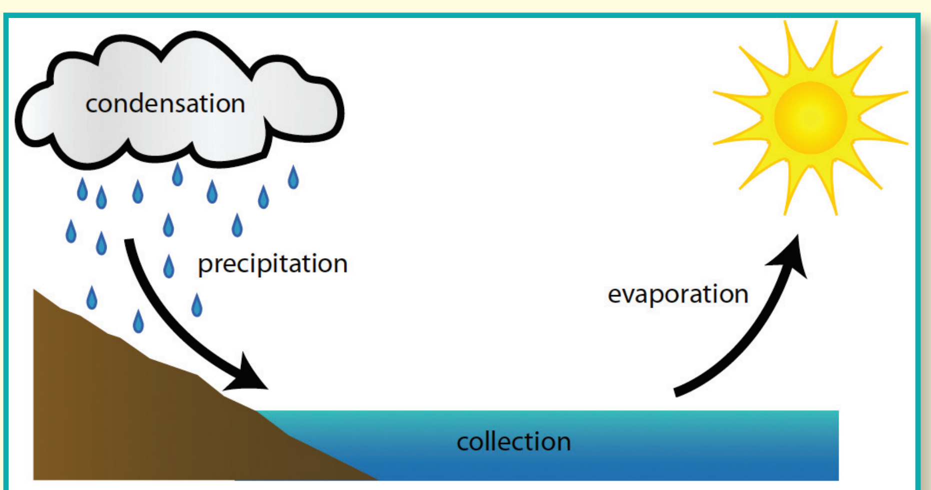
The Water-Cycle Journey

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

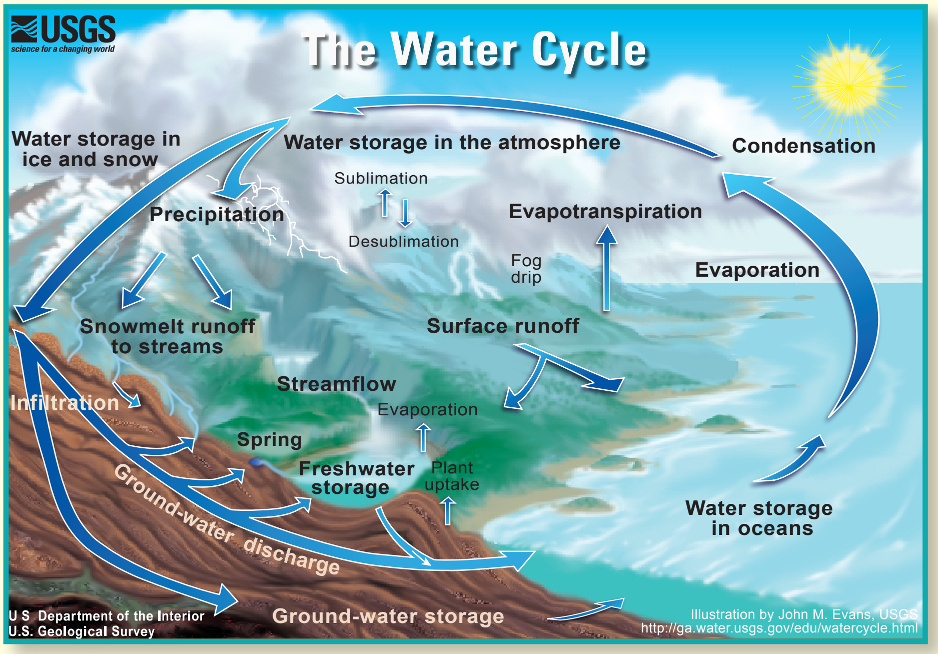
The water cycle is a more complex cycle than is often diagramed for students. Water moves among many locations in this closed Earth system. Water molecules can get "stuck" in certain locations, such as in glaciers or groundwater, for millions of years, whereas surface water can move quite quickly from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

Water-Cycle Diagrams

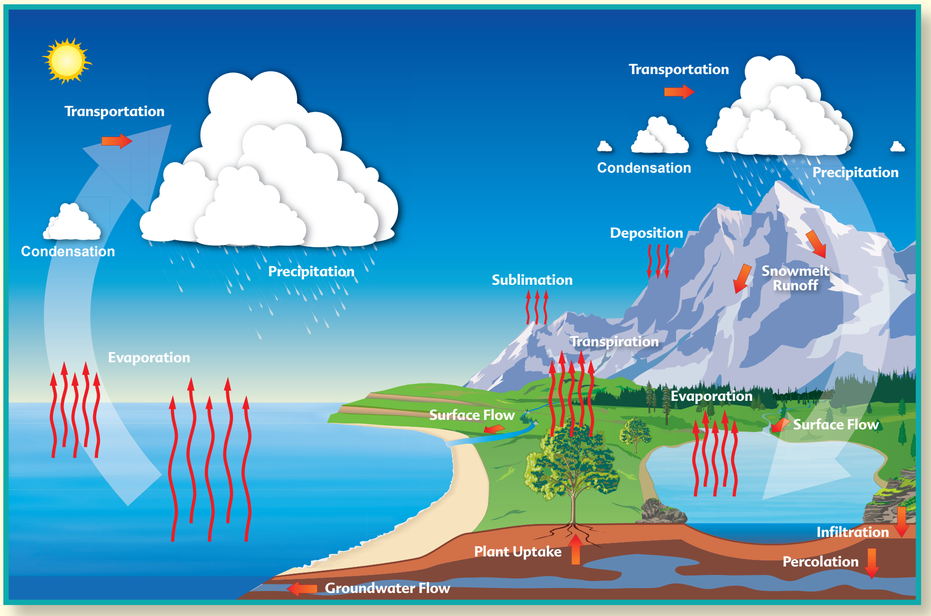
There are many informal conceptions about the water cycle, and some concepts, like groundwater, are particularly difficult for students to understand. Science-education researchers suggest using carefully constructed models and/or visualizations to help students build a more correct understanding of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



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



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



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

Student Thinking

Groundwater

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

Scenario

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

Question

Where does water that we get from wells come from?

Scientific Answer

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

Student Answers

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

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

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

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

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

What Would You Do?

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

Where is Fresh Water Located?

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

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

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

The Forgotten Reservoir of Water

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

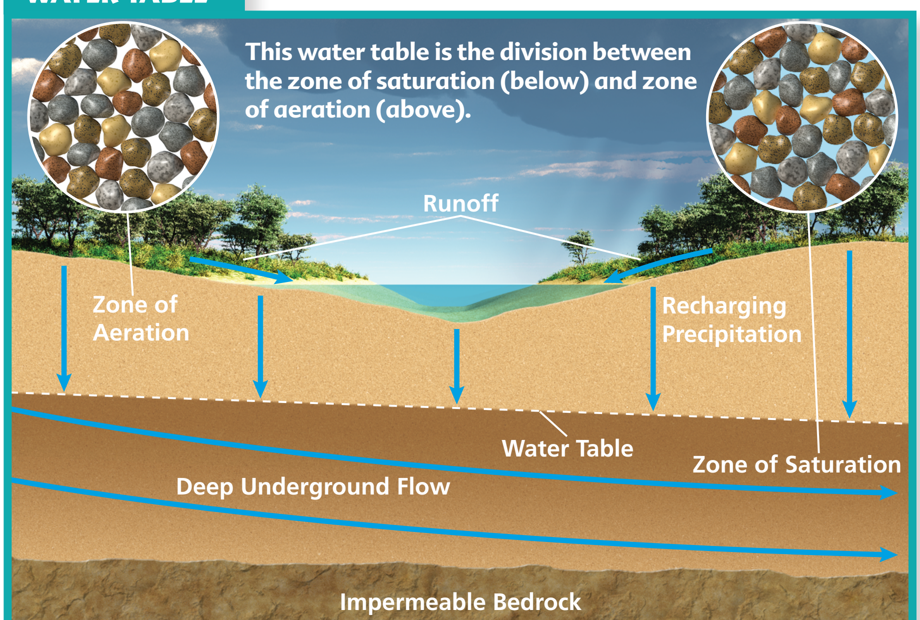
Water Table, Aquifer, and Groundwater—Different Words for the Same Thing?

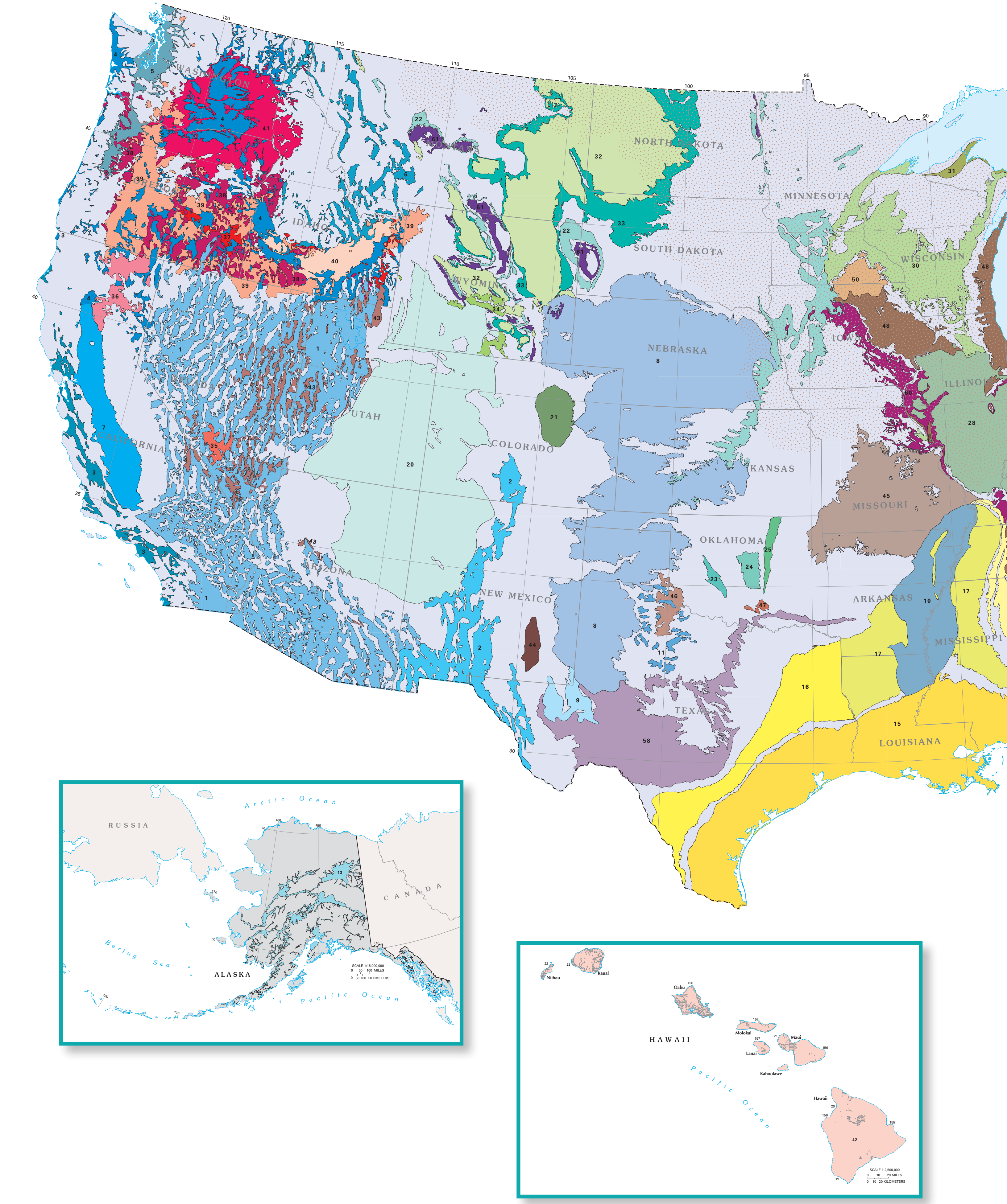
The terms ***water table,*** *aquifer,* and *groundwater* are often confused and sometimes used interchangeably. They are all related—they refer to aspects of water that occurs underground—but they are not the same. The simplest of the terms to understand is *groundwater,* which means just what it says—"water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

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

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

WATER TABLE

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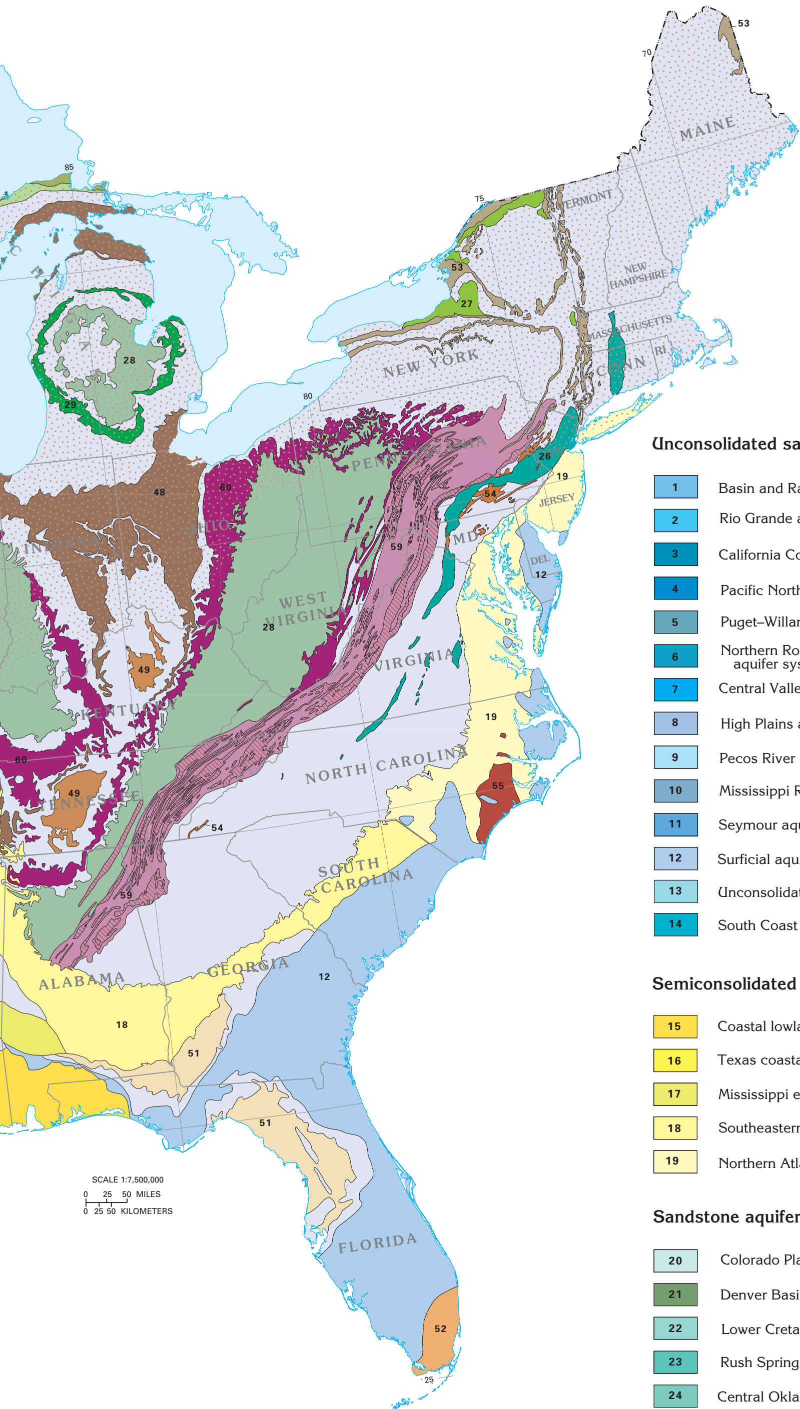


This map shows the different types and locations of underground aquifers in the United States. Use this map to help gauge your students' understanding of groundwater and aquifers.

Unconsolidated sand and gravel aquifers

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

Semiconsolidated sand aquifers

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

Sandstone aquifers

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

Basaltic and other volcanic-rock aquifers

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

Carbonate-rock aquifers

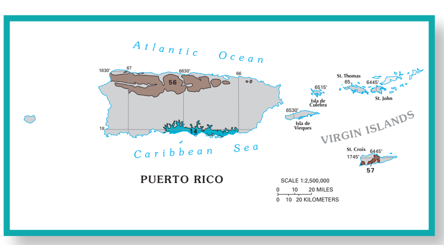
- 43 Basin and Range carbonate-rock aquifers
- 44 Roswell Basin aquifer system
- 45 Ozark Plateaus aquifer system
- 46 Blaine aquifer
- 47 Arbuckle–Simpson aquifer
- 48 Silurian–Devonian aquifers
- 49 Ordovician aquifers
- 50 Upper carbonate aquifer
- 51 Floridan aquifer system
- 52 Biscayne aquifer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

Sandstone and carbonate-rock aquifers

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

Glacial deposit aquifers overlie bedrock aquifers in many areas

Not a principal aquifer



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

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

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

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

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

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

Watersheds

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

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

Teaching Tip

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

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

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

Teaching Tip

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

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

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

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

Why Teach About Watersheds?

Watersheds are natural ways of dividing and connecting landscapes. They provide a great tool for thinking about the ecology and land use of a region, because as water flows over and through the ground, it can pick up sediment, nutrients, and pollutants and carry them downstream. Like the water, the nutrients and pollutants that flow to the outlet of the watershed can affect ecological processes along the way. Nutrients such as nitrogen, phosphorous, and potassium—found in many household items, including cleaning products, fertilizers, road sediment, and so on—can accumulate at the mouth of a watershed and disturb the natural balance of nutrients and plant and animal life. In addition, management practices and land use changes can have a significant impact on a region's water resources by changing

the quality, quantity, and flow of the water. Understanding how watersheds function, learning how water connects the landscape (e.g., an action such as introducing a pollutant into a river in one place affects water downstream), and recognizing trends in how people have changed how watersheds function, all help students appreciate the importance of watershed management.

Teaching Tip

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

Student Thinking

Watersheds and Rivers

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

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

Ask Your Students

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

In the Classroom

Splish, Splash: Water's Journey to My Glass

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

Materials

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

Directions

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

Discuss

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

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

Case Study

The Urban Water Cycle

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

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

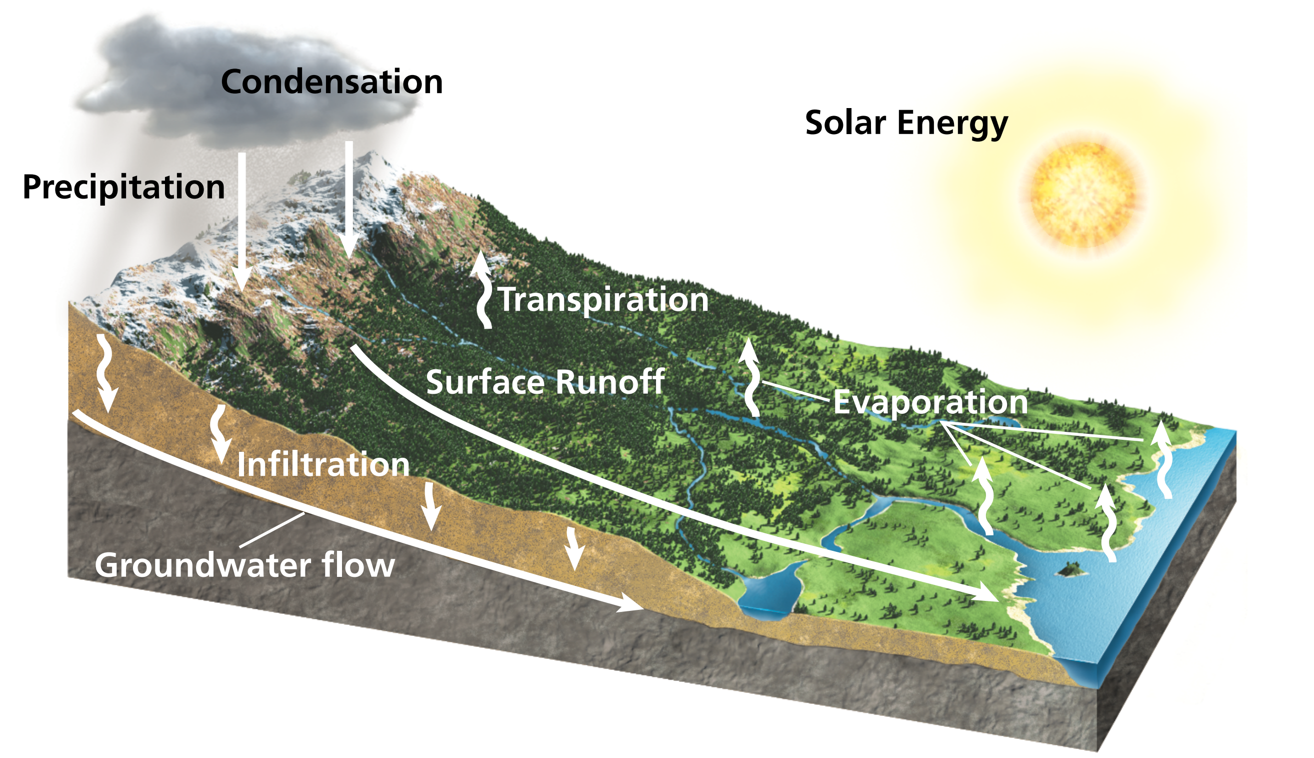
The urban water cycle describes a landscape filled with impermeable surfaces forcing water to runoff through complex drainage systems. In many locations, including California, there are two systems for drainage: **wastewater** treatment and storm drain. The wastewater treatment system collects water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

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

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

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

NATURAL WATER CYCLE



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

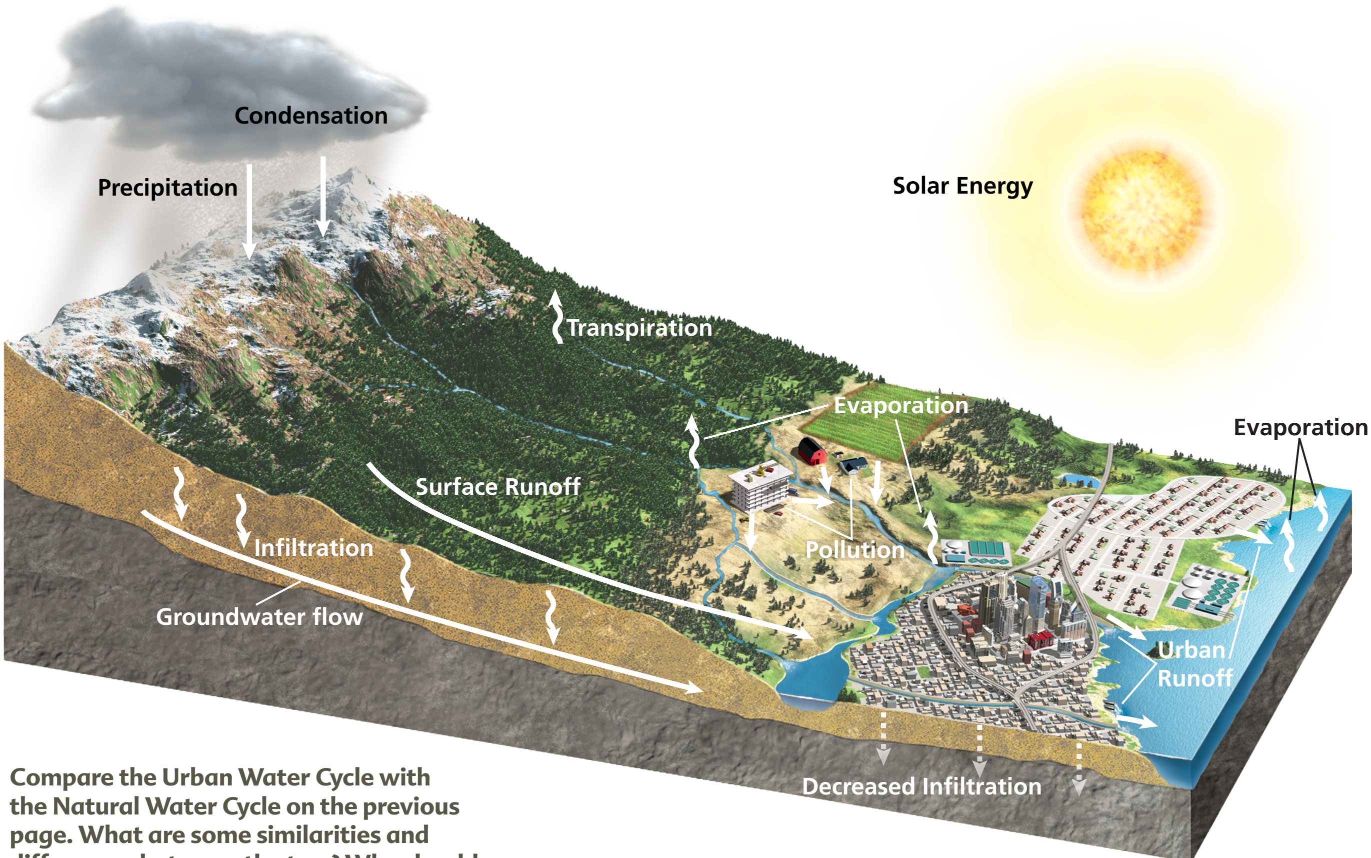
While these storm-drain systems seem like engineering wonders, they can wreak havoc on the natural flow of water. Water that would normally infiltrate the ground and recharge groundwater reservoirs can no longer penetrate the surface. Interestingly, the act of infiltration slows down the movement of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

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

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

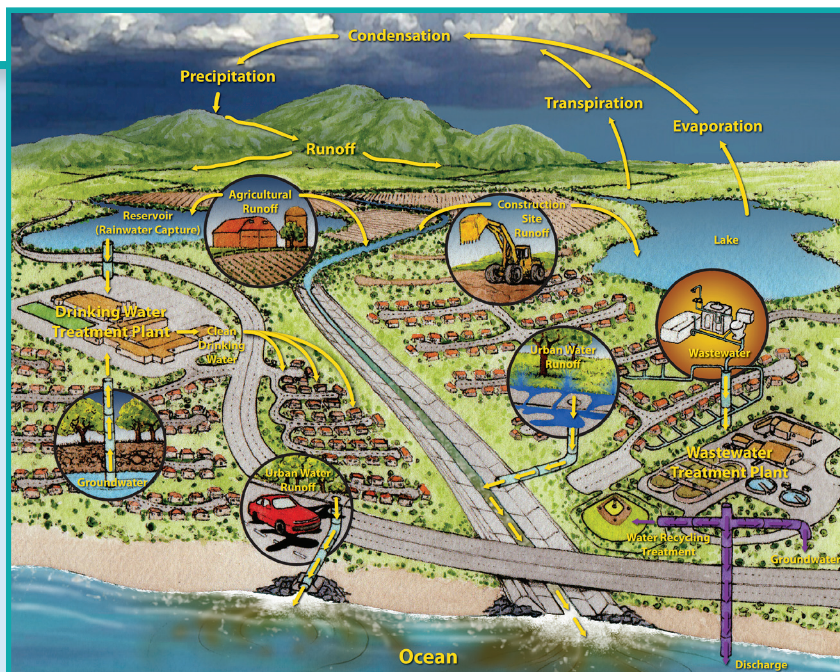
Many cities have recognized that the alterations in surfaces and natural flow are important concerns for freshwater resources. Cities that are looking for better management of water have been promoting an increase in permeable surfaces through use of permeable pavements, rain gardens, green roofs, and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

URBAN WATER CYCLE



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

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



Pictures of Practice

The Urban Water Cycle

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

Students: Grade 6

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

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

Classroom Context

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

Video Analysis

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

Reflect

What would you teach about the urban water cycle?

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

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Teaching Resources

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

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

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

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

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

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

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

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

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

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

3 Changing Natural Flows Of Water

by Ari J. Posner

The development of human civilization is inextricably linked to water. Over time, we have learned to move and use water in ways that help our communities grow. Today, these human structures (i.e., dams, canals, irrigation systems, and so on) are simply a part of our everyday interaction with water. Your students likely cannot imagine our world any other way.

Throughout history, different civilizations have learned to divert water to human communities for many reasons. More than 6,000 years ago, the Mesopotamians irrigated fields lying between the Tigris and Euphrates rivers in present-day Iraq (Trimble, Steward, & Howell 2008). Beginning about 5,000 years ago, the Egyptians established agricultural irrigation near the banks of the Nile River. The Nile was a source of wealth and power for the Egyptians. In the United States, some of the oldest irrigation canals, dating to approximately 3,000 years ago, were recently discovered along the banks of the Santa Cruz River near Tucson, Arizona. In this chapter, we explore how human structures and human communities—throughout history and in present day—alter the natural flow of water and some of the consequences of these actions.

Innovations in Moving Water

Your students may know that the Romans were great builders. They likely have heard about or seen ancient structures built by Romans or other civilizations that were unprecedented innovations of their time. Even in their current state, the remnants of Roman aqueducts and dams provide a sense of the enormous scale and scope of Roman water-engineering projects. The vast majority of their constructions were built to carry fresh and clean spring water from the mountains down to cities. Some of these aqueducts are still in use today!

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.2 3.3.2 3.5.1-3	The Geography of Where We Live California's Economy-Natural Choices
Grade 4	4.1.3-5 4.2.6 4.4.7	Reflections of Where We Live Cultivating California
Grade 5	5.3.d-e	Our Water: Sources and Uses
Grade 6	6.2.b 6.2.1	The Dynamic Nature of Rivers River Systems and Ancient Peoples
Grade 7		
Grade 8	8.6.1 8.8.4 8.12.1 8.12.5	 Struggles with Water Agriculture and Industrial Development in the United States Industrialization, Urbanization, and the Conservation Movement

Interestingly, few advances were made during the 16 centuries between the Romans and the Age of Enlightenment in Europe, when the scientific method began to take hold. The intervening centuries were also known as the Dark Ages, and during these years, the Europeans suffered greatly from diseases associated with poor quality drinking water and lack of adequate sanitation. During this time, city water supplies were gathered from the very streams and rivers into which people's sewage was dumped. As populations increased, urban centers expanded, and the recognition that water was linked to human health led to increased need for a safe and secure water supply.

Your students may have learned about ancient civilizations, the Dark Ages, and other important historical periods in social studies. For example, in sixth grade, California students study ancient civilizations; students progress to the medieval period and beyond in grade 7. Water for human use and water's connection to human health are both intrinsically interesting and relevant topics for students; and both these topics can be explored in the context of history, of present-day communities, or of science classes. Making connections to what students have learned in other disciplines deepens their cross-curricular understandings.

Freshwater played such an important role in historical cultural development that the term **hydraulic society** was coined to describe areas in which water diversion was used on a large scale to convert arid lands into productive agriculture. Due to the scale and costs

CHAPTER OVERVIEW

Through various ways, people have influenced how water moves on Earth. Because of our dependence on water for everyday activities such as drinking, eating, washing dishes and laundry, and showering, we have found ways to increase people's access to freshwater. Even in ancient times, the Romans and Egyptians found ways to move water to human communities. Today, we use dams, aqueducts, and canals to control where water goes and how it is stored, just as humans have done historically. However, our human water systems are not without environmental consequences.

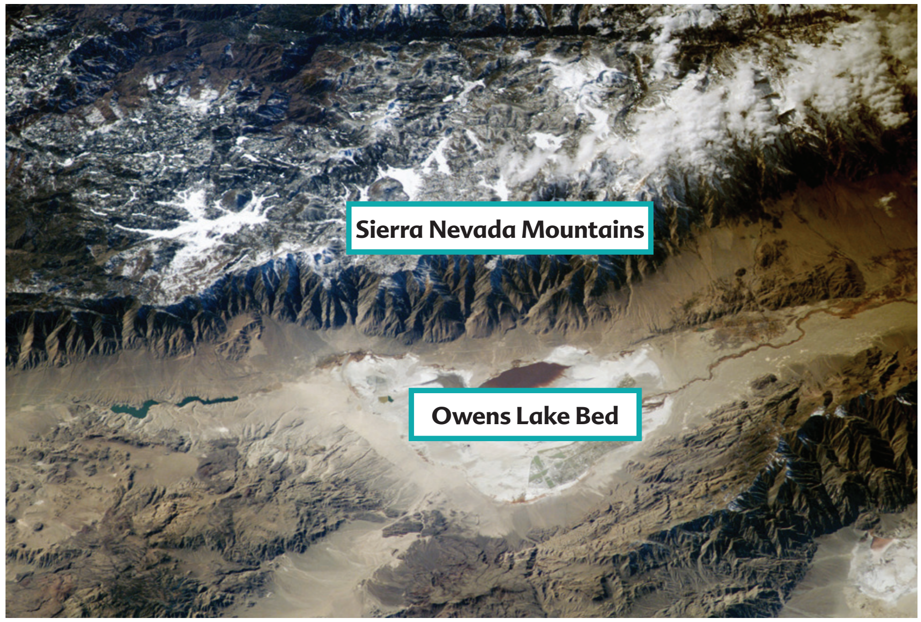
Through urbanization, we have had great impact on water movement just by paving roads and parking lots and building sidewalks in cities and suburbs. Places where water once penetrated the soils of open lands are now covered by impenetrable asphalt and concrete, resulting in changes to both surface runoff and groundwater flow.

This chapter reviews how humans have altered the flow of water, highlighting examples of how human-made structures and systems have benefited some communities but have also impacted natural systems and cycles.

associated with these vast projects, hierarchical organization of society was needed. Governments around the world, from Sri Lanka to Peru, Egypt to China, have used water diversion techniques to build empires. In California, William Mulholland earned his reputation as the man who brought water to Los Angeles, resulting in the creation of the second-largest U.S. city. He became the first head of the Los Angeles Department of Water and Power, where he designed the Los Angeles aqueduct that traveled more than 250 miles from Owens Lake in the eastern Sierras to Los Angeles. All of the water flows by gravity with no energy source needed for pumping. Through aggressive purchases and bribery, he led the acquisition of irrigation rights across Owens Valley for transfer to Los Angeles. His methods resulted in the California Water Wars and the complete draining of Owens Lake. Consequently, today the Owens lake bed is the source of alkali dust storms that periodically spread through the area.

In 1849, when large numbers of forty-niners crossed the continent in the search for gold, their biggest obstacle was the absence of water. Many travelers died of thirst on the trip, while others paid up to $100 for a drink of water. Today, stretches of some of the most inhospitable land on the continent are the source of much of our country's agricultural production. California is the country's leading supplier of food, and has been for more than 50 years. This success is the result of water-moving technology that is very expensive, both economically and environmentally, as well as a system of subsidizing water rates for agricultural use.

Let's take a closer look at how humans divert water to suit their own purposes through using dams, canals, and aqueducts. These structures may be near your students' neighborhoods or even close to your school. Knowing more about these structures—how they work and why we use them—will not only improve your students' understanding of their own communities, but also prepare them to be more knowledgeable community members when issues about water arise in their futures.



Owens Valley sits at the base of the Sierra Nevada near Lone Pine, California. After water was diverted from Owens Lake to the Los Angeles Aqueduct in 1913, the lake was quickly drained, leaving behind salt flats.

Dams

Historically, dams were built in association with water wheels used to mill agricultural products. In modern times, large turbines have been incorporated into dam walls, and electricity is produced when water is released through them. Dams are also built to raise the water level for diversion into irrigation canals.

A dam is a barrier that impounds water. The lake formed behind a dam is called a reservoir. The earliest dams were built for flood control. Dams can catch the flood wave that occurs after a big storm.

The raising and storing of water can also serve as a source of energy. Your students can think of water behind a reservoir like a battery in which energy is stored and can be used when needed. Dams release water as they need to generate electricity. The amount of energy stored in a reservoir is a function of the height of the reservoir. The height is the difference between the upstream and downstream water levels. The flow rate is determined by the size of the penstock (dam intake structure) and turbine. Scientists use this information to calculate the amount of power that can be provided by any particular dam.

Many dams are built to store water for municipal and agricultural uses. As the saying goes, "April showers bring May flowers," but what are growers to do in August? The reality is that rain often does not fall when we need it. Therefore, we store a large amount of water running out of the mountains as snow melts in the spring so that we can use it throughout the summer and fall. For this reason, your students may think that dams make water that is then sent to their homes. They may also think that dams purify and clean the water that is released. When talking about dams, make sure to ask students to share their ideas about the purpose of dams because it is likely that some students may be confused about this concept.

Folsom Dam is a concrete gravity dam along the American River in California.

Glen Canyon Dam is a concrete arch dam on the Colorado River in Arizona.

Your students may also believe that all dams are built and work the same way. However, no two canyons are the same, and therefore, no two dams are the same. Yet, dams come in two basic shapes, so this is one way to help your students tell the difference between different types of dams. The first is made of earth or concrete and, by virtue of its mass, is able to stop the force of the water without eroding away, tumbling over, caving in, or splitting. These are called **gravity dams;** the simplest forms of these dams are embankments constructed of earth or rock. The second type of dam is known as the **arch dam,** and is made mainly from concrete. Force from the water onto the arch is transferred to the walls of the canyon. This design allows dams to be much thinner, which is an important consideration when talking about hundreds of thousands of tons of soil and concrete building a large-scale gravity dam would require.

While many of your students may be aware of the advantages of dams, most have probably never thought about the problems they present. Although dams have been instrumental in the development of our country and the world, the benefits of dams have come at a big cost. Besides their multibillion-dollar price tag, the few that have failed caused great destruction (the failure of the St. Francis Dam built by William Mulholland resulted in the end of his career). Dams have altered the natural cycles of some of the most beautiful and diverse ecosystems around the world.

The most obvious downside of dams is that they separate upstream and downstream waters. Fish migration along streams between spawning grounds and feeding grounds may be severed by dam construction. Rindge Dam on Malibu Creek is currently being studied for removal because of its negative impact. According to American Rivers (2010), more than 700 dams have been removed in the United States, and 58 more were slated for removal in 2009. Rindge Dam was built in the 1920s to provide water for May Knight Rindge's family and cattle. It lost most of its functionality by the 1950s because it filled in with sediment, and was decommissioned in 1967. Today it remains as nothing more than a barrier to steelhead trout that once spawned in Malibu Creek (*Malibu Times* 2009).

To address the problem of fish migration, modern dams have fish ladders. The ladders allow fish to climb around the dam, but many fish still die by becoming lost in the lake because they can't feel a downstream river flow or by being sucked into the dam turbines. The John Day Dam on the Columbia River was built in 1968. That same year the Oregon Fish Commission reported that 40 percent of the Chinook Salmon got lost somewhere in the reservoir behind the dam (Lake Umatilla) and 31,000 fish did not make it to their spawning grounds that year (CCRH 2010).

Dams also affect soil along the course of a river. Not only do they impound

Rindge Dam on Malibu Creek, completely filled with sediment, is slated for removal so that Steelhead trout can access Upper Malibu Creek.

A fish ladder on the Columbia River helps fish on their journey upstream, but is not as successful in helping fish on their way down.

water, but they also stop the sediments carried with water. The water velocity slows as it enters the dam's reservoir, and sediments suspended in the water begin to settle to the bottom. These sediments would normally be carried downstream, bringing with them beneficial nutrients. They would also settle along the river's banks, providing, among other things, critical habitat for fish eggs.

Another potentially negative effect of dam construction relates to the water itself. If you have ever swum in rivers or lakes below a dam, you likely notice that the temperature of the water is much cooler than surface water behind the dam. The very cold water released by the dam comes from deep in the reservoir. Clear, cold water is great habitat for the green alga *cladophora,* which is replacing producers in the natural warm-water food web. Releasing cold water may negatively or positively impact the species that live below the dam. These changes may make the system completely different than the natural river and wreak havoc on native invertebrates (such as insects) and other consumers.

In addition, a river's natural flow cycle is characterized by periodic flooding. Natural flooding is instrumental in building beaches, recycling nutrients, and creating backwaters that are excellent habitat for a variety of species. Natural river processes are critical for the survival of a wide variety of organisms. River otters and muskrats are no longer found in the Grand Canyon. Four of the eight native Colorado River fish are gone, and two more are struggling for survival. Native birds, lizards, frogs, and many of the Grand Canyon's native insects are disappearing as well. In addition, native vegetation along the river's edge is absent or stunted due to the lack of nutrients and the invasion of competing non-native plant species. When a dam is constructed, it stops the flow of natural cycles in stream-side habitats that depend on the water.

Your students may be unaware of controversies surrounding dams. They may hear that hydroelectric power is cleaner than burning fossil fuels, so dams are good things to build. But every energy system has a trade-off. When a dam is built, there can be cultural, social, and ecological consequences. Rivers and canyons were often the preferred location of prehistoric peoples, whose stories, petroglyphs, pictographs and sacred burial grounds are lost forever with the creation of reservoirs. Prior to the environmental movement of the 1960s and the National Environmental Policy Act of 1969, most battles were over water rights and who would pay for the projects. The most famous of these contentious agreements is the Colorado River Compact of 1922, which allocated water between the seven states that make up the Colorado River watershed. More recently, the push to remove old and obsolete dams is gaining strength.

Pictures of Practice

Why Do We Build Dams?

When students are asked about dams, most of them recognize that dams form lakes behind them and, therefore, store water. Students may not be clear about why this water is being stored, and other functions of the dams, such as making hydropower or the possibility of reducing the risk of downstream flooding during small or medium-sized rains. Dams play an important role in the American West, especially in states such as California, which has many large urban areas and a vast agricultural industry that depends upon an extensive network of dams and canals. Teaching about dams can help students understand why dams are necessary for our communities, as well as how they affect the natural habitat along the rivers and canyons in which they are built.

Students: Grades 3 and 6

Location: California (an inland and a coastal community)

Goal of Video: The purpose of watching this video is to see how students describe dams in order to help you prepare for instruction on the topic.

Classroom Context

Students in this video live in both an inland community near the American River and a coastal community in southern California. The interview clips shown in this video were taken before instruction about how dams work. The first part of the video shows third-grade students describing how dams work. These students live near Folsom Dam in California. The second half of the video shows sixth-grade students answering the same question. These students live around the San Diego area. Think about the different types of responses you hear from students in the same grade, as well as different responses between grade levels.

Video Analysis

In this video, third and sixth graders were asked the same question: Why do we build dams? Dams are primarily built to retain water, and control the pace at which water is released. Dams are also built to create hydropower by raising the water level in the reservoir and releasing it as power needs to be generated. While dams are built to store water for communities or agriculture, dams are not built to clean or purify this water (see Dams, on page 56, for more information). As you listen to the third-grade and sixth-grade students describe dams, think about how their answers match or do not match the description of dams made previously. For example, several students identify that dams are used for water storage, while only a few of the sixth-grade students mention that dams are used for generating power. Other students, such as the third-grader Thomas, describe dams as providing drinking water and water we can use for cleaning and bathing. Even Salma and Zachary, who mention hydropower, appear to have several gaps in their understanding of this concept. Compare each student's answer to the scientific description provided in this chapter, and plan how to help students improve their understanding given the ideas that they bring to the classroom before instruction.

Reflect

How would you respond to student ideas about dams?

Given the diversity of ideas you heard during the video, how could you use this information to plan your instruction on dams? What are the concepts that students seem to grasp? What are the main misconceptions you heard? How would you target these misconceptions during your teaching?

In the Classroom

Controlling Natural Water Flows

Dams, and the reservoirs behind them, have dramatically altered human civilization. Through their construction, we are able to live in once inhospitable climates and grow food on lands that were once desert. In fact, with the abundant sunshine and warmer temperatures of arid climates and the enhanced ability to water crops at any time of the year, irrigated lands are some of the most productive in cultivation. Getting water to these arid locations involves other human-made structures, such as canals and channelized rivers. Dams and canals often come at a high cost for sustaining natural environmental systems, wildlife that live in natural systems, and the water quality on which all life depends. The activities below are designed to help students understand the history, function, and trade-offs of human-made water systems. They are intended to help students get to know their own surroundings and the connection we all have to our own watersheds and connections to water around the globe.

Explore the local water structures in your own community. It is likely that a canal or dam is located close to your school, neighborhood, or community. Have students discuss the costs and benefits of the structure. What problem or issue was the structure built to address? Are there other solutions to this issue? There may be differences of opinions. In the past, dams were thought to protect downstream communities from floods. Can they accomplish this when they are kept relatively full in order to store water and generate electricity? Are there public safety issues regarding building in flood plains? Use "Surf Your Watershed," housed on the EPA's website, to learn more about local water structures and stream flows, and to get links to watershed issues: http://cfpub.epa.gov/surf/locate/index.cfm.

Have students choose a dam or canal from either another part of the world or from another community in the United States. Use Google Earth to explore the structure and have students research online. Allow students to share what they learned about the structure with their classmates, specifically focusing on cost-benefit trade-offs of the structure to the local community and natural ecosystem. Download Google Earth for free at http://earth.google.com/.

Have students make a water modeling unit that involves a comparison of a stream before and after the introduction of a dam. For example, the Great Explorations in Math and Science program offers a middle- school unit called "River Cutters" that has students explore different river models (http://www.lhsgems.org/GEMSrivercutters.html). EnviroScape is one example of river model kits that students have fun exploring. These kits can be used to show different ways people modify their local waters (http://www.enviroscapes.com/).

Student Thinking

Learning About Dams

Students may learn about great building accomplishments in ancient civilizations, but sometimes they do not learn about modern engineering projects, such as dams, in their own communities or even dams far away that have an impact on their locale. Many of these local facilities—dams and treatment facilities—offer education programs for students, and visiting these sites can not only be fun and rewarding for students, but also help educators make abstract concepts more concrete for their students.

Scenario

Your school has become involved in a local river-study project because the community wants to improve the health of the local salmon and trout populations. A dam along the river above your community has installed a fish ladder, and scientists are studying if this new ladder is helping to increase salmon returning to the upper parts of the river. The dam offers tours for school children, so your classroom will be visiting the dam later in the year, and you want students to have a solid understanding of how dams work before you go. Although the content is not directly tied to your standards, you want to include a short unit on dams to prepare your students. However, instructional time will be limited, so you will have to focus what you talk about. You give your students a short pre-assessment to see what your students do and do not know so you can narrow what you teach. Consider the responses below and brainstorm a plan for your lessons on dams.

Question

What is a dam? Why do we build dams?

Scientific Answer

A dam is a barrier that blocks, or controls, the flow of water. We often build dams to store water, raise the water level behind the dame, or generate hydroelectric power.

Student Answers

Amber: A dam is where all the water stops so it won't flood into different spots. If the dam breaks then all the water can flood and really hurt people.

Rickie: I think we build dams so that water would stay in one area for us to drink, wash our hands, and clean ourselves with because we wouldn't have that clean water if we didn't have the dam.

Sasha: Dams have tunnels that water travels through. The water goes through there really fast to make energy.

Jordan: Dams keep a lot of fish in the lake so that we can fish and get food.

Katelyn: I don't really know. I think this is what a dam is. I think it stops the water maybe and makes a big lake. Maybe they make these so that we can have lakes and can fish?

What Would You Do?

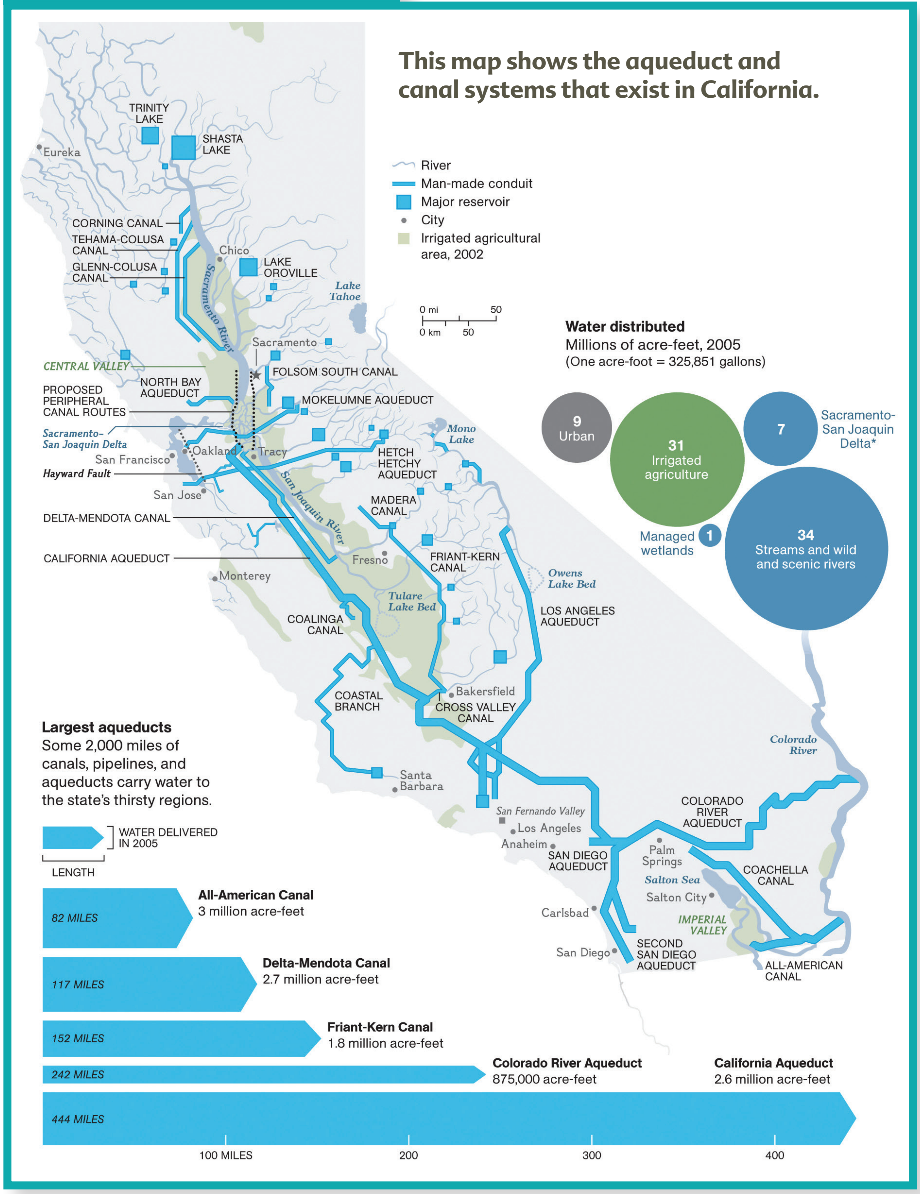
1. Of the misconceptions, which would you want to target most during your teaching about dams? Why?
2. What kind of post assessment would you do to ensure students understand what a dam is and how dams are used?

Canals and Aqueducts.

Canal is a general term for any human-made channel built to convey water. In general, **"aqueduct"** refers to a canal that is built to convey fresh and clean water for consumption, either in cities or in agricultural fields. Your students may be more familiar with a waterway canal, which is built as part of a transportation grid to move cargo by boat. A truly ingenious development was the **lock,** which uses a series of interconnected pools to lift boats over a watershed divide and allow passage to more areas. In some states, especially in the American West, canals are simply a part of everyday life. They may even be in your students' or your school's own backyard.

Alongside dams, canals were an essential part of a hydraulic society, and have made and broken civilizations. With regard to population expansion into the western United States, the role of canals cannot be overstated. In modern times, the aqueducts that bring water to southern and central California and Arizona are some of the largest in the world. They allowed arid areas to be converted into areas that were more habitable for humans and gave rise to large-scale agricultural production in these areas.

REPLUMBING CALIFORNIA



The Colorado River Aqueduct, one of the three major aqueduct systems that make living in Los Angeles possible, carries water 242 miles, from Lake Havasu on the Colorado River, to Lake Matthews in western Riverside County. Built by the Metropolitan District Water Commission, the aqueduct was under construction for eight years and was finished in 1941. The aqueduct lifts water 1,617 feet through five pumping plants. There are 92 miles of tunnels, 63 miles of concrete canals, 55 miles of concrete conduits, and 144 siphons totaling 29 miles. A large raised-relief map of the Mojave Desert, built for the design of the aqueduct, is on display at the General Patton Museum, at Chiriaco Summit, off I-10 in the Mojave Desert.

According to the California Department of Food and Agriculture, the state's agricultural sales first exceeded $30 billion in 2004, making it more than twice the size of any other state's agriculture industry (CDFA 2006). This is all possible due to the extensive network of canals, in particular the California Aqueduct, which carries the waters coming from the Sierra Nevadas to the sunny and warm Central Valley.

Probably one of the most fascinating stories in all canal-building history also takes place in southern California. In 1901, the California Development Company, seeking to realize the Imperial Valley's vast potential for agricultural productivity, dug irrigation canals from the Colorado River. Heavy silt loads, however, inhibited the flow, and new residents of the valley became worried. These two problems prompted the engineers to create a cut in the western bank of the Colorado to allow more water to reach the valley. Unfortunately, heavy floodwaters broke through the engineered canal and nearly all the river's flow rushed into the valley. By the time the breach was closed, the present-day Salton Sea was formed. An incredibly diverse ecosystem and an important feeding ground for migratory birds, the Salton Sea's water quality has deteriorated over time. The build-up of salinity, accumulation of local agricultural runoff, and other issues have led to serious concerns about its restoration and revitalization. There is much debate about if and how it can be restored and if it can continue to support a thriving ecosystem (http://www.saltonsea.ca.gov).

Around the world, the diversion of waters from rivers has resulted in a dramatic decrease in the size and number of wetlands, marshlands, and estuaries. These ecosystems are the most diverse and productive of the landscape. They also play an important role in filtering and cleaning of waters before they enter lakes and groundwater. Your students may have also heard that wetlands, marshes, and estuaries also serve as critical spawning and nursery areas for many fish and bird species.

One of the most dramatic examples of loss of wetlands and estuaries is the Colorado River Delta, which once covered almost two million acres. That is 3,000 square miles, or about the same size as Rhode Island and Delaware combined! With the construction of the Hoover Dam in the 1930s, as the reservoir filled, not one drop of water reached the delta for more than six years! This pattern was repeated with the construction of the subsequent dams. With water drawn off the river by both the United States and Mexico there is little to no flow of water to the delta, and only a remnant (approximately 5 percent) of the once-thriving delta wetlands exists today. Now it is designated a biosphere reserve by the United Nations.

The Salton Sea is California's largest lake. While the lake was created by a canal failure, it is now home to abundant wildlife. Due to high pesticide runoff from local farms, the Salton Sea has algal blooms as shown in the satellite photograph.

Highway ramps twist over a flood-control channel in Sweetwater Marsh in San Diego, California.

Groundwater Pumping

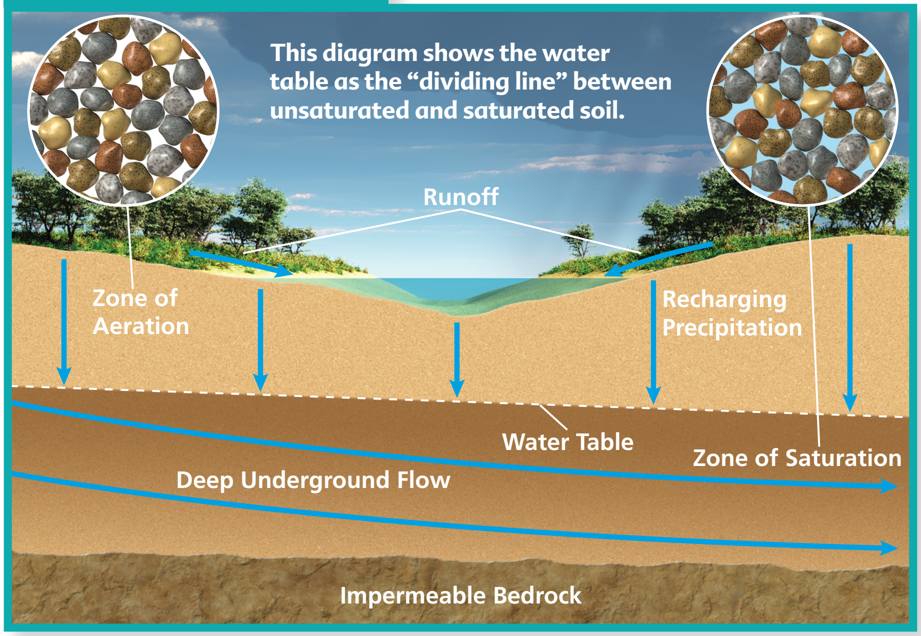
Although we don't often think about it, groundwater is a very important source of water. Groundwater, as the term suggests, is water that is stored in the ground, often in aquifers, as discussed in Chapter 2. Although students may envision groundwater to be underground lakes and rivers, this is not true. Water seeps into the ground through soil particles, collecting in the spaces between them. Eventually, the water reaches an impenetrable layer of rock, and it begins to fill the empty spaces, causing the soil layer to become saturated. The top of this area is known as the water table. The level of the water table varies naturally from season to season and year to year. Groundwater is recharged, or replenished, from rainfall, and also through the bottom of surface water bodies such as lakes and streams. During times of drought, there is less recharge, and the water table is lowered; in rainy times, it is higher.

Many communities around the world rely on groundwater as their primary water source. In rural areas, many homes use wells for their source of water. Groundwater is also used for irrigation.

For decades, in the West, water users pumped groundwater without a thought of the possible consequences. Across the arid regions of the western United States, groundwater pumping has changed streams from perennial to intermittent and ephemeral. **Perennial streams** run all the time, **intermittent streams** run in the spring during snow melt, and **ephemeral streams** only run when it rains. Riparian habitats, the areas of highly productive vegetation in and along the sides of streams, were historically pathways for migratory land animals such as bears, wolves, and mountain lions, as well as many bird species. They were also home to aquatic organisms such as beavers, river otters, and invertebrates. Many of these streams were characterized as having very shallow riverbeds that allowed floods to spread up to a half mile on both sides of the main channel. The excessive pumping of groundwater has decreased the underlying support of the surface stream, and has resulted in floods scouring at the bed and banks of the river, creating the steep banks and highly incised rivers we see today.

Even though we cannot see it, changing the level of a water table can dramatically alter a landscape. Using groundwater at a rate higher than the recharge rate lowers water tables, changing both the shape of our streams and the plants that are able to live there. For example, as groundwater levels drop, tree's roots cannot reach available water, causing them to dehydrate. The loss of long stretches of riparian areas has been one of the most dramatic changes to our landscape, and has affected the plants and animals that live in them.

WHAT IS A WATER TABLE?



Even today, groundwater pumping is very difficult to regulate, and many goals of regulation are not met. Water districts are set up by local and state governments and are administered similar to other districts, such as school and fire. Federal, state, and local regulations exist to deal with water pumping and the associated water rights (More in Chapter 6 on water rights and regulating water use).

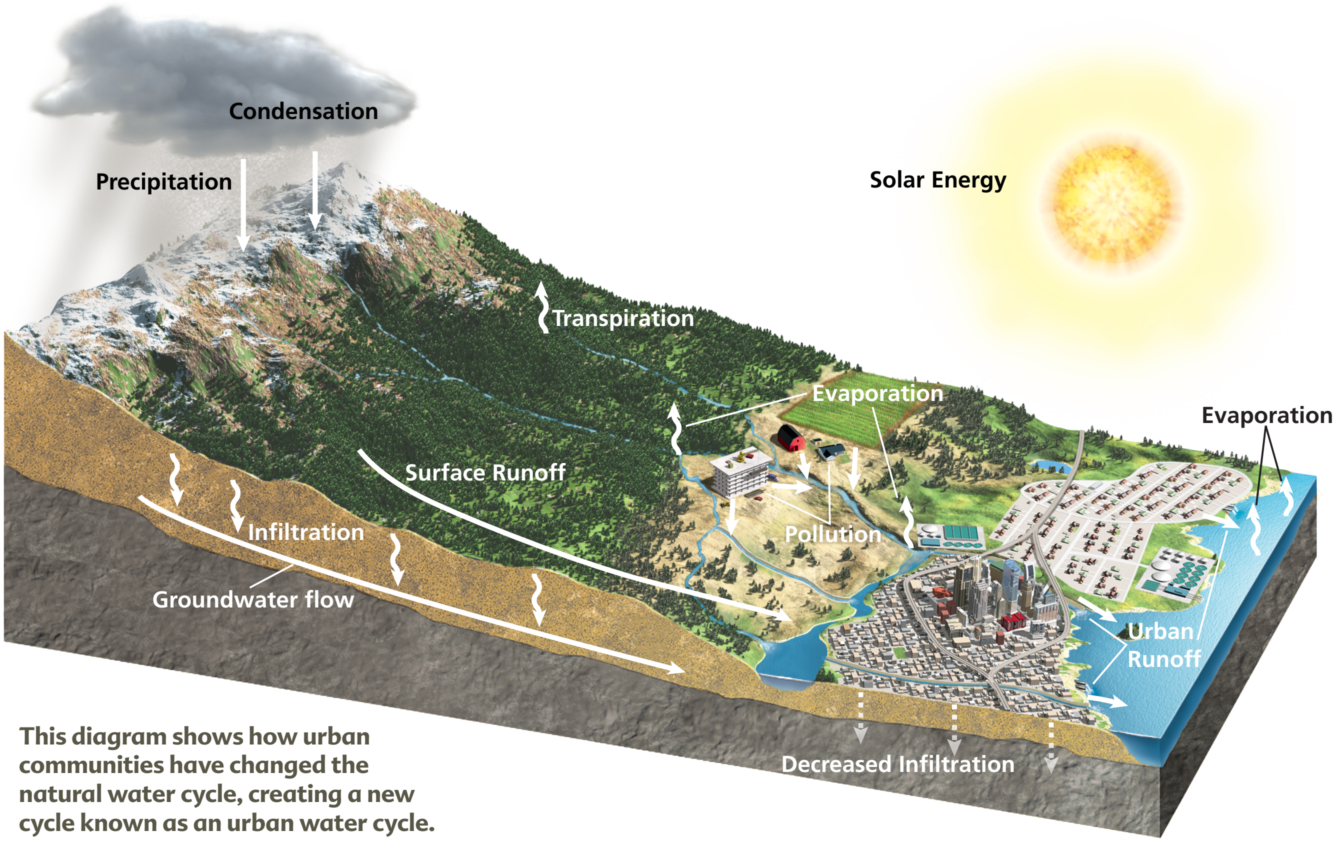
Urbanization

Your students have probably studied the trend that has been occurring since the Industrial Revolution of a steady migration from rural to urban areas as people search for jobs and greater opportunity. Cities became very densely populated with high-rise apartments, housing and industry in close proximity to each other, and inadequate and often hazardous sanitation and public health facilities. **Urbanization** is obviously the motivation for many of the projects mentioned in this chapter and also the source of much water pollution. Many of the cities we see today, especially in California and the West, look very different from cities of industry that were established earlier, such as those found on the East Coast or in Europe. Because of greater awareness, and municipal zoning, issues such as population density, open space, traffic congestion, sanitation, and environmental impacts are now considered before new construction projects can begin.

Beginning after World War II, the federal government aided in the development of suburbs by providing loans and leveling large areas for housing. Over the years, cities have become more and more spread out across the landscape, occupying great areas of land. Traditionally referred to as suburbs, these areas can now extend even farther out from the city; such far-reaching developments are called **exurbs.** This new city form has a number of impacts on water resources.

One of the easily observable problems with urbanization and suburbanization is the installation of pavement. As discussed in Chapter 2, urbanization has created a new type of water cycle—an urban water cycle. Unlike natural surfaces, pavement does not allow water to percolate into the ground; it is impermeable. The transformation of wild lands to urbanized lands often

URBAN WATER CYCLE



This diagram shows how urban communities have changed the natural water cycle, creating a new cycle known as an urban water cycle.

means conversion from 100 percent permeable soils to up to 75 percent impermeable areas. This change means that rain that once fell and replenished groundwater supplies now runs off into storm drains and channels. Streams that once filled slowly as storms progressed and water gradually seeped through the upper layers of soil into the stream now become a raging torrent almost instantaneously as rainwater runs off of rooftops and streets directly into the water body. Groundwater that was once recharged by water infiltrating soil layers receives less water because the water is flowing as runoff on city surfaces.

Cities that are looking for better water management have been promoting an increase in permeable surfaces through the use of permeable pavements, rain gardens, green roofs, and landscaping around homes, businesses, and streets. Permeable pavement allows storm water to seep through the pavement and infiltrate the ground below. Rain gardens are planted depressions in the landscape that may be dry but, during rains, allow water to collect and slowly seep into the ground. The gardens contain natural soil and vegetation to help soak up the additional rainwater. Some cities also sell rain barrels at low costs to residents for collecting rainwater. Other cities have even restricted when people can water their lawns in order to conserve water and help reduce any excess water from entering the storm-drain system. Read more in **Chapter 2, Case Study: The Urban Water Cycle.**

Teaching Tip

Helping students understand how groundwater is stored can be difficult. A simple way to visualize the concept is to fill a large sponge with water. Place the filled sponge on a counter and ask students if they believe there is water in it. Once students have given their hypothesis, ring out the sponge into a bucket to show all the water that was stored. Explain to them that the sponge is a permeable surface, like many soils, and that it held water much like groundwater is collected under land's surface. This can be used to begin a discussion on the importance of groundwater.

Pictures of Practice

What Is Groundwater?

Students are often exposed to bodies of water, such as lakes, rivers, and oceans, which helps them develop a better understanding of surface water. But visualizing what groundwater looks like can be very challenging because it is nothing like what students experience on the surface. This disconnect can lead to the misconception that groundwater flows under the surface of land much like a river or stream. It is difficult for students to visualize groundwater as existing in the pores of soil. In addition, students in the United States have a difficult time grasping the importance of groundwater because many of them live in urban areas where their water is supplied by utility companies rather than wells in their own backyard. Showing the mechanics of a pump or well can be helpful, but students may still need additional instruction about **water scarcity** and how groundwater is a vital water source for many people around the world.

Students: Grade 6

Location: San Diego, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students share their ideas about groundwater.

Classroom Context

These students discussed groundwater while learning about the water cycle, but the topic was not covered in depth. Thus, these students know that groundwater is a water source and part of the cycle but have not yet fully developed their ideas on this concept.

Video Analysis

During the preinterviews, students indicated that they understood that water penetrated soil during rain storms, but also indicated they were visualizing groundwater existing in a "layer" of water, which could be "flattened" or pressed down by people walking on the surface. In reality, groundwater exists in the permeable layers of the soil and eventually saturates to a level (the water table) so that any previously empty space is filled with water. The top of this saturated area is called the water table, above which is unsaturated soil. During the classroom discussion, Ms. Fortunato reminds students of a video that they watched previously in class that showed how water is extracted from the ground. Around the world, different people are faced with different challenges when it comes to obtaining clean water. Some people walk miles just to pump their own water from a well, while others turn on their faucet and see water. In the video, students share what they learn about pumping groundwater. In the end, Ms. Fortunato expresses her frustration with trying to help students relate to the difficulties of retrieving groundwater when most of her students do not have direct experience with wells.

Reflect

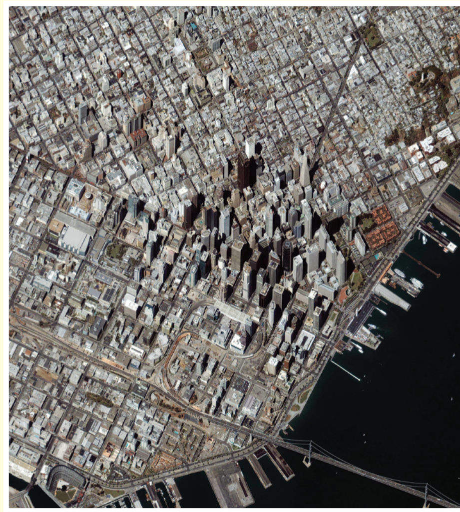
What do students need to understand about groundwater?

Ms. Fortunato tried to help her students understand the importance of groundwater around the world by showing them a video of children pumping water in Africa. How could you help students connect to groundwater in their own areas? In the preinterviews, students describe groundwater as underground layers of water. What concepts would you teach about groundwater to help them improve their understanding?

In the Classroom

Permeable and Impermeable Surfaces

Permeable and *impermeable* surfaces may be new terms to your students, but these surfaces describe things your students experience everyday. They describe the school parking lot, the basketball courts on campus, driveways, backyards, and the schools' lawn-and-garden space. Permeable surfaces are ones that allow water, or other fluids, to flow through the surface. Impermeable surfaces do not allow fluids to pass through. Instead, the fluids flow until they reach an outlet or permeable surface, often carrying substances with them. For example, a parking lot is built so that rainwater flows toward drains. As the rainwater travels to the drain, it carries oil and debris with it. In this activity, students will learn about differences in permeable and impermeable surfaces.


San Francisco, California

Materials

- Aerial photos of local school or neighborhood
- Rulers
- Graph paper
- Calculators
- Pencils

Directions

1. Prior to this activity, download and print aerial images of your school area and surrounding neighborhoods or areas that may interest your students. Download Google Earth for free at www.earth.google.com.
2. To introduce the concept, place the words "permeable" and "impermeable" on the board, and ask students to go to the board and add related words below each.
3. Pass out aerial photos of the school and surrounding neighborhood, rulers, and graphing paper. Tell students to have calculators ready.
4. The percent of permeable surface can be figured out by using an overlay of graph paper and shading the permeable areas. After the permeable areas are shaded, count the number of shaded squares and divide that number by the total number of squares. The other area should be impermeable surfaces.
5. To calculate the percentage, students will multiply their answer by 100.
6. Have students share their calculations with the class. If students used similar aerial photos, discuss the similarities or differences in calculations. If students used different aerial photos, discuss patterns among the different areas.

Discuss

1. Do you think there is enough permeable area on our campus? Why or why not?
2. Which surfaces on our campus may have an impact on the quality of water that leaves our campus?
3. What kinds of changes could we make on our campus to increase the amount of water that infiltrates into soil?

Student Thinking

Path My Water Follows

When they turn on the faucet, students often do not think about the sources of their water. In fact, most of us don't. We may not realize all the human structures that must be built in order to bring water to our homes. In municipal areas, these include not only dams and canals, but also treatment facilities and the plumbing that moves water around the community. In rural areas, the connection between sources of water (often a well) and the faucet is much more direct.

	Common Student Ideas	Scientific Concepts
Water for homes in water-rich areas	Clean drinking water comes directly from a lake or river near the home. Rain fills up wells.	Water must be treated first, so it may come from a reservoir or even an aquifer. The water is treated at a municipal treatment facility first and then goes through the community plumbing system.
Water for homes in arid areas	Water comes from canals or when it rains.	Water may be transported hundreds or thousands of miles through aqueduct systems, or pumped from groundwater. All the water must go to a treatment facility before being sent through pipes to reach homes.
Wells and groundwater	Groundwater is found in underground rivers, lakes, or human-made storage areas. Wells pump water directly to the faucet.	Groundwater exists in pore spaces in soil and cracks and fissures in rocks. Groundwater rarely exists in open spaces underground. Wells pump groundwater, but the water (when used for drinking water) is typically treated before going to faucets for use.
Wastewater	Water from the toilet and shower/sink drain flow directly into a lake.	Water goes through a wastewater treatment facility or into a septic tank once it exits a building. Wastewater can go through primary, secondary, and tertiary treatment, making it even cleaner than drinking water.

Ask Your Students

1. Where does water in your home come from?
2. Describe every step that water takes before it reaches your faucet.
3. How do you know this water is clean? What happens to the water from the source to your sink?
4. Where does your water go after you flush the toilet or take a shower?

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Teaching Resources

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

Heal the Bay urban runoff: http://www.healthebay.org/about-bay/pollution-101/urban-runoff

Information about California water: http://www.water.ca.gov/

National Geographic Society Geoguide: Dams: http://www.nationalgeographic.com/geoguide/dams/

National Geographic Society video on California canals: http://ngm.nationalgeographic.com/videoplayer#/?titleID=californias-pipe-dream&catID=1

National Geographic Society water-footprint calculator: http://environment.nationalgeographic.com/environment/freshwater/water-footprint-calculator/

The Groundwater Story video: http://www.kingcounty.gov/environment/waterandland/groundwater/education/animation.aspx

UC Davis Myths of California Water: http://watershed.ucdavis.edu/myths/index.html

4 Water Quality in Freshwater Systems

by Ari J. Posner

Many of your students will be aware of water shortages (i.e., droughts) and community efforts to conserve water. Students in the western United States, especially in California, may have grown up hearing and learning about ways to reduce water useage. In the last few years, Californians have been called upon to help solve this problem. For example, Los Angeles has implemented citizen directives, such as watering only at specific times of day and only three days a week. Santa Monica holds public workshops to introduce community members to gardening with plant species that are adapted to dry habitats. Throughout the southwestern United States, television commercials run on network channels to explain the severity of the water shortages.

It is possible that a few of your students will be aware that the quality of our water is also a serious issue with many implications. For example, in less developed countries nearly one billion people do not have access to adequate clean water. However, water quality is not just a concern for less developed areas of the world. A few years ago, a nationwide outbreak of ***E. coli*** bacteria prompted a recall of fresh spinach from California when several people died and hundreds more became ill. Although investigators were unable to confirm the exact source of the *E. coli,* the water just upstream from the spinach fields was contaminated with cow manure. In the United States, there are also water-quality issues related to drinking bottled water. While many people believe that bottled water is cleaner or safer to drink compared with tap water, in reality, bottled water companies around the United States actually have to follow less rigorous water safety standards compared with municipal water utilities. In this chapter we explore issues of water quality and processes by which water is polluted and treated.

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.g-h 3.1.2 3.5.1-2	 The Geography of Where We Live California's Economy—Natural Choices
Grade 4	4.1.5	Reflection of Where We Live
Grade 5	5.1.f 5.3.d-e	 Our Water: Sources and Uses
Grade 6	6.2.a-b 6.5.e	The Dynamic Nature of Rivers
Grade 7		
Grade 8	8.5.e 8.12.1 8.12.5	 Agriculture and Industrial Development in the United States Industrialization, Urbanization, and the Conservation Movement

Water: The Universal Solvent

In order to consider the issue of **water quality,** it will be helpful to first think about a unique property of the water molecule. In particular, your students may have heard that water is known as the universal solvent. It's easy enough to say this, and to have a general sense of the idea that lots of things can mix with water, but what exactly does it mean for water to be a solvent? And why in particular is water, compared with other molecules, such a good solvent?

Simply speaking, water is a good solvent because it can dissolve more things than any other substance. Let's consider a few terms here. A solvent is a substance that dissolves another substance. The substance that dissolves into the solvent is called a **solute.** When a solute dissolves into a solvent, the resulting mixture is called a **solution. Dissolving** is the process in which a solute mixes with a solvent and breaks down at a molecular-level scale. Because of this small scale, when a solute dissolves, you can no longer see the solute in the solution mixture.

A common example of dissolving is salt dissolving in water. Remember from Chapter 1 that water molecules are polar, meaning that the oxygen side of a water molecule has a negative charge and the hydrogen side of the water molecule has a positive charge. In chemistry, opposite charges attract. Thus, when salt crystals dissolve in water, the polar nature of the water molecules pulls the salt crystals apart into Na^+ ions that are attracted to the negatively charged oxygen sides of the water molecules, and Cl^- ions that

CHAPTER OVERVIEW

All living organisms on Earth depend on a very limited amount of freshwater that is constantly recycled through water-cycle processes. It is also important to understand, though, that living things are limited not only by the quantity of water on Earth, but also by water's quality.

Water is commonly known as the universal solvent because lots of substances can easily dissolve into it. Often these substances are pollutants that affect the quality of water and whether it can be used by humans or other organisms. Many other pollutants in water, such as trash, oil and some pesticides, are insoluble. In order to be proactive about keeping our water clean, we need to understand the sources of various pollutants, the affects they have on nature and our bodies, and how we can treat water that has been contaminated to make it useable.

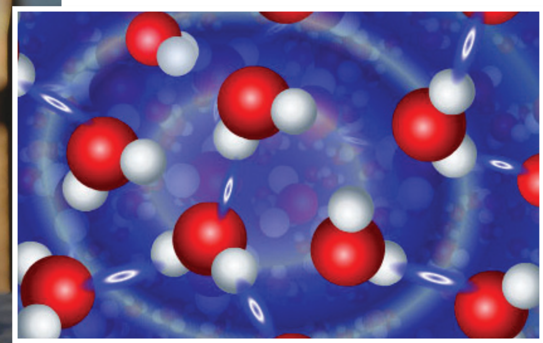
This chapter discusses how water mixes with others substances, the definitions of water quality and water pollution, common types of water pollution, and methods humans use to treat water.

are attracted to the positively charged hydrogen sides of the water molecules.

Because substances are broken down at the molecular-level scale in a solution, substances in solution are too small to be seen. This is why we don't see salt floating in a saltwater solution. Salt water looks just like regular water. Substances dissolved into water are generally broken down at such a small level that they also cannot be filtered out of the water. This is why filter paper or a coffee filter will not separate salt or other dissolved substances from water.

The polar nature of the water molecule is what makes water such an extraordinary solvent. Water dissolves substances by surrounding charged substances and pulling them apart. Substances that have a **net electrical charge** can dissolve into water. (Lots and lots of substances on Earth have net electrical charges.) This idea also helps us understand why some substances do not dissolve into water. Oil, for example, is a nonpolar molecule with no net electrical charge. Because of this, water molecules cannot pull apart oil molecules, and oil consequently does not dissolve in water. Learn more about the polar nature of water at http://www.visionlearning.com/library/module_viewer.php?mid=57.

So, how does the idea that water is an extraordinary solvent connect to the issue of water quality? In natural water systems, as water travels over land and underground, it attracts and dissolves many natural materials along its path. The oceans are salty solutions due to the dissolved minerals of the land that have been carried through watersheds to those oceans. As it moves across the land or underground, water also encounters various substances introduced into the environment by people. Once water mixes with these substances (whether they be natural or introduced to the environment by humans), it can be difficult to separate out the water again.



Water is called the universal solvent.

While water can mix with larger materials (such as trash in a lake or sand and silt in a river), many other water-quality issues have to do with water mixing with smaller materials that are too small to easily see. These include substances that are dissolved into water at the molecular-level scale, as well as microscopic organisms, such as bacteria, that are suspended in water but are so small that they can hardly be noticed with the naked eye. Note that a **suspension** is another type of mixture that can be distinguished from a solution. While solutions are mixtures with particle sizes at the molecule or ion level, suspensions are mixtures in which the particles mixed into a liquid such as water have diameters that are greater than one micrometer. Substances in suspension may appear to be very tiny, but they can generally be seen with the naked eye or with the aid of a simple magnifying tool. Substances that are suspended in water can be separated from water through **filtration.**

What is Water Quality?

Everyone knows that water is H_2O, but what exactly is water quality? Water moves through the landscape and picks up many materials along the way, both natural and **anthropogenic** (human-made). Water quality includes the physical, chemical, and biological characteristics of water. The study of water quality concerns the initial conditions of the water (the rain); the physical, chemical, and biological reactions that occur along its flow path; where the water flows to; and how long it takes to get there. The importance of water quality cannot be overstated. It is essential for supporting the ongoing survival and well-being of all species living in Earth's biosphere. Many physical characteristics of water are qualities that the human senses can distinguish, such as temperature, clarity, and turbidity (cloudiness) of water.

Another important characteristic of water with which your students are probably already familiar is pH. Students learn about pH of substances in upper elementary or middle school, but they may already have ideas about "acids" based on things they have heard or seen in movies or real life. However, they need pH to begin to make comparisons among substances. pH is a measure of the number of hydrogen atoms in the water (hydrogen atoms are constantly jumping from oxygen to oxygen. It is the basis for whether a liquid is an acid (relatively large amounts of hydrogen atoms, resulting in successively lower, or more acidic, pH values), an alkalai/base (fewer hydrogen atoms and successively higher pH values), or neutral (pH of 7, that of distilled water). Most natural waters are near neutral pH. When the pH of waters fall outside of the general range 6–8.5, the waters may not be safe for humans, animals, or most plants, and so may be detrimental to ecosystems. We use the properties of acids and bases to help us clean our homes and prepare our food. Weaker acids and bases are relatively safe. Handling acids and bases with more extreme pH numbers requires safety gloves, as these substances can chemically burn skin tissue.

Water quality also describes the types of minerals found in water. One way to assess the minerals in water is to measure water's conductivity, or the amount of current that a sample of water will conduct. Distilled water is only H_2O (all dissolved minerals have been distilled out), and does not conduct electricity. For example, conductivity is a good indicator of how salty the water is because salt water conducts electricity better than freshwater. With the addition of chemicals, water's conductivity increases. Therefore, we use this test to get a general sense of chemical concentration, or Total Dissolved Solids, without knowing the specific chemicals in the water.

Nitrates, pesticides, and metals are some of the substances we can test for specifically; these are common chemical measures of water quality. Dissolved oxygen concentration is another chemical characteristic of interest. All waters have a certain amount of dissolved oxygen that comes from **osmosis** resulting from contact with the air (aeration) as moving water bubbles over obstacles and as a byproduct of photosynthesis by aquatic plants and algae. Too little dissolved oxygen will have **deleterious** effects on living things. Water-quality test kits made for classrooms usually include the tools to assess many of these characteristics of water.

Water also carries with it many biological organisms. The most concerning are usually bacteria and viruses. The most widely known bacteria is *E. coli,* which is often the reason for beach warning signs following heavy rains. *E. coli* can enter a body of water from human sewage or when animal excrement left on lawns and in streets runs into storm drains and is carried by water into a stream or river. While many

Teaching Tip

Share with students some household examples of acids and bases of varying degrees on the pH scale. Ask students to tell you which substances are the strongest acids and bases. Which are closest to neutral? Why?

Substance	Typical pH
Lemon juice	2.3
Tomatoes	4.3
Vinegar	2.2
Distilled water	7.0
Orange Juice	3.7
Baking soda	8.3
Ammonia	11.6

pH SCALE

ACIDIC ↑ / NEUTRAL / BASIC ↓

Environmental Effects	pH Value	Examples
	pH = 0	Battery acid
	pH = 1	Sulfuric acid
	pH = 2	Lemon juice, Vinegar
	pH = 3	Orange juice, Soda
All fish die (4.2)	pH = 4	Acid rain (4.2-4.4) Acidic lake (4.5)
Frog eggs, tadpoles, crayfish, and mayflies die (5.5)	pH = 5	Bananas (5.0-5.3) Clean rain (6.5)
Rainbow trout begin to die (6.0)	pH = 6	Healthy lake Milk (6.5-6.8)
	pH = 7	Pure water
	pH = 8	Sea water, Eggs
	pH = 9	Baking soda
	pH = 10	Milk of Magnesia
	pH = 11	Ammonia
	pH = 12	Soapy water
	pH = 13	Bleach
	pH = 14	Liquid drain cleaner

The pH scale measures how acidic a substance is and ranges from 0 to 14. Seawater has an average level of 8; even the slightest deviation can have adverse affects on marine life.

In the Classroom

Water-Quality Testing

Water-quality testing is a common lab investigation students may do during upper-elementary or middle school years. Upper-elementary students may test the temperature and pH of the water environment and conduct basic inventory counts of living things. Middle school students can test additional factors that affect water quality, such as dissolved oxygen, nitrogen, or other nutrients, and do more extensive biodiversity counts.

For water-quality—testing activities use the guide below to help you and your students better understand the factors that are tested and what this information tells you about the health of the environment. The information below tells you 1) what is measured, 2) what the healthy or normal range is for freshwater environments (Research the historical ranges for your local creek to determine healthy ranges for your region.), 3) how changes in the factor impact the environment, and 4) what might contribute to changes in the factor. Use this information to plan your activity around water quality testing.

TEMPERATURE TESTING	
What it measures:	The air and water temperature of environment.
Healthy range (freshwater-creek):	Water temperature should range from 10°C to 25°C; air temperature varies with weather.
What it impacts:	Water temperature influences content of dissolved oxygen (as the temperature of the water goes up, the lower the concentration of dissolved oxygen gas); the rate of photosynthesis by algae and other aquatic plants; the sensitivity of organisms to toxic wastes, parasites, and diseases; and the timing of reproduction and migration of aquatic organisms.
Contributors:	Sunlight, seasonal and daily changes, shade, air temperature, stream flow, water depth, inflow of groundwater or surface water, and the color and turbidity (cloudiness) of the water. Other factors include soil erosion and storm-water runoff.

pH TESTING	
What it measures:	The acidity or alkalinity of water, ranging from 0 (highly acidic)—14 (highly basic), with 7 being neutral.
Healthy range (freshwater-creek):	Living organisms can only survive within narrow pH ranges. A healthy pH for aquatic life lies in the range of 6.5—8.5
What it impacts:	A deviation in either direction could be fatal to life in the creek, with fish being more reactive to changes toward alkalinity. pH (and temperature) also impact ammonia concentrations.
Contributors:	Can be affected by type and amount of plant and animal life in the water; largely affected by various chemicals in the water from urban runoff; important indicator of changing water.

TURBIDITY TESTING	
What it measures:	How cloudy the water is measured in Jackson Turbidity Units (JTU) or Nephelometric Turbidity Units (NTU).
Healthy range (freshwater-creek):	Turbidity ranges are large. Clear streams can be as low as 10 NTU. However, during a rain event in an erosive watershed, turbidity can exceed 250 NTU.
What it impacts:	High turbidity can reduce photosynthesis in plants because less light passes through cloudy water.
Contributors:	Particles such as clay, silt, and algae affect how clear or cloudy the water is. Turbidity can come from soil erosion, waste discharge, urban runoff, eroding stream banks, and excessive algae.

NUTRIENT TESTING	
Nitrogen (Nitrate) Testing	
What it measures:	The level of nitrogen present in nutrient form.
Healthy range (freshwater-creek):	Total nitrogen limits in most California creeks is 10 ppm*, but levels as low as 2 ppm can impact creek health.
What it impacts:	Excessive nutrient levels can lead to algal and aquatic weed growth that in turn depletes the available oxygen in the water column.
Contributors:	Runoff containing detergents, fertilizers, animal waste, industrial waste, or sewage, contributes to elevated nutrient levels as does excess dumping of vegetative material.
Dissolved Oxygen (DO) Testing	
What it measures:	The amount of oxygen dissolved in water.
Healthy range (freshwater-creek):	Minimum for DO for supporting coldwater fish should not be less than 7.0 mg/L.
What it impacts:	The dissolved oxygen concentration in water can directly affect reproduction, incubation, changes in species, and death of adult and juvenile fish and other organisms. As dissolved oxygen levels in water drop below 5.0 mg/L, aquatic life is put under stress. Levels remaining below 1—2 mg/L for a few hours can result in large-fish kills.
Contributors:	Water temperature (see temperature testing), DO sources such as photosynthesis, DO drains such as respiration and breakdown of organic material, and salinity. Low dissolved-oxygen levels usually result from algal blooms, human waste, and animal waste.

HEAVY METALS TESTING (ZINC, COPPER, LEAD, MERCURY)	
What it measures:	The amount of heavy-metal dust
Healthy range:	Metals occur naturally in the environment, but human activities (such as industrial processes and mining) can dramatically alter their distribution.
What it impacts:	When metals are released into the environment in higher-than-natural concentrations, they can be highly toxic and cause major disruptions in aquatic ecosystems.

* ppm is a common scientific standard for measurement and stands for parts per million
* mg/L is also a common scientific standard for measurement and stands for milligrams per liter (occasionally made equal to ppm).

Adapted from Heal the Bay water quality resources: www.healthebay.org bacteria are harmless or even beneficial (we need bacteria in our stomachs to help digest food), others are very dangerous and can cause illness or even death for humans and other organisms.

Despite the infinite complexity of all that exists in water and how it got there, there are some relatively simple tests that we can do to characterize water and determine if it is safe for various purposes. Recent technologies are now allowing scientists and water managers to find very small quantities of substances (such as pharmaceuticals) in our water. We are still trying to determine what impact these small quantities may have on human health and aquatic life and how to regulate them, but their presence in our water is now a recognized area for research, with possible public health and ecosystem ramifications.

Water Pollution

As we discussed, water as found in nature is rarely pure H_2O. But how do we decide whether water is safe to use (even if it is mixed with other substances) or if it is polluted? Pollution describes the unwanted substances in the water. In general, water is polluted when it has substances in it that make it unfit for its intended use, such as drinking, swimming, or protecting aquatic life. Water pollution is a major global problem; the extent is probably shocking and inconceivable to most students and teachers in America. Water pollution is likely the leading worldwide cause of deaths and diseases; it accounts for the deaths of more than 14,000 people daily! Water pollution is not unique to the developing world. Many lakes, streams, estuaries, aquifers, and other water systems in the United States have been classified by scientists as polluted. Have your own students explore the natural water systems located in their communities to see if these systems have been classified for water pollution.

Water pollution is also not just a modern phenomenon. The Romans discharged their sewage into nearby rivers. The polluting of these rivers led them to construct the aqueducts that brought fresh spring water from the mountains to drink. Although the Romans understood the connection between human waste, water pollution, and human health, it was largely forgotten in Europe through the Middle Ages. During this time (and still today in many parts of the developing world) many people died of cholera and typhoid outbreaks related to the proximity of sources of water and discharges of human waste. An English physician named John Snow finally pieced together the connection in 1854 When a cholera outbreak in the Soho district of London was centered on the Broad Street well, he suggested the well was the source of peoples' illness. Despite the skepticism of officials, they agreed to stop use of the well, and soon the outbreak subsided. Despite this discovery, the proximity of cesspools to wells continued unabated for some time.

Water pollution sources are described as **point source** or **nonpoint source.** Point sources of pollution are those that you can point to, such as a pipe through which industrial effluent is released into a stream. Examples of point source pollution include discharges from wastewater treatment, industrial, manufacturing plants, and development sites as well as urban runoff from streets. Point source pollution other than urban runoff has been relatively easy to address through the regulation and monitoring of these sources. Nonpoint source pollution refers to **contaminants** that reach our water sources through other means that are more difficult to identify. Nonpoint source pollution comes from municipal and agricultural runoff, mining, and forestry. This type of pollution has proven to be much more difficult to regulate due to our inability to track pollutants in our water to a specific source. Some of the most common pollution culprits are motor oil from leaky automobiles, diesel from trucks, pesticides, herbicides, and fertilizers, along with plastics, trash, and sediment. Despite the difficulty in tracking the sources of runoff, many activities that occur in cities and towns, such as construction sites, and on farms are regulated in order to reduce the pollution generated. You may have noticed tubes

Point source pollution has an identifiable source or discharge point. Nonpoint source pollution does not have an identifiable source, making it more difficult to control.

In the Classroom

Examining Water Quality in Your Neighborhood

Water quality and human activities are intimately connected. While some water-quality characteristics are easily identifiable, others require testing and scientific instruments to witness. Students can experience scientific inquiry firsthand as they collect and test water samples, make connections between water quality and human activities, and become more familiar with their watershed. The following activity is designed to promote critical thinking, expose students to scientific tools and methods, and promote a sense of ownership of their own community's water quality. There are many materials available to build this type of activity for your classroom. See also **In the Classroom: Water-Quality Testing** for more information on factors to test and why.

Materials

- Glass containers with lids, cleaned thoroughly
- Labels
- Water-quality test kits (varies depending on your analyses)

Directions

1. Have students bring in small containers, which can be sealed closed. Containers should be washed thoroughly.
2. Have students collect water samples around their school or local community. Students should record the time and date of collection, as well as a detailed description of where the sample was collected. Possible locations include the following:

   a. Drinking-water fountains
   b. Home faucets
   c. Local streams and lakes
   d. Parking-lot retention ponds
   e. Street runoff
   f. Home gutter downspouts
   g. Rain
   h. Puddles
   i. Ocean

3. Have students make observations of the water samples and conduct additional water-quality analysis. Materials will vary depending on the investigations your students complete. Students can test the factors described in **In the Classroom: Water-Quality Testing.** Have multiple groups of students run identical analyses on the water samples in order to pool classroom data.
4. When comparing results from different samples, discuss what is upstream of each sample and how you expect it to impact the results. Have students conduct Internet research to resolve any unanswered question about water contaminants.

Discuss

1. Which water sample(s) are in their healthy range? How did you make a decision about whether the sample was healthy?
2. What other tests would you like to conduct? Why?

These four beakers show water with different pollutants.

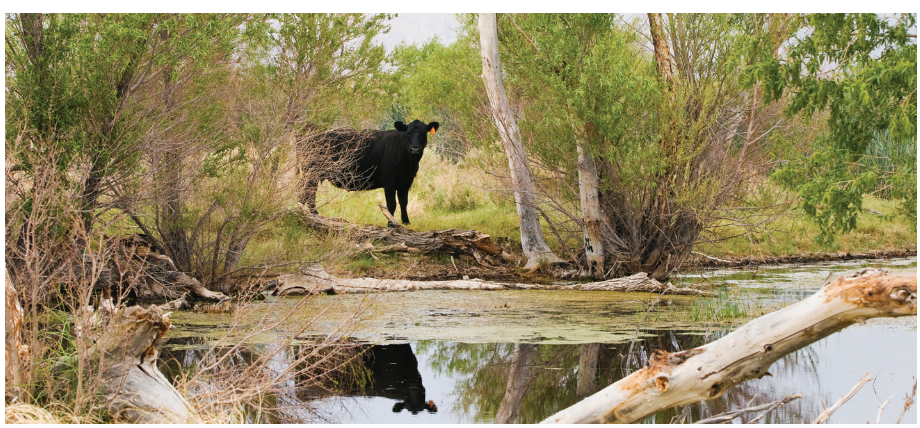
of straw or straw bales, or sandbags, surrounding construction sites, which are examples of the regulations associated with the Environmental Protection Agency's National Pollutant Discharge Elimination System. These barriers preventsediment runoff. While knowing where pollution comes from is critical, we also must understand what types of pollution are occurring.

Disease-Causing Pollutants. Examples of water pollutants that are disease-causing agents are bacteria, viruses, protozoa, and parasitic worms. These types of pollution come from either human and/or animal waste. Disease-causing pollutants are, as one would expect from their name, a significant threat to human health. In the case of human waste, the United States has, for the most part, done an excellent job of collecting and treating our waste before it is dumped into local waterways. However, these contaminants and animal waste regularly show up on California's beaches. In 2009, beach pollution prompted swimming advisory days and more than 18,000 closings at ocean, bay and Great Lakes beaches in the United States (Dorfman & Rosselot 2009). Nearly three quarters of the closure and advisory days were issued because monitoring found the presence of bacteria associated with fecal contamination. However, local officials in most cases were unable to determine the source of the contamination. Bacterial contamination is also found in rural areas where water is from local wells and sewage is held in septic tanks. These septic tanks and waste disposal fields often leak, resulting in contamination of groundwater.

Oxygen-Demanding Wastes. A second category of water pollutants is oxygen-demanding wastes from either humans, plants, or animals used for livestock. Oxygen-demanding wastes are organic materials (e.g., dead plants, manure, sewage, and so on) in water that are decomposed by bacteria. The process of bacterial decomposition requires oxygen, so when there are many oxygen-demanding wastes in a body of water, bacteria will thrive and use much of the dissolved oxygen in the water. When dissolved oxygen is depleted, other aquatic organisms that require oxygen are negatively impacted.

A common source of this class of contaminants is Concentrated Animal Feeding Operations (CAFOs), which may refer to feed lots where cows or other animals are raised before slaughter. During a ten-year period in California, the number of swine CAFOs decreased by 50 percent, but the number of animals per operation rose 200 percent (Stubbs & Cathey 1999). Just to get a sense of the scale of the issue, one dairy cow produces 120 pounds of manure per day, which means a 1,000-head dairy operation produces approximately 60 tons of manure per day, or the equivalent amount of sewage for a city of about 27,000 people. In California's Central Valley, there are 1.4 million dairy cows producing 84,000 tons of manure per day (Allbright, 2010). If and when these wastes make it to water sources, they are decomposed by oxygen-demanding bacteria. Large populations of decomposing bacteria converting wastes will deplete oxygen levels in the water (**eutrophication**). When oxygen levels are below 5mg/L, waters can be hazardous to aquatic life.

Water-Soluble Nutrients. Another class of water pollutants is nutrients. The major source of these contaminants is runoff from agricultural fields, treated wastewater, and runoff from neighborhood yards and golf courses. Fertilizer use has increased by a factor of 10 since World War II, and some consider the amounts used to be more than what can be taken in by the plants to which they are applied. In California, 200 kg/hectare/year (178 lbs/acre/year) of fertilizer, or more, is used on corn and other crops. The major chemical ingredient of fertilizers is nitrogen, in the form of nitrate, and



Livestock waste is a major source of pollution but can be prevented by disposing of waste appropriately and controlling livestock's access to local streams.

this chemical can have a serious impact on health when ingested. Levels of nitrates in drinking water are frequently found to be above safe levels set by governments in industrialized countries. Nitrate concentrations in animal waste and sewage are also very high. The reduced form of nitrogen–ammonia–is extremely toxic to aquatic life. Nitrate is converted into nitrite in the body. Nitrite lowers the blood cells' ability to carry oxygen. This prevents oxygen from reaching the brain, which can be fatal, especially for infants drinking formula with high concentrations of nitrate; drinking formula with too much nitrate can lead to blue-baby syndrome. In people with environmental illnesses, poor oxygen transport and utilization is already an issue, causing fatigue and muscle aches for example, so chronic exposure to nitrates in drinking water can only serve to exacerbate the problem. Nitrate has also been strongly linked to gastric cancers.

Organic Compounds. Water can also be polluted by a number of organic compounds, such as oil, solvents, gasoline, plastics, and pesticides, which are harmful to humans and all plants and animals that live in the water. These contaminants can come from industrial effluent, household cleaners, polluted runoff, plastic water bottles, and plastic bags (which are often mistaken for food by marine animals), as well as surface runoff from yards, streets, and farms. Contamination from oil spills is an increasing concern. The consequences of oil spilling from offshore oil drilling, as well as freshwater oil spills, are profound and widespread. Oil coats the water surface, getting on to birds' feathers and mammals' fur, which reduces their ability to regulate body temperature, leading to hypothermia. In an attempt to clean themselves, animals ingest oil, causing kidney damage, altered liver function, and digestive-tract irritation. In addition, as oil washes onto land, it kills plants that play a crucial role in reducing erosion.

Suspended Sediment. Suspended sediment in waters is also a potential water pollutant. Excessive levels of suspended sediment causes depletion in the water's light-absorption capacity, reducing photosynthesis of aquatic plants. The role of sediments in water cannot be overstated, as they often serve as a medium for transporting contaminants. As contaminants enter the water, they attach themselves to sediments and travel along with them. Thus, understanding sediment transport is crucial to understanding where and how contaminants travel through our waterways and along our shores. Sediments also smother habitats, such as rocky cobble, which is critical for steelhead- and salmon-egg hatching.

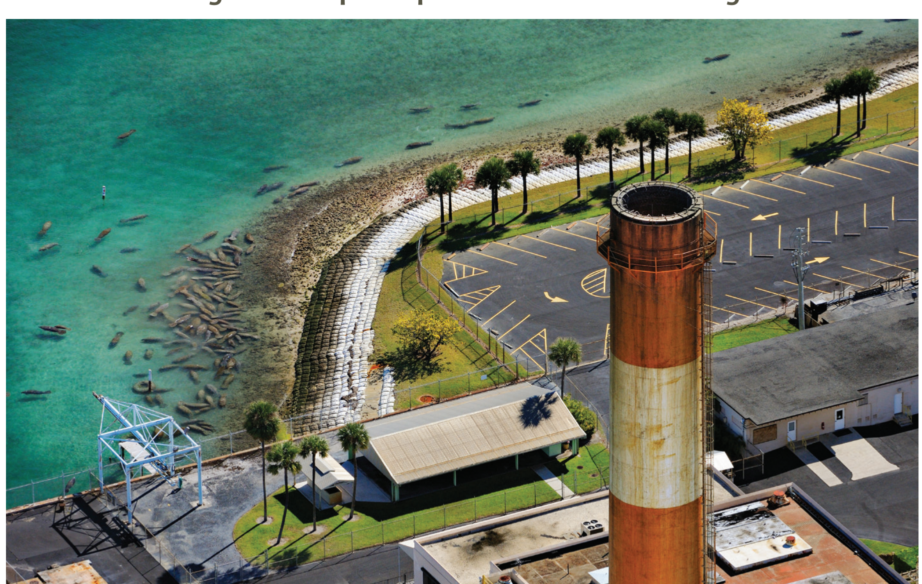
Thermal Pollution. Thermal pollution, unlike most other types of water pollution, does not relate to substances that are mixed with water. Instead, thermal pollution refers to the degradation of water quality due to increased water temperature. Usually, the increase in water temperature is caused by processes involved in industry and/or energy production. Many industrial processes, along with power generation, produce large amounts of heat. Industrial facilities use water to cool the machinery used, and this water is then released into nearby waterways.

Metals. While many heavy metals, such as zinc, copper, mercury, and lead, occur naturally in the environment, human activities are altering how these metals show up in our freshwater. More concentrated metals can lead to toxic conditions for aquatic life. Alternately, calcium and magnesium are two minerals that can be a form of pollution from runoff and erosion. These two minerals can actually reduce absorption of toxic metals in fish.

Water Treatment

While humans may be responsible for certain types of water pollution, we have also engineered ways to treat and reuse water. Students may be unaware that humans have treated our water in some way as far back as the ancient Greek and Indian civilizations of more than 3,000 years ago. Motivated by their taste buds, these ancient civilizations boiled, strained, and used gravel and sand filters to improve the taste of water. It wasn't until the 1670s that a Dutch scientist Antonie van Leeuwenhoek, made the first microscope, which led to the discovery of water microorganisms. This led people to begin to filter their water for home use; filters were made of wool, sponge, and charcoal. In 1804, the town of Paisley, Scotland, was the first

Florida manatees gather at a power plant's warm water discharge.



Pictures of Practice

What Is Water Pollution?

When asked what water pollution is, most students can readily explain pollution as trash thrown away by humans that enters our water. Students can readily identify items visible to the naked eye, such as cigarette butts, plastic bottles, and bags. This type of debris is certainly a water-pollution problem. However, when students are asked about other sources of water pollution, they may be lost or not able to identify invisible pollutants. Chemicals released by manufacturing, cars, and lawns and farms are large contributors to water pollution but can be hard for students to identify because they may not be visible, or the source of the pollution is not easily connected to the area that is impacted. For example, yard fertilizers and pesticides run into storm drains and simply "disappear" from students' world. Likewise, if students are asked how pollution gets into water, they may point to littering but not identify different types of runoff. It is important that students understand that there are many pollutants that get into the water—in different ways—so they can better understand how to prevent pollution from entering the water systems in the first place.

Students: Grade 6

Location: San Diego, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students share their ideas about water pollution.

Classroom Context

Previously, students had been exposed to water pollution when they went on a garbage pickup in the local area. This gave many students a firsthand look at trash that pollutes their freshwater, but also reinforced their tendency to identify trash and large debris as the main, or only, source of pollution. In this lesson, students are reviewing their ideas about pollution, which is a concept weaved throughout many lessons in Ms. Fortunato's water unit.

Video Analysis

During the video, students have a discussion to review the meaning of water pollution. Listen to student responses, such as how several students talk about visible trash they found when they cleaned a canyon. Although these are serious contributors to water pollution, other sources such as toxic chemicals and pet waste in runoff are also part of the issue. Ms. Fortunato points out this kind of pollution to her students and continues by explaining that it often enters into the water cycle through runoff when it rains. It is important to make the distinction that although rain contributes to runoff by "sweeping" pollution into the sewers, it is a natural process and not actually a cause of pollution. One student—Emily—says, "It is not the rain's fault." It is also important that students see that runoff occurs all the time and not just during rainstorms. People overwater their yards and office-building grounds, and agriculture irrigates almost year round. Ms. Fortunato reinforces this concept by calling pollution unnatural or "not natural."

Reflect

What should students know about water pollution?

With so many important topics surrounding the subject of water pollution, it is hard to know where to begin. How would you teach about water pollution in your class? What do you see as the most important concepts to teach? Also, Ms. Fortunato introduces the words "substance," "toxins," and "chemicals" to students. Why would it be important to further explain these words?

In the Classroom

Contaminants in the Water Cycle

How can a region's water supply become contaminated? Water pollution sometimes includes the contamination of bodies of water that we use as sources of drinking water. Pollution can get into the water cycle through both point and nonpoint sources. Understanding the relationship between the water cycle and contamination in drinking water will help students to identify potential threats to drinking water. Students will review the water cycle and identify point and nonpoint source pollution to drinking water sources.

Materials

- Hydrological (water)-cycle diagram
- EPA Safe Drinking Water Act poster: http://www.epa.gov/safewater/publicoutreach/images/landscape_1200x776.jpg
- Paper, pencil/pen

Directions

1. Review the hydrologic (water) cycle using the diagram, including the processes of evaporation, condensation, and precipitation.
2. Explain that, depending on where you are in the world, the drinking water may come from groundwater, surface water such as lakes, rivers, and reservoirs, or desalinated seawater. Consider using EEI's Water For Life map.
3. Display the EPA Safe Drinking Water Act poster.
4. Have students think about the water cycle as they identify and list the surface and groundwater sources of drinking water shown in blue text. Students will then point out and list the potential threats to these drinking sources in the red text.
5. Review point and nonpoint source pollution in the context of water. Explain to students that point source pollution is pollution originating from a single, identifiable source, such as a discharge pipe from a sewage plant and runoff from storm-drain systems. Tell students that nonpoint source pollution is pollution that happens as water moves across the land or through the ground and picks up pollutants, such as agricultural runoff that carries sediment, nutrients, and pesticides with it.
6. Have students review each potential threat and classify them as either point or nonpoint source pollution.
7. As an extension, consider having your students investigate and list potential threats to the drinking water in your location, such as any wastewater treatment plants, landfills, farms, construction sites, and factories. Create a custom map that identifies these sites, as well as the main source of your community's drinking water.

Discuss

1. Why is knowing about the water cycle so important to understanding water quality?
2. What can you do to prevent water contamination in your area?
3. Do you think point or nonpoint source pollution is more harmful to drinking water?

Student Thinking

How Does Water Get Polluted?

Students in agricultural areas may be very aware of dangers from upstream cattle grazing or unseen pesticides in water. Students in cities may be more attuned to litter and other forms of visible pollution. Some urban students may seem perplexed by the notion of invisible pollutants. Likely, few students will know that chemicals that have been buried can leak into our ground and local water when their containers corrode after years of exposure to moisture. Many students will believe that if water looks clean, it's probably okay to drink.

	Common Student Ideas	Scientific Concepts
Sources of pollution	Students may focus on pollution caused by people intentionally throwing trash or "bad" things into the water.	A lot of the pollution in our water comes from nonpoint source pollution, resulting from water runoff collecting pollutants in its path. It can be difficult to pinpoint the source, and oftentimes this pollution is not intentional.
Substances in pollution	Students may focus on visible pollution, or "dirty" looking water. Students may describe trash being thrown into water but not mention invisible chemicals.	Many of the worst pollutants are invisible chemicals. Not all of these chemicals can be classified as "good" or "bad," just potentially negative in certain habitats or proportions. Water can have a safe pH but be toxic due to another pollutant.
Impacts of pollution	Students may focus on pollution "killing" living organisms in water.	Some pollution that enters our freshwater systems kills living organisms, but much of this pollution enters the food chains and remains in the bodies of freshwater organisms. It biomagnifies in the tissues of animals higher up on the food chain (examples are DDT, PCB's, and mercury). Other pollution, such as nutrients and organic molecules, triggers problems such as algal blooms and low oxygen conditions in streams and lakes.

Ask Your Students

1. What are some examples of water pollution?
2. How do different types of pollution enter our waterways?
3. How could you tell whether water is polluted? If water looks clear, does that mean it is clean?
4. Can groundwater be polluted? What kinds of pollutants could you find in groundwater? What kinds would you not find in groundwater, and why?
5. What are some consequences of different types of pollution for humans and other living things?

Student Thinking

Define *Water Pollution*

Water can become polluted in many ways, but it is often the invisible pollutants that are forgotten by students. Sometime polluted water is visibly obvious, but oftentimes we must test for various pollutants. In schools, students often begin studies of water quality during upper-elementary or middle schools. Sometimes teachers will use water-quality kits and take kids to local streams and ponds. Other times teachers may bring in samples for students to test in the classroom.

Background

Your school ordered new water-quality testing kits this year, and this will be your first time to use these kits in an extensive water-quality unit. Your students will be going to a local creek to test water quality above and below a large shopping area. You want to make sure students know enough about water quality before the investigations so they get the most out of the data-collection experience. You also want to work on vocabulary with your students and are collecting information about students' prior knowledge by asking them to define, in their own words, several key concepts they will be studying in the unit. Consider how your students defined water pollution in the responses that follow and think about how to use this information to guide your instruction during the unit. The scientific definition you are using for "water pollution" is "harmful substances that reduce the quality of water."

Question

What is water pollution?

Student Answers

Abby: Water pollution is where icky water from the sewer comes into the salt water of the ocean. It gets dirty from all the things that we've just dumped into the sink. Even farms make rivers dirty because of all the hay and food that get into it.

Olivia: I've heard of water pollution before but no one has ever explained it to me. It's bad for water because when you pour garbage into the water then the fish kind of die.

Ruby: Water pollution means dirty water. Like you can just tell its dirty because it smells bad and looks like it would be bad to go swimming there.

Thomas: Water pollution is where people just leave on sinks and showers, and they just leave it running, running, and running. Then it just gets wasted.

Reflect

1. What are strategies you could use to help students revise their definitions of water pollution?
2. What are the most obvious misconceptions you see in these students responses? How will you address those misconceptions given the scientific definition they should know at the end of the unit?

to have a municipal water-treatment system consisting of huge sand filters. Water from the filtration system was delivered by truck for the first three years. Afterward, a system of pipes was installed for direct delivery. This system, designed by Robert Thom, paved the way for municipal water systems around the world and helped popularize the notion that cities should deliver safe drinking water to their citizens.

In 1854, British scientist John Snow linked water and cholera by observing an outbreak at a particular well in London, which was then shut down. He suggested the use of chlorine to treat the water before consumption. Chlorine treatment was found to be extremely effective for preventing cholera, and soon cases of typhoid and dysentery were also eliminated. In 1908, Jersey City, New Jersey, was the first city to implement chlorine treatment for its water supply. Today, approximately 98 percent of all drinking-water systems that disinfect their water use some form of chlorine, while the remainder use other methods such as ozone or ultraviolet light (ACC 2010). The following section describes the methods used in most drinking-water treatment processes.

Drinking-Water Treatment

Water is obtained and treated differently in different communities. Also, it is important to note that in rural areas, many people obtain water from their own wells. Throughout the United States, about 16 percent of the population uses self-supplied (rather than public-supplied) water (USGS 2010). This means that the vast majority (about 84 percent) of Americans receive their water from public-supplied sources. Most public-supplied water is taken from surface water, though groundwater also accounts for a significant portion of the public-water supply (USGS 2010). In California 70 percent of supplied water comes from surface water, and 30 percent comes from groundwater. Once water is taken from the natural system, some of the following methods are used to make water safe for human use. Note that different treatments are used in different communities, depending on both the community's available resources and the quality of the water source used by the community. The following information is taken from the EPA Water Treatment Process website located at http://water.epa.gov/learn/kids/drinkingwater/watertreatmentplant_index.cfm.

This series of photos shows what happens when a powdered purifier (Pur) is added to a polluted jar of water, killing bacteria and settling other pollutants such as floc.

After water enters the drinking-water treatment plant, one of the first treatments it receives is called **coagulation.** In the coagulation process, chemicals including alum are added to the water. These chemicals neutralize the charges of suspended particles in the water and allow the particles suspended in the water to stick or clump together with the coagulant, forming **floc.** Clumps of floc are heavier than the water, so they settle to the bottom in a process called **sedimentation.** The rest of the water floating above the floc moves on to the next step in the process, called filtration**.**

In filtration, the water is passed through materials, including sand, gravel, and charcoal, to remove very small particles that may still be suspended in the water. Although the water may look very clean after filtration, it may still have invisible substances in it that can be harmful to humans who drink the water. So, next in the process, water can be disinfected to kill any bacteria or other microorganisms living in the water. Three methods used for **disinfection** include chlorination, ozonation, and ultraviolet radiation. Finally, many communities in the United States add fluoride to treated water in an effort to reduce tooth decay. As of 2006, about 69 percent of the U.S. population using public water received fluoridated water (Center for Disease Control 2010).

More detailed information about drinking-water treatment may be found in the 1999 EPA brochure "Drinking Water Treatment."

After all treatment has been completed, water is stored and then sent through pipes to peoples' homes, farms, and businesses in the community.

Your students may have a wide range of awareness of how, or even if, their local water is treated. Some students may be aware that their water has been chlorinated, because they can smell the chlorine. Some may have heard discussions about the advisability of fluorinating municipal water. Many of your students may have never considered the need for water treatment before. Some local water districts sponsor field trips in which the treatment plants are visited and explained, and many of them have seen websites in which the process is diagrammed and explained.

Wastewater Treatment

Some students are actually not aware that drinking water treatment and

The California coast is used for many purposes, including a location for a water-treatment plant in Ventura, California.

wastewater treatment are separate processes. It is important for students to understand not just how their drinking water is treated before it is sent to their house, but also what happens to the water that they use and then send down the drain. Wastewater treatment helps to maintain the quality of water in the natural-water systems that humans, as well as other living organisms, depend upon. The following brief description of wastewater treatment processes is taken from the EPA, "Primer for Municipal Wastewater Treatment Systems." This detailed booklet may be found online at http://www.epa.gov/owm/primer.pdf.

The first stage of wastewater treatment is called primary treatment. When wastewater enters the treatment facility, large debris is filtered out with screens. After large objects are filtered out, the water is usually sent to a chamber in which smaller solid materials, such as sand and grit, can settle to the bottom. Still smaller particles suspended in the water are allowed to settle out in a sedimentation tank. The solids that settle out in the sedimentation tank are called primary sludge or biosolids. Biosolids can sometimes be used elsewhere, such as layering in landfills or for composting.

Secondary treatment comes next. Secondary treatment is a biological treatment process that removes dissolved organic material from wastewater. The partially treated wastewater from the settling tank flows by gravity into an aeration tank. Here, it is mixed with solids containing microorganisms that use oxygen to consume the remaining organic matter in the wastewater as their food supply. The aeration tank uses air bubbles to provide the mixing and the oxygen, both of which are needed for the microorganisms to multiply.

From here, the liquid mixture, composed of solids with microorganisms and water, is sent to the final clarifier. Here, the solids settle to the bottom where some of the material is sent to the solids-handling process, and some is recirculated to replenish the population of microorganisms in the aeration tank to treat incoming wastewater (http://www.regulatorystaff.sc.gov/orscontent.asp?pageid=654).

Before being released (e.g., into a river or an ocean), wastewater usually undergoes some final additional treatments. These additional treatments include tertiary treatment and disinfection. Tertiary treatment may include several processes such as sand filtration and filtering water with active carbon. These remove additional suspended particles and toxins. Tertiary treatment may also include denitrification, which reduces ammonia and nitrate levels. Other processes, such as microfiltration and **reverse osmosis,** can be used to remove salt, **pathogens,** and other particles.

Tertiary treatment can clean wastewater to a point at which it is as clean as distilled water, and even cleaner than our tap water or bottled water. This stage of treatment makes the popular slogan, Toilet to Tap, a real possibility for arid regions with limited water resources. Wastewater that is reused is called reclaimed water and is marked by the use of purple colored pipes. At present most reclaimed water is used for irrigating parks, golf courses, and other green spaces. In California, hundreds of millions of gallons are recycled every year and much of it is used to augment groundwater supplies.

The final treatment step is disinfection, in which microorganisms are the target pollutant. Through use of chlorine, ozone, or ultraviolet light, these microorganisms are reduced.

Teaching Tip

Ask your students to compose a list of pollutants that they would want to treat for in the local tap water. This can be done individually, in teams, or as an entire group. Pollutants can be biological, chemical, and even thermal. You can remind them of this at the outset, or list these items in separate columns during share-out, and then ask the class to name or identify the categories. This activity can be followed by research into what pollutants are treated for in the local waters, and which types of treatments are used to treat which types of contaminants. This is a great opportunity for your students to take their knowledge about water pollution and water quality to the next step.

Student Thinking

How Do We Clean Water?

Students sometimes think that clean water is the same as clear water. They know that bottled water is safe to drink because it has been cleaned, and they know that it is safer to drink water from the faucet at home instead of water from a stream, canal, or creek. Students begin to learn about water pollution and ways to clean water as early as upper-elementary and middle school when they learn about the water cycle and ways pollutants enter and exit that cycle. However, they may not be given opportunities to think about how their own tap water is cleaned. The purpose of this activity is to examine sample student ideas about how people clean water in order to plan your instruction on the topic.

Scenario

Your class just completed a unit on water pollution. Last year, your students also did extensive activities on the water cycle. You are ready to teach your students about water treatment and ways people clean water. You ask your students to complete a short quickwrite activity to share what they know about cleaning water. Your plan is to use this information to tap into their prior knowledge and to inform how you approach teaching the topic. Look at the question and responses from students and then reflect on the questions below.

Question

Describe as much as you know about how people clean water and make it safe to drink.

Scientific Answer

Water is cleaned in different ways depending on how we plan to use it. For drinking water, it goes through three general steps—coagulation, filtration, and disinfection. Chemicals are added to help settle particles (in coagulation) and to kill microbes (in disinfection).

Student Answers

Annie: Water is cleaned by going in this "thingee" that cleans the water. It takes all the fish stuff out and the mud and other bad stuff.

Jessica: I think they put something that gets all the bad stuff out of the water. They put a kind of poison into it. It kills all the bad stuff and then that's how it makes freshwater.

Rachel: We clean water by taking out the germs. I don't really know how it happens, but we kill all the bad things in the water that would make us sick.

Jacob: I think water gets cleaned by going through a factory that washes the water and makes it into freshwater that we can drink.

What Would You Do?

1. What concepts will you start with given what your students know from this preassessment?
2. What are the most obvious misconceptions you see in these student responses? How will you address those misconceptions?

Pictures of Practice

How Do We Clean Water?

Teaching about water treatment can be a challenge. Municipal water treatment facilities are far removed from students' everyday lives, so the idea that water is already treated before it enters their house may come as a surprise to students. Students have ideas about what makes water clean and how this happens, and they have basic rules they use to decide if water is clean enough to drink. For example, students may think that if water looks clean, or is clear, they can drink the water. Other students may think that all water must be filtered before it can be used for drinking. Today, many students have experiences with home filtration systems on their faucets or Brita and Pur pitchers. Few students actually know how these work, let alone how water treatment and filtration occur at larger scales. They may realize that sewage is treated at some point, but may not readily identify drinking-water treatment. In addition, the materials used to filter water may surprise students, especially materials such as charcoal. Discussing home filtration and large-scale drinking-water treatment and sewage treatment can help students better understand the different types of treatment we use on our water.

Students: Grade 6

Location: San Diego, California (a coastal community)

Goal of Video: The purpose of watching this video is to see students discuss water treatment as they design and build water filters.

Classroom Context

In previous lessons, students have defined the words "water pollution," "filter," and "watershed." They have also discussed where they could go to find clean drinking water if water no longer came from their faucets. In this lesson, students make a water filter, using basic materials, to better understand how layers in the filter pull out different pollutants.

Video Analysis

This video begins with students discussing if the water that comes from the faucet is clean. At first, it seems that students understand that the water is clean because it is filtered, but the conversation quickly changes when one student brings up the home filtration system that attaches to her faucet. This leads to the idea there are different levels of clean water. While home filtration systems do eliminate some minerals from tap water, drinking water straight from the tap in the United States is generally safe because of the regulations on drinking water. However, some students may have heard warnings about potential pollutants in their tap water, so discussing local-area concerns is important. Next, students participate in the activity in this chapter **In the Classroom: Build Your Own Filter** to learn more about how filters work. Once students had completed the activity, both Lizzy and her partner Zach better understood how a water filter worked. However, Zach admits to still being confused at how we get clean drinking water because he knows that, even in a clear glass of water, there can still be toxins and chemicals. In reality, water is not cleaned in one step like in the classroom activity but generally goes through three steps that treat both visible and invisible pollutants and toxins—primary, secondary, and tertiary treatment, then disinfection.

Reflect

What should students know about water filters and water treatment?

Water treatment facilities and practices are complex and difficult to teach, but making this process more visible to students is important. How would you teach about water treatment so students have more awareness of these systems? What concepts would you focus on? What would be the main take-home message from your lessons?

In the Classroom

Build Your Own Filter

Like the layers of the ground, water filters also have layers that help to remove pollutants found in water. In the natural water cycle, when rain hits the ground it soaks through layers of soil, sand, and rocks, with each layer cleaning the water along the way. Likewise, during filtration at water treatment plants or in personal home filters water might pass through layers of sand, gravel, and/or charcoal before additional chemicals are added to kill invisible microbes. In this activity students learn more about how filters work to remove pollutants.

Materials

- 2 one-liter soda bottles (one per group)
- Glass beakers or cups
- Pollutants (coffee grounds, sea salt, cooking oil, and dried beans)
- Filter layers (cotton balls, thick paper towel, thin tissue, sand, gravel)

Directions

1. Prepare soda bottles by cutting off the top portion of the bottle. When the top is flipped upside down, it should rest just inside the main part of the bottle, serving as a funnel.
2. Prepare pollutants and filter layers by placing them into containers with spoons so that students have access. One student from each group will need to mix their pollution, while another student will pick out filter layers. Give each group of students a soda-bottle filter apparatus and one cup of clean water.
3. Ask students what they already know about how water is filtered. Guide the conversation to the idea of layers being used in filters. Tell students that today they will design filters to see if they can get clean water.
4. Demonstrate how to pollute water by adding one spoonful of each pollutant to a clean cup of water. Don't add too much! Demonstrate ways students can use the filter layers in their design. Students will layer materials into their inverted soda-bottle top (funnel), so that as polluted water is poured, it funnels into the main part of the bottle.
5. Have each group discuss their plans for the filter. What layers do they want to include? How thick? And in what order? Once designed, have one student retrieve the filter layers and have the group build their filter by layering the materials into the inverted bottle top, then placing the top just inside the main part of the bottle.
6. Have students prepare their pollution, and then test their filter design. At this point do not share strategies with students. Results will vary, but likely, many groups will still have polluted water after it makes it way through the filter.
7. Have students share what they believe was successful and unsuccessful in their first design.
8. Have students redesign their filters based on results from the first test. Remind students to pour slowly and carefully because it matters!

Discuss

1. What factors helped to make your filter better? Why do you think this was important?
2. How does the ground help clean water, while pavement and concrete do not?
3. If your water looked clean, do you think it still has pollutants that you cannot see?

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Teaching Resources

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

EPA’s water-quality education resources: http://www.epa.gov/students/teachers.html#epawater

National Geographic Society water resources: http://environment.nationalgeographic.com/environment/freshwater

Project WET’s resources on water quality: http://www.projectwet.org/water-resources-education/water-quality-education/

UC Davis Myths of California Water: http://watershed.ucdavis.edu/myths/index.html

USGS water-quality education page: http://water.usgs.gov/education.html

5 Water Concerns for Wildlife and Humans

by Abraham Miller-Rushing, Anica Miller-Rushing, Marcia S. Matz, Tara G. Treiber

Water is essential to our survival and to the survival of all plants and animals. Even so, it is easy for us to go through our lives without thinking about how much water we use, where it goes after we use it, and how our use of water affects other people and the environment. This chapter describes the impacts human activities have on freshwater.

Some human activities influence water abundance. Other human activities influence water quality. Both are a concern we should understand because they potentially affect our own communities and the wildlife that also depends on abundant, clean, freshwater. We take a closer look at activities changing the makeup of natural aquatic systems, such as the introduction of invasive species, the draining of rivers and estuaries, and the introduction of chemicals, specifically nutrients, that cause eutrophication. We then look more closely at other related issues around water abundance, which can fluctuate drastically from years of minimal precipitation to years of heavy precipitation, depending on weather trends. Lastly, we consider access to clean water, as well as activities that affect water quality and threaten humans and wildlife, leading to problems such as **biomagnification.** With all of these issues, people are currently working on solutions so that our communities can continue to function while simultaneously reducing our impacts on water.

Water Has Limits

As humans, we often think of freshwater as ours. It is vital to our survival—it is necessary for our bodies, our agriculture, the planet on which we live—and many believe it is also necessary for our recreation and psychological well-being. As the human population rapidly grows, the demands we place on this valuable resource multiply. Our demands are outstripping the supply, as shown in

GRADE	STANDARD	EEI UNIT
Grade 3	3.3.c-d 3.1.2 3.5.3	Living Things in Changing Environments The Geography of Where We Live California Economy—Natural Choices
Grade 4	4.3.b 4.1.5	 Reflections of Where We Live
Grade 5	5.3.d	Our Water: Sources and Uses
Grade 6	6.5.e	
Grade 7	7.3.a 7.3.e	Shaping Natural Systems through Evolution; Responding to Environmental Change
Grade 8	8.6.1 8.12.1	 Agriculture and Industrial Development in the United States

several examples shared in Chapter 3 (e.g., draining of Owens Lake). It is a simple equation—water is a finite resource, and we are exploiting water in ways that make it less usable (water pollution) and less available (consumption) for people today and in the future. Yes, water changes form and location all over Earth, but no new water is created in the water cycle (see **Chapter 2–Water Cycle**). Yet, as we use water every day, most of us do not think about the limited amount of freshwater available to people. We take showers; we wash our dishes and clothes; we cook and drink; we buy items that required water to produce (basically everything we buy); and we play in the lakes and rivers that we live near. In the United States, we have come to expect and rely on readily available, inexpensive, and clean water. Your students may find it difficult to imagine living any other way. They are used to going to the tap and getting clean water whenever they want.

But consider the following facts (from *National Geographic* April 2010, and Millennium Ecosystem Assessment 2005):

The human population is growing by about 83 million people each year, so water demand will keep increasing unless we change how we use it.

- Two-thirds of our freshwater is used to grow food.
- It takes 1,799 gallons of water to make a pound of beef (i.e., abut 35 filled bathtubs).
- It takes 108 gallons of water to grow a pound of corn (i.e., 2 filled bathtubs).
- U.S. swimming pools lose 150 billion gallons of water to evaporation every year.

CHAPTER OVERVIEW

Human activity has had numerous consequences on the quality and quantity of freshwater, as well as the organisms that depend on it. Many of our practices, while necessary for our communities, also pose potential threats and health concerns to wildlife and ourselves. For example, humans affect the diversity of living organisms in freshwater by altering water flow through damming, filling in wetlands, channelizing rivers, influencing changes in climate, and introducing invasive species to new aquatic habitats.

Humans also face threats related to the lack of abundance of clean water. By using water for agriculture, manufacturing, and industrial uses and by increasing pollution and causing changes in Earth's climate, humans have been altering the water supply to support our communities. While Americans typically get clean and abundant water from their taps, access to water is inequitable around the world. Americans use around 100 gallons of water per day, and Californians use around 189 gallons of water per day, whereas, in some countries, women may need to walk miles to get five gallons of water to be used solely for cooking and drinking.

This chapter reviews the impact people have on freshwater systems that potentially influence our own human communities, as well as all the other living things that depend on freshwater.

After reading these facts it is easy to throw up one's hands and say the problem is too insurmountable to change. However, we must learn what we can do to help solve the problem and then start doing it. Every problem that arises from human activity also comes with a solution. Teaching ourselves and our students about the value of water is one important step toward preserving our freshwater resources.

Freshwater is a vital resource for all living things on Earth, including this Cape Buffalo herd and Cattle Egret flock in Botswana.

Threats to Diversity of Life in Freshwater

Freshwater ecosystems are used not only for our drinking water, agriculture, industry, and recreation, but also they provide homes to an extraordinary number of species on Earth. Students may only think of fish, birds, and frogs as living things found in freshwater, but there are abundant aquatic plants, microscopic organisms, snails, mussels, insects, and many other types of amphibians and reptiles. Like us, a huge number of these organisms rely on clean, healthy freshwater ecosystems. Yet, these organisms can be forgotten when we consider our water problems. Students may believe that humans' need for water takes precedence over wildlife's without making the realization that all living things are connected. The health of our natural systems is vitally important to the health of human systems.

Interestingly, the health of our aquatic systems is actually being threatened at a greater rate than land and ocean ecosystems. Consider the following information:

> Lakes, swamps, and rivers make up less than 0.3 percent of freshwater and less than 0.01 percent of all the water on Earth. Yet these waters are home to as many as 126,000 of the world's animal species, including snails, mussels, crocodiles, turtles, amphibians, and fish. Almost half of the 30,000 known species of fish live in lakes and rivers, and many aren't doing well.… Freshwater animals in general are disappearing at a rate four to six times as fast as animals on land or at sea. In the United States nearly half of the 573 animals on the threatened and endangered list are freshwater species. (*National Geographic* 2010).

When students think about threatened or endangered species, they may point to land or marine animals, such as the polar bear, the gray wolf, sea turtles, certain species of owls, and so on. Some may name aquatic species such as the California tiger salamander or fairy shrimp, but for the most part, students

Teaching Tip

Although many of the facts and figures about water are eye-opening for adults, they can also cause fear and anxiety among children—a phenomenon that David Sobel calls **ecophobia.** He writes, "[m]y fear is that our environmentally correct curriculum will end up distancing children from, rather than connecting them with, the natural world. The natural world is being abused, and they just don't want to have to deal with it" (Sobel 1995). Sobel recommends providing opportunities for children to have positive experiences with and in the natural world, ideally with an enthusiastic adult who can act as a positive role model. Beginning with local problems that students can actually do something about is also an important first step. When any environmental issues are shared with students, always consider generating a practical solutions list that students can act upon. Following these recommendations can help young students develop an appreciation and empathy for the natural world. For more instructional strategies see Olson and Bang's "Avoiding the Big Scare," which is referenced at the end of this chapter.

have little awareness of freshwater species in peril, even those in their local communities. Students also need to learn more about why species become threatened or endangered, and how we can prevent these problems.

While nationally the Endangered Species Act (ESA) of 1973 is the guiding legislation protecting wildlife in peril, individual states have their own legislation that is specifically designed for the state's critical habitats and species. For example, the California Endangered Species Act (CESA) parallels the federal legislation, but it specifically focuses on protection of species and subspecies found in California, such as the California tiger salamander. Have students find out more about endangered species in their state or community. For example, California's Department of Fish and Game oversees CESA and updates their list of threatened and endangered species up to four times a year (http://www.dfg.ca.gov/wildlife/nongame/list.html).

When protection measures are taken rapidly and in earnest, people can turn even the most endangered species into great success stories. For example, the California Condor, with less than two dozen individuals in the wild in 1982 had 192 individuals in the wild by 2010 (San Diego Zoo 2010). Even more success has been found with recovery of the historic range of the Little Kern golden trout. Once endangered due to change in aquatic habitat from livestock and logging runoff, and the introduction of non-native rainbow, brown, and brook trout, this species' range was fully restored by 1997. When presenting these precarious situations to students, make sure to share success stories to show that people have the power to bring about change. Explore more success stories like the California condor and Little Kern golden trout at the Center for Biological Diversity (http://www.esasuccess.org/reports/).

The Los Angeles River is a habitat that many waterfowl have learned to enjoy in urban areas. Yet estuaries such as this one in Ventura, California, provide a serene and more natural habitat for waterfowl.

What Is Causing Freshwater Ecosystem Change?

Many human activities affect the health of freshwater ecosystems. These activities include withdrawing water for human use, pollution (particularly nitrogen pollution), changes in land use, activities leading to climate change, and the introduction of invasive species. Although it is difficult to predict all aspects of how freshwater ecosystems will respond to these changes, we can examine likely scenarios of future changes. Here are some likely changes identified by the Millennium Ecosystem Assessment (2005), which assessed the consequences of ecosystem change for human well-being, and involved the contributions of more than 1,360 experts worldwide.

Changes to the Water Environment. In general, an increase in temperature, eutrophication (i.e., increases in nutrients, algae, and plant growth leading to reductions in dissolved oxygen), and **acidification** (largely from acid rain) cause changes in freshwater. These things change the water environment for freshwater species, and some plants and animals may not be able to cope with changes. They either move to other locations or potentially disappear altogether in the affected areas.

Changes to Water Flow. Water availability is projected to decrease in many of the world's rivers but also increase in some rivers. That means that river habitats will be altered because of the changes in water flow. Some of the changes will benefit plants and animals that can handle them, while plants and animals not equipped to cope may decline.

Climate Change and FreshWater. Climate change will probably lead to increased precipitation and flooding across more than half of Earth, and decreased precipitation and drought in other parts of the world. Aquatic habitats used to a certain amount of rain may suffer or disappear, while flooding could scour other areas.

Changes to Water Quality. Increases in human water use are expected to lead to an increase in untreated wastewater discharges in developing countries. Because of the increase in water use, the wastewater treatment systems will not be able to keep up. If wastewater is discharged without treatment, discharge sites, and even ecosystems downstream, could be affected.

Introduction of Invasive Species. Many non-native species are introduced into an aquatic ecosystem by accident or even intentionally. These species may outcompete the native plants and animals, changing the biological makeup of a given ecosystem.

Keep in mind that not all changes will be as adverse as those described previously—it depends on the region and the goal of conservation in those areas. Even if some of these projections happen, there are many aquatic species that could survive, or even thrive, in the new conditions.

Many of the primary drivers of these changes are human activities, such as development along aquatic and coastal areas and runoff from industrial, residential, and agricultural areas. For example, when excess nutrients from sewage discharge or fertilizers runoff into our water systems, eutrophication occurs, a phenomena that leads to abundant algae and plant growth. This causes a decrease in oxygen levels as algal blooms die off, impacting water quality for plants and animals.

The impact from these human activities can be reduced through careful planning and protection of our freshwater systems. For example, Aquatic Diversity Management Areas (ADMAs) are used to protect watersheds from habitat degradation. ADMAs can be applied to protect a single aquatic species or full-scale biodiversity. The agricultural industry can follow best management practices, such as reducing fertilizer use, being more accurate in applying pesticides, and keeping livestock away from streams. Homeowners can reduce the use of fertilizers and pesticides on their yards, follow guidelines when visiting an aquatic habitat, and speak out if they see a threat to their local freshwater. Many of the solutions are within our grasp; knowing the issues is the first step to remedying the problem. The Environmental Protection Agency lists several conservation practices that industry and individuals can follow at http://www.epa.gov/bioiweb1/aquatic/conservation.html.

Invasive species are another concern related to freshwater biodiversity. Invasive species are any species introduced to a new area where the species will cause environmental or economic harm to the area. Invasive species are considered a leading cause of extinction or biodiversity loss in aquatic habitats. The words "invasive," "nonnative," and "native" could be confusing to students. They may ask what is considered native, or what the difference is between non-native and invasive. Native species are ones that are in their historic range, while non-native refers to species introduced to a new range by humans. The key difference between non-native species and invasive species is that invasive species are deemed to have negative impacts on the new environment. Many non-native species could be called invasive because of their adverse effects, but there are also non-native species that do not harm their new environment.

The Zebra mussel (top) and Quagga mussel (bottom) are two prolific freshwater invasive species.

Taking a closer look at individual invasive species can help students understand that there are patterns in the way these species are introduced and controlled but also differences that make each situation unique. Consider the following two examples, looking for patterns and differences.

One iconic freshwater invasive species is the zebra mussel, native to Eurasia, introduced to the United States in 1988. It is believed that the species came to the United States through **ballast** water from ships. Ships take on ballast water in order to level and weigh down their ships for transportation of goods, and when they reach their destination, they release the water. Since introduction, the zebra mussel, along with the closely related quagga mussel, have plagued the Great Lakes and freshwater habitats in the eastern and central United States. Both types of mussels have made their way to the West and are now established in many freshwater habitats in California and other western states. The quagga mussel made its way to California using the Colorado River Aqueduct system, which supplies

Pictures of Practice

Runoff and Our Environment

Students: Grade 6

Location: San Diego, California (a coastal community)

Goal of Video: The purpose of watching this video is to see how student ideas about runoff develop in the lessons.

Students quickly learn that trash and debris have a negative impact on our environment. They see debris in their local waterways or hear stories about animals ingesting plastics or becoming entangled in debris. This type of pollution is certainly a problem, especially in urban areas. Trash and debris are the foundation knowledge that many of your students will bring to your classroom with respect to pollution and our environment. Yet, there are many forms of pollution that students may not easily recognize but will need to learn more about, including urban, industrial and agricultural runoff. With respect to farms in particular, students may not readily recognize that agriculture has potential impacts on our environment, especially our freshwater systems. They may see farms as "natural" places, yet farms require a lot of human-engineered technologies, such as irrigation, pesticides, and fertilizers. In addition, ranches and livestock operations produce a great deal of manure that must be carefully controlled and disposed of without getting into our water systems. Discussing these sources of pollution and their impacts on our water systems will help students develop a more complete understanding of water quality and the health of aquatic life.

Classroom Context

In the previous lessons, students discussed pollution and built their own water filters to better understand how people can clean water. In this lesson, students have discussed water rights and how water is allocated to different types of users—agriculture, manufacturing and industry, cities, mining, and the environment. After doing an activity about water, Ms. Fortunato brings the two concepts—water rights and water quality—together in an activity in which users put potential pollutants back into the water system.

Video Analysis

At the start of the week, students were asked to describe as much as they know about how runoff could change our water systems. Runoff of pollution into freshwater systems is one of the leading causes of biodiversity decline in these ecosystems. Most of this runoff comes from agriculture (livestock, farms) and from urban runoff. Ms. Fortunato does an activity with students in which they learn about runoff from different industries, as well as from cities. They briefly talk about runoff from ranches, mines, cities, farms, and manufacturing. Through the activity students learn that different industries not only take water from natural systems, but also that pollution from those industries can enter the freshwater through runoff.

Reflect

What would you teach about runoff and your local environment?

What concepts would you teach about runoff in your local area? Why are these concepts important for students to know? Many aquatic organisms do not die because of runoff, so how would you respond to Salma's ideas?

Case Study

The Colorado River Delta: Rapid Changes

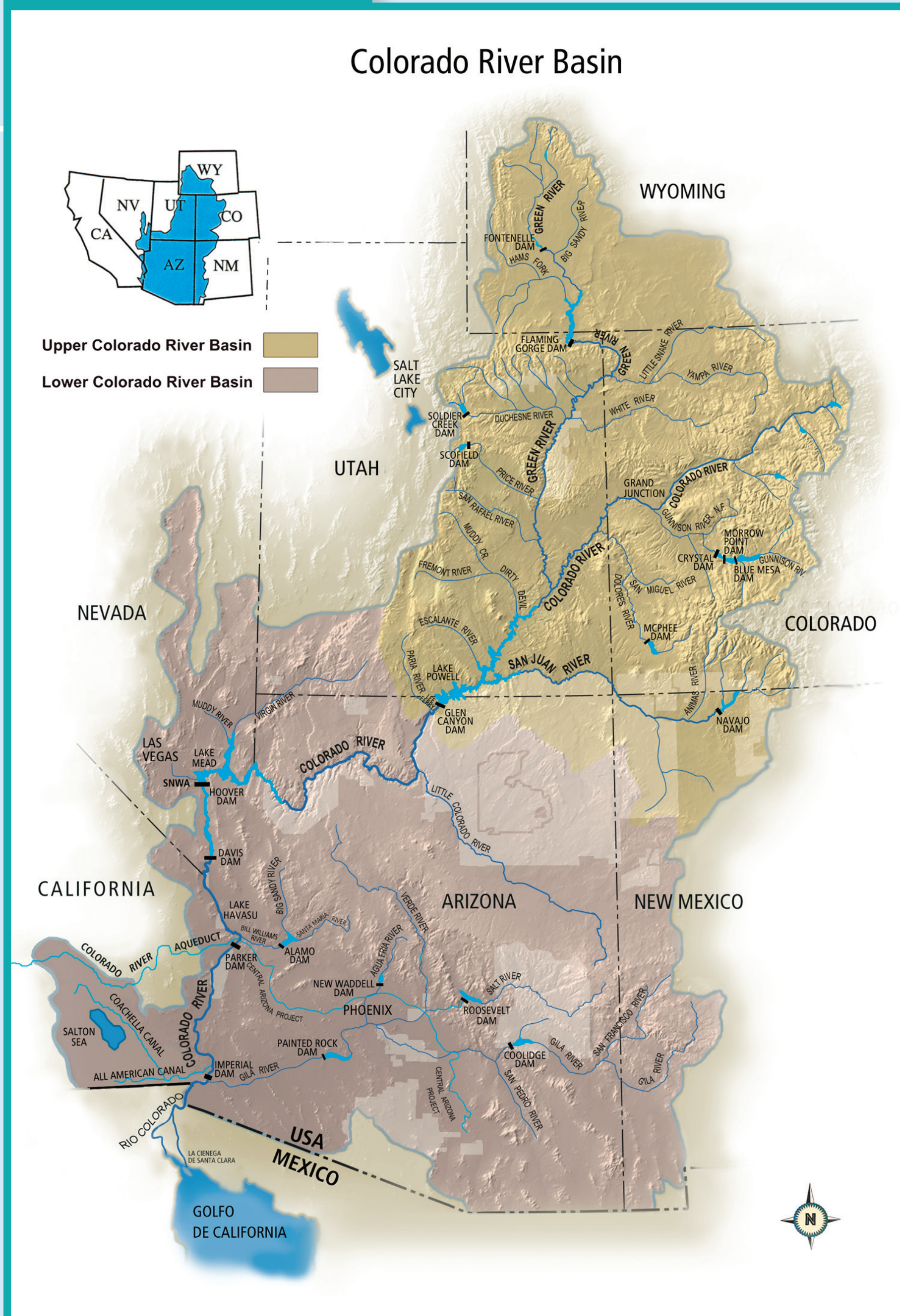
The Colorado River is an iconic river that people use for drinking water, agriculture, and recreation. It is also a habitat for a diverse group of plants and animals, including many endangered species. The Colorado River flows through seven states and two countries (the states are Wyoming, Colorado, Utah, New Mexico, Arizona, Nevada, and California in the United States and then into Mexico). It receives runoff from 243,000 square miles of land (equal to 8 percent of the contiguous United States), and provides an essential component of life for the people, plants, and animals that live within its watershed and also for the people living in different watersheds throughout the Southwest that use waterpiped to them from the Colorado.

Life for plants and animals in the Colorado river delta changed dramatically when several dams were built along the river beginning in the 1930s. Before the dams, silt and water from the river supported vast, diverse wetland-plant communities. Marshes and surrounding areas also sustained jaguars, beavers, and thousands of species of birds. Today, because of reservoirs and other water diversions, the Colorado River rarely flows to its end at the Gulf of California (also known as the Sea of Cortez). This loss of freshwater and the conversion of surrounding lands to farmland have decimated the natural wetland habitats on the delta—only about 5 percent of wetlands in Mexico remain. The wetlands used to cover close to two million acres but now consists of just more than 100,000 acres. Much of the remaining wetlands, which were once forests of cottonwood and willow, are now dominated by non-native species such as saltcedar and arrowweed. At least five bird species no longer occur in the delta, including the southwestern willow flycatcher, the fulvous-whistling duck, and the sandhill crane. Other species that thrived in the area are threatened, including the vaquita porpoise, the world's smallest marine mammal. There are thought to be fewer than 250 vaquita left in the world. The totoaba, a steel-blue fish that grows up to 7 feet and 300 pounds, and that once supported a commercial fishery, is now virtually extinct. The Colorado delta clam was once extremely abundant and an important part of the ecosystem but is now endangered. The diversion of water from the Colorado River to agriculture and cities (mostly in the United States) and the introduction of water pollution from runoff has irreversibly changed the delta.

Recognizing these changes and the importance of preserving the remaining habitat, local and international communities have sought to protect the Colorado river delta. In 1974, Mexico designated portions of the Colorado river delta as a reserve zone. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) designated more than three million acres of the upper Gulf of California and the Colorado river delta as a biosphere reserve in June 1993. In addition, 618,000 acres within the Colorado river delta have been designated as a Ramsar Wetland, a designation for wetlands of international importance for their ecology or hydrology. Despite these protections, the future of these wetlands will largely be determined by how people in the United States use the Colorado River's water. The plight of the Colorado river delta brings up some difficult-to-answer questions: If these wetlands were in the United States (where most of the water is used), would we be more inclined to make the tough decisions necessary to protect them? How does the location of important ecosystems affect their protection?

What does the future flow of the Colorado River look like? The river depends on melting snow from high atop many mountain ranges for 90 percent of its flow. Because the Colorado River has its headwaters in Colorado, it drains a great deal of snowmelt from the Rocky Mountain ranges. Take a look at the map Colorado river basin to note several of the major rivers that feed the Colorado River and where these rivers originate. Climate model projections forecast higher temperatures, shorter winters, less snow, earlier spring runoff, and increased evaporation—leading to estimates that runoff in the Colorado river basin will decline between 6 and 20 percent by 2050. This reduction in runoff will translate into less water availability for people, plants, and animals and could intensify the effects of future droughts. For example, recent models for southern Nevada suggest that a 10 percent reduction in runoff would cause water shortages 58 percent of the time by 2050. If runoff is reduced by 20 percent, water shortages could occur 88 percent of the time, which would alter life for plants, animals, and people in the Southwest. These water shortages could very well keep the Colorado river delta on a path toward a very different and much drier ecosystem than it was just 100 years ago (Waterman 2010).

COLORADO RIVER BASIN



Student Thinking

Adapting to Change

Students may struggle with understanding biological adaptations, especially adaptations to environmental stresses such as habitat destruction, **overexploitation,** pollution, and other threats. They may see adaptation as something individual organisms can "choose" to do, rather than a genetic predisposition toward survival. Students may wonder why organisms cannot find other places to live when their homes are changing.

Scenario

Your students are in small groups discussing animal adaptations with a specific focus on water pollution as a driving factor. As you walk around the class, you overhear some answers your students are giving to the discussion, and you decide to give your students a short journal-writing assignment at the end of the discussion in order to see how many students do not understand adaptation. Look at the journal responses that follow and think about how you would respond in your teaching.

Question

How do plants and animals adapt to changing environments? How does this happen? How long does it take?

Scientific Answer

Some species may have adaptations that allow them to continue to exist in areas experiencing environmental changes, but other species may be less successful when these changes occur. Adaptations are genetically determined and passed on to offspring. Individuals that do not possess a certain adaptive trait are less likely to survive. Those that have the adaptive trait will pass this trait on to their offspring, eventually changing the genetic makeup of a population, as the adaptive trait becomes more common.

Student Answers

CJ: If an organism was adapted to live in a specific habitat and that habitat changes then the animal might die or it would have to adapt to the new environment. I think it would take about a few years for it to adapt.

Leah: If an animal had adapted to a certain habitat and then that habitat was changed I think that animal would have to change the way they live to keep life going. I think it would take about a century to actually have the animals fully adapt.

Reagan: I think it would take quite a bit of time to readapt. Because it's kind of like moving to a new place and trying to make new friends. Because you can't just say, "want to be my friend? Okay." You have to get to know them. So in readaptation, you would say, "this is where I am now. This is what I have to do." And you have to try really hard to do it. If the water was going darker, it would need to try to see better. It would need to work on its eyeballs, and it would need to use its senses more.

What Would You Do?

1. What do these students not understand about adaptation? What are the key misconceptions that you see in their answers?
2. What type of follow up could you do with the class to ensure all students understand this topic?

water to southern California residents. Because of the way these species grow, a major concern is that they clog pipes that take in water for utility companies, and impact hydropower operations. One solution that is being used to prevent the spread of these invasive species is educating recreational boat owners about how to drain their water and clean and dry their boats and equipment after use. Although all mussels clean and filter water, making it clearer and less polluted, the negative impact of these nonnatives outweigh their advantages.

Another aquatic invasive species is the New Zealand mudsnail, which was first discovered in the United States in 1987. Scientists are not sure how the mudsnail made its way across the Pacific, but, like the zebra mussel, the mudsnail may have come in ballast water. Because the first sighting of the mudsnail was on the Snake River in Idaho, another possibility is that the mudsnail was introduced when anglers were stocking rivers with fish imported from outside the United States. Because this species has no native predators, and because they grow in great density, they outcompete native snails and insects for food. This species actually thrives in disturbed aquatic habitats. Like the zebra and quagga mussels, the solutions to contain the spread of mudsnails involve educating recreational boat users (fishing boats, kayaks, canoes, and so on), as well as other recreational users, such as anglers and swimmers. Likewise, fish hatcheries and aquarium traders need to also be aware of the species and take precaution to prevent its spread (e.g., inspecting their products and disposing of any contaminated products).

The All-American Canal runs for 80 miles in the southwestern United States, bringing water from the Colorado River to several California cities and agricultural areas.

New Zealand mudsnail

While ballast water is often the culprit for introducing invasive species into aquatic habitats, sometimes the introduction happens because people accidentally or intentionally release organisms into new areas. The impact of an invasive species could vary depending on each situation—for example, clogging pipes and/or outcompeting native species. Each invasive species likely has a management plan that includes actions you or your students can take to prevent their spread. Spending time exploring local invasive species may make this threat more real to your students and motivate them to be more conscientious about fragile freshwater habitats.

Threats to the Abundance of Water

When we think about when water was considered abundant, we think of a time when the world's population was much, much smaller and when people lived only in areas where water was clean and easily accessible. In those times, there were fewer demands on supplies of available water than there are today. People still changed their environments, but with a smaller population, the consequences of water use were also much smaller. In the United States many still believe that water is an abundant resource. Your students may even believe water is abundant, although more and more water issues are making their way into our homes and communities. In some areas, such as southern California and the American Southwest, water issues have been publicly discussed for years.

Today, we understand that freshwater is a finite resource and that we increasingly demand more of it. Much of our demand for water results from the recent explosion in the size of the world's population. More people require more water, and because many people now live a long distance from adequate supplies of freshwater, we must move water resources to parts of the world that would not otherwise be able to sustain communities. In California alone, some 2,000 miles of canals, pipelines, and aqueducts carry water to the state's thirsty regions (Bourne 2010).

Besides the rapid growth in the number of people in the world, there are other threats to the abundance of water that multiply demands on freshwater. Other demands made on our water resources include, but are not limited to, changes in land use, including development and agriculture; water diversion projects, including dams and reservoirs; manufacturing and industrial uses of water; increases in pollution; extraction of groundwater; and changes in climate that could affect evaporation rates, flooding, droughts, and annual snowmelt.

Overall, the amount of freshwater available (for both humans and other species) is shrinking while our human population and demands are expanding. Some communities are making efforts to conserve more water, but much of the world's water supply is under stress—there are more demands on water than water available. Where water use exceeds the natural renewable water supply, freshwater-dependent ecosystems and human health are at risk.

Access to Clean Water

In the United States, it can be tough for students to imagine a life in which it is difficult, almost impossible, to access clean water. Most of us turn on the tap and out flows clean, freshwater. We generally do not have a good sense of how much water we use on a daily basis, neither do we think about how much water a certain activity will require before we start it. However, these are daily considerations for people in many other parts of the world. Think about how different our actions might be if we were given a limited amount of water that we could use throughout the day—no more. If we were given even ten times what the poorest people subsist on—let's say we were given 50 gallons at the start of our day and everything we washed, rinsed, drank, cooked with, or flushed had to be taken out of that 50 gallons—how would that change our views toward water? Would we use it differently the next day? Would we make different decisions about how we use and appreciate our water?

Villagers scoop the dregs from a water tank filled the night before in Isiolo, Kenya.

We know that access to clean water has global consequences for us all. Access to clean water not only affects the number of times we can wash our clothes in water (some people in arid regions have never considered wasting water for such a use), but it also affects parts of our lives that may seem disconnected from water, such as education or child care.

Communities in which clean water becomes accessible and plentiful are transformed. All the hours previously spent hauling water can be used to grow more food, raise more animals, or even start income-producing businesses. Families no longer drink microbe soup, so they spend less time sick or caring for loved ones stricken with waterborne diseases. Most important, freedom from water slavery means girls can go to school and choose a better life. The need to fetch water for the family, or to take care of younger siblings while their mother goes, is the main reason very few girls in Konso (a community in Ethiopia) attend school. (*National Geographic* April 2010)

Teaching Tip

After discussing past, present, and future water shortages, both locally and worldwide, students accessing their own water use can be a very powerful exercise. Typical Americans use about 100 gallons of water per day, whereas in parts of Africa, people must walk miles a day to gather fewer than five gallons, which must be used for cooking and drinking. There are several online calculators that your students can use to assess their own water use based on their daily habits. Have students calculate their typical daily water use and then discuss with them:

- Which activities require the most water? Were you surprised to learn this? Why or why not?
- How can you conserve water in your daily life?
- In terms of water use, how do you think your life compares to that of a student your age in Africa?
- How might our lifestyles change if less water were available in California in the future?

Water calculators also look at one's lifestyle choices, which typically average closer to 2,000 gallons of water per person per day. Try the National Geographic Society water-footprint calculator at http://environment.nationalgeographic.com/environment/freshwater/water-footprint-calculator/, which is one example.

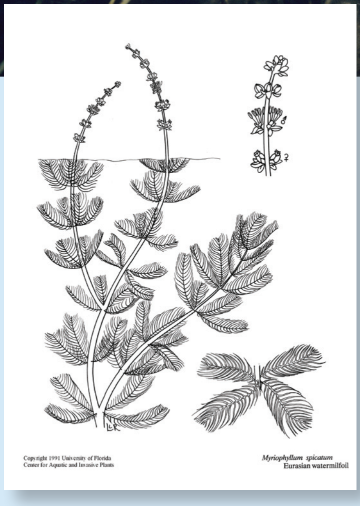
Case Study

Eurasian Watermilfoil

Picture the following scenario: You work hard and escape for a few weeks each year to a beautiful lake to rest and rejuvenate. You eventually buy a house on this lake. You are thrilled to be living in this amazing spot. You enjoy hearing the loons call at night, you watch fish swim under your dock, and you swim in the cool water. You shop and dine in the local town that caters to the tourists that flock to this region to enjoy this lake. Then, a boater launches his boat into the lake with a piece of a plant attached to his propeller. He has no idea that this plant, which he must have snagged in a lake in another state, is an invader that will take up residence in this lake and change the ecosystem and the human community forever.

The invader in this case is called Eurasian watermilfoil, and is an escaped species from the aquarium trade. Although native to Europe, since its introduction into the United States in the 1940s, it has traveled to most states and parts of Canada. Once it is introduced into a lake or pond, it crowds out most other native plants to such an extent that they can no longer grow. It changes the amount of sunlight that penetrates the lake, alters nutrient concentrations, limits the mixing of water (creating ideal conditions for mosquitoes), and can lead to reductions of oxygen in the water (which is bad for fish and invertebrates). The mats of milfoil also make it difficult for people to enjoy the lake, interfering with swimming, fishing, and boating. In sum, the Eurasian watermilfoil completely changes the lake.

So, your town and state decide to try to eradicate it. However, this process is extremely difficult, costly, and almost impossible to complete because this plant is very hardy—broken pieces of plant left in the lake will root and grow new plants. Removing every individual before they can establish (they can establish in just one summer season) is the best hope. Unfortunately, in your town it was not caught in time, and now Eurasian watermilfoil is well established. Now your town is economically stressed because of the decline in tourism dollars—who wants to come swim, boat, and fish in a lake choked with weeds? Stores and restaurants have closed, property values have plummeted, and town-infrastructure projects have been halted because of the decrease in tax revenue.



Not only has Eurasian watermilfoil changed the lake, but also it has changed the entire community, both ecologically and commercially.

Eurasian watermilfoil is one of the most ecologically and economically destructive invasive species, but there are many others that have similar negative effects on freshwater ecosystems, including zebra mussels, carp, and some species of snails. Many other invasive species have less obvious effects on human uses of ecosystems but can dramatically affect native plants and animals. Read more about how U.S. Department of Agriculture scientists are working to control the spread of watermilfoil at http://www.ars.usda.gov/is/AR/archive/mar99/foil0399.htm.

Student Thinking

Threats to Diversity of Life in Freshwater

Students often have trouble understanding the diversity of life in freshwater ecosystems because much of the diversity consists of microscopic plankton, macroinvertebrates, clams, and small fish—species we hardly ever see and that live in an environment not familiar to us. Often, the only awareness of freshwater biodiversity students bring to the classroom might be the fish they can catch. Students frequently talk about freshwater in terms of recreation rather than biodiversity. “Oh, that spot is too dirty to swim.” Or “That’s not a good place to fish for trout.” Understanding the species (including the small and microscopic species) that make up the biodiversity of freshwater ecosystems and how they are interconnected is a critical component to understanding why biodiversity is important.

	Common Student Ideas	Scientific Concepts
Changes in biodiversity in freshwater	Fresh water places mostly have fish, frogs, and a few other living things. Humans do not really affect these places except through fishing.	Freshwater animals are disappearing at a rate four to six times as fast as animals on land or at sea. Humans are affecting biodiversity in freshwater through the use of fertilizers and pesticides, by introducing invasive species, overfishing, and altering Earth’s climate.
How invasive species change communities	Anything living in the local environment is supposed to be there. If there are lots of one type of living thing, that means it is in the right environment.	Invasive species often outcompete native species and can affect ecosystems by altering the biodiversity and the natural functioning of the system.
The role of wetlands and estuaries	Wetlands are swampy, mosquito-infested, useless pieces of land.	Wetlands are the most biologically diverse of all ecosystems, are natural water purifiers, store and regulate water flow (important to control flooding), store carbon, protect the young of many animals, and provide habitats for numerous animals and plants, including many migratory birds.

Ask Your Students

1. What species (other than fish and frogs) make up food webs in lakes and rivers? How can biodiversity in these ecosystems be protected?
2. Why is it that invasive species often “take over” ecosystems? What are some consequences to native species? Why?
3. What roles do wetlands play for organisms? For humans?
4. If we were to visit [local example] wetland area, what species would you expect to see there? If students only mention mammals and birds, encourage them to think about smaller animals such as insects, as well as plant species.

If Your Water Ran Out!

Pictures of Practice

In the United States, we rarely think about what we would do if we went to our faucet and no clean water came out. Yet, some Americans have been faced with water shortages before. In times of severe droughts, or when storms cause power outages or water contamination, people are faced with the reality of locating clean, freshwater for hydration, cooking, and bathing. In many countries around the world, this is their reality each and every day. Posing the question to students will not only provide the opportunity to talk about where water comes from, but it can also provide the opportunity for students to think about their local water resources. Where would they go to find water in their local communities? Would they feel that the water was safe to drink?

Students: Grade 6

Location: San Diego, California (a coastal community)

Goal of Video: The purpose of watching this video is to listen to student ideas about what they would do to find clean, freshwater.

Classroom Context

At the start of each lesson in Ms. Fortunato's water unit, she has students respond to a "problem of the day" focused on a water topic. In today's lesson she poses the question, "What would you do if you turned on your faucet at home and no water came out?" Students are given several minutes to write their answers before sharing out through whole-group discussion. Some students in class have an extra "advisory" period with Ms. Fortunato, and these students have gone out to explore the local water resources, including the San Diego River. Students bring these experiences into the discussion.

Video Analysis

As students discuss the problem of the day, several students share that there is no clean water located near their homes. These students are from diverse communities around the San Diego area, but most seemed to think that local surface waters are not available or not clean enough to drink. San Diego is a coastal desert area with limited resources, and most surface waters are affected by different types of runoff—especially urban runoff. Rebecca contributes two ideas for getting access to water given that she does not have local surface water near her home—she could buy water at the store or collect rainwater. Rebecca decides that she would prefer purchasing water at the store because the rainwater that her family collects is not clean enough for drinking. Lizzy raises the point that some people cannot afford to purchase water at the store. Ms. Fortunato says that her students have a disconnect about where their water comes from and how it gets to their tap; she says that her students do not realize they live in an area with few available surface-water resources. As shown in their discussion and interviews, most students default to saying they would have to buy water at a store.

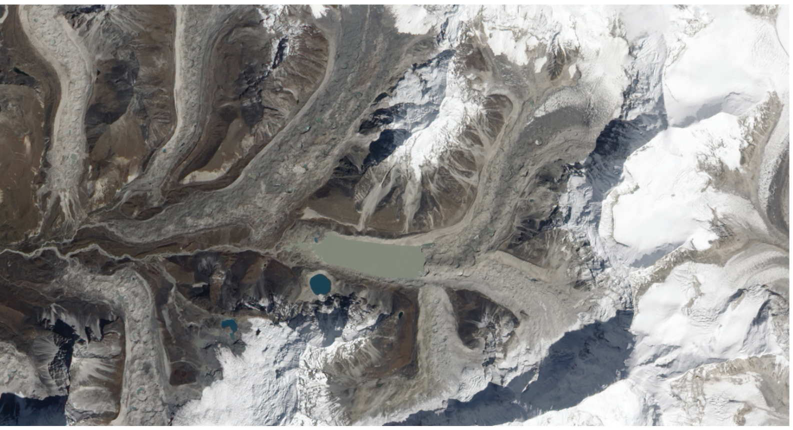
Reflect

How would you respond to students' solutions for finding water?

How would you respond to students' ideas for finding water—buying at the store, collecting rainwater, moving to a new location, or using salt water instead? In your local area, what methods for finding water would be available to your students? How would you help students better understand these resources and make the connection between resources and their tap?

Case Study

Snowmelt in the Himalayas and the Tibetan Plateau



The Imja glacier melts rapidly, forming a large lake at its base. These glaciers eventually feed the Ganges River.

Glaciers in the Himalaya and the Tibetan Plateau feed many of Asia's greatest rivers—including the Yangtze, Yellow, Mekong, and Ganges—and provide critical resources for 2 billion people (nearly a third of the world's population) and countless organisms. In recent years, the amount of ice and snow in these regions has steadily declined. The Tibetan Plateau and its surrounding mountains contain the largest volume of ice outside the polar regions, and their glaciers are melting at rates never observed before. Scientists are finding that these geologic expanses are more sensitive to recent changes in climate than almost any other place on Earth. The Tibetan Plateau is, on average, heating up twice as fast as the global average of 1.3 degrees Fahrenheit over the past century and is warming even faster in some places. For thousands of years the glaciers have formed what some call Asia's freshwater bank account—an immense reservoir of ice and snow. The addition of new ice and snow each year (deposits) has historically offset the amount that melts (withdrawals). However, in recent years, melting has been outpacing the additions of new ice and snow. Of the 680 glaciers Chinese scientists monitor closely on the Tibetan Plateau, 95 percent are losing more ice than they are adding (*National Geographic* 2010).

Scientists debate the precise rate of glacial melting because of the complexity of the factors involved, but it is clear that glaciers are melting quickly. It is possible that melting may speed in the future—as more glaciers melt, they expose more dark soil, which absorbs more sunlight than does the snow, causing temperatures to warm faster. Chinese scientists believe that 40 percent of the Tibetan Plateau's glaciers could disappear by 2050. If these glaciers continue melting, they will release a lot of water in the short run, but as they get smaller and smaller, there will be much less water for Asia's greatest rivers. The declines in water could lead to shortages of water, electricity, and food production.

These changes are happening in a region of the world that can seem far away, but the same types of changes that are occurring in Asia are also happening closer to home. For example, many mountains in the western United States are receiving less snow in the winter, and that snow is melting earlier in the spring than it has in the past. These changes are stressing water supplies in many of the cities, towns, and farms that depend on **meltwater,** including those in western states.

According to scientists at Scripps Institution of Oceanography, the warming climate will continue to reduce the water supply in the western United States (Scripps 2001). Critical water sources, such as snowmelt in the Sierra Nevadas, will decline by 15 to 30 percent in the twenty-first century. Earlier snowmelts cause meltwater to occur before reservoirs and water users can safely capture and store the water. California's water-resource managers, the public, and ecosystems will have to deal with new conditions—lower stream flows in conjunction with increased demands.

Although it may be natural to think that these changes are caused by forces beyond our control, we can each make changes that affect the potential outcome of declines in snowmelt. See Chapter 7 for examples of ways we can conserve water and reduce our contribution to climate change.

Case Study

What About Freshwater and Changing Climate?

Some basic physical principles that are incorporated into global climate models are relatively easy to understand. One of these is that warm air can hold more water vapor than cool air. Because warm air can hold more moisture than cool air, the climate along the Equator, where the sun's rays are most direct, tends to be warm and wet. Conversely, climate at the Poles tends to be cold and dry. Following the fact that warm air can hold more moisture than cool air, models predict that increases in air temperature will bring more frequent episodes of heavy precipitation. However, rainfall amounts aren't expected to increase evenly across the planet; instead, models project that most of the areas with traditionally arid climates will become even drier, and areas with wet climates will become wetter. Overall, regions are expected to see increases in extreme weather events such as droughts and floods.

In a warming climate, more and more of the precipitation that falls will arrive as rain instead of snow, especially in the mountain regions. When snow falls in the mountains, it creates a free-and-easy method of storing water. In the spring and summer, as the snowpack melts, the water runs downhill over time, moving through the watershed where it can be utilized for agriculture, business, and household needs. In many areas, the winter months already see plentiful precipitation, while the spring and summer can be drier. The melting snowpack is an important water source during those times. If precipitation falls as rain instead of snow in these mountain regions, it will flow downstream and won't be available in later times of need. This problem could be devastating to many states, especially California, where the primary source of water in the state is the snowpack of the Northern Sierras. Southern California already faces water shortage issues—should the snowpack disappear, this situation could worsen. Additionally, the lack of water, combined with warming trends and possible droughts, may also increase the likelihood of a greater number of wildfires.

Agriculture is also at risk from global climate change. Many crops are grown in a particular location due to their need for a particular temperature or rainfall amount. Farmers have determined over time where and when to plant particular species. As rainfall patterns and temperatures change, some crops may not be able to grow in areas where they have been raised in the past. Warming temperatures also favor an increase in insects that can damage crops; these can be difficult to manage without the use of toxic pesticides. Increased carbon dioxide in the atmosphere also seems to encourage the growth of certain classes of plants, most commonly known as weeds. In California, agriculture is a $30-billion industry that directly employs more than one million people and grows more than half of the nation's fruits and vegetables. The agricultural industry will need to be ready to adapt to the consequences of global climate change, or it could experience huge economic impacts that could ripple through the entire U.S. economy.

When excess nutrients build in water, this can lead to water being depleted of oxygen (hypoxic). Three jars show diminishing life as water becomes hypoxic.

Although we do not have to walk miles and miles a day for our water, we are affected by the consequences of the scarcity of clean water in other regions. The decisions made by people in those regions can affect us all.

Pollution. As discussed in Chapter 4, water pollution is a major problem. It has been suggested that it causes about 14,000 deaths per day worldwide, and is responsible for countless incidents of diseases. In addition to the acute problems of water pollution in developing countries, industrialized countries continue to struggle with pollution problems as well.

Many pollutants directly harm people or wildlife by making them sick or hampering their growth. However, many pollutants also have indirect effects. For example, silt-bearing surface runoff (a form of pollution that may come from construction site runoff) can inhibit the penetration of sunlight through the water column, limiting the ability of aquatic plants to photosynthesize. Thus the entire food chain is affected by the pollution.

As you can imagine, pollution comes from a wide variety of sources. Many of these sources are covered in Chapter 4. Here we focus on pollution from agriculture because it is one of the most widespread sources of pollution in the United States and a source of pollution often not considered by students. Students tend to focus on trash or debris as pollution but not chemical runoff from farms.

Agriculture depends on access to clean, freshwater—it uses 70 percent of surface freshwater resources worldwide (FAO 1996). Despite its dependence on clean, freshwater, agriculture is also one of the primary sources of water pollution. Agricultural pollution can be found in many forms—runoff from barnyards, feedlots, and cropland carries away manure, fertilizers, ammonia, pesticides, livestock waste, oil, toxins from farm equipment, soil, and sediment. Farmers are at the heart of a paradox. They rely on clean, freshwater and are a major source of pollution at the same time. The cause for the paradox is complex.

The government provides farmers subsidies to keep their water costs low, which in turn keeps the price of food low for consumers. Because of the subsidies, the high cost of efficient-but-expensive irrigation systems, the expense of controlling pollution (farmers already do a lot of things to help control pollution), and a mix of other factors, the agricultural industry as a whole tends to use water at unsustainable rates and continues to generate lots of nonpoint source pollution.

According to the National Water Quality Inventory, agricultural nonpoint source pollution is the leading source of water quality-impacts to rivers and lakes, the second largest threat to wetlands, and a major contributor to groundwater contamination and estuary degradation (EPA 2005). Nitrogen from fertilizers, manure waste, and ammonia turns into nitrate and nitrite. High levels of these toxins in water can lead

Did You Know?

- One out of eight people lacks access to clean water.
- Americans use about 100 gallons of water at home each day.
- Millions of the world's poorest people subsist on fewer than five gallons per day.
- 46 percent of people on Earth do not have water piped to their homes.
- Women in developing countries walk an average of 3.7 miles to get water.
- 3.3 million people die from water-related health problems each year.
- Proper hand washing alone can cut diarrheal diseases by some 45 percent.
- Access to clean water is not solely a rural problem. All over the developing world, many urban slum dwellers spend much of the day waiting in line at a pump, which hopefully will have water running that day.

(*National Geographic* 2010)

Brown, silt-laden freshwater meets the ocean. Runoff carries sediments, chemicals, and other debris to the ocean, changing marine habitats.

to a depletion of oxygen, killing aquatic life. Nitrates also soak into the ground and end up in drinking water. Most of the nonpoint source pollution from agriculture is caused by practices that we can change, such as poorly applied pesticides and fertilizers or poorly timed intervals for applications, poorly located feeding of livestock, and poorly planned field plowing. Recognizing the value of freshwater to all of us, numerous farmers and ranchers are working with government and nongovernmental programs to reduce agricultural pollution by following best practices.

Our farms are the source of our nutrition and are critical to our health, yet they are also key factors in the health of our freshwater. We need to make sure both our population and our freshwater are healthy and sustainable for our long-term benefit. This includes a long-term plan to make sure farmers can grow enough food with minimal impact on our water.

Biomagnification. "Eat lower on the food chain" is a familiar phrase when discussing the burden that humans can place on the environment. What is usually overlooked is how eating "lower on the food chain" can actually make a difference in our health.

Plants are able to produce their own energy, using sunlight and water. If the water that they absorb has been contaminated with toxins from agricultural, industrial, or even residential runoff, those toxins are stored in the cells of plants. The more contaminated water plants store, the more the toxins accumulate in plant tissues (**bioaccumulation**). Scientists are able to measure the concentration of toxins present in the tissues of plants and animals. By comparing the concentration of a toxin present in an organism with the concentration present in its surrounding environment, we can assess the build-up of toxins in that organism (**bioaccumulation factor,** or **BAF**). We have learned that although many plants and animals accumulate toxins, they are able to continue living. By studying the presence of toxins in plant and animal tissues, we have discovered that some toxins are water-soluble and some are not. Toxins that are water-soluble will be dissolved and so can be excreted by an animal. Toxins such as DDT and mercury are not water-soluble. They cannot be excreted and are stored in the fat of an animal.

Along with other animals, humans must consume the energy we need to supply the fuel for our daily activities. The higher the activity level, the greater the demand for energy. Herbivores graze on fuel that stays in one place while predators hunt moving prey.

Teaching Tip

To give students a more concrete connection to water pollution, it can help to explore examples from their own lives. For example, how is the water they drink or use in other ways stressed by pollution? The pollution can come directly from runoff, industrial waste, or wastewater discharge, or indirectly from the stress we are placing on the availability of freshwater in general. If the "solution to pollution is dilution," an approach often used, what happens when there is less water to dilute the pollution? What happens when we start competing for smaller and smaller amounts of the available clean, freshwater?

It is also crucial to show how many ways a region's water can become contaminated. Often students think it must be one bad industrial plant that is releasing all of the pollutants. It often is not the fault of just one source but many, perhaps smaller, sources of pollution that contaminate our freshwater, as in the example of nonpoint source pollution. For example, phosphorus runoff from fertilizer from many yards, and small dirt roads can pollute lakes and streams, causing eutrophication.

Check out your local water at http://cfpub.epa.gov/surf/locate/index.cfm and http://safewater.tetratech-ffx.com/ccr/index.cfm.

Consumers, such as birds, large fish, and humans are at the top of the food chain because they require so much energy. They must consume a great deal to supply that energy. Each time a predator consumes a plant or an animal that has toxins in it, those toxins are absorbed into their bodies and stored in their fat. As each larger animal in the food chain consumes more and more prey, the toxin level builds up, or is magnified (biomagnification). While the smaller amounts of toxins may not have been lethal to the plants or animals on the lower levels of the food chain, the effect of ingesting multiples of toxins can be lethal or cause serious health problems to animals higher up.

The greater the biomagnification of the toxin, the greater the health risk.

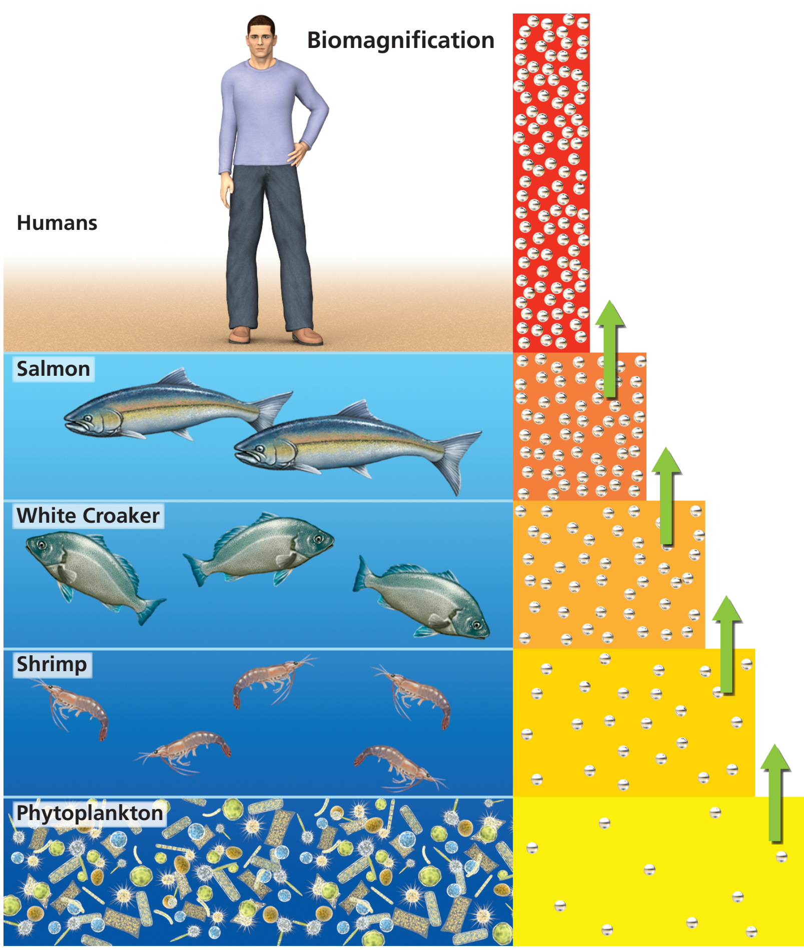
Considering the effects of bioaccumulation and biomagnification, eating lower on the food chain may be something to think about.

A classic story of biomagnification is the story of DDT (a commonly used pesticide from WWII to the early 1970s and also used for mosquito eradication) and the bald eagle. DDT contamination from agricultural and urban runoff was going into water bodies where aquatic invertebrates were absorbing it. These invertebrates were eaten by fish, which were, in turn, eaten by the bald eagles. The DDT concentration magnified at higher **trophic levels** of the food web, meaning that the eagles were exposed to large quantities of the pesticide. In the 1700s it was estimated there were 300,000 to 500,000 bald eagles in the contiguous United States. By the 1950s, there were only 412 nesting pairs. The decrease in the bald eagle population was largely due to biomagnification. DDT inhibited calcium production, making eagle's eggshells thin and making male eagles infertile. In 1972, DDT was banned in the United States, and by 1992 the population of bald eagles in the United States had rebounded to more than 100,000 individuals. The bald eagle was removed from the Endangered Species List in 2007 and is heralded as one of the great success stories of the environmental movement. While DDT was banned in the United States, it is still used in other countries around the world as an agricultural insecticide and for disease vector (e.g., mosquito) control.

Biomagnification of insoluble toxins has had two documented health impacts in California. In the 1960s and 1970s, the California brown pelican population came close to extinction due to DDT use. Like the bald eagles, the pelican eggs thinned causing breakage. After DDT was banned, the populations rebounded. In 2009, the U.S. Fish and Wildlife Service removed the species from the Federal Endangered Species List. Read more about DDT use in Chapter 7 of the Ocean Guide of this series.

A second serious health danger developed in California's Central Valley where mercury was mined, as well as in the gold-mining areas where mercury was used to process the gold. During the process, large amounts of mercury were deposited in the local sediments and waterways. As recently as 2004, fish from reservoirs and streams in the Bear-Yuba watersheds had "bioaccumulated sufficient mercury to pose a risk to human health."

BIOMAGNIFICATION



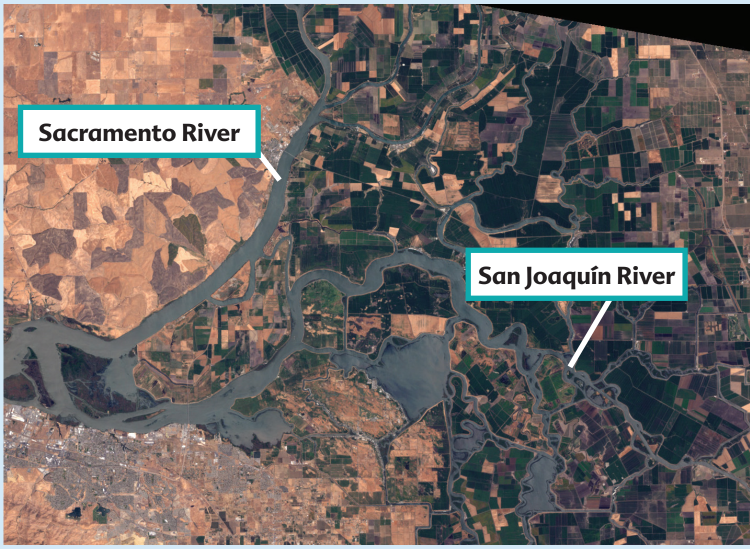
Each step of the food chain results in increased levels of a toxin. An animal at the top of the food chain collects a greater concentration of the chemical than organisms lower in the food chain.

Case Study: The Sacramento-San Joaquín River Delta

California is the most populous state in the United States, with an estimated population of more than 37 million residents. Every one of those people needs water for drinking, bathing, and cleaning. Industries throughout the state require large amounts of water as well, especially agriculture. In California, most of that water comes from the Sacramento and San Joaquín rivers. These rivers drain the watersheds of the northern part of the state, and come together at an area known as the Sacramento-San Joaquín river delta before emptying into the Pacific Ocean through San Francisco Bay.

Over the course of their journeys to the delta, the river waters are moved and diverted through a series of dams, levees, and aqueducts. The levees channel the rivers as they come together. Today, instead of joining in a marshy wetland, the rivers join via a series of smaller rivers divided by marshy islands. The levees help to keep the rivers from flooding the communities that surround the delta and keep both rivers from meandering, as they would have in the past. The levees' creation also uncovered fertile soil for farming. But the levees were originally built in the 1850s—with limited modernization over the years—and many officials are concerned about their stability.

The aqueducts of this region move water to other parts of the state. The largest aqueduct is known as the California Aqueduct, and it carries water to many farms throughout the central and southern parts of the state. Without the water, it would be difficult, if not impossible, to grow the crops for which the state is known, including oranges, grapes, avocados, and strawberries. Indeed, without this water from the Sacramento-San Joaquín river delta, agriculture would not be possible in the Mediterranean climate of the central and southern portions of California. The aqueduct also brings water to the major cities of the southern part of the state, including Los Angeles, the most populous city on the West Coast, and the second most populous city in the United States.



The Sacramento and San Joaquín Rivers drain most of the state of California. This NASA Landsat image shows the abundant agriculture that takes advantage of the fertile soils of the delta. Fish populations in the delta are in peril due to human activities affecting the health of this region.

Unfortunately, this diversion of water is not without impact on the natural river-and-delta systems. Dams and levees on the river interrupt its flow, making it difficult for many species to live. The southernmost population of the Chinook salmon lives and breeds in the Sacramento River. The Chinook salmon is an important species for commercial and subsistence anglers, both of whom rely on the species for their livelihood. Dams make it difficult for the salmon to return to their breeding grounds. Additionally, movement and use of the water, as well as development along river banks, results in increased sediments in the water. These sandy or muddy waters can smother the salmon eggs, preventing them from hatching.

Another species heavily impacted by the delta use is the delta smelt. Delta smelt populations have plummeted over the past 50 years. The population has been so drastically reduced that it is now endangered. There are many potential causes of the population

Delta smelt are now endangered due to population decline over the last 50 years.

decline, including the reduced flow of water in the delta, water pumps, and water pollution in the form of chemicals and sediments that has impacted overall ecosystem health.

The Sacramento-San Joaquín Delta is incredibly important to California. It provides water for many different interests, including cities, farms, and manufacturing. It is estimated to provide the water for more than 50 percent of the state. With so many relying on the successful functioning of the delta, a joint federal and state group was tasked with its care. CALFED was created to manage the delta and its use. This agency was tasked with balancing the needs of all the different interests vying for water from the delta.

To help the Chinook salmon recover, CALFED and other agencies removed dams along the Sacramento River. To help the delta smelt rebound, less water is being drawn from the delta from December to June, allowing more substantial water flow through the delta during those months. These decisions have not been without controversy, however. Many claim the reduction in water pumping has devastated central California's agriculture and caused the loss of thousands of jobs. Today, CALFED has been replaced with the newly-formed Delta Stewardship Council, which is made up of gubernatorial and legislative appointees with expertise in water management. The council is charged with developing a Delta Plan that is required to balance the co-equal goals of ecosystem protection and reliable water supply. Included in the plan will be a Bay-Delta Conservation Plan that focuses on needed ecosystem restoration and protection efforts. Plan authors must look at the water needs of species, cities, industries, and agriculture, and try to ensure that water distribution is fairly balanced. But many wonder if a successful balance is even possible with the growing population of the state, its agricultural interests, and a highly degraded ecosystem. The Delta Plan is scheduled for completion by 2012.

The situation is not hopeless and the delta is not a lost cause. The solutions are complex, and the responsibility for them becomes one of, not just legislation, but also individual action as well. A variety of actions that need to be taken in order to preserve this area and the state's water supply for the future have been identified. To protect people from flooding and prepare for sea-level rise due to climate change, the levees need to be reinforced or, in some cases, rebuilt. This needs to be done carefully with the improved knowledge of engineering and water flow available today. Working to improve the quality of the water moving through the watershed and reducing pollution will help all species, including humans, reliant on the delta. Working to reduce central and southern California's reliance on the water from the region will help as well. Municipalities can work to increase water recycling and reuse. Every individual can work to reduce water usage through simple actions such as watering plants only when needed, planting native and drought-resistant gardens, turning off water when not needed (like when brushing one's teeth or shampooing hair), and reducing one's overall water use. If all these actions, individual, local, and state, can occur, the Sacramento-San Joaquín river delta can continue to effectively supply Californians with the freshwater they need for generations to come without destroying the natural ecosystems that also rely on this precious resource.

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Teaching Resources

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

California Dept. of Water Resources education materials: http://www.water.ca.gov/education/

EPA WaterSense Kids: http://www.epa.gov/WaterSense/kids/index.html

Monterey Institute interactive lesson on biomagnification: http://www.montereyinstitute.org/noaa/lesson13.html

National Geographic Society 10 Things You Can Do: http://environment.nationalgeographic.com/environment/freshwater/top-ten/

UC Davis Myths About California Water: http://watershed.ucdavis.edu/myths/index.html

U.S. Geological Survey definitions: http://toxics.usgs.gov/definitions/bioaccumulation.html

U.S. Geological Survey water Q&A: http://ga.water.usgs.gov/edu/qahome.html

6 Water Rights and Human Communities

by Ari J. Posner

In the United States and around the globe, there are political struggles related to securing clean and abundant water resources. This may not seem like a real issue to your students because they simply turn on the tap and safe drinking water flows. Yet, even cities in the United States are continually monitoring the safety of municipal drinking water and promoting conservation efforts. In other parts of the world, access to safe drinking water is more of an issue.

The way we use and share water in our communities is a complicated issue. Students, however, may not understand how complicated the issue can become. Did you know that almost three-fourths of Earth's major watersheds are shared by multiple nations? Imagine what happens when one country has a population larger than their own water can supply. For example, India has 17 percent of the world's population, but only 4 percent of the world's accessible freshwater (Berg & Hager 2007). Imagine if one country has higher or lower water quality standards compared to a neighboring country. Water does not follow political boundaries.

Water is a limited natural resource, so there is inevitable tension and unrest that occurs when people try to secure their supply. This chapter builds on concepts already introduced in Chapters 4 and 5, taking a closer look at political and social issues related to freshwater such as supply and demand for water, water rights, and public-health concerns.

Water Scarcity and Stress

In the United States, almost all water scarcity issues have been addressed using technological solutions. Water scarcity can be talked about in two ways—physical scarcity and economic scarcity. Physical water scarcity happens when there is a lack of water due to droughts or depletion in surface or groundwater resources due to consumption or lack of conservation. Economic scarcity happens when people lack the

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.2 3.5.3	The Geography of Where We Live California Choices—Natural Choices
Grade 4	4.1.5 4.5.3-4	Reflections of Where We Live
Grade 5	5.3.d-e	Our Water: Sources and Uses
Grade 6		
Grade 7	7.3.a 7.3.e	Shaping Natural Systems through Evolution Responding to Environmental Change
Grade 8	8.8.4 8.12.1	Struggles with Water Agriculture and Industrial Development in the United States

technological or financial capital to take advantage of existing water resources that are accessible. For example, some countries or communities do not have sufficient infrastructure to transport water to people who need the water.

As discussed in Chapter 3, technology, such as canals and aqueducts, is needed to transport water from distant sources to areas of water scarcity. But these canal systems cost money that some communities cannot afford.

The demand for water has increased and is expected to increase further, while our supplies of water are decreasing. When human communities experience higher demands for less supply, they experience **water stress.** Water stress happens when supply of water does not match demand, or when other factors (i.e., water quality or water flow) are not sufficient for healthy ecosystems. Typically dry areas such as the Middle East and large portions of the Western United States exhibit high water stress as shown in the map on the next page.

Water scarcity and water stress are issues of growing concern in the United States. Some signs to consider include the following events, which have occurred since 2007. These are from a list of events described by Glennon 2009:

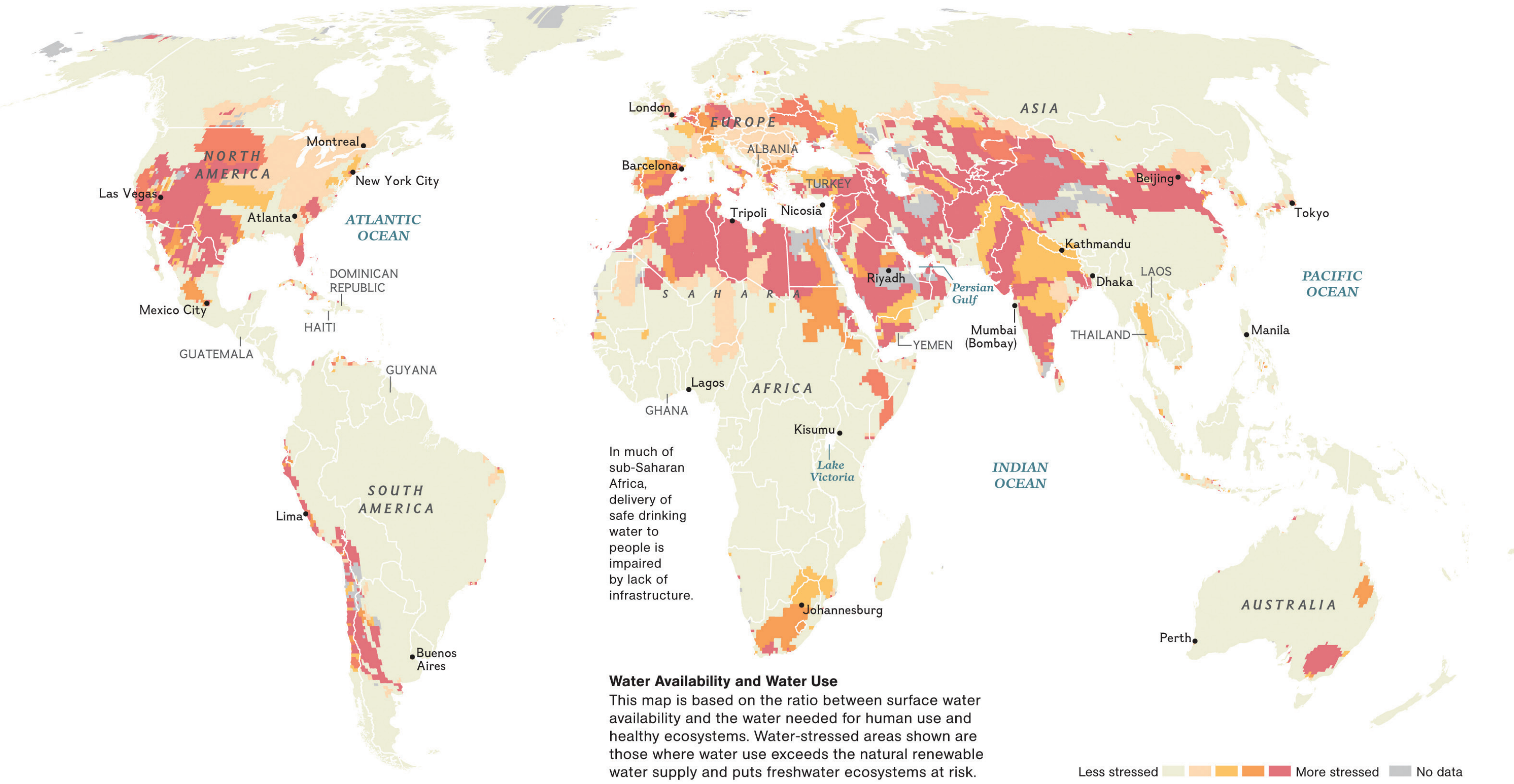
- Farmers in the western states watched their crops struggle because of lack of irrigation water.

CHAPTER OVERVIEW

Water politics are becoming increasingly heated as the population around the world grows and water supplies decrease. In the United States, the illusion of limitless freshwater is common in our communities. From turning on the faucet to washing clothes, the water used in our everyday lives is accessible and clean, and we've come to depend on that.

Water quality and water politics go hand in hand, and will only grow in importance in the future, as clean water supplies decrease. How are rights to water determined, and how will they be determined as freshwater becomes harder to obtain? The answer is not simple, because there are many different laws that govern water. There are even places, such as California, where many rules apply making the issue even more complex. Historically, the United States followed Riparian Doctrine to determine one's right to water, but Prior Appropriation, is another widely used doctrine in the American West. Conflict can arise when two countries or even two people believe their right to clean water is being threatened.

This chapter explores issues related to water rights and water politics and how human activities are making water a scarce resource.



This map is based on the ratio between surface water availability and the water needed for human use and healthy ecosystems. Water-stressed areas shown are those where water use exceeds the natural renewable water supply and puts freshwater ecosystems at risk.

- The government of the city of Atlanta, Georgia, banned the use of water for car washing, lawn watering, as well as swimming pools when the region was three months short of running out of water.
- The town of Orme, Tennessee, was forced to bring water in from Alabama in trucks as they ran out of their own reserves.
- According to the Scripps Institution of Oceanography, Lake Mead, which supplies water to every major city in the American Southwest, could become dry by 2021.
- A South Carolina paper company had to lay off hundreds of workers, because it could not discharge its wastewater into the river, due to low flows.
- At least thirty-five U.S. states are fighting with neighboring states and countries over water.

All of these issues mentioned are due to water stress brought on mostly by physically scarcity (either through droughts or overconsumption of water). In cases of extreme drought, cities also adopt political and behavioral solutions. Many of your students will be familiar with the now-common practice of limiting days and times when lawn irrigation is permitted, where the government and water companies help regulate water use. But in developing countries, there is little existing infrastructure to distribute water to communities, let alone government assistance and guidance when water needs to be rationed in drought conditions.

Water and Politics

Who really owns water? It is a natural resource found on Earth. How do we decide who owns the resource, and how it is divided among people? It is common for students to believe that whoever discovers the water or who names the body of water is able to decide what happens to it. It is also common for people to believe that if you own land with water, the water is also yours to use. However, because water is a limited resource, there are several laws protecting how we use the water.

In the United States, there is one key set of laws that governs water resources. As populations moved from England to America, they brought their traditional water laws with them. This set of laws is known as the **Riparian Doctrine** (*riparian* refers to rivers). The Riparian Doctrine originated in medieval times when landowners owned the rivers or streams that traversed their property. This meant they had the rights to water that flowed through those rivers or streams. The landowners could even seek compensation for loss of water that had been diverted upstream. The only way that non-landowners could obtain water was if they were granted permission from a landowner. Nowadays, the Riparian Doctrine still guides our decisions about water. It states that those who own property along the edge of a water body have the right to use that water as they wish, so long as it does not affect water for other riparian landowners. When this policy was put into place, the major uses of water were for domestic and livestock water needs. However, several political conflicts arose even within this system.

Water Politics in California. One example of **water politics** to discuss with students is how water was claimed during the California Gold Rush. This example makes a nice connection for students between science and social science concepts. California is also a great example of a place where two laws govern water rights. The Gold Rush began when gold was found at Sutters Mill in 1848, along the American River. At that time, water wheels played an important role in mining and timber industries. Some larger water wheels required upstream dams to increase the velocity of the water. In the dry West, these dams began to compromise the water use of some of the other riparian landowners downstream. Thus began the new doctrine that would be applied across the west, **Prior Appropriation,** which can be described to students as "first dibs" (also known as appropriative rights). During the California Gold Rush, miners were arriving everyday along the streams of the Sierra Nevada. There was an agreed-upon, unwritten law that new miners could not divert water so as to impact miners who were already there. For Prior Appropriation, a user must show that water is diverted for beneficial use.

A tomato seedling is stunted by salt buildup during a drought in California.

Because California is a state with dual water rights—both the Riparian Doctrine and Prior Appropriation are observed—the state has the **California Doctrine.** Some argue that the dual system is more efficient than favoring only appropriative rights, which has helped California manage its water shortages. Landowners still apply for water rights under the Riparian Doctrine, but appropriative rights are used to govern allocations and can be passed on or transferred to others.

When Many Rules Apply. One might call California's dual system a plural system instead because there are even more doctrines governing water rights (BLM 2001). In addition to the Riparian and Appropriative rights, there are also separate doctrines for groundwater and pueblo rights. The sheer number of these doctrines may confuse your students—which doctrine applies in which situation? A response to this question is that the state owns the water (public trust), and users hold a right to a certain amount of water. Riparian and Appropriative rights are two water-law systems that can be used to allocate water to people.

Pueblos represent another unique situation. Pueblos are communities of Native Americans. Pueblo rights are derived from Spanish law in which Spanish or Mexican pueblos have claim to water. Pueblo rights take precedence over other water rights. When determining pueblo rights we must look at the entire watershed that feeds the river or stream traveling through the original pueblo. Pueblos have rights to surface and underground water from this watershed. However, pueblos can only take water from the watershed within their modern city limits. That means that a pueblo citizen cannot go to a place outside of the pueblo limits and pull water off the watershed. Also, pueblos cannot sell excess water outside the city limits.

Groundwater is another source of water that is sometimes regulated by governments. Some states, such as California, are not authorized to manage groundwater. Thus, in these states the groundwater goes largely unregulated. In some areas, the amount of water that can be extracted has been defined by a court. In other areas, groundwater may be managed by agencies that obtain their authority from the Water Code, or there may be little or no management. Students may question who owns the water underground, and the answer is that it varies from area to area, and there is no consistent regulation of this important reservoir of water.

As surface water becomes depleted, farmers have begun to rely more heavily on groundwater to sustain their crops. The fact that groundwater is largely unregulated has led to many conflicts. One of the most dramatic impacts of increasing groundwater use in California is that of **land subsidence.** The U.S. Geological Survey (USGS) describes land subsidence as a process that "occurs when large amounts of groundwater have been withdrawn from certain types of rocks, such as fine-grained sediments. The rock compacts because the water is partly responsible for holding the ground up. When the water is withdrawn, the rock falls in on itself." (See Water Science for Schools: http://ga.water.usgs.gov/edu/earthgwlandsubside.html.) Thus, excessive groundwater extraction can result in ground compaction. In the San Joaquín Valley, land subsidence related to groundwater extraction has resulted in an almost 50-foot drop in the land surface!

Individual Rights or the Common Good. Another context to teach water politics to students is in the context of determining individual rights to water versus government control of water for the common good. One of the core issues related to natural resources is that of public trust. The Public Trust Doctrine (PTD) holds that certain resources are above private ownership and held in the trust of government to benefit the common good of the people. The government must administer these resources in the interest of the public. Each state varies in its own policies for protecting natural systems and overseeing what happens along rivers and streams. Exploring the idea of public trust through research or debates among students could provide an engaging classroom activity around water politics, especially when connected to local area issues.

California is currently going through some major battles related to **instream flow,** in which public trust has played a role. "Instream flow" describes the rate that water flows in a river. Changes to instream flow can greatly affect some of the fish populations that reside in the river. In order to protect those species and regulate flow, some conservationists are pressuring the government to list various fish species as endangered. With the protection of the Endangered Species Act and defining the habitat required by that species, minimum stream flows are set, as well as some of the spring high flows, to protect and create fish breeding and feeding grounds. This species protection sets up a controversial situation because farmers, who could benefit from access to the water in those rivers, are barely getting by with their current water allocations. This conflict has resulted in the now familiar debate in which one side argues that we are putting more value on a tiny fish rather than on our communities, while the other side argues that losing this species could mean an unraveling of the entire ecosystem.

Withdrawing water from the streams around Mono Lake, California, was a notable controversy because environmentalists were at odds with the City of Los Angeles on how the water should be used.

This fight is reaching the boiling point for the farmers of the Westlands Water District in California's Central Valley. The seminal court case is *National Audubon Society v. Superior Court Alpine County.* The National Audubon Society brought suit to limit the amount of water taken (or diverted) from the streams around Mono Lake. The Supreme Court ruled in favor of the National Audubon Society, forcing the other parties to amend water rights permits. This means that less water can be diverted for human communities in order to ensure the health of the natural community, placing the two at odds. This story provides a good case to discuss with your students, as it leads to many questions regarding how to make decisions about water use and how society deals with balancing environmental, economic, and personal issues. This case also shows how the government plays a role in determining water rights, especially given all the doctrines that may be used to make a decision.

Summary of Water Politics. Water rights and politics can provide both historical or modern-day issues to discuss with students. In recent years, there has been much criticism of the water rights and appropriations systems across the West and California, so students have likely heard something about water in their own communities. It is important to point out that despite the commonly held belief that Prior Appropriation was a marked change from the Riparian Doctrine, the fact that both of these doctrines are based on "use" is a critical link. Under current patterns of water use, California faces the prospect of chronic water shortages by 2020. Discussing conservation of water on the part of users is also necessary. **Water conservation** will be discussed in more detail in Chapter 7, providing example actions of what students can do as conscientious users.

Pictures of Practice

Who Owns Water?

Centuries ago, water rights in the United States were not an issue. There was abundant, clean water for people to use. As the population of the United States expanded, this changed. Native Americans believed that water was a sacred gift and that altering a local environment could upset the balance within the larger ecosystem. European settlers started making claims on water, following traditional Riparian Doctrine. Those that had water on their land had rights to water (and could not impede water of other landowners). In the dry areas of the American West, water was an incredible asset for ranches and mining operations, although many of the people using water did not necessarily own the land on which it flowed. During the California Gold Rush, water was the key to gold mining, so miners worked out a system of "first dibs" in order to protect their rights. Nowadays, much of the American West follows the "first dibs" rules (appropriative rights), while much of the American East still follows traditional riparian rights. California follows both. Discussing water rights and talking through different scenarios can help break down the complexity of the topic for students.

Students: Grade 6

Location: San Diego, California (a coastal community)

Goal of Video: The purpose of watching this video is to hear students' ideas about who owns water, as well as the challenge of learning about water rights.

Classroom Context

In previous lessons, students discussed water pollution and water treatment when they were posed with the question of how they could access clean water if it no longer came from their faucet. Students started thinking about who owns water and realized that they cannot simply get water from anywhere. After students had read about water rights, Ms. Fortunato posed the question again. The discussion shown in the video occurred after students had read about water rights in California.

Video Analysis

At the start of the video, students discuss that the people of California own water, but that the water is placed in the trust of the state of California. The class discusses what it means for people to own water and the difference between individual ownership and collective ownership. Taylor helps to clarify for his classmates that the California Doctrine refers to collective ownership of water. The class then discusses both riparian rights and appropriative rights. The segment shown in the video is students sharing what they had learned about riparian rights. Note that most students talk about landowners' right to use the water but do not mention their responsibility for putting back the same quantity and quality of the water, which is an important aspect of riparian rights. As shown in the postinterviews, learning about water rights was one of the most challenging things students did all week. Zach, and other students, originally thought that water was owned by the people who found or named the water. After these lessons, Zach realizes this is not the case. Thomas seems to grasp a much more complete understanding of riparian rights compared to his classmates but focused mainly on water quantity and not necessarily on returning the same quality of water.

Reflect

What should students know about water rights?

Water rights can be confusing to students because water cannot be owned like land is owned. What concepts would you teach about water rights?

In the Classroom

Water Allocations

Water conflicts tend to arise when water becomes scarce, either due to increased population or decreased precipitation. In years of abundant precipitation, most water users get their share. In drought years, this is not always the case. In this activity, students explore what happens to water allocations during different years.

Materials

- Two buckets (one filled with water)
- 16-ounce cups or glasses
- Blue tape

Directions

1. In this activity you will have eight students role-play as different stakeholders that must share water along a river. Research your local area to make these stakeholders relevant. Consider having the following types of stakeholders—agriculture/farming, rancher, environmental preserve, mine operations, manufacturing, one or two cities, power plant, and another industry that is found in your local area. After determining your eight stakeholders, decide the stakeholder's allocations: either 32 ounces (2 cups), 16 ounces (1 cup) or 8 ounces (1/2 cup). Stakeholders that use a lot of water get 2 cups, while stakeholders that use less water get 1 cup or half a cup of water. Make labels for each stakeholder, with their name on one side of the label and allocation on the reverse side.
2. Using the tape, outline a river on the carpet or floor that is about 8 to 10 feet long.
3. Have the eight students draw a stakeholder label from a hat, followed by a number (numbers 1 through 8) that determines their order along the river. Have students line up along the river.
4. The first round of this activity will represent a normal year with ample precipitation. Start with the first stakeholder and ask what his or her allocation is. Give the student enough cups to hold the assigned allocation, and fill the cups using the bucket of water. Move on to all of the stakeholders. In this round, all students should receive their allocation.
5. Have students pour their water back into the bucket, then pour 1/3 of the water from the bucket into a second bucket. The water remaining in the first bucket will now represent all the water available in a drought year.
6. Repeat the activity as done in step 5, but because it is a drought year, at least two of the stakeholders at the end of the line should not receive their water.

Discuss

1. Is it fair that [X] and [X] did not receive water? What is a solution in a drought year, and who should come up with this solution?
2. Ask students to consider how this might be different if it was Riparian Doctrine and all eight stakeholders owned land next to the river (e.g., each stakeholder would have to return the water undiminished and unpolluted).

Student Thinking

Water Ownership

Students, especially those in urban areas, may have never thought about who owns and controls the water in their area. They may have heard of controls on days and times to water their yards, but they likely think that water from their cities is limitless. Oftentimes, the city water comes from a location far away, taking water from other communities. While controls vary depending on surface or groundwater, each state and federal government regulations ensure that one user does not impede the use of others drawing from the same water source.

	Common Student Ideas	Scientific Concepts
Water ownership	Whoever lives near water owns the water, or if you live in a city you have limitless water from the city. If you name the body of water, you have a claim to it.	Water is owned by state or federal entities, but rights are granted to individuals for a certain amount of use. Individuals cannot take so much water that it reduces another user's access. Surface water is more controlled than groundwater.
Water use	People cannot get in trouble for using too much water.	Individuals may pay more if they use more than a certain amount of water, or they may be fined for violating regulations on the amount of water they can use, especially when watering yards.
Owning land and owning water	If people own the land, then they own any water on the land or underground.	Owning land does not ensure limitless access to the surface or groundwater. A landowner cannot change the amount of water flowing to another landowner. Aquifers may have regulations that all users must follow.

Ask Your Students

1. Where does your water come from and who do you think owns the water? Why do you think [X] owns the water?
2. What might be the social, financial, or political consequences for using too much water?
3. How might owning land influence the rights you have to the water that flows through your property?

Pictures of Practice

Conflicts Over Water

In drought-stricken areas, students may be aware of conflicts over water because they have grown up with people and industries fighting for their fair share of water. In other areas with more abundant water, students may not be familiar with these conflicts. Conflicts over water rights and water quality happen around the globe, from international conflicts in the Middle East and on the U.S.-Mexico border to local conflicts about rivers and streams in local communities. People fight over water just like they fight over other precious resources, such as gold, diamonds, and oil. Water is more precious than many of these other resources because it is vital to life. When students are presented with such conflicts, they may bring up ideas about “sharing” and “fairness” and find it difficult to understand why people fight over water. Discussing the complexity of the issue with students will help them see different perspectives about the topic, including how different stakeholders make their claims for water.

Students: Grade 6

Location: San Diego, California (a coastal community)

Goal of Video: The purpose of watching this video is to hear students’ questions and ideas about why people fight over water.

Classroom Context

At the start of each lesson in Ms. Fortunato’s water unit, she has students respond to a “problem of the day” focused on a water topic. In today’s lesson she poses the scenario, “Imagine two towns that sit on opposite sides of a lake. Who do you think has the right to use that water?” Students write for several minutes, then share out as a whole group. This is the first activity in Ms. Fortunato’s lessons on water rights, so students have not yet learned about doctrines governing who owns water. However, students have discussed conflicts over water in different scenarios over the past few weeks of class.

Video Analysis

Ms. Fortunato says that students are finding it challenging to understand conflicts over water. Students want water to be equitably distributed, or shared, among the people who want the water, but when money or other factors come into play, the access to water may not be “fair.” In California, there are two key doctrines that govern who gets the water—riparian rights (if the water is on your land) or appropriative rights (allocations based on seniority and use). When conflicts arise, the government or a third-party official can step in to resolve the conflict, although many disagreements about water are ongoing. When presented with scenarios about water conflicts, students will engage in debates about who owns the water. In this lesson, you will hear students describe their ideas about sharing and fairness. Salma seems especially perplexed by the topic. She thinks that the person who decides what happens to water is the one that lives “next to the body of water.” Salma never seems to gain an understanding of the conflict, and in her post interview, she says it was one concept she still does not understand well.

Reflect

How would you teach about water conflict?

Think about the ideas shared by students. If these students were in your classroom, how would you respond to their questions? What concepts about water conflict would you teach to students and why are these important?

Case Study

Water in Border Regions

Water does not recognize international boundaries, and the California-Mexico boundary has long been a source of contention between the United States and its southern neighbor. Regarding border-related water quality, there are two primary areas of concern. The first is near the Tijuana/San Diego border. For years Tijuana had a severely inadequate wastewater-treatment system. In many cases, untreated effluent was dumped into the ocean, which then floated north, contaminating California beaches. The United States invested, and continues to invest, millions of dollars to provide clean water and to treat effluent in Mexico along the border region. The EPA-administered U.S.-Mexico Border 2012 Program is providing tens of millions of dollars to border communities on both sides to protect water and air quality. In Tijuana alone, there are eight water-related infrastructure projects, nearly all of which target improving wastewater facilities and the adequate treatment of effluent.

Another primary area of concern is farther inland, along the New River, which passes through Mexicali in Baja California, Mexico, and runs north into Calexico, California. The New River's water is polluted with waste from agricultural and chemical runoff from industry irrigation in the United States (18.4 percent) and Mexico (51.2 percent), sewage from Mexicali (29 percent), and manufacturing plants in Mexico (1.4 percent). When the New River makes its way to Calexico, California, the water contains numerous contaminants, such as pesticides and heavy metals. The river also has pathogens that cause numerous illnesses, such as polio, cholera, and hepatitis. The contaminants in this river are far above acceptable levels set by the U.S. Environmental Protection Agency (EPA) and California EPA, making it one of the most polluted rivers in the United States.

To the right, a surfer heads into waters contaminated with sewage from Mexico. Water issues have long been a problem along the border between the United States and Mexico. The photograph above shows Mexicali, Mexico, (left) and Calexico, California, (right) as two different types of communities that can contaminate water in different ways.

While many are working on solving the problems along the New River, there is no comprehensive plan in place that meets the needs of both countries and all parties involved. With financial support from the United States, Mexicali has improved sewage treatment and reduced untreated discharge. The New River is an excellent example of some of the issues faced by bordering countries trying to learn to share resources across their borders.

In the Classroom

Water Wars Around the World

Much of this chapter has discussed water politics in the United States and close to home. However, students should be given opportunities to learn about water issues around the world. This activity explores water resources in the Middle East, an area where water is more precious than gold. Two of the earliest Middle Eastern civilizations, Egypt and Mesopotamia, developed along rivers where water was plentiful. Today, dwindling water sources become a common source of conflict. In this activity, students will explore the role of freshwater in the Middle East region.

Materials

- Physical map or atlas of Middle East region
- Blank Middle East outline map, http://education.nationalgeographic.com/education/mapping/outline-map/?map=MiddleEastPolitical
- "Water Deal Elemental to Mideast Peace, Experts Say" article, http://news.nationalgeographic.com/news/2008/06/080603-israel-water.html

Directions

1. Display or turn to the physical map of the Middle East region.
2. Using the map, ask students to locate ancient Egypt and Mesopotamia (modern Iraq), and then name other countries of the region.
3. Distribute the blank Middle East outline map and have students label countries. Prompt students to look at the physical geography and features of the region and point out water sources—both fresh and salt water. Major rivers include the Jordan, Tigris, Euphrates, and Nile. Other major surface waters include the Persian Gulf, Red Sea, Gulf of Aden, Mediterranean Sea, Caspian Sea, Dead Sea, Gulf of Aqaba, Sea of Galilee, and Gulf of Suez. In addition to surface water, students should also label the large underground water resources, such as aquifers, in the region. For example, the Yarkon-Taninim aquifer, the Eastern aquifer, and the Nablus-Gilboa aquifer. For more background information on water resources see http://www.fao.org/nr/water/aquastat/countries/iraq/index.stm.
4. Ask students to think about the importance of freshwater as they consider the following quote taken from a *National Geographic Daily News* article: "Many of the wars of this [twentieth] century were about oil, but the wars of the next century will be about water." —*Former World Bank V.P., Ismail Serageldin.*
5. Distribute and read *"Water Deal Elemental to Mideast Peace, Experts Say"* article.
6. Revisit the map and identify key areas of potential and current conflicts around water. Then lead a class discussion using the "Discuss" questions below.

Discuss

1. Why did civilizations develop along rivers? Why was water important?
2. Why is freshwater a source of conflict in the Middle East region?
3. What short-term solution to water scarcity is Israel exploring? What are some of the benefits of this solution? What are some other possible solutions you would consider?

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Teaching Resources

California Education and the Environment Initiative: http://www.calepa.ca.gov/Education/EEI/default.htm

National Geographic Society Freshwater 101: http://environment.nationalgeographic.com/environment/freshwater/freshwater-101/

USGS Water data for California: http://waterdata.usgs.gov/ca/nwis/

USGS water resources for California: http://water.usgs.gov/

Water Education Foundation resources: http://www.watereducation.org/watersources/subpage.asp?rid=&page=382

7 Water Solutions for Our Future

by Jose Marcos-Iga, Tania T. Hinojosa, and Tara G. Treiber

"Anything else you're interested in is not going to happen if you can't breathe the air and drink the water. Don't sit this one out. Do something"
Carl Sagan

While we may not experience it in our own daily routines, Earth is experiencing a freshwater crisis that is affecting many people around the globe. As water shortages spread, we could feel the impacts (and already have to some degree). For example, food supplies and food prices may change based on water availability, along with other impacts that might affect our economic stability, our cost of energy, and so on. We know that water scarcity and water quality are problems and that scientists, entrepreneurs, and everyday citizens are in the midst of finding solutions to alleviate these problems. Understanding the core issues and how human use of water impacts our communities is only the initial step. We must also learn how to be participants in our water solutions.

As populations and economies grow, so too will the demand for water. Promoting in our students a deep understanding of our water footprint (beyond the water we use for drinking and bathing), and the ways we can help reduce that footprint, is one way to empower students to protect the freshwater resources all living things depend upon.

Water conservation happens on many different levels. In order to maximize conservation and use water most efficiently, we need to consider water-use decisions that can be made by individuals and families, by communities, and by businesses and government. Additionally, developing cost-efficient technologies that improve use of water will contribute to sustaining our freshwater supply. In this chapter, we will discuss the water crisis, as well as how to raise

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.2 3.4.1–2 3.5.1–3	The Geography of Where We Live California Choices—Natural Choices
Grade 4	4.1.5 4.5.3–4 4.4.7	Reflections of Where We Live
Grade 5	5.3.d 5.7.3	Our Water: Sources and Uses
Grade 6		
Grade 7		
Grade 8	8.3.2 8.3.6 8.8.4 8.12.1 8.12.5	 Struggles with Water Agriculture and Industrial Development in the United States Industrialization, Urbanization, and the Conservation Movement

awareness of water consumption by individuals, and the current technologies that exist for being green about the water that we use.

Is the Water Crisis Crystal Clear?

Most of us have grown up learning that water is a valuable resource and that we need to use it wisely. Over the years, water conservation campaigns have come and gone with seasonal droughts. Many of us have changed our showerhead, taken shorter showers, and made sure we only run full loads in our dishwasher. Most people are also more conscientious about when and how they water their lawns. But is this enough?

A recent study that included 32,000 adults from 15 countries found that people tend to view water issues, such as water quality and shortages of freshwater, very seriously (GlobeScan 2009). Water issues are perceived to be more serious than other environmental problems such as air pollution, loss of biodiversity, and depletion of natural resources. Nonetheless, when looking carefully at

CHAPTER OVERVIEW

As water issues become increasingly globalized, international organizations are stepping in to assist in the access to clean drinking water. The United Nations and other groups are aiding countries that do not have reliable access to clean water because of economic, political, and geographical issues. Innovative technologies that will ensure freshwater availability, such as desalination and rainwater harvesting, are vital to all Earth's people, including many in the United States.

Although it is extremely important to understand that water issues are of global concern, understanding local water issues and policies is also important. Reducing one's own water footprint can have a great impact on the overall availability of freshwater to people locally and globally. Small actions like buying local products, installing low flow faucets and toilets, and reducing overall consumption of products, can go a long way toward ensuring that freshwater is available for generations to come.

This chapter will review the issues the world is facing with freshwater scarcity, the solutions that are being introduced, and the ways students, and their schools and communities, can help.

the views by country, only 60 percent of Americans view freshwater shortages to be a very serious issue. To put this in perspective, in a country like Mexico, where water scarcity has historically been a salient problem with impacts felt by the majority of the population, 92 percent of the respondents rate the issue as very serious.

The study also found that the perception of water-issues seriousness has increased consistently over time. But is awareness enough to move individuals into action? When asked who is responsible for ensuring clean water availability, Americans, along with respondents from the United Kingdom and Russia, tend to hold water companies accountable. Canadians, along with citizens in China and India, believe that ensuring clean water availability is the responsibility of the government. Only in Mexico do the majority of respondents hold citizens responsible.

When people put the weight of responsibility for issues such as freshwater availability on the government and the private sector (i.e., water companies), typical citizens tend to feel there is not much they can do. Findings like the ones from this study can help you predict how students may feel about freshwater issues. If they believe the government or water companies are responsible, they may feel there is little they can do to help.

The government is responsible for helping to regulate water, as discussed in Chapter 6. Water, as a shared natural resource, is regulated by the government for the benefit of the people. But government and the water companies that distribute water are not the only ones that can be part of the solution. In this chapter, we first explore some ways governments and nongovernmental organizations are stepping in to assist in freshwater issues. We then review innovative technology that may alleviate some of our freshwater problems. Lastly, we share actions that each and every citizen, family, school, and community can do to become part of the solution.

Villagers and a donkey get water from a trough in Marsabit, Kenya.

Mitigation of Our Water Problems

While we each are responsible for our own water use, governments and organizations are continuously working to develop efficient and safe water-use practices. Sometimes these practices are called **mitigation** strategies, because they are aimed at reducing the impacts that will be felt if left unregulated. Governments, nongovernmental organizations (NGOs), and international aid organizations are engaged in mitigation because they foresee water issues we will experience in the next few decades or even the next few years, and they are trying to reduce the potential impacts we will experience.

When asked who makes decisions about water problems or water conflicts, students may point to the government, yet they do not understand how government steps in to remedy a conflict. They may not realize that many countries do not have the same accountability system that we have in the United States. Discussing different levels of government cooperation and policy may help students understand the role government plays at different levels—from local water decisions to global water crisis.

Global Policy—The World Water Council and United Nations. Because some governments do not or cannot assist its people on water issues, there are international organizations that aid these countries. These organizations look at water from a global perspective and try to build collaborations between nations.

The United Nations Environment Programme (UNEP) is one of the major players in world water issues. When the United Nations General Assembly passes resolutions and sets international goals, some of these goals are monitored and assessed by UNEP. For example, in 2000, the United Nations passed a resolution called the Millennium Declaration. This declaration included target goals for getting clean water to all communities, especially those in water-stressed areas. The United Nations has long upheld the belief that access to freshwater is a basic human right.

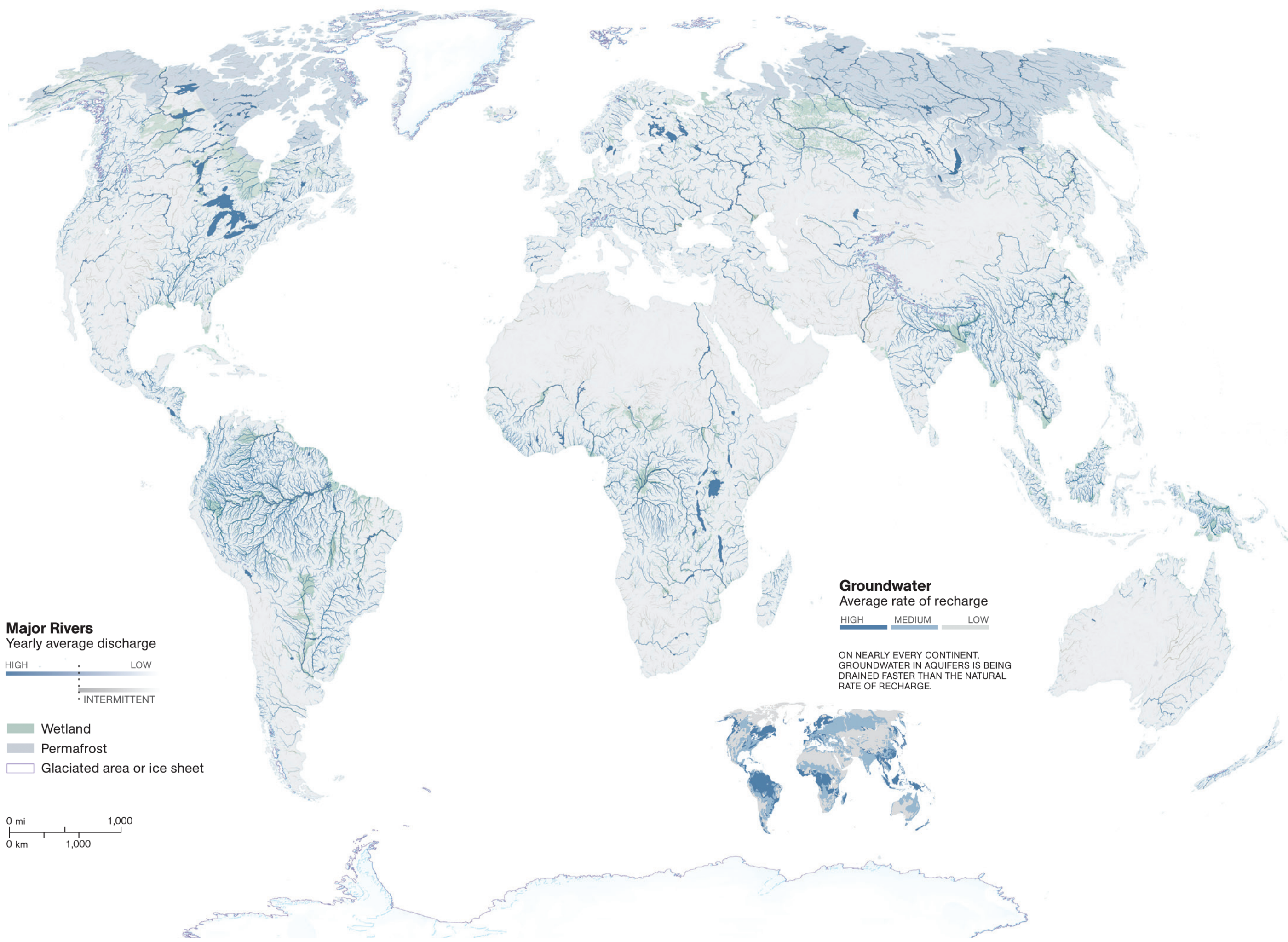
When the Millennium Declaration was created, UNEP (as well as several other organizations) was charged with carrying out the UN water policy and monitoring the progress made on the freshwater goals. Most of these goals related to developing water-resource-management systems in struggling countries, especially those with poor sanitation systems as well.

In addition to UNEP, the United Nations also created UN-Water, a division responsible for helping to share resources between countries and organizations. The UN-Water division is the central clearinghouse for all reports and publications on world water issues, many of which are published in six or more languages. You can visit UN-Water to download the latest progress reports on issues such as safe drinking water and sanitation. In this way, countries can learn solutions from each other, rather than feeling alone on these issues.

Your students may have heard of the United Nations, and would like to know more about how international organizations work. Discussing the UN approach to freshwater is one way to introduce the organization to your students. Because so many countries share water—from lakes or rivers along borders, to underground aquifers—international organizations are important resources for reducing conflicts over water and supporting global cooperation for solving the world's big problems. Simply show your students a map of the world's watersheds with no political boundaries included, and then overlay a map of pollitical boundaries. Students will quickly realize that regulating water is important at the international level.

The Right to Water

"The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses. An adequate amount of safe water is necessary to prevent death from dehydration, reduce the risk of water-related disease and provide for consumption, cooking, personal and domestic hygienic requirements".
—UN Committee on Economic, Social and Cultural Rights



Case Study

Aid for Water-Stressed Communities

SODIS, a Swiss-pioneered method for water-disinfection in tropical and subtropical countries, uses only a clear water or soda bottle made of PET plastic and six hours of solar exposure on a sunny day. After six hours of placing the bottle in full sunlight, the UVA radiation from the sun will kill viruses, bacteria, and most parasites in the water, making it safe to drink. Placing the bottles on a piece of shiny metal can enhance the disinfection efficiency. More information: www.sodis.ch.

Mixing a powder made by the corporation Pur into polluted water not only kills bacteria but also makes dirt, metals, and parasites clump together so they can be filtered out, leaving crystal clear water in just 30 minutes. Population Services International and other aid groups distribute the Purifier of Water product to help combat waterborne diseases (*National Geographic,* April 2010)

Some 900 million people lack access to safe drinking water. Sipping water through a LifeStraw filter at any water source reduces the transmission of bacteria and viruses. Thousands of ten-inch LifeStraws were donated to Haiti after the 2010 earthquake. Each filters about 160 gallons, but there is now a new model that filters up to 265 gallons (*National Geographic,* November 2010).

In impoverished rural areas, clean water is often miles away from the people who need it, leaving them susceptible to waterborne diseases. The sturdy Q Drum holds 13 gallons in a rolling container that eases the burden of transporting safe, potable water—a task that falls mostly to women and children (*National Geographic,* November 2010).

National Policy—The Clean Water Act. As discussed in Chapter 4, the Clean Water Act (CWA), enacted in 1972, is the primary federal law for surface water protection in the United States. The CWA is aimed at reducing pollutant discharges into waterways and financing municipal wastewater treatment facilities, and managing polluted runoff as well as the allowance of certain pollutant concentrations. For example, the CWA set Water Quality Standards that outlined specific substances to measure for water quality that protects human health and aquatic life. The standards for each body of water are determined by how the water is used—whether for drinking, fishing and recreation, habitats, or homes, farms, and industry. A single body of water can have multiple uses—for example, a river can be used for recreation and fishing on one segment and reserved for habitat protection on another. Each segment is monitored according to different standards, but it must meet its standards regardless of whether the segment above or below has stricter or more lenient standards. You can imagine the challenge associated with these standards given that many bodies of water are shared, and upstream activities have substantial impact on downstream environments.

The Clean Water Act is the major piece of American legislation to discuss with your students. The Safe Drinking Water Act is also another cornerstone piece of water legislation. Both are excellent examples of how the government plays a role in water issues, especially in making sure that our water is clean and safe to drink, and that cities, industries, and agriculture also meet particular water standards. Students may wonder what happens to people and industries that do not follow laws. In many cases, the polluter cannot be identified, and thus, the burden of cleanup may fall to government agencies or to cities. But when the polluter is identified, the person or industry may face fines and be responsible for cleaning up their mess.

Even developed countries such as the United States have water problems. This photograph shows a city worker clearing trash from Ballona Creek in Los Angeles, California. Imagine the water conditions for living things found in this creek. Would you be willing to drink this water if no other water was available?

Local Policy and Programs. In order for global or national policies to have an effect at the community level, local agencies and programs must see that these policies are tailored to the needs of the community. For example, rural areas may focus on runoff from agriculture more than the storm/urban runoff that is such a pressing issue in urban areas. In urban and municipal areas, local officials have to pay attention to two major sources of water pollution from runoff: the storm-water runoff after heavy rains and the ongoing water being discharged by people through overwatering yards and washing cars and driveways. It doesn't matter whether it is a rainy or dry time of year, there are always sources of runoff in local communities. Developing local policy and plans are important for seeing that water is protected in one's community.

Storm water/urban runoff represents an excellent example of how local communities handle water issues. Decades ago, many urban communities allowed for a great deal of natural space to be converted to impermeable surfaces, such as pavement and concrete. Cities installed storm-water systems to drain precipitation from these surfaces in order to prevent flooding. Today, many of these systems are outdated or overwhelmed by the volume of storm water/urban runoff. A 10-acre parking lot can drain 270,000 gallons of storm water after a one-inch rainstorm! (American Rivers and Midwest Environmental Advocates 2008) Another problem with impermeable surfaces is that pollutants, such as trash, fertilizers, pesticides, oil, and other engine fluids, are carried along our streets by rain or urban water, enter the storm-drain system and are released into streams and marine areas, where the pollutants can harm aquatic plants and animals and threaten public health.

Local communities are trying to control their storm-water runoff by reintroducing permeable (or pervious) surfaces. In some situations, a mayor or city council can designate funds to be used for this purpose. However, if the city wants to formally change the building codes in their communities, a city ordinance must be passed. You may hear this approach called "Low Impact Development" or LID. An LID approach mimics the predevelopment runoff conditions by infiltrating or capturing and using rainwater. LID focuses on a specific site at which something is being redesigned or built for the first time, to determine the best approach for managing storm-water and urban runoff. Oftentimes LID includes the use of rain gardens, green roofs and rainwater harvesting, and permeable pavement options. Most cities in California now include plans or handbooks for LID development.

On even smaller scales, individual homeowners and businesses are introducing permeable surfaces. For example, the Aquarium of the Pacific in Long Beach, California, has installed permeable pavers in their walkways. Unlike traditional concrete sidewalks, permeable pavement allows water to soak, or percolate, through to the ground. Permeable pavement is recommended only for low traffic areas, such as sidewalks, roofs, bike lanes, driveways, and some parking lots. For example, the City of Santa Monica, California, has permeable pavement parking lots and parking strips along the streets. Consider reviewing the urban water cycle from Chapter 2 with students to help them better understand why local governments and businesses are so concerned with permeable surfaces.

Teaching Tip

When students think of sources of pollution in freshwater, it is easy for them to think of things they can see. Their familiarity with images of contaminants coming out of factories can lead them to focus almost exclusively on pollution from industry instead of pollution they may contribute as community members. Many sources of pollution come from our own neighborhoods. The good news is that these are the sources that students and their families can do something about. Examples of these include (source: Environmental Protection Agency 2010):

- Oil, grease, and toxic chemicals from motor vehicles
- Pesticides, fertilizers, herbicides, and insecticides from lawns and gardens
- Viruses, bacteria, and nutrients from pet waste and failing septic systems
- Heavy metals from roof shingles, motor vehicles, and other sources

Have students research ways that they and their family members can protect water quality in their everyday lives. Students can develop a class brochure describing ways to protect water quality that they can share with family members and students in other classes.

This storm-drain sign in La Jolla, California, warns citizens against dumping pollution down the drain.

Case Study

True Cost of Water

Water is something we often take for granted because water comes into our homes and leaves our homes with simple actions such as turning on a faucet or unplugging a drain. These simple actions are miraculous when you consider how many things go into making them happen. For much of human history, and, indeed, for a great deal of the world today, access to clean and freshwater was not so simple.

In the United States, we are able to turn on that faucet because of the creation of a system of pipes, aqueducts, wells, and filtration plants. These have been built and refined over time as settlements and governments have grown. Consider the amount of infrastructure and the number of people involved in bringing that water to our faucets. All of this work costs money—money to build and maintain the aqueducts and pipes and money to pay for electricity to power the water-moving pump and water-cleaning filters.

The business of water is huge, and managing water resources can be difficult in terms of balancing fiscal issues with human needs. Companies, public and private, get paid by the amount of water used by their customers; therefore, it is often in their best interest to encourage consumption and use of large amounts of water to keep their business in the black.

Terms and treaties decide how water is distributed and where it is available. Many water-rights policies were established years ago and have not changed much over time. One of the slogans that has been a problem in encouraging water conservation is "use it or lose it." This policy essentially states that if an area uses less water currently than in the past, it is demonstrating that it does not need as much and is forfeiting the rights to future increases or may have to pay more for additional water in the future. This can encourage the overuse of water at times just to make sure that it will be available for the future.

Due to availability, need, and subsidies, the cost of water can vary greatly from region to region. In urban

areas, due to greater water needs and associated infrastructure costs, water tends to be more expensive than in rural areas, which alone can encourage conservation. Water for agriculture is heavily subsidized. Farmers often pay less for their water than it costs to pump it to them. Because they are not paying the true cost of the water, farmers may have few incentives to conserve.

There are many indirect costs associated with water use as well. Overuse of water can lead to less water for power generation at dams and to habitat loss and decline of organism populations. Underuse or misuse can cause flooding, pollution, and other problems. All of these can have huge economic impacts. Using the optimum amount of water, in a water efficient system is important both environmentally and economically for our society.

This brief introduction to the intricacies of the economics of water use and conservation shows how complex the issues can be. These complexities make it almost impossible to calculate the true cost of water. As a result, it is important for every person to do what he or she can to help conserve water whenever and wherever possible and to engage in water efficient practices, from turning off faucets to rainwater collection to reducing potential pollutants that enter our water systems.

Case Study

Successful Agriculture

California is known for its agricultural industry. In 2008, California had 81,500 farms and ranches. California was the top producer for dairy products in the United States, supplying Americans with 22 percent of the milk consumed across the country. Nearly half of the fruits, nuts, and vegetables grown in the United States are grown in California! (CDFA 2010).

Unfortunately, this industry is also responsible for utilizing large quantities of freshwater, and for causing polluted runoff that is drained into the California freshwater and the ocean. We depend a great deal on California having a successful agricultural industry. There are several examples of California farmers using water-friendly practices. Importantly, most of these successful farmers are using technology that already exists! For example, almost 40 percent of California farms are now using water-efficient **drip irrigation** systems, as compared to the old system of flood irrigation, which requires much more water (Pacific Institute 2010). You may wonder why more farms have not converted to the new system, but changing irrigation systems requires a financial investment. This money is ultimately returned because the farmer saves on water cost, but some farmers cannot afford the initial investment cost. Luckily, many farmers are seeking financial assistance to change their systems by using low-interest loans from the state.

Water in the Coachella Valley in California represents a notable example of how state mandates led to local successful water programs for agriculture. The Coachella Valley Water District (CVWD) draws water from the Colorado River. Because of its location in the deserts of southeastern California, this area has notably high **evapotranspiration** rates. An evapotranspiration rate tells a farmer how much water will likely be lost from crops due to natural evaporation and transpiration. To put these rates in perspective, Coachella Valley has a rate of 74 inches per year, compared to 57–58 inches per year in

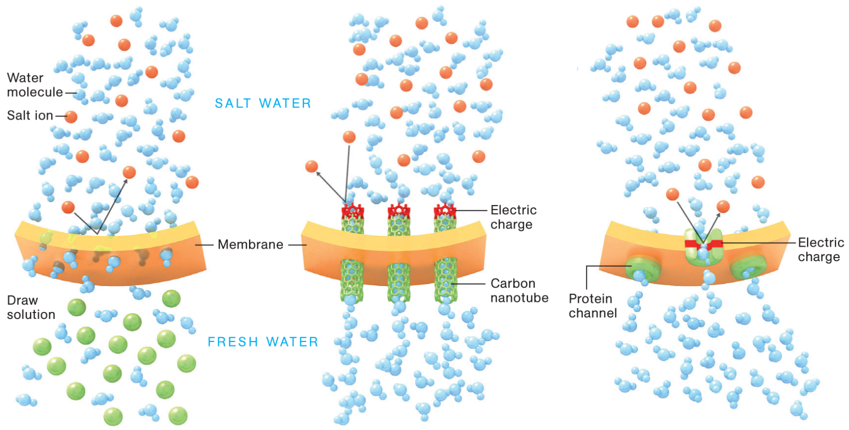
the Central Valley and 33 inches per year along the coast (Cohen 2010). That means Coachella Valley crops lose a lot of moisture to natural evaporation and transpiration compared to other locations in California.

Coachella Valley was faced with a predicament. It is located in an area with high water loss to natural processes but also needs to meet state and federal water-conservation targets to reduce the water drawn from the Colorado River. Thus, the CVWD designed an initiative called the Extraordinary Water Conservation Program. One of the key pieces of this program was conversion to micro-irrigation (drip irrigation) along with detailed plans for the most efficient times and volumes of water that should be used for specific crops. Farmers monitored crops carefully to improve their understanding of a crop's need for water and to avoid overwatering. Because a great deal of water used to irrigate has salts in it, another cornerstone of the plan was to improve plant productivity by monitoring soil salinity carefully. While the Coachella Valley program is not fully realized, this area has saved up to 75,000 acre-feet of water and improved water efficiency by 10–15 percent for most participating farmers (Cohen 2010).

Read more agricultural success stories at the Pacific Institute's "California Farm Water Success Stories: http://www.pacinst.org/reports/success_stories/.

METHODS OF DESALINATION

Three technologies promise to reduce the energy requirements of desalination by up to 30 percent. The race is on to see which will take the lead.



FORWARD OSMOSIS
Water molecules migrate by natural osmosis, without energy input, into an even more concentrated "draw solution," whose special salt (green) is then evaporated away by low-grade heat.
On the market: 2010-2012

CARBON NANOTUBES
An electric charge at the nanotube mouth repels positively charged salt ions. The uncharged water molecules slip through with little friction, reducing pumping pressure.
On the market: 2013-2015

BIOMIMETICS
Water molecules pass through channels made of aquaporins, proteins that efficiently conduct water in and out of living cells. A positive charge near each channel's center repels salt.
On the market: 2013-2015

Innovation

Much of the technology to address our water problems already exists or is currently being developed. As societies around the world become increasingly aware of looming water-scarcity and water-quality issues, technology developers are rising to the challenge. These technologies typically use one of two approaches: either increasing supply of water or focusing on conservation and reducing demand for water.

Desalination. The first technology, **desalination,** is an innovation that will increase water supply. Water desalination is the process of removing salt and other minerals from water. Because 97 percent of water on Earth is salty, water desalination may continue to gain importance. Currently, 300 million people get their water from the sea or from **brackish water** (i.e., water with salinity levels that are higher than freshwater, but lower than seawater). This number is double that of a decade ago. We will first review different desalination methods and then take a closer look at trade-offs that may limit the positive gains of such technologies.

Currently, the two most common methods of desalination are brute-force distillation and reverse osmosis. Brute-force distillation is when water is heated until it evaporates, leaving the salt behind; the evaporate is then captured and condensed back to the liquid phase. Reverse osmosis is when water is pumped through a selective membrane that, under pressure, allows the water molecules to pass but not the salt ions (i.e., Na^+ and Cl^- ions). Using energy to push water through a membrane (reverse osmosis) is cheaper than heating water (distillation) but is still not very cost effective (Lange 2010).

The increased demand for cost-effective ways to desalinate water is leading to renewed efforts to develop new desalination technologies. The following three technologies are expected to be available within the next five years:

- Forward Osmosis: Similar but more efficient than reverse osmosis, this process uses the natural migration of water molecules into an even more concentrated "draw solution," with a special salt that is later evaporated by way of low-grade heat.
- Carbon Nanotubes: The mouths of these carbon cylindrical structures are electrically charged. This charge repels the positively charged salt molecules in the seawater. Freshwater molecules then slip through the tubes free of salt.
- Biomimetics: Mimicking living-cell membranes, aquaporin—proteins that conduct water in and out of cells—are used to transport water molecules across a membrane. A positive charge near each protein channel's center repels the salt.

While desalination may be touted as a potential solution, some experts warn that the trade-offs of desalination make it unrealistic for many locations. Desalination focuses on increasing supply, as opposed to reducing demand (or conserving the water we have). Desalination is an energy-intensive process, despite new technologies, and is also an expensive process. The process produces high concentrations of salty water known as brine that can be very difficult to dispose of due to its impacts on water habitats and the species that live nearby. In addition, the transportation of water from coastal areas to inland communities requires additional energy and financial costs. Another drawback is that taking in ocean water for desalination impacts marine life around the intake area, especially plankton populations, fish eggs, and larvae. Groundwater desalination is considered more promising than ocean desalination. Much of our groundwater is too saline for use without treatment. For example, 75 percent of the groundwater sources in New Mexico require additional treatment due to salinity (Alley 2003). Desalinating groundwater requires less energy than ocean water, with fewer environmental consequences. Even with new desalination technologies in the works, reducing demand for water (as opposed to increasing supply) is still considered the most effective solution to our water problems.

Drip Irrigation. Drip irrigation, also known as trickle irrigation or micro-irrigation, is a form of irrigation in which water is delivered drop-by-drop to the root area of a plant. Drip irrigation can be one of the most water-efficient methods of irrigation because evaporation and runoff are minimized. This technology reduces demand for water from the agricultural sector, which is an effective strategy for water conservation.

Today, drip irrigation is widely used in commercial agriculture, as well as in backyard gardens, which saves countless gallons of water. Combined with new information technologies, farmers can improve their water efficiency. For example, some farmers use real-time weather monitoring technology that provides information about evapotranspiration rates. With this information they can determine irrigation needs to avoid over watering their crops.

Rainwater Harvesting. Rainwater harvesting is an increasingly popular innovation, especially in water-stressed areas such as the southwestern United States. Rainwater harvesting is a cost-efficient system that many people in the general public may find interesting. In fact, some of your students may actually have rainwater-harvesting systems at home.

Rainwater collection is not a new practice; it can be traced back almost 2,000 years to places such as Thailand, where water would be collected from roofs into jars and pots. Water harvesting is the process of collecting rainwater from roofs, parking areas, and other pervious and impervious surfaces to store for later use. The rainwater can be collected, slowed down, or routed through the landscape using micro-basins, swales, roof gutters, cisterns, and other structures. Oftentimes this water is then used to supplement home water use, especially for watering a home garden or lawn. Water harvesting reduces dependence on rivers and groundwater reserves, and it also alleviates some of the pressures being placed on storm-water systems.

Reclaimed Water. Wastewater treatment is an innovation that keeps on evolving with the advent of new technologies. Reclaimed water is also sometimes called recycled water and is the output product of tertiary-treated sewage water. After physically removing solids and impurities and chemically disinfecting much of the bacteria and reducing other contaminants, reclaimed water can be used in sustainable landscaping irrigation or to recharge groundwater aquifers. As described in **Case Study: Successful Agricultural,** on p. 134, reclaimed water can also be a solution for agricultural irrigation.

Some of the most innovative technologies being used today for wastewater treatment integrate the benefits of wetland plants and traditional treatment plants. Such is the case of the Sweetwater Wetlands in Tucson, Arizona, where an artificial wetland is designed to clean the backwash water from a treatment plant (i.e., water pumped in reverse through the treatment process to clean filters) (Oshant Hawkins 2007).

Wetlands are often described as nature's water filters. This is because wetland plants and soil use their natural ability to trap bacteria, viruses, and metals to clean water that passes through. Wetland plants are capable of absorbing pollutants into their cells, especially nutrients. The dead plants at the bottom of the wetland help trap solids and provide conditions for the growth of important microbes; some of these also attach to the stems of living plants. Through various processes such as decomposition, predation, and neutralization, these microbes are able to transform contaminants into less harmful forms and to transform nitrogen compounds into nutrients that

Developers in Loreto Bay in Baja California use treated wastewater to irrigate.

Teaching Tip

Determine whether there are any "green buildings" near you that are built to take advantage of rainwater harvesting. Some newer buildings use rainwater harvesting for irrigating decorative plants, or other purposes. A good example is the David Brower Center in Berkeley, California (http://www.browercenter.org/building), which uses rainwater for irrigation and toilet flushing. Also, consider bringing in photographs of rainwater systems to share with students so that they can create a visual image of how these systems work.

Case Study

Boston Conservation: A Success Story

by Sandra Postel, Freshwater Fellow, National Geographic Society

It's hardly in a water-short region, so it may come as a surprise that Boston, Massachusetts, stands out as one of the biggest success stories in urban conservation in the United States. In 2005 the total water use in greater Boston dropped to a 50-year low —a stunning achievement, especially in light of the city's booming economy in recent decades. And the region's water demand has continued to drop: by 2009, it had fallen 43 percent from the 1980 peak.

Why and how did this New England capital come to add this feather to its cap? Back in the 1980s, Boston faced a familiar problem: its demand for water would soon outstrip the reliable supply of its water system. Its 412-billion-gallon reservoir was tinkering on half- to a quarter-full, setting the greater Boston area up for significant problems should a drought take hold. The region was using about 350 million gallons a day (mgd) back then, when safe levels were considered 300 mgd.

The water authority responded as most water providers would in such a circumstance—by looking for new water sources to expand the supply.

The best option seemed to be a diversion from New England's biggest river, the Connecticut, which runs all the way from the northern tip of New Hampshire to the Long Island Sound. The proposed diversion would siphon new supplies over to the Quabbin Reservoir, which had been created decades earlier by damming the Swift River in western Massachusetts and drowning four rural towns. Aqueducts carry drinking water 65 miles from the glistening Quabbin to the toilets and taps of greater Boston, passing through the Wachusett Reservoir along the way. When citizens and environmental groups heard of the diversion scheme, they wasted little time in voicing concern about the ecological impacts, including potential harm to efforts to restore Atlantic salmon to the Connecticut River. They pushed for a different approach—reducing Boston's water demand rather than expanding its supply.

In response, the newly established Massachusetts Water Resources Authority (MWRA)—the water wholesaler for 2.5 million people and more than 5,500 large industries in Boston and 50 surrounding communities—began an aggressive conservation program. It set out to detect and repair leaks in the aging pipes of the water distribution system. It retrofitted about 350,000 homes with efficient plumbing fixtures, such as low-flow showerheads. It conducted water audits of large industrial facilities and refurbished water meters to better track how much water the agency sells to communities. The MWRA also raised water rates and stepped up public education about conservation.

An additional boost came in 1988, a year after the program got under way, when Massachusetts became the first state to require low-volume toilets in all new construction and remodeling—an important precursor to the federal efficiency standards passed four years later.

In a unique arrangement, MWRA also funds a citizen watchdog group called the Water Supply Citizens Advisory Committee. Aided by active citizen participation, the conservation program produced a steep and steady decline in greater Boston's water demand: total use in 2009 was 70.9 billion gallons (268.5 million cubic meters) per year, a 43 percent drop from the 1980 peak of 125.5 billion gallons (474.9 million cubic meters).

Today, the Quabbin Reservoir is brimming with water, and the diversion from the Connecticut River is no longer on the table. The conservation program also proved cost-effective, and spared Greater Boston residents the estimated $500-million-dollar capital expense of the diversion project.

But the story isn't over. Controversy swirls over what to do with the "surplus" water in the Quabbin. With its customer base now using so much less water per person, MWRA is looking for a way to spread its fixed costs among more customers. Within the last six years it has added five more communities to its service area. For their part, environmental groups would like to see the "surplus" used to restore more natural flows to the Swift River in order to improve fisheries and other ecosystem benefits. The debate about the best use of "surplus" water is one that a growing number of cities around the country would probably love to be having.

Taken from "Lessons in the Field: Boston Conservation" at http://environment.nationalgeographic.com/environment/freshwater/lessons-boston-conservation/.

Water flows quickly from our faucets, making it easy to waste water.

What would life be like if you had to carry all the water you used from the source to your home? Would you waste water?

help plants grow. In addition to serving as natural filters, wetlands also provide excellent habitats for migratory birds and other life forms, including bats, bobcats, and a wide array of insect species.

Actions to Protect Our Water

In the last 100 years, the rate of increase in demand for water in the world was double the rate of population growth over the same period. Recent analysis shows that scarcity of water is becoming a key concern of the twenty-first century. We do not have to wait until national and global policies are in place or utility companies come up with innovative solutions. In this section, we describe the concept of the water footprint and how each of us can reduce the size of our own water footprint.

Water Footprint. Similar to the carbon footprint, the water footprint is an indicator of water consumption that includes both direct and indirect water use from either a consumer or a producer of goods. The direct water footprint is measured as the amount of water used by an individual in home, work, or school. The direct water footprint includes the water we drink or use to brush our teeth, shower, flush the toilet, and wash our dishes. To reduce our water footprints, we can engage in simple solutions such as installing water-saving toilets and showerheads, brushing our teeth with just one cup of water, and maintaining our home gardens with water-efficient techniques, such as mulching, to prevent evaporation.

The indirect water footprint of an individual is the total amount of water used to produce the goods and services consumed by an individual. Each item we consume has its own footprint—its own amount of water that went into making the item. If we added all the water footprints of all the products we consume, it gives us the water footprint for a person.

Hidden Water Consumption. Beyond the water we use every day for drinking, bathing, washing, and cooking, there is an entirely different

Teaching Tip

Organize your students into small groups and ask each group to reflect about different ways they and their families may use more water than they need in their day-to-day lives. Ask the groups to also think about how they and their families might be able to use less water. The following questions can help you guide your class discussion:

- What are some ways you use water at home?
- Can you remember the last time you or anyone in your house wasted water?
- How was the water wasted?
- How could it be prevented?
- Do you think it is important to use water responsibly?
- Why? Students can also fill out a water use chart, like the one found at http://www.k12science.org/curriculum/drainproj/personalwaterusechart.html.

Student Thinking

Reducing Water Use

Students are often unaware of both the need to conserve water and the ways in which water can be conserved. Water is so accessible in the United States that students are usually able to turn on a faucet, flush a toilet, or get ice from their refrigerator without ever thinking about where this water comes from or how much they are using in the process. In addition to having easy access to water, students are not likely to have any experiences or ideas that would inform them about all of the water required to produce their food, clothes, medication, and plastics. By raising student awareness of how water is used and ways it can be conserved, you can provide them with the opportunity to make educated decisions about how to use the precious resources most efficiently.

	Common Student Ideas	Scientific Concepts
Water conservation	We can conserve water by turning off the faucet when we brush our teeth.	Water conservation involves consideration of food we eat, clothes we buy, energy we use, and so on. Water is used to make products, so water conservation involves being a smart consumer as well as implementing behavioral changes like taking shorter showers and turning off the faucet while brushing our teeth.
Origins of water	Water is limitless. Our cities and dams actually make water for us to use.	Water is a form of matter, so it cannot be created or destroyed. It must come from and go somewhere. There is only a limited amount of water in fresh, liquid form on Earth. Cities and dams do not create water but rather manage or store water for future use.
Rainwater	We cannot use rainwater to drink or in our homes.	Rainwater harvesting is an excellent way to supplement home water use. With the proper treatment this water can be as clean or cleaner than other water sources. It is also a great water source for a home garden.

Ask Your Students

1. How does your city get water to send to homes? Where does this water come from? Should there be a limit for how much you can use? (Or, for rural areas: Where does water come from in your well? Is there a limit to the water in your well?)
2. How could rainwater harvesting help you reduce your water footprint?
3. Water is used for more than flushing toilets, drinking, and taking baths. What are some other ways you think freshwater is used to support your lifestyle? How might this influence what you buy the next time you go shopping?

and less visible dimension of water consumption. Water is needed to produce virtually every consumer product in the global market. The amount of water used to create a product is referred to as hidden, or virtual, water.

The term *virtual water* was created as a "tool for water management and to give countries, companies and individuals a clearer measure of their water footprint" (*National Geographic* 2010). "Virtual water" refers to the actual volume of water used in producing a certain amount of a specific item. For the numbers following, keep in mind that a typical bathtub holds 50–60 gallons of water.

For example, producing one pound of beef requires 1,857 gallons of water. The virtual water for meat production includes the water the animals drink as well as the water used to grow their feed and clean their waste. Some meat products require less water. For example, producing a pound of sausage requires 1,382 gallons of water, while one pound of chicken only requires 469 gallons of water. Fruits and vegetables require far less. Growing one pound of apples requires 84 gallons of water. The manufacturing of cotton clothing is particularly water intensive. For example, 2,900 gallons of water are required to make a pair of jeans (see *National Geographic* 2010, for more information).

It is perhaps an unsurprising fact that simply being American means we use more water than people in other nations. In the United States, an average person uses 80 to 100 gallons of water per day. The average Californian uses 189 gallons per day. That's about 330,000 gallons of water per year, or 6,000 filled bathtubs! In contrast, the average Chinese citizen uses less than half of what an American citizen uses each year.

As global citizens we need to recognize that freshwater is a resource that we must share and conserve for future generations. Even though freshwater seems limitless from our faucets—an endless supply from our city water source or from our wells—many people in the United States and abroad do not have easy access to water and, therefore, are more conscious about their use. Teaching students about this important resource is an important step for preparing future generations of citizens to care about and conserve

Teaching Tip

The concept of *virtual water* may leave some students feeling overwhelmed. However, this topic provides a great opportunity to discuss why some food items and common goods take more water to produce than others, and how students' choices as consumers can make a difference in water conservation. A few examples that students may be able to relate to include the amount of water needed to produce a hamburger and the amount needed to make a pair of jeans.

1 hamburger = 634 gallons of water
1 pair of jeans = 2,900 gallons of water

Ask students to discuss why it's important to think about where our food and other products come from: What does it matter? Why should we care? What can we do with this information to make a positive difference?

PRODUCT	VIRTUAL GALLONS USED PER POUND
Beef	1,857
Processed sausage	1,382
Processed Cheese	589
Chicken	469
Eggs	400
Fresh Cheese	371
Bananas	103
Apples	84

It takes approximately 2,900 gallons of water to make a single pair of jeans.

Every person has a choice about how how water is used. The left image shows a man in a neighborhood in California watering his yard with municipal water. The right image shows a couple that collects rainwater to irrigate their yard. Rainwater harvesting is a great solution for homeowners in arid climates.

our freshwater. Consider the following suggestions for ways that your students, your classroom, and your community can act to be part of the solutions.

What Can You and Your Family Do?

Reduce Direct Water Use. One of the most important thing students can do is turn off faucets and take shorter showers each and every day. Additionally, there is much that can be done around the home. For example, when ready to upgrade bathrooms, make sure to install low-flow showerheads, faucets, and toilets. Did you know that a low-flow showerhead can save 15 gallons of water for just a 10-minute shower? Multiply that by everyone in your family taking showers almost every day, and that adds up to real savings. Another easy practice is to repair any water leaks around your home—inside and out. Leaks can add up to almost 10 gallons of water per day! Also, when ready to upgrade, consider a front-load washing machine that uses about half the water of a top-loader. Make sure to adjust the water level accurately. Using a dishwasher is also more efficient than washing by hand. Dishwashers use 4–6 gallons of water, while handwashing an equivalent number of dishes uses almost 20 gallons.

Reduce Hidden Water Use. You can reduce your hidden water footprint by paying attention to three more habits at home—food choices, energy choices, and other products you buy. An American's daily diet requires about 1,000 gallons of water to produce. One way to reduce this water use is to eat fewer meat and dairy products or choose grass-fed products over grain-fed products. Reducing energy use around the home and reducing fuel use in the car also saves on water because it takes water to make energy. For example, it takes 13 gallons of water to make one gallon of gasoline. Lastly, reducing the number of products you buy can also save water. A single pair of jeans requires 2,900 gallons of water, some of which is used to grow cotton. Rethink whether you need a new t-shirt or new jeans or whether you can manage without them.

Rethink Your Yard. Almost 60 percent of a person's water footprint goes to yard maintenance. Make sure to water lawns following your water restriction. Another strategy might be to **xeriscape** your yard or install a permeable patio that allows water to flow through to the ground, while also reducing the amount of vegetation that needs to be watered. Xeriscape is a landscaping strategy that utilizes native plants and gravel that require no additional irrigation. Consider installing rainwater harvesting systems to supplement your other water source. This source of water can be used for your yard or garden.

What Can Your Classroom and School Do?

Reduce School Water Use. Have students investigate the number of toilets and faucets found in the school and determine how much water could be saved by replacing them with low-flow faucets and toilets. They could develop a school-improvement plan that could be shared with other classrooms and school staff. If irrigation is used, have students research the existing irrigation system—when does the school water, how often, for how long, and with how many sprinklers? Is there a way to improve this system by watering at different times of day or even by installing drip irrigation?

Rethink the School Cafeteria. Schools offer students numerous food options from the cafeteria. Imagine if these options were labeled by the amount of water used to make them. Have students look closely at the food options offered in the school cafeteria. Are several meat and dairy options offered? Can any of these be replaced by vegetable or fruit options? Propose to the cafeteria to have one day a week on which meat options are not offered or reduced (e.g., Meatless Mondays).

Green School Grounds. Every school is different, so a class should first investigate its school grounds to determine which areas have impermeable or permeable surfaces and whether the class can adopt a project to improve school grounds. The project might include installing a rain garden or xeriscaping a portion of the lawn, both of which will introduce your students to native plants. Students can also research options for permeable pavers and make recommendations to the school about places where these materials could be used instead of traditional concrete. For example, the playground may have surfaces that could use permeable pavers. Students can take on a project to clean school grounds so less potential pollutants are washed away by rain. Lastly, students may research organic plant fertilizers and treatments that could be used to replace any of the traditional pesticides and fertilizers used by the school.

Teaching Tip

Have students identify permeable and impermeable surfaces around their school. Present the following list of areas to students and help them identify which areas are impermeable. Then conduct a class discussion about how to increase permeable surfaces around the school. Have students construct a plan for "redesigning" their school or a plan for how they would build a school using permeable surfaces. If possible, undertake a class- or school-wide project aimed at reducing impermeable surfaces on the school campus.

- Parking area
- Grassy play area
- Gravel/sandy play area
- Sidewalk
- Field for different sports
- Basketball or gym court
- Rooftop
- Driveway
- Street

For example lessons and more information, explore the following resources: http://www.crd.bc.ca/watersheds/protection/howtohelp/reduceimpervious.htm.

What Can Your Community Do?

Reduce Impermeable Surfaces. Especially in urban areas, reducing impermeable surfaces is a top water solution. This not only alleviates problems with storm-water runoff and pollution, but it also helps to recharge the groundwater. Communities should look at surfaces that can be replaced with permeable pavement, like sidewalks, driveways, bike trails, and parking lots, and develop long-term plans for how to replace those surfaces. In addition, homes and businesses can install rain gardens, green roofs, and xeriscape to help with groundwater infiltration.

Green-Space Irrigation. When cities develop green spaces, parks, sports fields, or even municipal golf courses, installing efficient irrigation systems can be one strategy to reduce water use in those spaces. Upgrading existing irrigation systems may require an upfront investment but can be financially and environmentally rewarding over time.

Clean the Streets. Initiate or participate in community-wide programs to keep trash off streets and out of local waterways. Community cleanups help to reduce the amount of debris entering the storm-drain system, which eventually makes its way to our freshwater and marine ecosystems.

Keep local water clean by reducing personal litter and joining a community cleanup.

In the Classroom

My Water Footprint

Students are often interested in learning about how their water use compares to that of others. In this activity, students calculate their own water footprint and then compare it to average footprints from around the world.

Materials

- Computer/Internet Access
- Water Footprint preparation sheet

Directions

1. Before teaching this activity, explore water-footprint calculators. Determine which is most appropriate for your students. Once you determine the calculator, prepare a worksheet for students to gather information about home water use. The worksheet should help students easily enter data when using the calculator. Have student complete the worksheet at home before doing step 2.
2. Discuss the concept of a water footprint. Ask students to make a prediction about how many gallons of water per day that they think they use, then direct them to the water footprint calculator to calculate their individual footprint. Consider using National Geographic Society calculator: http://environment. nationalgeographic.com/environment/freshwater/water-footprint-calculator/.
3. Ask students if their footprint was larger than expected.
4. Talk about the smallest footprint in the class. What are the reasons the person had the smallest footprint?
5. As an extension, have students to compare their water footprints to the footprints of people who live in other countries. Use the following link to find the water footprint per capita per country: http://www.waterfootprint.org/?page=cal/waterfootprintcalculator_national. Keep in mind the global average water footprint is 1,243 m3/cap/yr. Alternatively, you can print charts like the following:

Country	Water footprint in m^3 per capita per year
USA	2,483
Canada	2,049
Mexico	1,441
United Kingdom	1,245

Data obtained from the Water Footprint Network, period 1997—2001

6. Once they compare their footprints to other countries, ask students to discuss why their footprints are different.

Discuss

1. In terms of water use, how do you think your daily life varies from someone your age in Mexico or the United Kingdom?
2. Which behaviors are you willing to change to save water? Which would be more difficult? Why?

Pictures of Practice

Water Use and Conservation

Conducting a water audit is the first step toward conservation. A personal water audit tells a person how he or she uses (and potentially wastes) water and gives areas to improve water conservation. For example, doing a water audit, or entering information into a water calculator, can tell a person if he or she use above average or below average water in the shower, for dishwashing, for washing clothes, and so on. The average American uses about 100 gallons of water per day, which is equivalent to roughly two bathtubs filled with water. Obviously most of this is not used for drinking! We may not pay careful attention to our personal water use, but knowing more about it can help us become better conservers of this precious resource.

Students: Grade 6

Location: San Diego, California (a coastal community)

Goal of Video: The purpose of watching this video is to hear about students' water audits and what they learned about use and conservation.

Classroom Context

At the start of their water unit, students conducted a personal water audit, focusing on obvious uses of water (e.g., drinking, brushing teeth, showers, washing dishes, and so on). Students calculated the number of gallons used over the course of a day and then shared their numbers with their classmates. Ms. Fortunato recorded everyone's water audit on the white board, which remained visible to students throughout the remaining unit. Ms. Fortunato and students used the information collected during the activity as a source of information for discussing how people use or conserve water.

Video Analysis

After completing the water audit, students reviewed their water use with their classmates. Students' water audits ranged from 30 gallons per day to more than 100 gallons per day. The average American citizen uses about 100 gallons a day. Ms. Fortunato poses the question to students, "Did you have a right to use the water in your personal water audit?" One students says yes, because he needed the water for hygiene (brushing teeth and showering). However, early in the discussion, Diana brings up the idea that she "wasted too much" water. Diana says that she used water she didn't need to use and did not think about people who don't have much water. She just kept using it because she could. Then Riley makes the case that all the people in the city share water, so when it is wasted that takes water away from the city. For the most part, students seem to realize that even though they have access to clean water and can use what they want, there is some degree of responsibility to not waste water. The idea of "fairness" becomes a key component of the discussion. Even though we pay for water, is it fair to use as much as we want? Students wrestle with this question during their post-interviews.

Reflect

What should students understand about water use and conservation?

On the one hand, people pay for water, so it "belongs" to them. On the other hand, water is a shared resource. How would you help students develop a better understanding of the balance between the two? Even though we seem to have limitless water for purchase, it is actually a valuable resource in need of conserving. Consider having your students conduct personal water audits and use their findings to discuss conservation practices.

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Teaching Resources

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

The Water Project: http://thewaterproject.org/

Glossary

acid rain
(A-sihd RAYN)
Precipitation with high levels of nitric and sulfuric acids. Acid rain can be human made or can occur naturally.

acidification
(uh-sih-dih-fih-KAY-shun)
Decrease in a substance's pH levels.

anadromous
(uh-NAD-ruh-mus)
Characteristic of an animal that migrates from salt water to freshwater.

anthropogenic
(an-thruh-puh-JEH-nihk)
Caused by people.

aqueduct
(AH-kwih-duhkt)
A pipe or passage used for carrying water over a distance.

aquifer
(AH-kwuh-fer)
An underground layer of rock or earth that holds groundwater.

arch dam
(ARCH DAM)
Tall, relatively thin structure that uses a curve (or arch) to block a flow of water.

ballast
(BA-luhst)
Heavy material, usually water, used to provide stability for large ships or other oceangoing vessels.

bioaccumulation
(bi-oh-uh-kyoom-yoo-LAY-shun)
Process by which chemicals are absorbed by an organism, either from exposure to a substance with the chemical or by consumption of food containing the chemical.

bioaccumulation factor, BAF
(bi-oh-uh-kyoom-yoo-LAY-shun FAK-tur)
Ratio of a substance, usually a toxic chemical, in an organism to the concentration of the substance in the surrounding environment.

biomagnification
(bi-oh-mag-nih-fih-KAY-shun)
Process in which the concentration of a substance increases as it passes up the food chain.

brackish water
(BRA-kihsh WAH-ter)
Salty water, usually a mixture of seawater and freshwater.

California Doctrine
(ka-luh-FOR-nyuh DAHK-trihn)
System of laws that says water rights can be determined by both ownership of land bordering the body of water (Riparian Doctrine) as well as an open marked (Prior Appropriation).

canal
(kuh-NAL)
Artificial waterway.

cetacean
(see-TAY-shun)
Type of marine mammal, such as whales and dolphins, whose body is similar to a fish.

chemical parameters
(KEH-mih-kul puh-RA-muh-turs)
Characteristic quality of an object or substance, such as temperature or pH.

clarity
(KLAIR-uh-tee)
Clearness or transparency.

coagulation
(koh-a-gyoo-LAY-shun)
Process of changing from a liquid to a thickened or semisolid mass.

confined aquifer
(kun-FIND ah-KWUH-fur)
Layer of water-bearing rock between two layers of less permeable rock.

contaminant
(kun-TA-muh-nehnt)
Harmful or toxic substance.

dam
(DAM)
Structure built across a river or other waterway to control the flow of water.

deleterious
(deh-luh-TEE-ree-us)
Harmful.

density
(DEHN-sih-tee)
Number of units in a given area.

desalination
(dee-sal-ih-NAY-shun)
Process of converting seawater to freshwater by removing salt and minerals.

disinfection
(dihs-ihn-FEHK-shun)
The act of cleaning and removing harmful microorganisms.

dissolve
(dih-ZALV)
To break up or disintegrate.

drip irrigation
(DRIHP eer-ih-GAY-shun)
System that delivers moisture to plants by tubes with holes that drop water.

E. coli
(EE KOH-li)
(Escherichia coli) Common bacteria found in the digestive system of many animals. Some strains of *E. coli* are dangerous to people.

ecophobia
(ee-koh-FOH-bee-uh)
Feeling of powerlessness to combat destruction of the environment.

endorheic drainage basin
(ehn-dur-EE-ihk DRAY-nihj BAY-sihn)
Watershed that empties into an internal body of water, not into the ocean.

ephemeral stream
(ee-FEH-muh-rul STREEM)
Body of water that flows only after a fall of precipitation.

eutrophication
(YOO-troh-fih-kay-shun)
The build-up of sediment and organic matter in bodies of water, which may cause a change in the productivity of the ecosystem.

evaporative cooling
(ee-VA-por-uh-tihv KOO-lihng)
Process in which warm air is pulled through a wet or moist medium, where it is cooled by evaporation.

evapotranspiration
(ee-VA-poh-tran-spur-AY-shun)
Loss of water from Earth's soil by evaporation into the atmosphere and transpiration by plants.

extinct
(eks-TIHNKT)
No longer existing.

exurb
(EHKS-urb)
Community or geographic area situated outside the suburbs of a city.

filtration
(fihl-TRAY-shun)
Process of separating solid material from liquids or gases.

fish ladder
(FIHSH LA-dur)
Series of steps overflowing with water, on which fish can migrate upstream around a barrier such as a dam.

floc
(FLAHK)
Tiny tuft or droplet of matter, usually found as a solution, filters into different media: solids and liquids, gases and solids, and so on. Also called a flock or flocculate.

geopolitical boundaries
(jee-oh-puh-LIH-tih-kul BOWN-dree)
Natural geographic feature that is used as a border or barrier between nations or other political entities.

gravity dam
(GRA-vuh-tee DAM)
Solid or hollow structure that blocks a flow of water with its own size and mass.

greenhouse gas
(GREEN-hows GAS)
Gas in the atmosphere, such as carbon dioxide or ozone, that absorbs solar heat reflected by the surface of Earth, warming the atmosphere.

groundwater
(GROWND-wah-tuhr)
Water found in an aquifer.

headwater
(HEHD-wa-tur)
The source of a river.

hydraulic society
(hi-DRAH-lihk suh-SI-eh-tee)
Community or civilization that controls its populace by controlling the supply of water. Also called a hydraulic civilization.

impermeable
(ihm-PUR-mee-uh-bul)
Not allowing liquids or gasses to pass through.

instream flow
(IHN-streem FLOH)
Measure of the cubic feet per second of water flowing in a specific area of a stream at a specific time.

intermittent stream
(ihn-tur-MIHT-tehnt STREEM)
River in which water flows for part of the year, usually during the rainy season.

invasive species
(ihn-VAY-sihv SPEE-seez)
Type of plant or animal that is not indigenous to a particular area and can cause economic or environmental harm.

land subsidence
(LAND sub-SI-dehns)
Process of a large area of land dropping or lowering due to water being withdrawn from the earth and aquifer below.

lock
(LAHK)
Structure on a waterway with gates at each end that allow the water level to rise and lower as they are opened and closed.

meltwater
(MEHLT-wah-tur)
Freshwater that comes from melting snow or ice.

mitigation
(mih-tih-GAY-shun)
To lower the severity of a natural or human condition.

nonpoint source pollution
(NAHN-point SORS puh-LOO-shun)
Toxic chemicals that enter a body of water from many sources.

osmosis
(ahs-MOH-sihs)
Movement of a substance (usually water) through a membrane, from a solution of less concentrated material to a solution of more concentrated material.

outflow
(OWT-floh)
Amount of water, sediment, and chemicals discharged by a river or other flowing body of water.

overexploitation
(oh-vur-ehk-sploy-TAY-shun)
Use or harvesting of a renewable resource to the point at which the resource is threatened.

Pacific Flyway
(puh-SIH-fihk FLI-way)
Route taken by many migratory birds of the Americas, stretching from Alaska to Chile.

pathogen
(PA-thuh-jehn)
Organism that causes a disease, such as a virus.

percolation
(pur-kuh-LAY-shun)
Movement and filtration of water through soil or rock layers.

perennial stream
(puh-REH-nee-ul STREEM)
River in which water flows continually all year.

permeable
(PUR-mee-uh-bul)
Allowing liquid and gases to pass through.

photosynthesis
(foh-toh-SIHN-theh-sihs)
Process by which plants turn water, sunlight, and carbon dioxide into water, oxygen, and simple sugars.

point source pollution
(POINT SOHRS puh-LOO-shun)
Pollution from a single, identifiable source.

polarity
(poh-LAIR-ih-tee)
Property of having or being attracted to poles, such as positive and negative electrical charges.

pollution
(puh-LOO-shun)
Introduction of harmful materials into the environment.

porosity
(por-AH-sih-tee)
The ratio of the volume of all the pores, or holes, in an object and the object's total mass.

Prior Appropriation
(PRI-ur uh-proh-pree-AY-shun)
System of laws that says water rights are not associated with land bordering the body of water, and may be bought or sold. Also called the Colorado Doctrine.

quadrat
(KWAHD-rut)
Plot of land marked off for the study of organisms.

recharge
(ree-CHARJ)
To renew or restore to a previous condition.

recharge rate
(ree-CHARJ RAYT)
Amount of water and time it takes to refill an aquifer.

reservoir
(REH-zuh-vwar)
Natural or human-made lake in which water is stored.

reverse osmosis
(ree-VURS ahs-MOH-sihs)
Water sanitation process that forces water through plastic sheets in order to remove microscopic pollutants and harmful molecules.

riparian
(ruh-PAIR-ee-un)
Having to do with a river or stream.

Riparian Doctrine
(ruh-PAIR-ee-un DAHK-trihn)
System of laws that says water rights belong to the person or people whose land borders the body of water.

riparian habitat
(rih-PAIR-ee-un HA-bih-tat)
Area along the banks of a river or other body of freshwater.

sedimentation
(seh-dih-mehn-TAY-shun)
Process of accumulating small, solid deposits left by erosion, ice, and wind.

solute
(suh-LOOT)
A substance dissolved into another substance.

solution
(suh-LOO-shun)
Substance in which a gas, liquid, or solid is evenly distributed in another medium.

solvent
(SAHL-vunt)
Substance that dissolves another substance.

standard atmospheric pressure
(STAN-durd at-mus-FEER-ihk PREH-shur)
Unit of measurement equal to air pressure at sea level, about 14.7 pounds per square inch. Also called an atmosphere or standard atmosphere.

storm-water runoff
(STORM-wah-tur RUN-ahf)
Excess water that overflows a road or other impermeable surface due to heavy rainfall.

surface tension
(SUR-fus TEHN-shun)
Property of the surface of a liquid in which the molecules act like a thin, elastic film, allowing it to resist external forces.

suspension
(suh-SPEHN-shun)
Act of hanging from something above, or being partly attached to something.

transect line
(TRAN-sehkt LIN)
Tape or string laid along the ground in a straight line between two structures, used to measure the distribution of organisms in the area (transect).

transpiration
(trans-puh-RAY-shun)
Evaporation of water from plants.

transpiration ratio
(trans-puh-RAY-shun RAY-shoh)
Difference (ratio) between the amount of water lost to the atmosphere (transpired) by a plant and the amount of plant growth. The lower the transpiration ratio, the more effectively the plant uses water for growth.

trophic level
(TROH-fihk LEH-vul)
One of three positions on the food chain: autotrophs (first), herbivores (second), and carnivores and omnivores (third).

turbidity
(tur-BIH-dih-tee)
Cloudiness or lack of transparency.

unconfined aquifer
(UN-kun-find AH-kwuh-fur)
Layer of water-bearing rock covered by permeable rock.

urban water cycle
(UR-bun WAH-tur SI-kul)
Processes and paths that water takes as it is used by a community, including stages of collection, transportation, storage, purification, distribution and delivery, and return to natural bodies of water. Also called the human-made water cycle.

urbanization
(ur-bun-ih-ZAY-shun)
Process in which there is an increase in the number of people living and working in a city or metropolitan area.

vernal pool
(VUR-nul POOL)
Ponds or small bodies of water that are dry for at least part of the year and usually do not have fish. Also called an ephemeral pool.

wastewater
(WAYST-wah-tur)
Water that has been used for washing, flushing, or industry.

water conservation
(WAH-tur kahn-sihr-VAY-shun)
Process of lowering the amount of water used by homes and businesses.

water cycle
(WAH-tur SI-kul)
Movement of water between atmosphere, land, and ocean.

water footprint
(WAH-tur FUT-prihnt)
Total volume of freshwater that is used to produce the goods and services consumed by an individual or a community.

water politics
(WAH-tur PAH-luh-tihks)
Public policies and programs surrounding water resources and water quality.

water quality
(WAH-tur KWAHL-ih-tee)
Chemical, physical, and biological characteristics of water for a specific purpose such as drinking.

water scarcity
(WAH-tur SKAIR-suh-tee)
Situation when the amount of water available does not meet the amount of water needed or wanted by a population.

water stress
(WAH-tur STREHS)
Situation faced by a nation or community when the amount of available water is less than 1,700 cubic meters per person.

water table
(WAH-tur TAY-bul)
Underground area near Earth's surface that is saturated with water. Also called water level.

watershed
(WAH-tur-shehd)
An entire river system or an area drained by a river and its tributaries.

xeriscape
(ZEER-ih-skayp)
To garden or design a landscape using the minimal amount of water.

zone of aeration
(ZOHN uv air-AY-shun)
Section of land above the water table containing both earth and air.

zone of saturation
(ZOHN uhv sa-chur-AY-shun)
Area below a water table, where groundwater saturates the rocks and soil.

Facilitator Questions

Chapter 1

Student Thinking: What Lives in Our Freshwater?

1. How would you teach students about biodiversity, especially microscopic organisms, found in freshwater ecosystems?
2. For many students, fish are just fish. How can you help students see both genetic and species diversity within and between populations of fish, frogs, and so on?
3. What would be the best way to explain the threats to freshwater animals from natural causes, the creation of dams, invasive species, and so on?

Student Thinking: Life in a Bucket of Freshwater

1. Students focus mostly on visible organisms. How would you help students understand the vast number of microscopic animals in the bucket?
2. What other misconceptions would you expect to hear from your students when asked this question?

Pictures of Practice: Exploring Ponds and Vernal Pools

1. What activities and investigations can you do in your local area to help students better understand these ecosystems?
2. In this video, students primarily focus on life that they can see, such as the fish they capture from ponds. What additional activities could you do to help them become more aware of microscopic life?
3. After visiting the Silvergate Preserve, students in the video understood more about the life in this type of habitat. What other benefits could you see in bringing your students into the field?
4. Thomas asks the question about salamanders finding a mate, and the scientist responds that the salamander needs a large population and space to do this. How could you build on this concept back in the classroom?

Chapter 2

Student Thinking: Water-Cycle Processes

1. When water condenses on the outside of a cold glass, students think the water comes from the inside of the glass (i.e., that the glass is leaking). How would you demonstrate that the moisture that collects on the glass is from the air?
2. Evaporation naturally leads students to believe that water disappears, or goes away. What evidence could you provide to students to demostrate that the water does not disappear but turns into a gas?
3. If a student suggested the idea of creating "new water" through any of these processes, how would you respond?

Pictures of Practice: Learning About Evaporation

1. Ms. Watkins's students have a diverse understanding of evaporation coming into their discussion. One student already knows that *evaporation* is when water turns from liquid to gas. Another student does not even know what the word means, and still another student believes the word means to disappear. How would you handle this diversity of ideas in your classroom?
2. One student stated that "evaporation" means "to go to clouds." This implies the idea that clouds are "containers." How would you help students improve their understanding of clouds?
3. In the post interviews, the word "disappear" is used to describe water changing from liquid to gas. How could you reteach this topic to improve your students' vocabulary understanding?

Student Thinking: What Makes up a Cloud?

1. Order students' ideas from least to most sophisticated. How did you determine your order?
2. Ruby and Abby talk about what they would see if a cloud was put under a microscope. Do you think these answers show an understanding of what clouds are made of?
3. Justin's answer is on the right path but not very sophisticated. How would you reteach this subject to help him understand the concept better?

Student Thinking: Groundwater

1. Order these students' answers from least to most sophisticated. How did you decide the most sophisticated? What are the key misconceptions in the other answers?
2. Both Sam and Jessica describe underground lakes and rivers as the source of groundwater. How would you help them understand that this is not what groundwater actually looks like?
3. Anna describes the water going into the well during precipitation rather than permeating through the soil. How would you reteach this concept to Anna?

Student Thinking: Watersheds and Rivers

1. Representations of water flow can be misleading. How can you help students connect water flow with topography as opposed to the orientation they see on a piece of paper?
2. What are some familiar examples of rural and urban river settings that you could use in class to help expand what students know about rivers?
3. Rivers run even when it's not raining. How can you help your students understand the variety of sources of river water?

Pictures of Practice: The Urban Water Cycle

1. With students' previous knowledge of storm drains, how would you expand their understanding of where rainwater goes in urban environments?
2. Zachary seems to be confusing cracks in the street with permeable surfaces. How would you help correct this misconception?
3. During the class discussion, Ben shows a good understanding of an urban water system, but most students imagine the natural water cycle in these locations. The natural water cycle is not an accurate depiction in urban areas. How could you help students move past their traditional understanding of water cycling to better understand urban systems?

Chapter 3

Pictures of Practice: Why Do We Build Dams?

1. What were the greatest differences between the third-grade student answers and the sixth-grade student answers? Did this surprise you, or did it match what you expected from students at different ages?
2. Third-grader Thomas confuses the use of dams with water-treatment facilities that provide clean water for drinking and bathing. How would you help correct this misconception?
3. While some students mention hydropower in their answers, their responses are not very sophisticated. How would you reteach this subject to ensure that students understood all the uses of dams?

Student Thinking: Learning About Dams

1. Order students' ideas from least to most sophisticated. How did you determine your order?
2. Several students see dams as structures that supply water to people or that provide fishing opportunities. If these students—for example, Jordan—shared their ideas in your class, how would you respond?
3. All students, with the exception of Sasha, spoke of what happens behind a dam (i.e., the creation of water behind a dam, a lake to fish, and so on). Sasha seems to know that dams can also be used for energy. How would you help students expand their understanding of dams?

Pictures of Practice: What is Groundwater?

1. Groundwater permeates the soil and fills small spaces, but students think of these as underground lakes and rivers. What causes these misconceptions? How would you approach teaching this topic in your own classroom?
2. Salma thinks that stepping on the ground may make it harder for us to access groundwater. If Salma shared this idea during a class discussion, what would you do next?

Student Thinking: Path My Water Follows

1. Students often think their drinking water comes directly from a pristine lake and is returned to a dirty lake or river after use. How could you use this information to plan your teaching about the path that water follows in and out of homes?
2. Arid urban areas use aqueducts, particularly in the American West. Aqueducts change the natural flow of water. Why would this system be important to teach to students? How does it change our natural water cycle?
3. Urban students may not be familiar with wells, and rural students may know about wells but have limited understanding of groundwater. What details about wells and groundwater would you find important to teach to your students?

Chapter 4

Pictures of Practice: What is Water Pollution?

1. In most upper-elementary and middle school instruction, there is still a tendency to associate pollution only with visible debris and trash. How can you help expand on students' understanding of microscopic pollutants while still validating their ideas about trash as an important contributor to water pollution?
2. Many sources of water pollution come from runoff with unidentifiable sources. Why would students find this difficult to understand? What would be the best way to teach about the relationship between rain and runoff?
3. Water pollution can also occur in areas with little precipitation, especially urban areas (often from overwatering yards, cleaning cars in driveways, and so on). How could you help students see that pollution happens anytime—rain or shine?

Student Thinking: How Does Water Get Polluted?

1. How can you help students understand that any trash that ends up on the ground has the potential to enter water through runoff?
2. What is the best way to teach about toxins and chemicals that are "invisible" in water?
3. What are some ways you could teach students that pollution has a wider range of effects than just "killing" living organisms? Many organisms can actually live in polluted systems but are not necessarily healthy.

Student Thinking: Define *Water Pollution*

1. Both Abby and Ruby use the word "dirty" when describing water pollution and talk about what they can see and smell as indicators of water pollution. How could you help students expand their understanding of this concept?
2. Olivia demonstrates a basic idea about water pollution. What would be your next step when working with Olivia?
3. Thomas's answer shows he is confused between water pollution and simply wasting water. If Thomas shared this in class, how would you respond?

Student Thinking: How Do We Clean Water?

1. Order these responses from least to most sophisticated. How did you determine your order? What concepts can you build from? What concepts would you want to correct through the course of your lesson on water treatment?
2. Both Jessica and Rachel understand that during the treatment process "bad stuff" is taken out of the water. Water treatment also includes disinfection (or adding things to the water). How would this concept fit into your teaching plans?
3. Jacob is able to identify that there is a "factory that washes the water." What do you think Jacob means by "washes the water?" How can you use this to plan your lesson on water treatment?

Pictures of Practice: How Do We Clean Water?

1. Water treatment for communities is much different than home filtration systems. What concepts from home filtration could you build from when expanding to large-scale treatment? Why might starting from something students see and experience—home filtration—make it easier to move to a large-scale system?
2. How could you incorporate the Build Your Own Filter activity into your classroom?
3. Zach and Lizzy discuss why their water is still dirty, and they believe the sand layer was one of the problems. This contradicts how water is naturally filtered by the ground, where sand plays a critical role. If you heard Lizzy and Zach's discussion, how would you respond?
4. Even after the activity, Zach admits that he is still confused about cleaning invisible pollutants in drinking water. What would be your next step in working with Zach?

Chapter 5

Pictures of Practice: Runoff and Our Environment

1. Ms. Fortunato uses a classroom activity to help her students better understand the impact of runoff on ecosystem biodiversity. What kind of activity would you do in your classroom to illustrate this important concept?
2. One type of runoff—agricultural runoff—was a key focus of the water unit in Ms. Fortunato's class. During students' preinterviews, they thought farms impacted water by using too much, but during post interviews, students mentioned agricultural runoff and pesticides. How would you teach about farms and our water systems so that students have a better understanding of trade-offs as opposed to "good" and "bad" actions?

Student Thinking: Adapting to Change

1. Order students' ideas from least to most sophisticated. How did you determine your order?
2. What does Leah seem to understand that CJ and Reagan do not yet understand?
3. How would your teaching be different in responding to Leah compared to Reagan?
4. No students mention passing genes to offspring, which is normal for students of this age. What concepts would you work on so that students are prepared to understand genes and evolution in future grade levels?

Student Thinking: Threats to Diversity of Life in Freshwater

1. How could you demonstrate the high extinction rate of freshwater animals in a way that would be compelling to your students without overwhelming them?
2. What invasive species in your community would be a good example to use in the classroom?
3. Think of an analogy you could use to help your students understand the role of wetlands in the water cycle.

Pictures of Practice: If Your Water Ran Out

1. What do you think your students would say about about the cleanliness of the surface water in your area?
2. Between the two solutions for obtaining water that were discussed (buying it bottled or collecting rainwater), most students preferred and related to buying bottled water. Do you think this view would be similar in other American classrooms? How would you teach about the benefits of rainwater collection?
3. Although not in the video during the post interview, Zach suggests that the ocean may be a potential place to get water, but that humans would just have to "become immune to drinking salt water." How would you respond to this misconception?

Chapter 6

Pictures of Practice: Who Owns Water?

1. Riparian rights encompass the right to use water and the responsibility of putting back the same quality and quantity of water. Why would riparian rights be difficult to learn? How would you go about teaching this topic?
2. Students may believe that water is owned by landowners or the people who first discovered the water. Other students may believe whoever names the water owns the water. How would you handle these ideas in your classroom?
3. Salma focuses on the idea that water should be equally shared. What would you do if this idea continued to come up during your classroom discussions?

Student Thinking: Water Ownership

1. How are water rights determined in your area? Are there any special circumstances of interest?
2. Your students have running water at their disposal that their family pays for. How can you help them see that the water they use is a shared resource?

Pictures of Practice: Conflicts Over Water

1. How is water controlled and distributed in your area? How would you teach these laws/doctrines to your students?
2. Students in Ms. Fortunato's classroom talk about what is "fair" when dealing with water distribution. How would you handle a discussion like this in your classroom?
3. Salma has trouble with the concept of water conflict, stating that the people who live "next to the body of water" should be the ones who decide what happens with it. How would you explain to Salma that this is not always the case?

Chapter 7

Student Thinking: Reducing Water Use

1. How can you demonstrate hidden water—especially water that goes into the products they consume?
2. With seemingly limitless water at your students' disposal, how can you demonstrate that there is a finite amount of freshwater on Earth?
3. Rainwater harvesting is becoming more common around the world and in the United States. How would you teach about rainwater harvesting when students may already have misconceptions about the cleanliness of rainwater?

Pictures of Practice: Water Use and Conservation

1. During the discussion about water use, one student states that he needed the water he used during his audit for hygiene. How would you respond to this student?
2. Diana and Riley begin to understand that water is shared with others in their city and that just because they are paying for water does not mean they have the right to waste it. How would you help other students achieve this understanding?
3. An important next step to this discussion would be to elaborate on the topic of water conservation and practical actions that each student can take in his or her daily life. Plan how you might approach this topic. Why would it be important to conduct water audits prior to discussing water conservation actions?

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 3				
Social Studies	3.1.1	Identify geographical features in their local region.	The Geography of Where We Live (e.g., California Connections: California Natural Regions (pg 42-47 Ocean & Coast))	Chapter 1, 2
	3.1.2	Trace the ways in which people have used the resources of the local region and modified the physical environment.	The Geography of Where We Live (e.g., California Connections: California Natural Regions (pg 42-47 Ocean & Coast)	Chapter 3, 4, 5, 6, 7
	3.4.1	Determine the reasons for rules, laws, and the U.S. Constitution; the role of citizenship in the promotion of rules and laws; and the consequences for people who violate rules and laws.		Chapter 7
	3.4.2	Discuss the importance of public virtue and the role of citizens, including how to participate in a classroom, in the community, and in civic life.		Chapter 7
	3.5.1	Describe the ways in which local producers have used and are using natural resources, human resources, and capital resources to produce goods and services in the past and the present.	California's Economy—Natural Choices	Chapter 3, 4, 7
	3.5.2	Understand that some goods are made locally, some elsewhere in the United States, and some abroad.	California's Economy—Natural Choices	Chapter 3, 4, 7
	3.5.3	Understand that individual economic choices involve trade-offs and the evaluation of benefits and costs.	California's Economy—Natural Choices	Chapter 1, 3, 5, 6, 7
Science	3.1.e	Students know matter has three forms: solid, liquid, and gas.		Chapter 2
	3.1.f	Students know evaporation and melting are changes that occur when the objects are heated.	Living Things in Changing Environments (e.g., California Connections: Sweetwater Marsh National Wildlife Refuge)	Chapter 2
	3.1.g	Students know that when two or more substances are combined, a new substance may be formed with properties that are different from those of the original materials.		Chapter 4
	3.1.h	Students know all matter is made of small particles called atoms, too small to see with the naked eye.		Chapter 4
	3.3.a	Students know plants and animals have structures that serve different functions in growth, survival, and reproduction.	Structures of Survival in a Healthy Ecosystem	Chapter 1
	3.3.b	Students know in different environments, such as oceans, deserts, tundra, forests, grasslands, and wetlands.		Chapter 1
	3.3.c	Students know living things cause changes in the environment in which they live: some of these changes are detrimental to the organism or other organisms, and some are beneficial.	Living Things in Changing Environments (e.g., California Connections: Sweetwater Marsh National Wildlife Refuge)	Chapter 1, 5
	3.3.d	Students know when the environment changes, some plants and animals survive and reproduce; others die or move to new locations.	Living Things in Changing Environments (e.g., California Connections: Sweetwater Marsh National Wildlife Refuge)	Chapter 5

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 4				
Social Studies	4.1.3	Identify the state capital and describe the various regions of California, including how their characteristics and physical environments (e.g., water, landforms, vegetation, climate) affect human activity.	Reflections of Where We Live	Chapter 1, 3
	4.1.4	Identify the locations of the Pacific Ocean, rivers, valleys, and mountain passes and explain their effects on the growth of towns.		Chapter 2, 3
	4.1.5	Use maps, charts, and pictures to describe how communities in California vary in land use, vegetation, wildlife, climate, population density, architecture, services, and transportation.	Reflections of Where We Live	Chapter 1, 2, 3, 4, 5, 6, 7
	4.2.6	Discuss the role of the Franciscans in changing the economy of California from a hunter-gatherer economy to an agricultural economy.	Cultivating California	Chapter 3
	4.4.7	Trace the evolution of California's water system into a network of dams, aqueducts, and reservoirs.		Chapter 2, 3, 7
	4.5.3	Describe the similarities (e.g., written documents, rule of law, consent of the governed, three separate branches) and differences (e.g., scope of jurisdiction, limits on government powers, use of the military) among federal, state, and local governments.		Chapter 6, 7
	4.5.4	Explain the structures and functions of state governments, including the roles and responsibilities of their elected officials.		Chapter 6, 7
Science	4.2.b	Students know producers and consumers (herbivores, carnivores, omnivores, and decomposers) are related in food chains and food webs and may compete with each other for resources in an ecosystem.	The Flow of Energy Through Ecosystems	Chapter 1
	4.3.a	Students know ecosystems can be characterized by their living and nonliving components.		Chapter 1
	4.3.b	Students know that in any particular environment, some kinds of plants and animals survive well, some survive less well, and some cannot survive at all.		Chapter 1, 5
	4.5.c	Students know moving water erodes landforms, reshaping the land by taking it away from some places and depositing it as pebbles, sand, silt, and mud in other places (weathering, transport, and deposition).		Chapter 2

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 5				
Social Studies	5.7.3	Understand the fundamental principles of American constitutional democracy, including how the government derives its power from the people and the primacy of individual liberty.		Chapter 7
Science	5.1.f	Students know differences in chemical and physical properties of substances are used to separate mixtures and identify compounds.		Chapter 4
	5.1.g	Students know properties of solid, liquid, and gaseous substances, such as sugar ($C_6H_{12}O_6$), water (H_2O), helium (He), oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2).		Chapter 2
	5.3.a	Students know most of Earth's water is present as salt water in the oceans, which cover most of Earth's surface.	Earth's Water (California Connections: Water to Grow a City; Lesson 3: From Fresh to Salt Water (watersheds); Lesson 4 Presentation: Managing California Water)	Chapter 2
	5.3.b	Students know when liquid water evaporates, it turns into water vapor in the air and can reappear as a liquid when cooled or as a solid if cooled below the freezing point of water.	Changing States: Water, Natural Systems, and Human Communities (California Connections: Salt Farming on San Francisco Bay)	Chapter 2
	5.3.c	Students know water vapor in the air moves from one place to another and can form fog or clouds, which are tiny droplets of water or ice, and can fall to Earth as rain, hail, sleet, or snow.	Preceipitation, People, and the Natural World (California Connections: The Sierra Snowpack)	Chapter 2
	5.3.d	Students know that the amount of freshwater located in rivers, lakes, underground sources, and glaciers is limited and that its availability can be extended by recycling and decreasing the use of water.	Our Water: Sources and Uses (California Connections: California Drought; Lessons on water use, conservation, wastewater treatment)	Chapter 1, 2, 3, 4, 5, 6, 7
	5.3.e	Students know the origin of the water used by their local communities.	CA Connections: The Sacramento-San Joaquín Bay Delta	Chapter 2, 3, 4, 6
	5.4.b	Students know the influence that the ocean has on the weather and the role that the water cycle plays in weather patterns.		Chapter 2
Grade 6				
Social Studies	6.2.1	Locate and describe the major river systems and discuss the physical settings that supported permanent settlement and early civilizations.	River Systems and Ancient Peoples (Delta Dynamos—The Sacramento and San Joaquín Rivers: A story about the largest river system in California, its flooding patterns and sedimentation, water management activities, estuary habitats as part of the food web, and human use of the Delta)	Chapter 3
Science	6.2.a	Students know water running downhill is the dominant process in shaping the landscape, including California's landscape.		Chapter 2, 4
	6.2.b	Students know rivers and streams are dynamic systems that erode, transport sediment, change course, and flood their banks in natural and recurring patterns.	The Dynamic Nature of Rivers (California Connections: The Sacramento-San Joaquín Bay Delta)	Chapter 2, 3, 4
	6.2.c	Students know beaches are dynamic systems in which the sand is supplied by rivers and moved along the coast by the action of waves.		Chapter 2
	6.2.d	Students know earthquakes, volcanic eruptions, landslides, and floods change human and wildlife habitats.		Chapter 2
	6.5.c	Students know populations of organisms can be categorized by the functions they serve in an ecosystem.	Energy: Pass it On!	Chapter 1
	6.5.d	Students know different kinds of organisms may play similar ecological roles in similar biomes.	Playing the Same Role	Chapter 1
	6.5.e	Students know the number and types of organisms an ecosystem can support depends on the resources available and on abiotic factors, such as quantities of light and water, a range of temperatures, and soil composition.		Chapter 1, 4, 5

California State Standard			Connections to EEI Model Curriculum	Teacher Guide Chapters
Grade 7				
Science	7.3.a	Students know both genetic variation and environmental factors are causes of evolution and diversity of organisms.	Shaping Natural Systems through Evolution	Chapter 1, 5, 6
	7.3.e	Students know that extinction of a species occurs when the environment changes and that the adaptive characteristics of a species are insufficient for its survival.	Responding to Environmental Change	Chapter 1, 5, 6
Grade 8				
Social Studies	8.3.2	Explain how the ordinances of 1785 and 1787 privatized national resources and transferred federally owned lands into private holdings, townships, and states.		Chapter 7
	8.3.6	Describe the basic law-making process and how the Constitution provides numerous opportunities for citizens to participate in the political process and to monitor and influence government (e.g., function of elections, political parties, interest groups).		Chapter 7
	8.6.1	Discuss the influence of industrialization and technological developments on the region, including human modification of the landscape and how physical geography shaped human actions (e.g., growth of cities, deforestation, farming, mineral extraction).		Chapter 3, 5
	8.8.4	Examine the importance of the great rivers and the struggle over water rights.	Struggles with Water	Chapter 3, 6, 7
	8.12.1	Trace patterns of agricultural and industrial development as they relate to climate, use of natural resources, markets, and trade and locate such development on a map	Agricultural and Industrial Development in the United States (1877—1914)	Chapter 3, 4, 5, 6, 7
	8.12.5	Examine the location and effects of urbanization, renewed immigration, and industrialization (e.g., the effects on social fabric of cities, wealth and economic opportunity, the conservation movement).	Industrialization, Urbanization, and the Conservation Movement	Chapter 2, 3, 4, 7
Science	8.3.d	Students know the states of matter (solid, liquid, gas) depend on molecular motion.		Chapter 2
	8.3.e	Students know that in solids the atoms are closely locked in position and can only vibrate; in liquids the atoms and molecules are more loosely connected and can collide with and move past one another; and in gases the atoms and molecules are free to move independently, colliding frequently.		Chapter 2
	8.5.d	Students know physical processes include freezing and boiling, in which a material changes form with no chemical reaction.		Chapter 2
	8.5.e	Students know how to determine whether a solution is acidic, basic, or neutral.		Chapter 4

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California Education and the Environment Initiative

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