ENVIRONMENTAL LITERACY TEACHER GUIDE SERIES

Earth's Freshwater

A Guide for Teaching Freshwater in Grades 3 to 8

NATIONAL GEOGRAPHIC

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
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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.

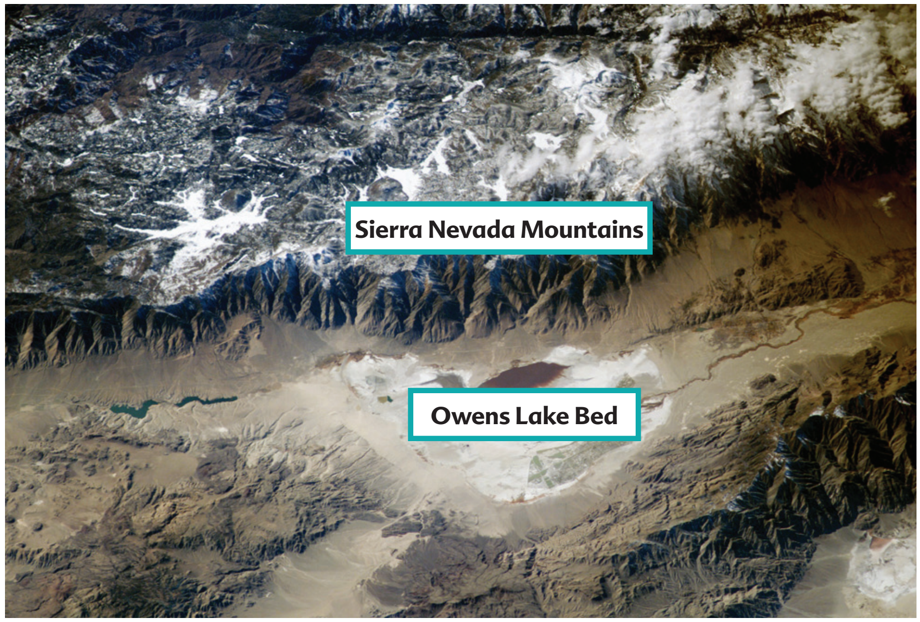
Through urbanization, we have had great impact on water movement just by paving roads and parking lots and building sidewalks in cities and suburbs. Places where water once penetrated the soils of open lands are now covered by impenetrable asphalt and concrete, resulting in changes to both surface runoff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

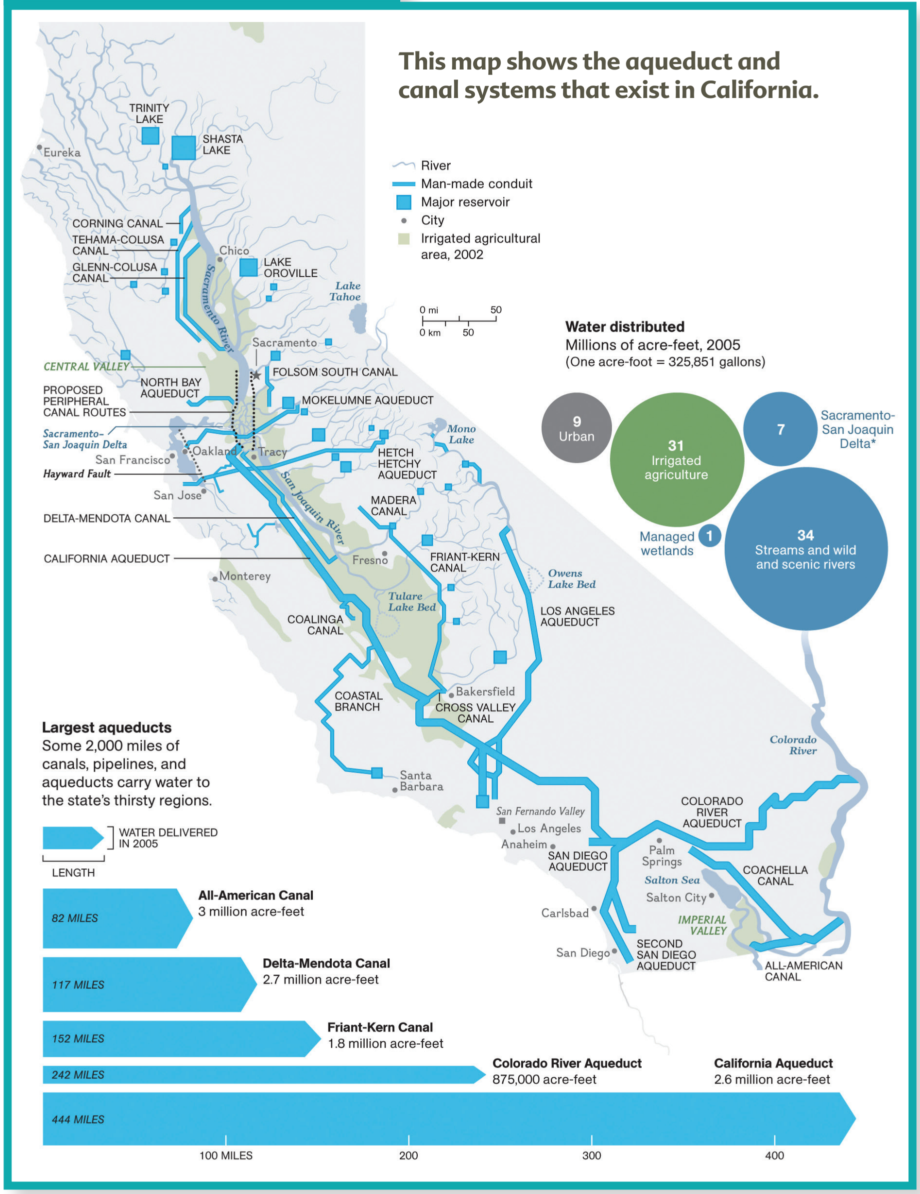
1. Of the misconceptions, which would you want to target most during your teaching about dams? Why?
2. What kind of post assessment would you do to ensure students understand what a dam is and how dams are used?

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

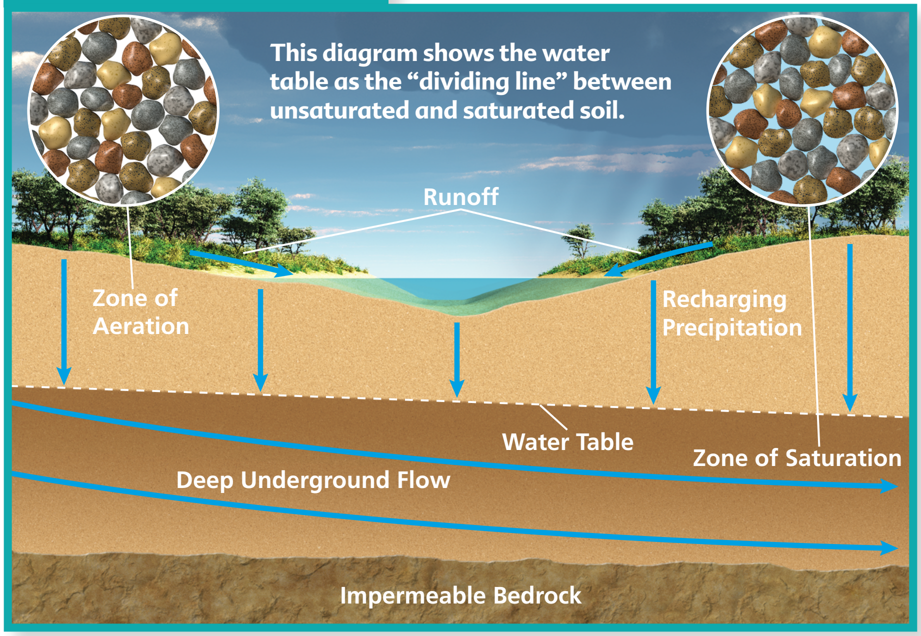
Although we don't often think about it, groundwater is a very important source of water. Groundwater, as the term suggests, is water that is stored in the ground, often in aquifers, as discussed in Chapter 2. Although students may envision groundwater to be underground lakes and rivers, this is not true. 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).

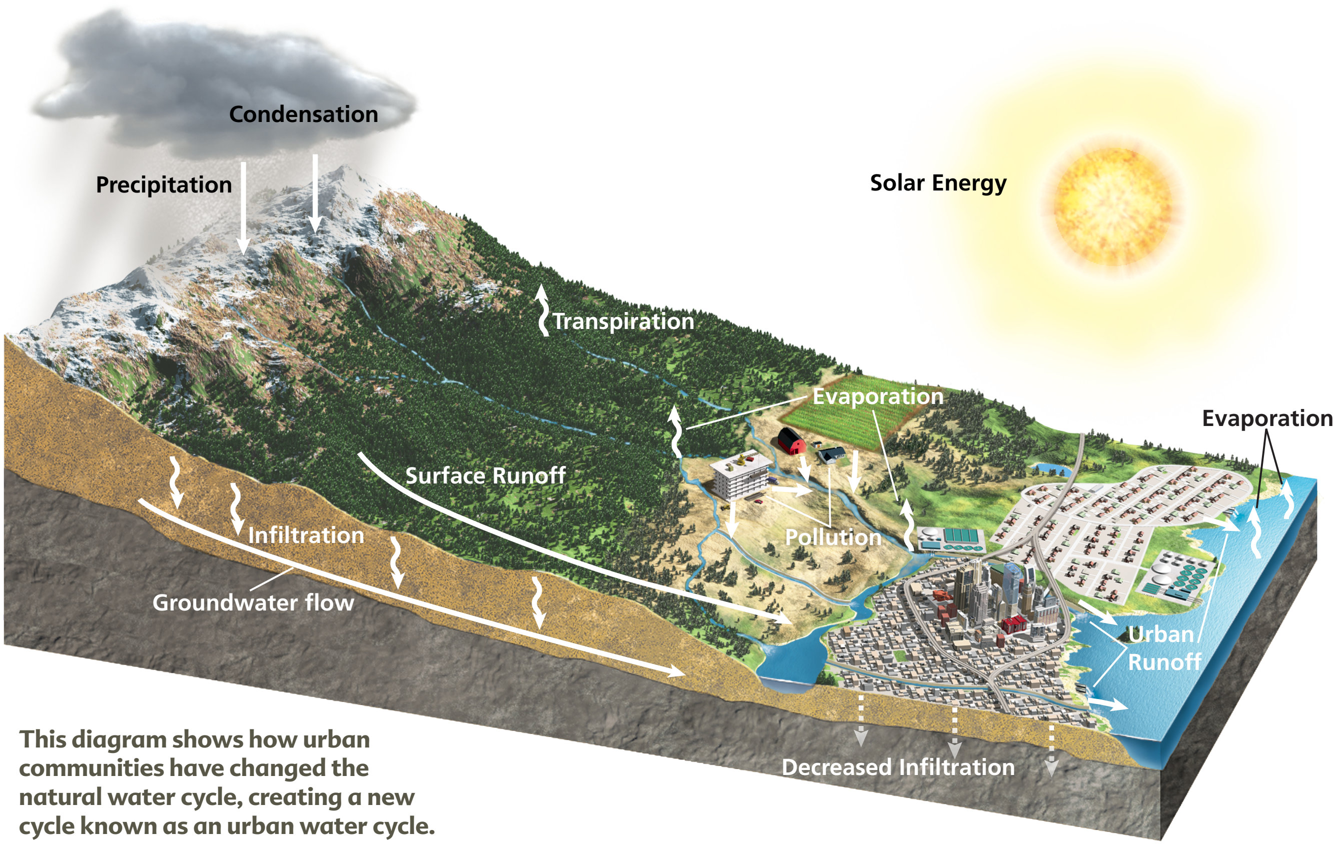
Urbanization

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

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