ENVIRONMENTAL LITERACY TEACHER GUIDE SERIES

Earth's Freshwater

A Guide for Teaching Freshwater in Grades 3 to 8

NATIONAL GEOGRAPHIC

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.

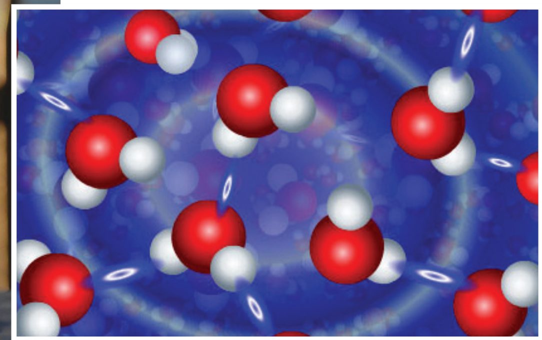
This chapter discusses how water mixes with others substances, the definitions of water quality and water pollution, common types of water pollution, and methods humans use to treat water.

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.

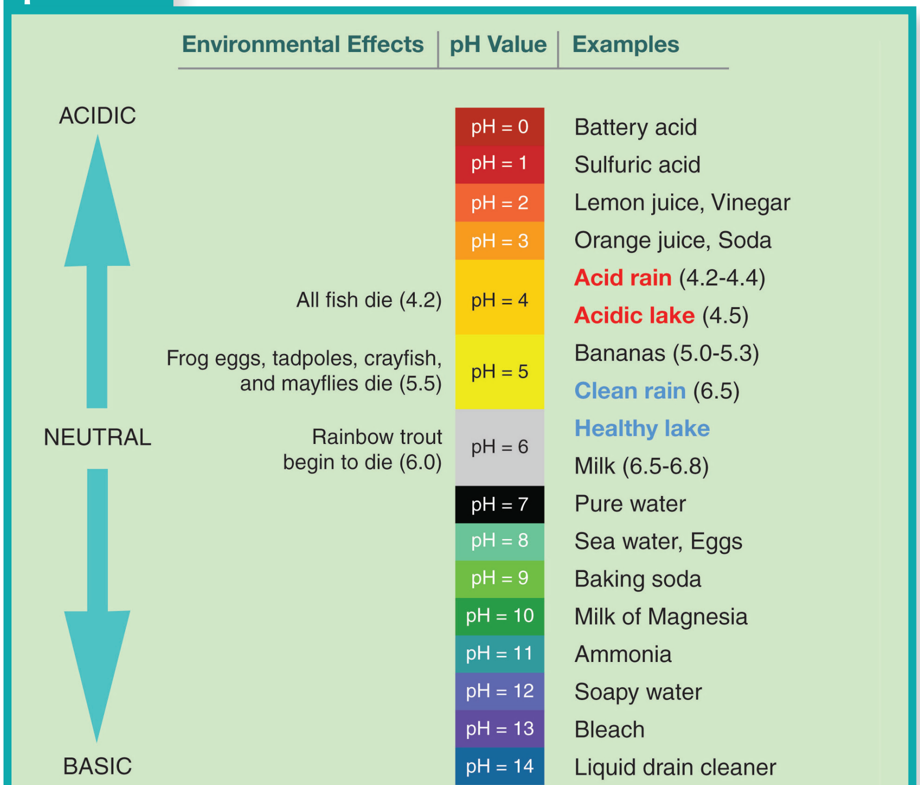
Water also carries with it many biological organisms. The most concerning are usually bacteria and viruses. The most widely known bacteria is *E. coli,* which is often the reason for beach warning signs following heavy rains. *E. coli* can enter a body of water from human sewage or when animal excrement 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



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.

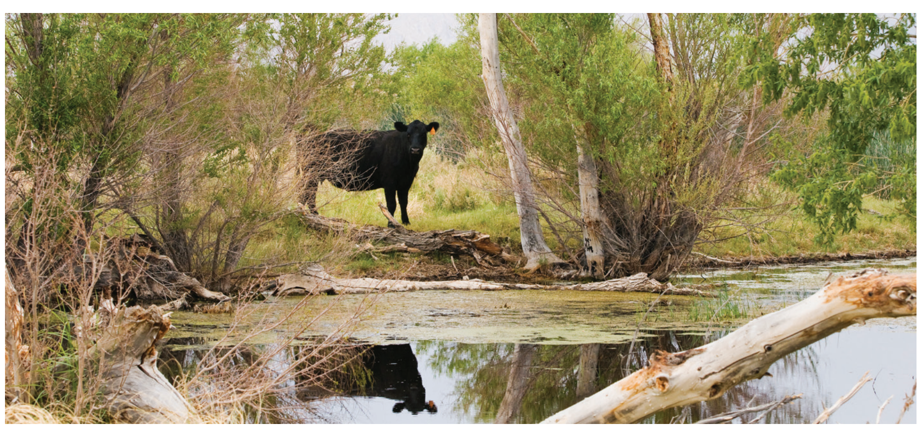
of straw or straw bales, or sandbags, surrounding construction sites, which are examples of the regulations associated with the Environmental Protection Agency's National Pollutant Discharge Elimination System. These barriers preventsediment runoff. While knowing where pollution comes from is critical,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

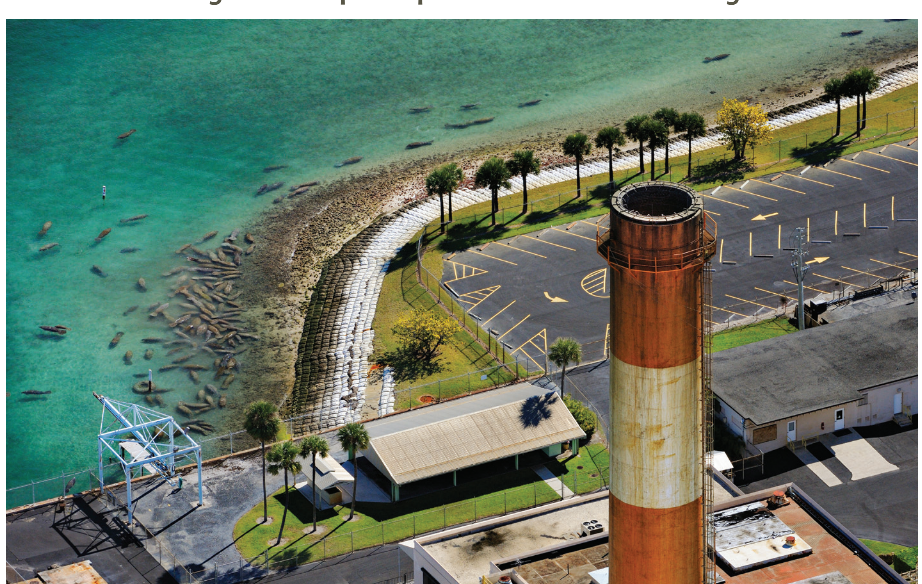
Thermal Pollution. Thermal pollution, unlike most other types of water pollution, does not relate to substances that are mixed with water. Instead, thermal pollution refers to the degradation of water quality due to increased water temperature. Usually, the increase in water temperature is caused by 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

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.

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.

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

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Instructional Editor	Lindsey Mohan, Ph.D. / National Geographic Society
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Copy Editor	Kate Matracia, NounSense

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Content and Educational Writers

EEI Introduction	Kristin M. Dell, B.A.
Water Introduction	Marcia S. Matz, M.A.
Chapter 1	Marcia S. Matz, M.A.
Chapter 2	Anica Miller-Rushing, M.Ed.
	Abraham Miller-Rushing, Ph.D.
	Marcia S. Matz, M.A.
Urban Water Cycle	Lindsey Mohan, Ph.D.
Chapter 3	Ari J. Posner, M.S.
Chapter 4	Ari J. Posner, M.S.
Water Treatment	Beth A. Covitt, Ph.D.
Chapter 5	Abraham Miller-Rushing, Ph.D.
	Anica Miller-Rushing, M.Ed.
	Marcia S. Matz, M.A.
The River Delta Case	Tara G.Treiber, B.A.
Precipitation and Climate	Tara G.Treiber, B.A.
Chapter 6	Ari J. Posner, M.S.
Chapter 7	Jose Marcos-Iga, Ph.D.
	Tania T. Hinojosa, M.ET.
True Cost of Water	Tara G. Treiber, B.A.
Boston Conservation	Sandra Postel, National Geographic Fellow

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