ENVIRONMENTAL LITERACY TEACHER GUIDE SERIES

Earth's Freshwater

A Guide for Teaching Freshwater in Grades 3 to 8

NATIONAL GEOGRAPHIC

7 Water Solutions for Our Future

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

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

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

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

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

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

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

Is the Water Crisis Crystal Clear?

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

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

CHAPTER OVERVIEW

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

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

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

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

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

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

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

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

Mitigation of Our Water Problems

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

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

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

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

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

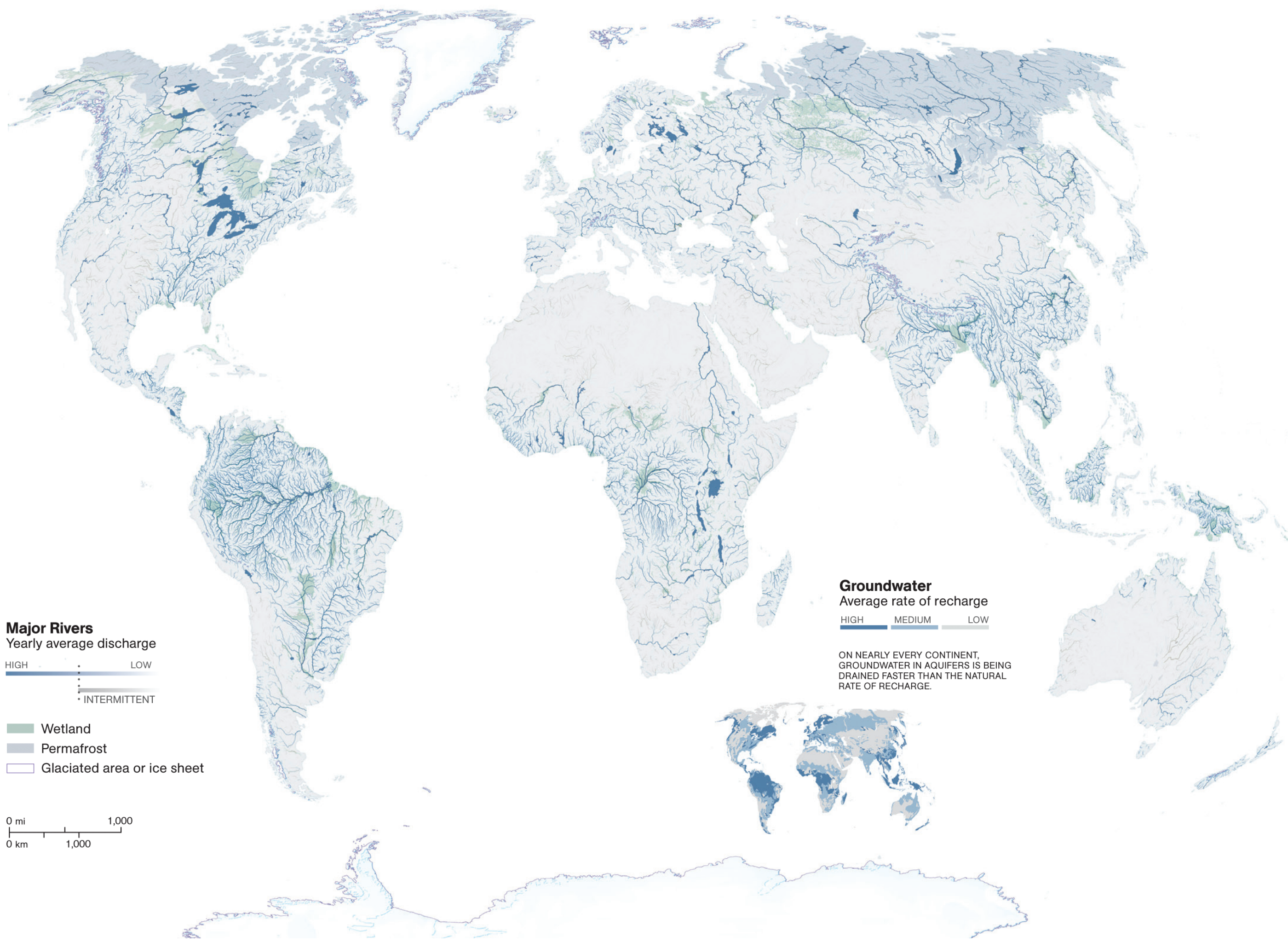
In addition to UNEP, the United Nations also created UN-Water, a division responsible for helping to share resources between countries and organizations. The UN-Water division is the central clearinghouse for all reports and publications on world water issues, many of which are published in six or more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

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

The Right to Water

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

—UN Committee on Economic, Social and Cultural Rights



Case Study

Aid for Water-Stressed Communities

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

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

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

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

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

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

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

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

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

system and are released into streams and marine areas, where the pollutants can harm aquatic plants and animals and threaten public health.

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

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

Teaching Tip

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

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

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

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

Case Study

True Cost of Water

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

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

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

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

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

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

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

Case Study Successful Agriculture

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

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

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

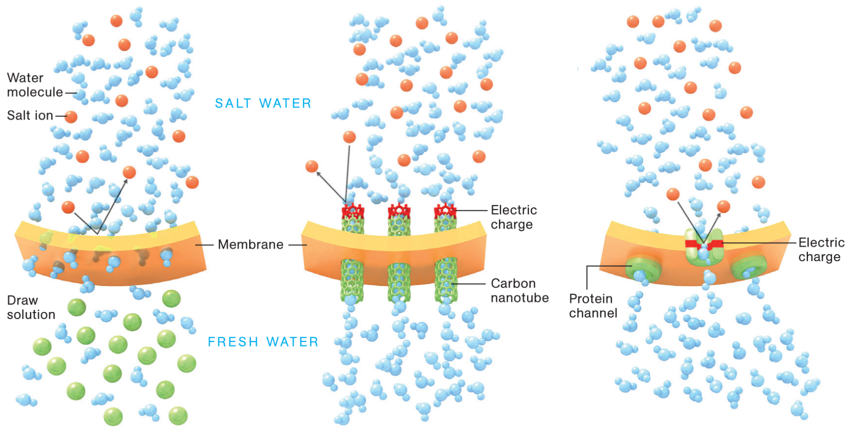
the Central Valley and 33 inches per year along the coast (Cohen 2010). That means Coachella Valley crops lose a lot of moisture to natural evaporation and transpiration compared to other locations in California.

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

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

METHODS OF DESALINATION

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



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

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

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

Innovation

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Teaching Tip

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

Case Study

Boston Conservation: A Success Story

by Sandra Postel, Freshwater Fellow, National Geographic Society

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

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

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

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

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

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

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

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

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

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

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

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

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

Actions to Protect Our Water

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

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

The indirect water footprint of an individual is the total amount of water used to produce the goods and services consumed by an individual. Each item we consume has its own footprint—its own amount of water that went into making the item. If we added all the water footprints of all the products we consume, it gives us the water footprint for a person.

Hidden Water Consumption. Beyond the water we use every day for drinking, bathing, washing, and cooking, there is an entirely different

Teaching Tip

Organize your students into small groups and ask each group to reflect about different ways they and their families may use more water than they need in their day-to-day lives. Ask the groups to also think about how they and their families might be able to use less water. The following questions can help you guide your class discussion:

- What are some ways you use water at home?
- Can you remember the last time you or anyone in your house wasted water?
- How was the water wasted?
- How could it be prevented?
- Do you think it is important to use water responsibly?
- Why? Students can also fill out a water use chart, like the one found at http://www.k12science.org/curriculum/drainproj/personalwaterusechart.html.

Student Thinking

Reducing Water Use

Students are often unaware of both the need to conserve water and the ways in which water can be conserved. Water is so accessible in the United States that students are usually able to turn on a faucet, flush a toilet, or get ice from their refrigerator without ever thinking about where this water comes from or how much they are using in the process. In addition to having easy access to water, students are not likely to have any experiences or ideas that would inform them about all of the water required to produce their food, clothes, medication, and plastics. By raising student awareness of how water is used and ways it can be conserved, you can provide them with the opportunity to make educated decisions about how to use the precious resources most efficiently.

	Common Student Ideas	Scientific Concepts
Water conservation	We can conserve water by turning off the faucet when we brush our teeth.	Water conservation involves consideration of food we eat, clothes we buy, energy we use, and so on. Water is used to make products, so water conservation involves being a smart consumer as well as implementing behavioral changes like taking shorter showers and turning off the faucet while brushing our teeth.
Origins of water	Water is limitless. Our cities and dams actually make water for us to use.	Water is a form of matter, so it cannot be created or destroyed. It must come from and go somewhere. There is only a limited amount of water in fresh, liquid form on Earth. Cities and dams do not create water but rather manage or store water for future use.
Rainwater	We cannot use rainwater to drink or in our homes.	Rainwater harvesting is an excellent way to supplement home water use. With the proper treatment this water can be as clean or cleaner than other water sources. It is also a great water source for a home garden.

Ask Your Students

1. How does your city get water to send to homes? Where does this water come from? Should there be a limit for how much you can use? (Or, for rural areas: Where does water come from in your well? Is there a limit to the water in your well?)
2. How could rainwater harvesting help you reduce your water footprint?
3. Water is used for more than flushing toilets, drinking, and taking baths. What are some other ways you think freshwater is used to support your lifestyle? How might this influence what you buy the next time you go shopping?

and less visible dimension of water consumption. Water is needed to produce virtually every consumer product in the global market. The amount of water used to create a product is referred to as hidden, or virtual, water.

The term *virtual water* was created as a "tool for water management and to give countries, companies and individuals a clearer measure of their water footprint" (*National Geographic* 2010). "Virtual water" refers to the actual volume of water used in producing a certain amount of a specific item. For the numbers following, keep in mind that a typical bathtub holds 50–60 gallons of water.

For example, producing one pound of beef requires 1,857 gallons of water. The virtual water for meat production includes the water the animals drink as well as the water used to grow their feed and clean their waste. Some meat products require less water. For example, producing a pound of sausage requires 1,382 gallons of water, while one pound of chicken only requires 469 gallons of water. Fruits and vegetables require far less. Growing one pound of apples requires 84 gallons of water. The manufacturing of cotton clothing is particularly water intensive. For example, 2,900 gallons of water are required to make a pair of jeans (see *National Geographic* 2010, for more information).

It is perhaps an unsurprising fact that simply being American means we use more water than people in other nations. In the United States, an average person uses 80 to 100 gallons of water per day. The average Californian uses 189 gallons per day. That's about 330,000 gallons of water per year, or 6,000 filled bathtubs! In contrast, the average Chinese citizen uses less than half of what an American citizen uses each year.

As global citizens we need to recognize that freshwater is a resource that we must share and conserve for future generations. Even though freshwater seems limitless from our faucets—an endless supply from our city water source or from our wells—many people in the United States and abroad do not have easy access to water and, therefore, are more conscious about their use. Teaching students about this important resource is an important step for preparing future generations of citizens to care about and conserve

Teaching Tip

The concept of *virtual water* may leave some students feeling overwhelmed. However, this topic provides a great opportunity to discuss why some food items and common goods take more water to produce than others, and how students' choices as consumers can make a difference in water conservation. A few examples that students may be able to relate to include the amount of water needed to produce a hamburger and the amount needed to make a pair of jeans.

1 hamburger = 634 gallons of water
1 pair of jeans = 2,900 gallons of water

Ask students to discuss why it's important to think about where our food and other products come from: What does it matter? Why should we care? What can we do with this information to make a positive difference?

PRODUCT	VIRTUAL GALLONS USED PER POUND
Beef	1,857
Processed sausage	1,382
Processed Cheese	589
Chicken	469
Eggs	400
Fresh Cheese	371
Bananas	103
Apples	84

It takes approximately 2,900 gallons of water to make a single pair of jeans.

Every person has a choice about how how water is used. The left image shows a man in a neighborhood in California watering his yard with municipal water. The right image shows a couple that collects rainwater to irrigate their yard. Rainwater harvesting is a great solution for homeowners in arid climates.

our freshwater. Consider the following suggestions for ways that your students, your classroom, and your community can act to be part of the solutions.

What Can You and Your Family Do?

Reduce Direct Water Use. One of the most important thing students can do is turn off faucets and take shorter showers each and every day. Additionally, there is much that can be done around the home. For example, when ready to upgrade bathrooms, make sure to install low-flow showerheads, faucets, and toilets. Did you know that a low-flow showerhead can save 15 gallons of water for just a 10-minute shower? Multiply that by everyone in your family taking showers almost every day, and that adds up to real savings. Another easy practice is to repair any water leaks around your home—inside and out. Leaks can add up to almost 10 gallons of water per day! Also, when ready to upgrade, consider a front-load washing machine that uses about half the water of a top-loader. Make sure to adjust the water level accurately. Using a dishwasher is also more efficient than washing by hand. Dishwashers use 4–6 gallons of water, while handwashing an equivalent number of dishes uses almost 20 gallons.

Reduce Hidden Water Use. You can reduce your hidden water footprint by paying attention to three more habits at home—food choices, energy choices, and other products you buy. An American's daily diet requires about 1,000 gallons of water to produce. One way to reduce this water use is to eat fewer meat and dairy products or choose grass-fed products over grain-fed products. Reducing energy use around the home and reducing fuel use in the car also saves on water because it takes water to make energy. For example, it takes 13 gallons of water to make one gallon of gasoline. Lastly, reducing the number of products you buy can also save water. A single pair of jeans requires 2,900 gallons of water, some of which is used to grow cotton. Rethink whether you need a new t-shirt or new jeans or whether you can manage without them.

Rethink Your Yard. Almost 60 percent of a person's water footprint goes to yard maintenance. Make sure to water lawns following your water restriction. Another strategy might be to **xeriscape** your yard or install a permeable patio that allows water to flow through to the ground, while also reducing the amount of vegetation that needs to be watered. Xeriscape is a landscaping strategy that utilizes native plants and gravel that require no additional irrigation. Consider installing rainwater harvesting systems to supplement your other water source. This source of water can be used for your yard or garden.

What Can Your Classroom and School Do?

Reduce School Water Use. Have students investigate the number of toilets and faucets found in the school and determine how much water could be saved by replacing them with low-flow faucets and toilets. They could develop a school-improvement plan that could be shared with other classrooms and school staff. If irrigation is used, have students research the existing irrigation system—when does the school water, how often, for how long, and with how many sprinklers? Is there a way to improve this system by watering at different times of day or even by installing drip irrigation?

Rethink the School Cafeteria. Schools offer students numerous food options from the cafeteria. Imagine if these options were labeled by the amount of water used to make them. Have students look closely at the food options offered in the school cafeteria. Are several meat and dairy options offered? Can any of these be replaced by vegetable or fruit options? Propose to the cafeteria to have one day a week on which meat options are not offered or reduced (e.g., Meatless Mondays).

Green School Grounds. Every school is different, so a class should first investigate its school grounds to determine which areas have impermeable or permeable surfaces and whether the class can adopt a project to improve school grounds. The project might include installing a rain garden or xeriscaping a portion of the lawn, both of which will introduce your students to native plants. Students can also research options for permeable pavers and make recommendations to the school about places where these materials could be used instead of traditional concrete. For example, the playground may have surfaces that could use permeable pavers. Students can take on a project to clean school grounds so less potential pollutants are washed away by rain. Lastly, students may research organic plant fertilizers and treatments that could be used to replace any of the traditional pesticides and fertilizers used by the school.

Teaching Tip

Have students identify permeable and impermeable surfaces around their school. Present the following list of areas to students and help them identify which areas are impermeable. Then conduct a class discussion about how to increase permeable surfaces around the school. Have students construct a plan for "redesigning" their school or a plan for how they would build a school using permeable surfaces. If possible, undertake a class- or school-wide project aimed at reducing impermeable surfaces on the school campus.

- Parking area
- Grassy play area
- Gravel/sandy play area
- Sidewalk
- Field for different sports
- Basketball or gym court
- Rooftop
- Driveway
- Street

For example lessons and more information, explore the following resources: http://www.crd.bc.ca/watersheds/protection/howtohelp/reduceimpervious.htm.

What Can Your Community Do?

Reduce Impermeable Surfaces.

Especially in urban areas, reducing impermeable surfaces is a top water solution. This not only alleviates problems with storm-water runoff and pollution, but it also helps to recharge the groundwater. Communities should look at surfaces that can be replaced with permeable pavement, like sidewalks, driveways, bike trails, and parking lots, and develop long-term plans for how to replace those surfaces. In addition, homes and businesses can install rain gardens, green roofs, and xeriscape to help with groundwater infiltration.

Green-Space Irrigation. When cities develop green spaces, parks, sports fields, or even municipal golf courses, installing efficient irrigation systems can be one strategy to reduce water use in those spaces. Upgrading existing irrigation systems may require an upfront investment but can be financially and environmentally rewarding over time.

Clean the Streets. Initiate or participate in community-wide programs to keep trash off streets and out of local waterways. Community cleanups help to reduce the amount of debris entering the storm-drain system, which eventually makes its way to our freshwater and marine ecosystems.

Keep local water clean by reducing personal litter and joining a community cleanup.

In the Classroom

My Water Footprint

Students are often interested in learning about how their water use compares to that of others. In this activity, students calculate their own water footprint and then compare it to average footprints from around the world.

Materials

- Computer/Internet Access
- Water Footprint preparation sheet

Directions

1. Before teaching this activity, explore water-footprint calculators. Determine which is most appropriate for your students. Once you determine the calculator, prepare a worksheet for students to gather information about home water use. The worksheet should help students easily enter data when using the calculator. Have student complete the worksheet at home before doing step 2.
2. Discuss the concept of a water footprint. Ask students to make a prediction about how many gallons of water per day that they think they use, then direct them to the water footprint calculator to calculate their individual footprint. Consider using National Geographic Society calculator: http://environment. nationalgeographic.com/environment/freshwater/water-footprint-calculator/.
3. Ask students if their footprint was larger than expected.
4. Talk about the smallest footprint in the class. What are the reasons the person had the smallest footprint?
5. As an extension, have students to compare their water footprints to the footprints of people who live in other countries. Use the following link to find the water footprint per capita per country: http://www.waterfootprint.org/?page=cal/waterfootprintcalculator_national. Keep in mind the global average water footprint is 1,243 m3/cap/yr. Alternatively, you can print charts like the following:

Country	Water footprint in m^3 per capita per year
USA	2,483
Canada	2,049
Mexico	1,441
United Kingdom	1,245
Data obtained from the Water Footprint Network, period 1997—2001	

6. Once they compare their footprints to other countries, ask students to discuss why their footprints are different.

Discuss

1. In terms of water use, how do you think your daily life varies from someone your age in Mexico or the United Kingdom?
2. Which behaviors are you willing to change to save water? Which would be more difficult? Why?

Pictures of Practice

Water Use and Conservation

Conducting a water audit is the first step toward conservation. A personal water audit tells a person how he or she uses (and potentially wastes) water and gives areas to improve water conservation. For example, doing a water audit, or entering information into a water calculator, can tell a person if he or she use above average or below average water in the shower, for dishwashing, for washing clothes, and so on. The average American uses about 100 gallons of water per day, which is equivalent to roughly two bathtubs filled with water. Obviously most of this is not used for drinking! We may not pay careful attention to our personal water use, but knowing more about it can help us become better conservers of this precious resource.

Students: Grade 6

Location: San Diego, California (a coastal community)

Goal of Video: The purpose of watching this video is to hear about students' water audits and what they learned about use and conservation.

Classroom Context

At the start of their water unit, students conducted a personal water audit, focusing on obvious uses of water (e.g., drinking, brushing teeth, showers, washing dishes, and so on). Students calculated the number of gallons used over the course of a day and then shared their numbers with their classmates. Ms. Fortunato recorded everyone's water audit on the white board, which remained visible to students throughout the remaining unit. Ms. Fortunato and students used the information collected during the activity as a source of information for discussing how people use or conserve water.

Video Analysis

After completing the water audit, students reviewed their water use with their classmates. Students' water audits ranged from 30 gallons per day to more than 100 gallons per day. The average American citizen uses about 100 gallons a day. Ms. Fortunato poses the question to students, "Did you have a right to use the water in your personal water audit?" One students says yes, because he needed the water for hygiene (brushing teeth and showering). However, early in the discussion, Diana brings up the idea that she "wasted too much" water. Diana says that she used water she didn't need to use and did not think about people who don't have much water. She just kept using it because she could. Then Riley makes the case that all the people in the city share water, so when it is wasted that takes water away from the city. For the most part, students seem to realize that even though they have access to clean water and can use what they want, there is some degree of responsibility to not waste water. The idea of "fairness" becomes a key component of the discussion. Even though we pay for water, is it fair to use as much as we want? Students wrestle with this question during their post-interviews.

Reflect

What should students understand about water use and conservation?

On the one hand, people pay for water, so it "belongs" to them. On the other hand, water is a shared resource. How would you help students develop a better understanding of the balance between the two? Even though we seem to have limitless water for purchase, it is actually a valuable resource in need of conserving. Consider having your students conduct personal water audits and use their findings to discuss conservation practices.

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Teaching Resources

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

The Water Project: http://thewaterproject.org/

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