5 Sustaining Our Freshwater Resources

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Learning Outcomes

After reading this chapter, you should be able to

- Describe how New York City worked with nature to improve its water supply.
- Illustrate the water cycle and how the planet's water is distributed.
- Define different types of water use.
- Analyze the methods used to meet global water demand.
- Describe the potential for global conflict over water.
- Describe different types of water pollution and ways to manage that pollution.
- Differentiate between the hard path and soft path approaches to water management.
- Discuss the role of forests in water management.

When viewed from space, Earth is a watery planet, with oceans covering over 70% of the planet's surface and glaciers, ice caps, lakes, rivers, and streams covering another 10%. Yet water shortages and access to clean, safe drinking water are a serious problem in virtually every region of the world. The abundance of ocean water is too salty for human use, and much of the freshwater is either polluted or inaccessible.

Given its importance and critical role in all human life, it is remarkable how poorly managed water is as a resource. We regularly use rivers, streams, and the oceans as a dumping ground for our wastes and allow contaminants like spilled oil and agricultural chemicals to pollute critical groundwater supplies. We dam rivers and use massive amounts of energy to pump water hundreds of miles to irrigate golf courses and suburban lawns in the middle of deserts. And we pay little attention to how the management—or mismanagement—of natural capital resources like forests, wetlands, and other open spaces impacts water quality in surrounding regions.

This chapter will examine issues of freshwater management and consider the challenges of both water *quantity* and water *quality*. The next chapter will examine issues and challenges associated with our oceans.

We will first discuss issues of water *quantity*, which involve ensuring that there are adequate supplies and that mismanagement of water does not result in flooding. Only a tiny fraction of water on the planet is accessible and suitable for human consumption, making wise water management a critical priority. We'll also see that just as with other critical resources like food and energy, water use varies greatly in different regions of the world. We will then consider issues of water *quality*, which involve ensuring that water is safe to use. Lastly, we will look at ideas and approaches for water conservation and sustainable water management, including efforts both to increase the availability of water on the supply side and to reduce usage on the demand side.

5.1 Case Study: New York City's Water Supply

New York City has long prided itself on the quality of its municipal drinking water, with some residents and city boosters going so far as to call it the "champagne of tap water." Over the years the city has garnered awards for the quality of its water relative to other major cities in the United States, and chefs and food experts have debated whether the city's water might have something to do with the quality of its pizza and bagels. A Southern California–based pizza business even goes so far as to spend $10,000 a year to have New York City tap water trucked across the country to use in making dough for its New York–style pizza.

The story of why New York City's water quality is so good and how the city addressed contamination can help us begin to understand the issues discussed in this chapter and the importance of sustaining freshwater resources.

Building a Water Supply System

As far back as the 1830s, city leaders in New York knew that, in order for the city to grow and thrive, they needed to do something about their water supply situation. At the time, the city drew its water from a patchwork of ponds, springs, and underground wells, but overuse and poor waste management were affecting both the quantity and the quality of the city's water supply. Massive fires burned through wood-framed buildings because water pressure was too low to fill fire hoses. Overpumping of wells led freshwater levels to fall below sea level, allowing the nearby ocean to seep in and contaminate groundwater supplies. The raw sewage and animal waste being dumped in the streets ran off and contaminated ponds and small reservoirs.

After a cholera epidemic (due in large part to poor water quality) killed thousands in 1832 and the Great Fire of New York burned 17 city blocks in 1835, city leaders embarked on a massive water development project that would change the course of New York City history. A dam was built on the Croton River north of the city, and a 65-kilometer (40-mile) covered aqueduct was built to carry water from there to the middle of Manhattan, where Central Park is located today. When the new water supply system opened in 1842, it carried 340 million liters (90 million gallons) of clean water every day to the thirsty city.

Sixty years later, the system was expanded on as city officials sought to prevent water shortages and inadequate supply while New York City grew and expanded. Water development projects were undertaken further north and west of the city in the Catskill Mountain region. An entire series of dams, reservoirs, aqueducts, and tunnels were constructed in the early 1900s, and by 1915 the Catskill Aqueduct was in operation.

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The Ashokan Reservoir in the Catskill Mountains is one of several to provide New York City with its water supply.

Today New York City's water supply system is still based almost entirely on the projects from the 1800s and early 1900s. Each day over 4.5 billion liters (1.2 billion gallons) of water are delivered to New York City's 9 million residents, with 10% of this water coming from the Croton portion of the system and 90% originating from the Catskill portion. The Catskill watershed region, over 160 kilometers (100 miles) away from the city, draws water from 19 reservoirs and 3 lakes spread out over a 500,000-hectare (2,000-square-mile) area. A **watershed** is an area of land where sources of water (streams, creeks) flow together to a single destination. These lakes and reservoirs are connected to the city by 10,000 kilometers (over 6,200 miles) of pipes, tunnels, and aqueducts. Because of differences in elevation, almost the entire system moves water through gravity, with a drop of water taking anywhere from 3 months to 1 year to travel from an upstate lake or reservoir to a customer in the city. As the water approaches the city, it's treated with chlorine to kill germs and pathogens, as well as fluoride for dental health and a couple of other chemicals to prevent corrosion of pipes.

Unlike most major urban water systems, New York City's drinking water is not filtered. In fact, New York has the largest unfiltered drinking water system in the United States. New York's water supply reservoirs were built in upstate areas that were covered in forests and that also had vast areas of intact wetlands. These forests and wetlands act as natural sponges and filters, absorbing rainfall and snowmelt and purifying the water in the process. Many other cities that draw their drinking water from nearby lakes and rivers need to have expensive filtration systems to remove sediment and other particles and contaminants before distributing water to residents.

Learn More: New York City's Water Supply

To get a sense of how vast the Catskill watershed region is, visit the following link:

https://www.dec.ny.gov/docs/water_pdf/nycsystem.pdf

Expanding Ecosystem Management

By the 1990s, however, things began to change for the worse in terms of New York City's drinking water. Increased development, road building, suburban sprawl, and other activities in the Catskill region were having a negative impact on water quality in surrounding reservoirs and lakes. U.S. Environmental Protection Agency (EPA) inspectors warned the city that it might have to build a $10 billion water filtration plant to address the issue.

Instead, New York City decided to take a different approach. The 1997 Watershed Memorandum of Agreement (MOA) was negotiated between New York City, New York State, the EPA, environmental groups, and municipalities and townships in the Catskills region. The MOA committed New York City to spend just under $2 billion on a range of initiatives intended to improve water quality in the Catskill reservoirs. These initiatives included purchasing and protecting lands surrounding reservoirs and lakes, as well as paying nearby landowners who agreed not to develop their lands commercially. In addition, the city helped upstate communities improve wastewater treatment plants, assisted dairy farmers with manure management, and worked with road departments to ensure that runoff from roads and highways was not entering reservoirs. Lastly, the city provided funding for upstate home owners to upgrade septic systems and for forest landowners to improve forest management practices. Collectively, these approaches are known as **ecosystem management** because they focus on maintaining water quality at the source rather than cleaning the water as it reaches its destination. Over the past 20 years, the ecosystem management initiatives undertaken as part of the MOA have proved effective enough that the EPA has granted New York City a series of "filtration avoidance determinations" that allow the city to operate its water system without a filtration plant.

The ecosystem management approach has been supplemented with high-tech features, including a network of hundreds of robotic buoys deployed across reservoirs to continually test and monitor water quality. These robotic water quality monitors test over 1.9 million water samples each year. In addition, the city has recently put in place the world's largest ultraviolet water disinfection facility. Water passes through containers mounted with ultraviolet lights that kill any microorganisms that might contaminate the water and make consumers sick.

While New York City water officials must always be vigilant in ensuring the quality of the city's water, the success of the MOA initiatives points to the importance of "source management" as an approach to meeting our water needs. Rather than spend $10 billion building a water filtration plant to treat polluted water at the back end of the system, New York City spent one fifth of that amount to ensure that its drinking water was not polluted at the source in the first place. Essentially, New York City has been investing in the natural capital resources of forests and wetlands in the Catskills region and letting this natural infrastructure provide the ecosystem service of keeping the city's water clean.

5.2 Freshwater Systems

Water is perhaps the most critical resource to human well-being and survival. Our bodies are made up of as much as 60% water, and while healthy individuals can survive weeks without food, they would last only a few days without water. We also rely on water to grow food, produce energy, and manufacture just about everything imaginable. In addition, we depend on and benefit from a range of ecosystem functions and services provided by water, including transportation, recreational activities, and wildlife habitat. We regularly rely on rivers, streams, and oceans to dilute and purify our waste products, although this use frequently conflicts with the other ecosystem functions and services that water provides. Despite all the ways we depend on water, we seldom give much thought to where it comes from and how it gets to us.

Water Distribution

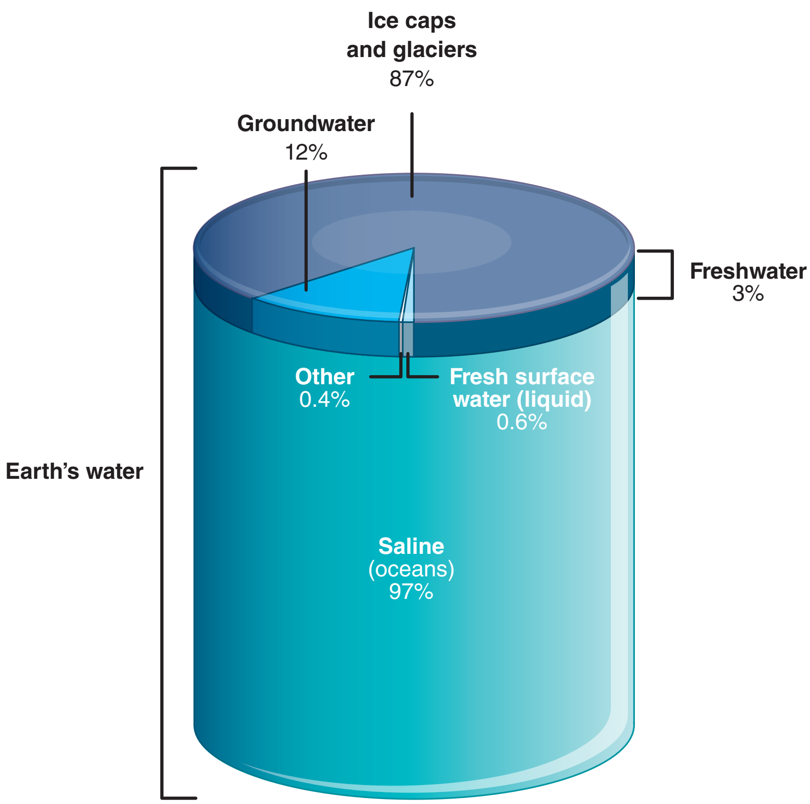
It's been said that we live on a "blue planet," since water covers nearly three fourths of the Earth's surface. However, when we account for where water is located and what condition it is in, we realize that water is not only a critical natural capital resource but also a *scarce* one. How can it be that such an abundant resource can also be scarce at the same time?

Imagine the world's water as 1 million individual 1-gallon containers. (In reality, there are 370 *million trillion* gallons.) For starters, about 970,000 (97%) of those containers would be filled with salty ocean water unsuitable for human consumption. It was this reality that inspired the line from *The Rime of the Ancient Mariner*, "water water everywhere, nor any drop to drink" (Coleridge, 1919/1990, lines 121–122). Another 26,100 gallons (2.61%) would be filled with ice and snow—nearly all of it from ice caps and glaciers in the Arctic and Antarctic regions, far from major human populations. Roughly 3,600 gallons (0.36%) would be filled with groundwater, with much of this (but not all, as we will learn) consisting of salt water also unsuitable for human consumption.

Out of the 1 million gallons we started with, only 300 gallons remain. Some of those 300 gallons consist of water vapor in the atmosphere, water found in saline or salty lakes, or water in the soil, leaving just about 180 gallons (0.018%) of fresh **surface water**—water on the surface of the Earth, found in rivers, wetlands, lakes, and reservoirs. Because this fresh surface water is the primary source of water for most people on the planet, we can see just how scarce and precious this resource actually is. (See Figure 5.1.)

Figure 5.1: Water distribution

Only 0.6% of the world's freshwater—0.018% of all water on Earth—is readily available as surface water for human use.



*Source: Data adapted from "Where Is Earth's Water?" by US Geological Survey, n.d. (**https://www.usgs.gov/media/images/distribution-water-and-above-earth**).*

Thankfully, nature has a way of constantly recycling, replenishing, and purifying water sources. In fact, unlike other resources (such as fossil fuels) that are permanently "consumed," global water supply is more or less fixed. This is because of the global hydrologic cycle. The **hydrologic cycle**, or water cycle, describes the movement of water between the planet's surface, atmosphere, soil, oceans, and living organisms. If we think again of our 1 million gallon containers, the water cycle is constantly moving water among the different containers, although human activities are increasingly interfering with this process and further complicating effective water management.

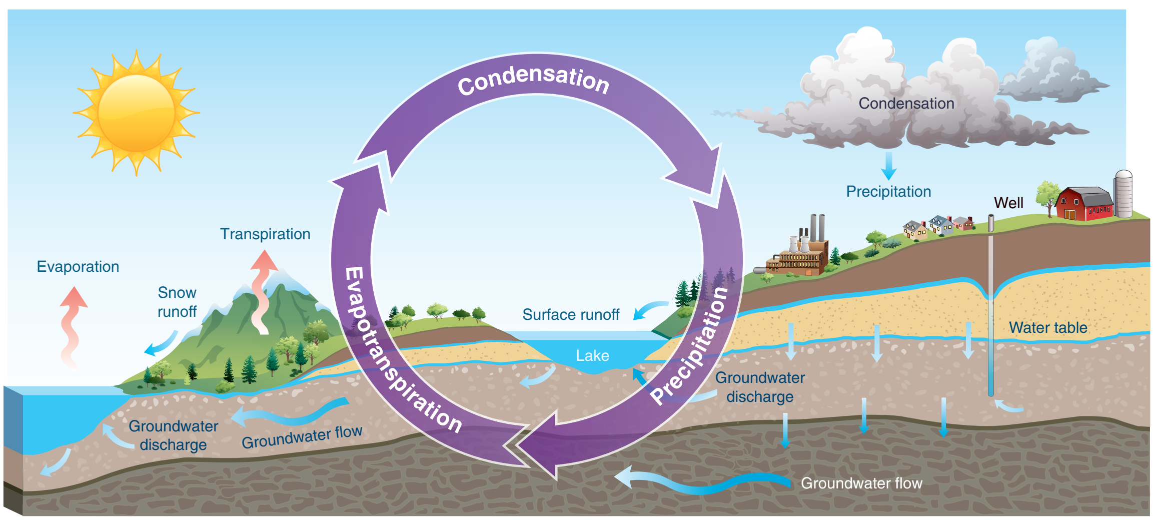
Water Cycle

The global water cycle is driven primarily by solar energy. Heat from the sun causes water to evaporate from surface waters and land surfaces and enter the atmosphere as water vapor. For example, it's estimated that solar energy evaporates roughly 425,000 cubic kilometers (km^3) of ocean water each year. To put that in perspective, *just 1* cubic kilometer of water is equivalent to a tank of water that is 1,000 meters (3,280 feet) tall, wide, and long, or 1 trillion liters (265 billion gallons). The amount of energy it takes to move this much water from the ocean to the atmosphere is massive. Roughly one third of all the solar energy striking the Earth each day is used to drive evaporation.

In addition to evaporation, plants draw massive amounts of water from the soil and release some of that water to the atmosphere as water vapor through a process known as transpiration. Evaporation and transpiration are together known as **evapotranspiration**. As water vapor from evapotranspiration rises into the atmosphere, it cools and condenses to form clouds (condensation) before falling back to Earth as rain and snow (precipitation). Evaporation, transpiration, condensation, and precipitation form the basis of the water cycle (see Figure 5.2).

Figure 5.2: The water cycle

The basis of the hydrologic cycle is condensation, precipitation, and evapotranspiration. Once water reaches the ground, it either runs off into nearby bodies of water or infiltrates the surface, where it reaches the water table and underground aquifers.



*Source: Based on "Ground Water and Surface Water a Single Resource," by US Geological Survey, 2013 (**https://pubs.usgs.gov/circ/circ1139/**).*

The processes of evaporation and condensation purify water naturally because only water molecules are pulled into the atmosphere, leaving any salts, contaminants, or pollutants behind. This is basically the same as making distilled water by boiling water and condensing the vapor. Roughly 90% of the ocean water evaporated each year falls back as precipitation over the oceans, where it mixes again with salt water. However, about 10% of that moisture falls over land surfaces as freshwater precipitation.

An even larger amount of freshwater precipitation is provided by evapotranspiration from plants and forests. In tropical forests as much as 80% of all precipitation comes from the direct recycling of evapotranspiration from plants. This feedback loop—more trees leading to more transpiration leading to more precipitation leading to more trees—is a key reason why forest management is so tightly linked with water management.

Overall, of the 110,000 km^3 of precipitation that falls over land surfaces each year, it's estimated that roughly one third comes from moisture drawn from ocean waters and two thirds from moisture from evapotranspiration from plants. This 110,000 km^3 of precipitation ends up doing one of three things. First, about two thirds of that water evaporates back into the atmosphere from land surfaces or through plant transpiration. The other one third either flows over land and enters rivers, streams, and lakes (surface water) or gradually percolates through soil and rock to enter underground aquifers (groundwater). It's this relatively small amount of water, roughly 37,500 km^3 per year, that replenishes the tiny sliver of fresh surface water illustrated in Figure 5.1 and represents the total renewable supply of fresh surface water on the planet. As with most other resources, this freshwater supply is unevenly distributed around the world. Atmospheric circulation patterns, topography, and proximity to water sources and forests are all factors that influence the amount of precipitation in a given location.

Human Impact on the Water Cycle

Human activities can also affect precipitation patterns and what happens to that precipitation after it falls to Earth. Under normal conditions, as precipitation reaches the ground, some of it is pulled below the surface by gravity through a process known as **infiltration**. This water eventually reaches the **water table**, a depth below ground where soil and rock are completely saturated with water. The saturated area immediately below the water table is known as an **aquifer**, an area of permeable rock and sediment from which water can be extracted.

Many communities, private home owners, factories, and farmers use pumps to pull groundwater from aquifers to the surface. As long as rates of infiltration are the same or greater than rates of extraction, the water level in the aquifer will be maintained. However, this is often not the case, and overpumping is resulting in aquifer depletion in many locations, such as with the Ogallala Aquifer in the U.S. Midwest (recall Chapter 4). As New York City discovered in the 1830s, overpumping of water from aquifers near the ocean can also cause the problem of **saltwater intrusion** as lower freshwater levels in the aquifer allow adjacent salt water to enter and contaminate that supply. Saltwater intrusion is a worsening problem in coastal regions around the world today.

Land use on the surface also affects how quickly aquifers can recharge. Developed areas like cities and suburbs have replaced grassland and forest soils with a lot of impermeable surface area. Most roads, driveways, parking lots, and roofs of buildings do not allow rain and melting snow to infiltrate into the ground and instead increase runoff. This increased runoff can result in more floods as too much water moves too fast across the surface and is not absorbed into the ground. Recent research demonstrates how too much impermeable surface area greatly worsened the impacts of Hurricane Harvey in Houston in 2017 (Zhang, Villarini,

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Heavily developed and paved areas create a problem for our water supply, since rain and snow cannot easily penetrate back into the Earth.

Vecchi, & Smith, 2018). More and more cities, municipalities, developers, and home owners are beginning to consider ways to cut down on water runoff and increase rates of infiltration in order to increase and improve groundwater supplies as well as prevent flooding.

The water cycle makes available the freshwater that all human life relies on, constantly recycling and replenishing this scarce resource. Unfortunately, human activities such as over-pumping of groundwater and paving of surface areas are negatively impacting both the quantity and quality of our water supply. This is happening at the same time that global water use and demand is increasing with population growth. The next section takes a closer look at global water use and how that demand can be met, given the finite supply of freshwater available to us.

5.3 Global Water Use and Demand

Recall that an estimated 110,000 km^3 of precipitation falls over land surfaces each year and that 37,500 km^3 of this enters surface waters or percolates into underground aquifers. This 37,500 km^3 represents the theoretical supply of renewable freshwater on the planet each year. If all this water were available to us, it would be more than enough to meet human needs. However, a few factors complicate this picture.

First, *where* this precipitation falls does not always align with where humans reside. For example, large amounts of precipitation fall to the ground and flow to the sea in sparsely populated regions of the Amazon basin in South America or in remote areas of central Africa. Second, *when* this precipitation falls can make water management challenging even in very wet places. For example, in tropical regions of Asia that experience heavy rainfall, as much as 80% to 90% of annual precipitation can fall during just a few months of the monsoon, with relatively dry conditions prevailing for the other months of the year.

Antoninapotapenko/iStock /Getty Images Plus

Tropical regions such as Asia can get 80% to 90% of their total annual rainfall in as little as 3 months due to natural weather conditions.

As a result, and despite adequate supplies of water on average globally, we face water shortages and scarcity in many regions. Over 2 billion people lack access to adequate and safe water supplies, and over 4 billion lack access to proper sanitation (World Water Assessment Programme, 2019). As a result, at least 2 million preventable deaths occur each year from water-related diseases that mostly claim the lives of young children (WHO, n.d.b). In some cases, problems arise from an absolute scarcity of water, whereas in others there is inadequate infrastructure to meet a population's water requirements. This section will consider those issues of water quantity: its use and demand and how human water needs are being met.

Let us return to the 37,500 km^3 that represents the theoretical supply of renewable freshwater each year. As much as half runs off the surface and to the sea in uncaptured floodwater. Humans build dams and other barriers to try to capture some of that runoff, but as we will discuss, that brings its own problems and challenges. Another 20% of the 37,500 km^3 of global freshwater supply is in regions that are not readily accessible. That leaves us with roughly 12,500 km^3 of what is known as **reliable surface runoff**, and it is this amount that is actually available for human use and consumption. So how do we make use of this reliable surface runoff? What are the environmental impacts of that use? And why do so many people around the world still face water scarcity and shortages?

How Water Is Used

Because we use and rely on water in so many different ways, we can measure water consumption differently as well. For starters, it's estimated that humans already appropriate over half of the 12,500 km^3 of reliable surface runoff each year, leaving less than half for all other species and organisms on the planet. We can first divide that human use or appropriation into two broad categories: instream uses and extractive uses.

Instream uses of water refers to the ways in which we use water without actually extracting it from its physical location. For example, water-based recreational activities like boating and waterskiing are common on many lakes and rivers in countries like the United States. While these activities do not involve a *direct* consumption of water, they may compete with or prevent the use of that water for other purposes.

Extractive uses of water refers to situations in which water is physically removed from its source location. In some cases this involves actual consumption, while others involve using and then returning the water to its source. For example, when water is extracted from a river or aquifer and used to irrigate a farm field, most of that water will evaporate to the atmosphere. This represents a **consumptive use** of water. In contrast, hydroelectric power plants divert large amounts of water from rivers and lakes to generate electricity (see Section 7.12), but that water flows back to the same river or lake. This represents a **nonconsumptive use** of water. The *Apply Your Knowledge* feature examines the environmental impact of nonconsumptive use.

Apply Your Knowledge: What Is the Environmental Impact of Nonconsumptive Water Use?

You can probably imagine the environmental impacts of chemical pollution and water consumption, but what about nonconsumptive water use?

To explore this question, consider the Brazilian Nuclear Power Plant (BNPP) in southeastern Brazil. The facility withdraws water from Ilha Grande Bay to cool equipment. Afterward, that water is returned to the bay. Aside from a small amount of water that is lost to evaporation, no materials are added or removed during the process.

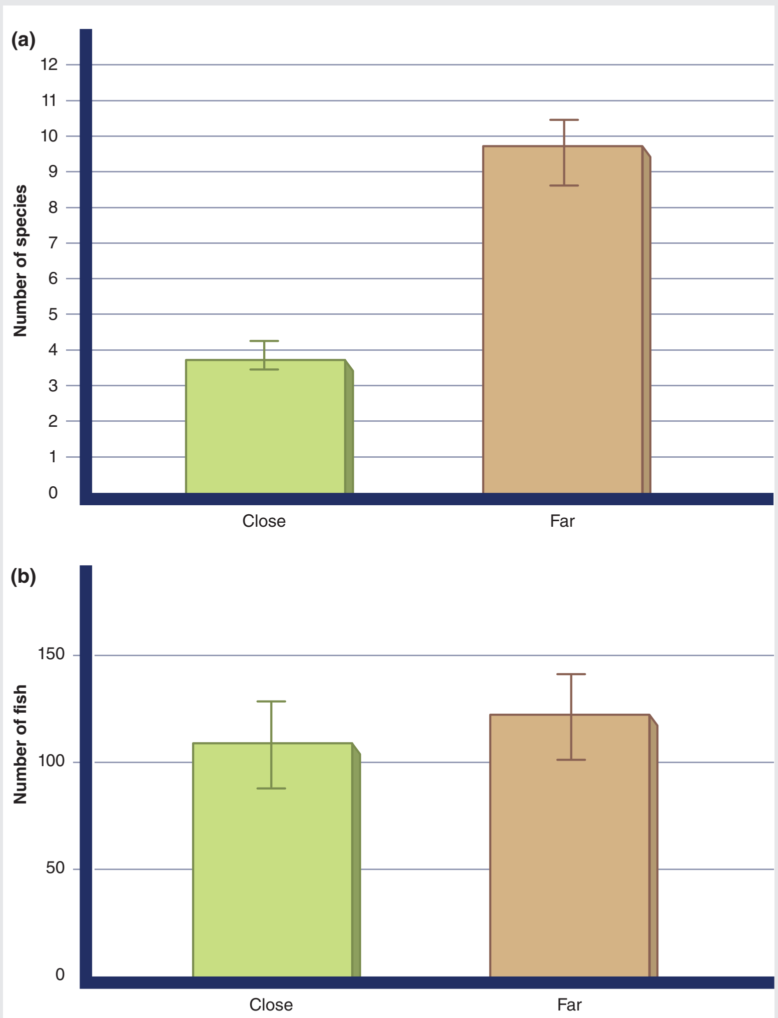
(continued)

Apply Your Knowledge: What Is the Environmental Impact of Nonconsumptive Water Use? *(continued)*

In a 2012 study, researchers investigated the environmental impacts of BNPP on Ilha Grande Bay (Teixeira, Neves, & Araújo, 2012). Researchers collected measurements of fish biodiversity and abundance near the power plant (within 200 meters) and in similar environments farther away (more than 1,500 meters). They then compared the two locations to highlight any differences. Some of these results are shown in Figure 5.3.

Figure 5.3: Impact of BNPP on biodiversity and fish abundance

Species biodiversity (a) and fish abundance (b) in Ilha Grande Bay. “Close” locations are less than 200 meters and “far” locations more than 1,500 meters from the BNPP facility.



Source: Data from “Thermal Impact of a Nuclear Power Plant in a Coastal Area in Southeastern Brazil: Effects of Heating and Physical Structure on Benthic Cover and Fish Communities,” by T. P. Teixeira, L. M. Neves, and F. G. Araujo, 2012, Hydrobiologia, 684.

(continued)

Apply Your Knowledge: What Is the Environmental Impact of Nonconsumptive Water Use? *(continued)*

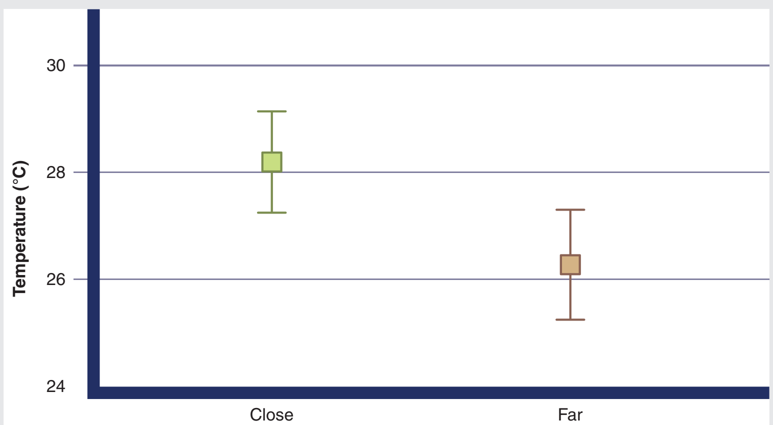
The first chart suggests that there is significantly less biodiversity (fewer species of fish) close to the power plant than there is farther away. In the second chart, the difference between the two measurements is small compared with the uncertainties of the two measurements. There appears to be a similar number of fish in both locations.

Take a moment to consider this data along with what you know about water use in this location. Can you explain how the power plant might be impacting fish in the surrounding ecosystem?

The power plant is affecting ecosystems by altering environmental conditions. According to the temperature data in the Ilha Grande Bay study, the water near BNPP is more than 4 degrees Celsius warmer than its surroundings (see Figure 5.4).

Figure 5.4: Impact of BNPP on water temperature

Temperatures at Ilha Grande Bay study locations.



Source: Data from "Thermal Impact of a Nuclear Power Plant in a Coastal Area in Southeastern Brazil: Effects of Heating and Physical Structure on Benthic Cover and Fish Communities," by T. P. Teixeira, L. M. Neves, and F. G. Araujo, 2012, Hydrobiologia, 684.

When the power plant cools off its equipment, the process warms the water that is extracted. This raises the temperature of bay locations with close proximity to BNPP. While many fish species can survive the cooler temperatures of the greater bay, relatively few have been able to thrive close to the power plant. With less competition, the species that can tolerate the warmer water are also able to achieve larger populations than they do elsewhere. The result is an environment that still has life but that is severely diminished in terms of biodiversity.

(continued)

Apply Your Knowledge: What Is the Environmental Impact of Nonconsumptive Water Use? *(continued)*

When industries like BNPP impact the environment by adding heat, we call it *thermal pollution*. Thermal pollution affects both freshwater and marine ecosystems like the one in Ilha Grande Bay. According to a recent study, the Mississippi River absorbs more heat from nonconsumptive water use than any other river in the world. Meanwhile, the Rhine River in Europe experiences the most significant temperature increases from thermal pollution of any major river. Coal and nuclear power plants serve as the pollution sources in both cases (Raptis, Van Vliet, & Pfister, 2016).

Thermal pollution is an example of a 21st-century environmental problem. Like many of our most pressing issues, it is the result of complex human and environmental systems that interact in sometimes unexpected ways. It demonstrates that we need to do more than just reduce material flows if we want a sustainable future. We also need to understand systems holistically and consider all the environmental factors that allow life to thrive.

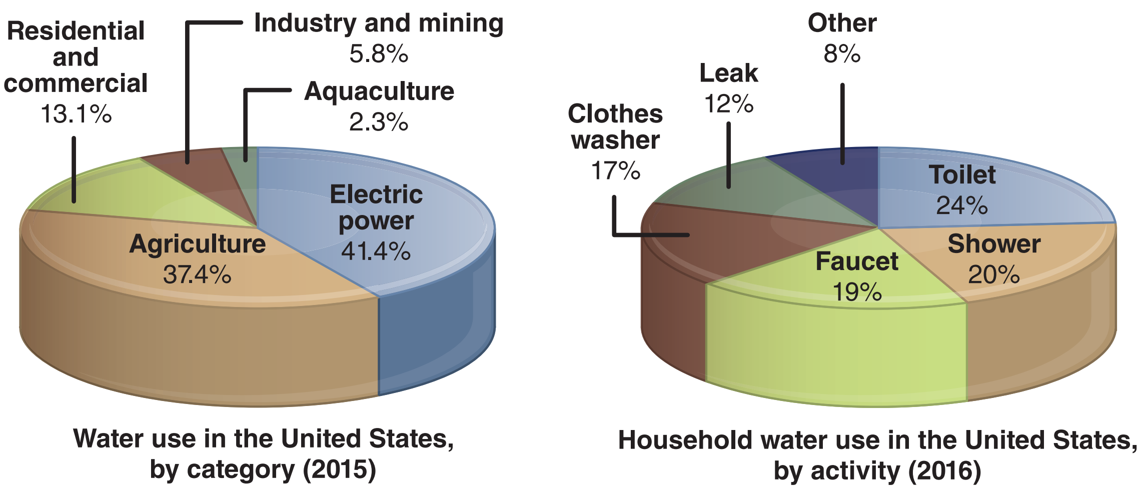
Who Uses Water (and How Much)

Globally, agriculture is the largest user of water, accounting for about 70% of all extractive water uses. However, this global average masks wide variations in water consumption by sector and in the overall amounts of water consumed. For example, in Africa and Asia agriculture accounts for over 80% of all water use, whereas in more industrialized countries of Europe, only 20% goes to agriculture while 60% goes to industry (Food and Agriculture Organization of the United Nations, 2016). Figure 5.5 shows a breakdown of average water use in the United States. But even within the United States, there can be significant variations in these figures. Most water use in the more industrialized and populated regions of the Northeast is for power plants, industry, and residential uses. In drier regions of the West and Southwest, over 80% of water use is for agriculture (Dieter et al., 2018).

Per capita levels of water consumption also vary widely among different regions of the world (see Table 5.1). This is partly a result of water supply and the infrastructure needed to deliver that water to people when and where they need it. It's also a function of factors like standard of living, how efficiently water is used in that country, the kinds of economic activities undertaken there, and the food choices people make. Water consumption generally increases with standard of living, and countries that produce highly water-intensive products like cotton and beef tend to have higher rates of per capita water use. This is one of the reasons why the United States and Australia, both big producers and consumers of beef, have some of the highest rates of per capita water consumption in the world.

Figure 5.5: Water use in the United States

These pie charts show average water use across the United States, but the breakdown can vary significantly by region.



*Source: Adapted from "Summary of Estimated Water Use in the United States in 2015," by US Geological Survey, 2018 (**https://pubs.usgs.gov/fs/2018/3035/fs20183035.pdf**); adapted from "Residential End Uses of Water, Version 2," by US Environmental Protection Agency and Water Research Foundation, 2016 (**https://www.waterrf.org/research/projects/residential-end-uses-water-version-2**).*

Table 5.1: Annual per capita water use around the world (1996–2005)

Low (<1,000 m^3)		Medium (1,000–2,000 m^3)		High (>2,000 m^3)	
Bangladesh	769	South Africa	1,255	Israel	2,303
Rwanda	821	Japan	1,379	Australia	2,315
Nicaragua	912	Thailand	1,407	Canada	2,333
Malawi	936	Germany	1,426	Spain	2,461
Guatemala	983	France	1,786	United States	2,842

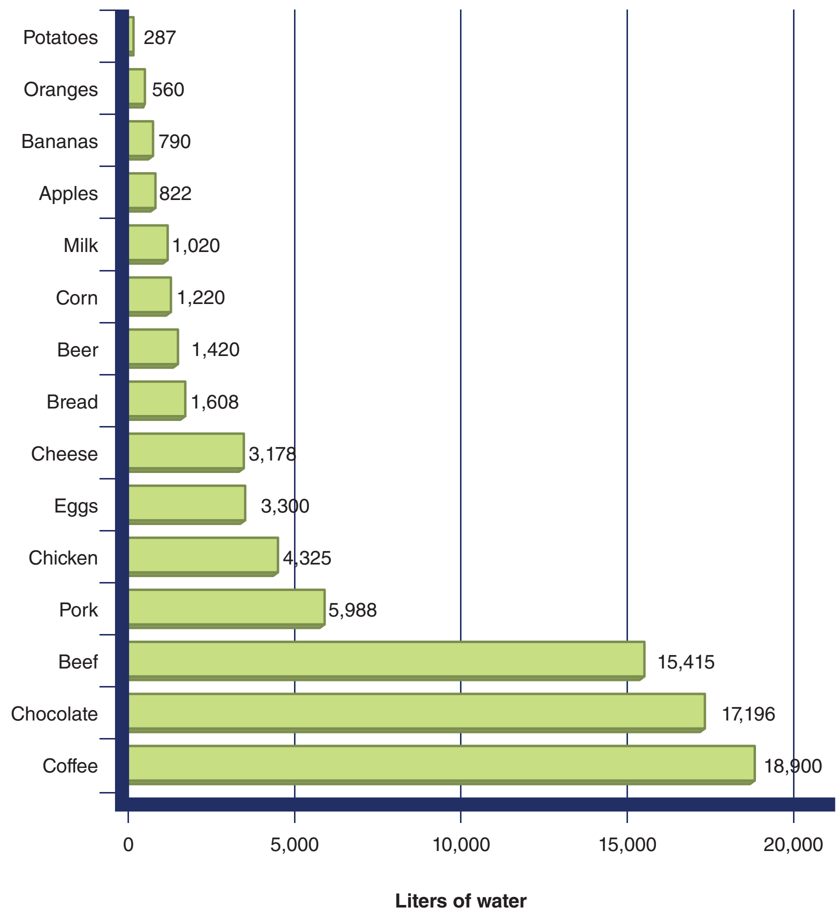
Note. 1 m^3 = 264 gallons.

Source: Data from "The Water Footprint of Humanity, by A. Y. Hoekstra and M. M. Mekonnen, 2012, Proceedings of the National Academy of Sciences, 109 *(**https://waterfootprint.org/en/resources/waterstat/national-water-footprint-statistics**).*

The example of beef illustrates an important concept known as **virtual water**, or embodied water. We may not think about it, but just about every item we use or consume required water to produce. In terms of food items, for example, it takes roughly 15,415 liters (4,072 gallons) of water to produce one kilogram of beef, and 1,608 liters (425 gallons) of water to produce enough wheat for a kilogram of bread (see Figure 5.6). But water is also used to produce nonfood items as well. For example, it takes roughly 5,400 liters (1,427 gallons) of water to produce one pair of jeans. For comparison, we use about 75 to 100 liters (20 to 26 gallons) of water for an average 10-minute shower.

Figure 5.6: Virtual water

This graph illustrates the liters of water needed to produce a kilogram of each of these food items. The amount of water required to produce the food we eat is not always obvious.



*Source: Data from "Product Gallery," by Water Footprint Network, n.d. (**https://waterfootprint.org/en/resources/interactive-tools/product-gallery/**).*

The virtual water concept helps illustrate how consumption decisions made in one location can impact water supply and management issues in another. In recent years California has been experiencing severe droughts and water shortages, and yet this state alone produces over a third of America's vegetables and two thirds of its fruits and nuts. It's estimated that the average American consumes over 1,100 liters (290 gallons) of California water every week by eating food products grown there (Buchanan, Keller, & Park, 2015). The virtual water concept also makes even clearer the problem of food loss and waste discussed in Chapter 4. Every time we waste food, we are also wasting all the water (and energy; see Chapter 7) used in the production of that food.

Learn More: Your Water Footprint

There are a number of sources that allow you to explore and calculate your "water footprint" in different ways.

- https://waterfootprint.org/en
- https://www.watercalculator.org
- https://water.usgs.gov/edu/activity-percapita.html

Challenges of Meeting Water Demand

Many regions of the world are already experiencing, or will soon experience, serious challenges in meeting their water needs. **Water scarcity** refers to a situation in which there is a physical, volume-based lack of water. It's estimated that close to 700 million people in 43 countries around the world currently experience water scarcity and that this number could more than double in the next decade (United Nations Department of Economic and Social Affairs [UNDESA], n.d.b). **Water stress**, in contrast, is a broader term that includes physical scarcity as well as issues of water quality and the accessibility or affordability of clean water supplies. Over 1 billion people are currently experiencing water stress, and this figure could grow as high as 4 billion in the decades ahead unless more effective and efficient water management practices are implemented (UNDESA, n.d.b). Later sections in this chapter will highlight ways we can address water scarcity and stress, as well as challenges related to water quality. Before that, however, let's have a look at some areas where meeting water demand is proving difficult.

Water Rationing in South Africa

One of the most high-profile and recent examples of water scarcity is playing out in the city of Cape Town, South Africa. Cape Town is a modern, bustling metropolis and a major tourist destination located at the southern tip of the African continent. It has a population (4 million) and climate similar to Los Angeles in Southern California.

After 3 years of severe drought and poor water management decisions, the city began to warn residents and businesses in late 2017 of "Day Zero," the day when municipal water would

Bram Janssen/Associated Press

Residents of Cape Town, South Africa, waiting in line for water. Water resources in Cape Town are at a premium, and restrictions are in place in response to severe water shortages.

be completely cut off and water would be available only through centralized distribution points. Cape Town was set to become the first modern major city in the world to run dry.

Severe restrictions on residential and agricultural water use and a return to more normal rainfall patterns in the latter half of 2018 helped Cape Town postpone Day Zero, but the water situation there is still precarious. Residents are still limited to using 50 liters (13 gallons) of water per day, farms outside the city have had their irrigation supplies cut off, and long lines can still be found at natural springs and grocery stores when supplies of bottled water are delivered. Cape Town offers a cautionary tale of how even major cities can be at risk of water scarcity, especially as global climate change alters precipitation patterns and weather.

Dams in China and the United States

One way to try to alleviate water scarcity and stress is through the construction of dams and water diversion projects. Dams are built across rivers to capture and store surface runoff in reservoirs. Dams can be utilized to control runoff to prevent floods, generate hydroelectricity, and supply water for agricultural, industrial, and residential uses. There are over 800,000 dams around the world, including close to 50,000 "large dams" that are 15 meters (50 feet) or higher. Combined, these dams capture and store close to 15% of global surface runoff for human uses. In the United States that figure is closer to 50%.

While dams can provide many benefits in terms of water supply and management, energy production, and recreation, they also have a number of problems associated with them. First, when rivers are dammed, they create reservoirs behind the dam that can displace entire communities. For example, China's massive Three Gorges Dam (the largest in the world) displaced 1.2 million people and flooded 13 cities, 140 towns, and 1,350 villages. Second, dams can have dramatic impacts on native fish and wildlife species as well as alter important ecosystem functions and services that rivers provide. For example, a series of large dams on the Colorado River have fundamentally altered that ecosystem and reduced the flow of water from that river to the ocean to virtually a trickle.

Competing Water Use Along the Colorado

The Colorado River also offers an example of a regional water system threatened by mismanagement, competing demands between users, and global climate change. The Colorado River originates on the western slopes of the Rocky Mountains in Colorado. From there it flows 2,400 kilometers (1,500 miles) to the Gulf of California in Mexico. Along the way, the Colorado River passes through mountain regions, deserts, and the Grand Canyon.

Filippobnf/iStock /Getty Images Plus

Damming of the Colorado River has drastically reduced the water level of Lake Mead. Here the former water level is indicated by the bathtub-like rings around the edges.

Almost 100 years ago, water managers in western states began a systematic process of building dams on the Colorado River and using massive water diversion systems to divide the river's water between urban areas and agriculture. Today nearly 40 million people in cities such as Las Vegas, Phoenix, Los Angeles, and San Diego depend on water from the Colorado River, while over 70% of the water withdrawn is used to irrigate 1.4 million hectares (3.5 million acres) of cropland that produces 15% of U.S. agricultural products.

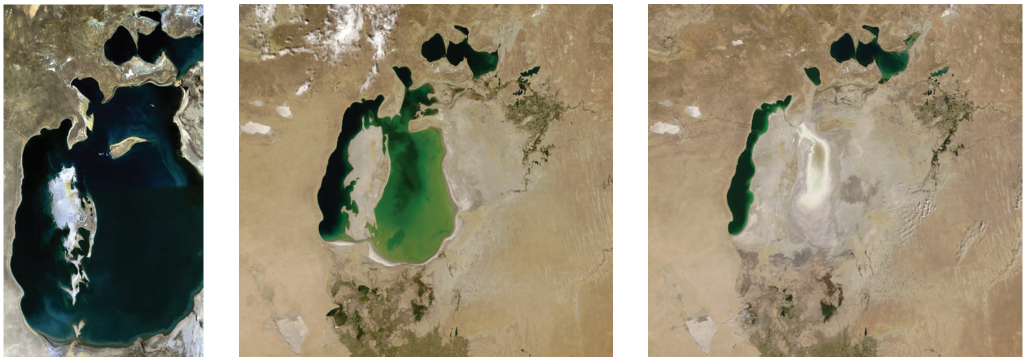
Since at least 2000, however, warning signs have been flashing for Colorado River water managers and others in the region. Water levels in Lake Mead and Lake Powell (fed by the Colorado) have dropped dramatically, revealing water lines like "bathtub rings" that show where the water level used to be. Decreasing winter snowfall totals in the Rocky Mountains, tied to global climate change, lead to reduced runoff and water supply in the summer months. Water shortages in the region are projected to get even worse with climate change, and water managers are already struggling to balance competing demands for water from urban and residential users versus agricultural users. Meanwhile, regional energy managers are making contingency plans for possible electricity shortages caused by declining hydroelectric production from the region's dams.

Water Diversion and the Aral Sea

An even more dramatic example of water misuse and mismanagement comes from central Asia. The Aral Sea, located on the border between Kazakhstan and Uzbekistan, was once the world's fourth largest lake and roughly the size of the country of Ireland. Up until the 1960s the Aral Sea supported hundreds of lakeside communities, provided an estimated 60,000 jobs in the fishing industry, and provided important wildlife habitat and ecosystem services for the region (Bennett, 2008).

At the time, the region was part of the Soviet Union, and Soviet engineers and planners made the decision to divert water from two major rivers, the Syr Darya and the Amu Darya, that fed freshwater to the Aral Sea. The water was to be used for irrigation for cotton and wheat production. Dozens of large dams, almost 100 reservoirs, and over 30,000 kilometers (20,000 miles) of canals were constructed.

Gradually, the Aral Sea began to shrink in size, and by 2000 it split into a small northern portion and a larger southern portion. A few years after that, the southern portion split again into an eastern and western half. And in just the past few years, the southeastern portion has dried up completely. Overall, the Aral Sea has lost over 90% of the water it once contained. The former lakeside is littered with the rusted hulks of old fishing boats, and strong winds whip up dust storms that blow over former lakeside communities and sicken whatever residents still remain.



University of Maryland Global Land Cover Facility and NASA, Earth Observatory

The Aral Sea has lost over 90% of the water it once contained and has split into several smaller seas. Before water diversion projects began in the 1960s, the Aral Sea was the fourth-largest lake in the world. By 1989 (left), the northern and southern part had begun to split. Between 2000 (middle) and 2009 (right), the southern part dried up almost completely. Water levels have remained essentially the same since 2009.

Meeting the challenge of water demand is made all the more difficult because water is a "transboundary" resource that moves across national borders and boundaries. This fact, combined with rising populations and the threat of water shortages, has made water resources a potential source of conflict between nations. This issue, and the idea of adequate water as a fundamental human right, will be the focus of the next section.

5.4 Water and Global Politics

In 2010 the United Nations (UN) passed a resolution that explicitly recognized "safe and clean drinking water and sanitation" (UN, n.d.c, p. 1) as fundamental human rights. The resolution recognizes that drinking water supplies should be sufficient, safe, physically accessible, and affordable (UNDESA, n.d.a). While the UN resolution does not specify what countries have to do to meet this human right, it does call attention to the seriousness of the problem and establish a clear baseline of human water requirements at 50 to 100 liters (13 to 26 gallons) per day. The UN cites research by WHO estimating that 24,000 children die *every day* from diarrhea and other preventable diseases caused by polluted water. This research also estimates that millions of women and girls in developing countries walk an average of 6 kilometers (almost 4 miles) every day to collect water for their families. This daily chore takes a physical toll and prevents young girls from completing schooling that might improve their lives.

The UN resolution comes at a time when two global challenges could be exacerbating issues of water availability and sanitation. As described in Chapter 3, global population is approaching 8 billion and is projected to hit 10 billion later this century. Increased population means increased water demand for direct and indirect (virtual water) uses, such as for agriculture. In addition, global climate change (discussed in more detail in Chapter 8) is complicating the water supply picture. Climate change is leading to changing weather and precipitation patterns, including more intense rains (and runoff) in short periods and prolonged droughts in others. Climate change is shifting where and when precipitation falls as well, making it difficult to predict and manage water supplies for a growing population. Finally, climate change and warming are leading to increased evaporation from surface water supplies and faster melting and retreat of major glaciers around the world. At least 200 million people depend almost exclusively on melting water from glaciers for their water supply, and in some of these places the glaciers are melting so fast that they are at risk of disappearing.

lubilub/iStock/Thinkstock

The UN has deemed drinking water a fundamental right. In many parts of the world, women and girls must walk miles each day to collect water for basic needs.

This combination of population growth and global climate change has led some experts to predict that major wars of the 21st century are more likely to be fought over water than any other resource, including energy. While the link between water and conflict has a long history, current conditions appear to be increasing the likelihood of future "water wars." There are 261 major river systems around the world that cross national borders. When upstream populations dam, divert, pollute, or somehow interfere with the quantity or quality of water flowing downstream, there is the potential for conflict.

Currently, some of the most contentious regions where a water war is likely to break out include the Nile River basin in Africa, the Euphrates–Tigris basin in the Middle East, and the Mekong River basin in Southeast Asia. The Nile River flows through parts of 11 countries. Dam construction in upstream countries like Ethiopia could result in tension and conflict with downstream nations like Sudan and Egypt. In the Euphrates–Tigris basin, major water diversion projects for irrigation in Turkey have affected river flow to Syria and Iraq. In the Mekong River basin, upstream dam construction, particularly in China, has altered downstream water flows and ecosystems. China has used its political influence and power to ignore complaints from other affected countries.

Even in the United States, there are numerous examples of legal conflict between states over water rights and access. The most well known of these disputes involve management of and access to Colorado River water in the arid Southwest. But even in the relatively wetter region of the American Southeast, a 30-year conflict over water is playing out. The "tri-state water wars" pit Alabama and Florida against Georgia over management of water from the Alabama-Coosa-Tallapoosa (ACT) and Apalachicola-Chattahoochee-Flint (ACF) river basins. Upstream Atlanta depends heavily on these river basins for meeting its municipal water needs, and as the city's population has grown, so has its use of these waters. In 1990 Alabama sued to prevent Atlanta from taking additional water from lakes fed by the ACT and ACF river basins. Eventually, Florida joined in the conflict, and in 2018 portions of the tri-state dispute reached as high as the U.S. Supreme Court before being remanded to the lower courts.

Meeting the world's demand for adequate water supplies needs to involve considerations of supply, management, and the necessity of that demand. Further complicating the picture are the issues of global climate change, discussed in Chapter 8, and water pollution, the focus of the next section. One approach to better meeting regional water demand is through privatization of water systems (see the *Learn More* feature box).

Learn More: Water Privatization

A somewhat controversial approach to managing municipal water systems is known as water privatization. Typically, city and municipal water systems around the world have been managed by government agencies or public utilities, whose primary goal was to deliver adequate water to residents at the lowest cost possible. However, in some cities these agencies and utilities were poorly managed and experienced high rates of water leaks and wastage. As a result, water privatization was proposed as a solution. Privatization involves selling water systems to private companies to manage on a for-profit basis.

Supporters of privatization argue that private sector companies are more efficient, are better able to manage large-scale water supply systems, and have the financial capital to invest in upgrades and other improvements to these systems. Critics argue that privatization is a violation of the principle of water as a human right, since it makes water a commodity that can be denied to individuals who lack the financial resources to pay for it. The reality probably lies somewhere in between, with a lot depending on how privatization is handled and what restrictions and requirements are placed on the company taking over a water system.

To learn more about water privatization and arguments for and against this approach, visit:

- https://blogs.ei.columbia.edu/2010/09/02/what-is-the-benefit-of-privatizing-water
- https://pacinst.org/wp-content/uploads/2002/02/new_economy_of_water3.pdf
- https://www.foodandwaterwatch.org/insight/water-privatization-facts-and-figures
- https://www.citizen.org/wp-content/uploads/top10-reasonstoopposewaterprivatization.pdf
- https://www.forbes.com/sites/adammillsap/2016/10/05/privatizing-water-facilities-can-help-cash-strapped-municipalities/#318792184b5c

5.5 Water Quality

Up until this point most of our discussion has focused on issues of water supply and availability, or water *quantity*. This section will take a closer look at the threats to water *quality* from various forms of pollution and what's being done to address it.

For as long as humans have lived in groups, they have diluted biological wastes by discarding them in nearby streams, rivers, and other bodies of water. As human populations grew, and as economic activity became increasingly industrialized and concentrated, the volume and character of that waste also changed. However, the solution to pollution remained dilution, and as a result, our waterways became more and more polluted over time.

In the United States this approach began to result in some dramatic and frightening examples of water pollution by the 1950s and 1960s. For example, pollution of Lake Erie was so bad by the 1960s that the lake was declared virtually dead and lifeless. In June 1969 the Cuyahoga River in Cleveland, Ohio, caught fire due to buildup of oil and debris on the river's surface.

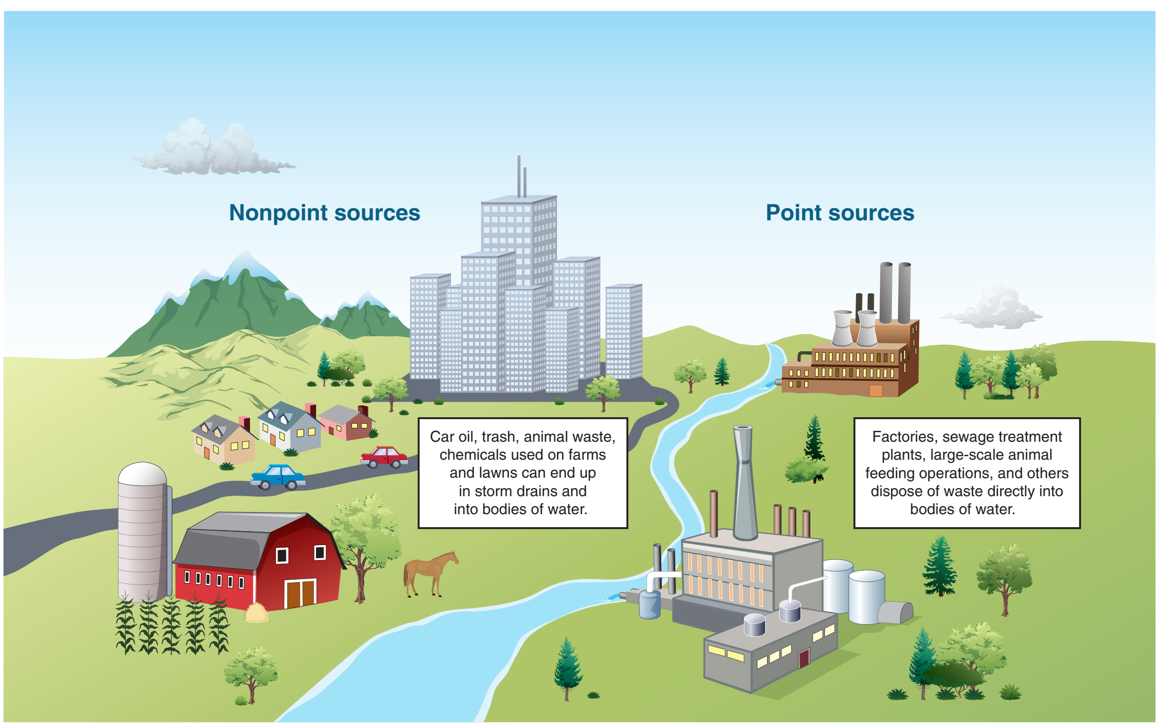
News stories and headlines featuring these and other water pollution disasters helped result in water-quality regulations that addressed some of the most glaring problems. However, threats to water quality and new forms of water pollution continue to be a challenge. The EPA (2016) recently completed a national assessment of rivers and streams. It reported that over half of river and stream miles in the United States are severely polluted, impaired, or in poor condition, meaning that those waterways did not meet federal water-quality standards.

Classifying Pollutants

The most basic breakdown of water pollution is between what are known as point sources and nonpoint sources of pollutants (see Figure 5.7). **Point sources** are fixed and stationary sources of water pollutants, such as a drainage pipe from a factory or discharge from a sewage treatment plant. **Nonpoint sources** are diffuse sources of pollution that are difficult to pinpoint. For example, cow manure running off of a farm field, lawn chemicals washed off of suburban lawns, and sediment washed into nearby streams and rivers from a construction site are all cases of nonpoint source pollution.

Figure 5.7: Nonpoint vs. point sources of pollutants

Nonpoint sources of pollutants are diffuse and more difficult to manage, whereas point sources are fixed and stationary.



Regardless of whether pollutants are from a point source or nonpoint source, they can be further classified into different types. The most common are listed in Table 5.2. All of these pollutants impair water quality in some fashion.

Table 5.2: Common types and sources of water pollutants

Type of pollutant	Common sources
Pathogens	Animal waste
Nutrients	Fertilizers, CAFOs, sewage treatment plants
Sediment and soil	Farms, construction sites
Oil	Parking lots, tanker and pipeline spills
Plastics	Litter, landfills
Heavy metals	Industry
Toxic substances	Pesticides, industry
Heat (thermal pollution)	Power plants

Another type of water pollutant that is causing increased concern is chemical compounds in items that we consume or use in our homes every day. For example, triclosan is an antibacterial and antifungal agent used in soaps, toothpastes, deodorants, and lotions. This chemical is washed down the drain and eventually enters rivers and streams, where it can be toxic to fish and other aquatic life. Likewise, ecologists have measured detectable levels of birth control hormones, antibiotics, caffeine, and other substances in hundreds of streams and rivers in the United States. Because these chemicals are not removed from wastewater in most wastewater treatment plants, they are excreted from our bodies and washed down drains before entering rivers, streams, and other waterways. Once there they can have serious detrimental impacts on fish and other forms of aquatic wildlife.

Managing Nonpoint Source Pollution

Managing nonpoint sources of water pollution is much more challenging than addressing point source pollution because nonpoint pollution of a waterway can originate from hundreds or even thousands of locations. After the high-profile water pollution disasters of the 1950s and 1960s, federal legislation was passed that targeted major point source polluters like factories and sewage treatment plants. But water pollution from nonpoint sources like agriculture (soil erosion, fertilizer runoff, manure runoff) and urban or suburban development (lawn chemicals, parking lots and streets, sediment from construction projects) has continued to worsen since then. In the example of New York City at the start of this chapter, nonpoint sources were causing problems with the city’s drinking water supply.

One of the most serious types of nonpoint pollution from agriculture is runoff of animal wastes and fertilizers, which can cause algal blooms, eutrophication, and aquatic dead zones. To prevent runoff, water-quality experts encourage farmers to practice some of the sustainable agricultural techniques described in Chapter 4, including contour farming and low-till or no-till agriculture. It also helps if farmers leave space for *riparian buffers*. A **riparian buffer** is a vegetated strip of land alongside a stream or river. The trees, shrubs, grasses, and other plants in a riparian buffer help trap soil, sediment, and other pollutants before they can enter a waterway. In New York City part of the funding provided to upstate farmers was to help establish and maintain riparian buffers in agricultural areas.

In urban and suburban areas, runoff of fertilizer from lawns, golf courses, and parks can also contribute to eutrophication and dead zones. Large amounts of water and melting snow running off of roofs, streets, parking lots, and driveways can cause both water-quantity problems, such as flooding, and water-quality problems as runoff picks up potential pollutants like road salt and oil spilled from cars and trucks. Here too, establishing riparian buffers around urban areas can help cut down on pollution entering waterways and slow the rate at which runoff enters streams and rivers, reducing flood risks downstream. Protecting existing wetlands and even establishing “constructed wetlands” that contain plants that can slow urban/suburban runoff and absorb excess nutrients can also help minimize nonpoint source pollution. Other approaches are outlined in Table 5.3. All of these approaches fall under the umbrella of watershed management, and they play an important part in the approach used to protect New York City’s water supply. They also have in common the idea that it is better to try to *prevent* pollution from entering waterways in the first place than try to clean it up after it’s already there.

Table 5.3: Approaches for minimizing urban and suburban runoff

Approach	Description
Riparian buffers	Vegetated strips of land alongside streams and rivers
Green roofs	A roof that is covered in plants and can absorb rainwater
Rain gardens	A garden in a depressed area that collects rainwater
Permeable pavement	A porous urban surface that allows rainwater to seep into the ground instead of running off
Wetlands	Swamps and marshes that contain plants that absorb nutrients and improve water quality

One of the most challenging forms of water pollution involves contamination of groundwater supplies. Unlike surface water pollution, groundwater pollution is hidden from view and potentially "out of sight and out of mind." Groundwater pollution is also much more difficult to clean up than surface water pollution. Whereas streams and rivers naturally flush themselves clear through running water, contaminants that enter groundwater get trapped there and can take years or decades to break down or dissipate. Major sources of groundwater pollution include leaks from industrial storage tanks, septic systems, and underground gasoline tanks, as well as seepage of agricultural chemicals like pesticides and fertilizers. In addition, hydraulic fracturing, or fracking, of oil and gas wells is increasingly being implicated in the contamination of municipal and residential groundwater supplies in some regions of the United States (see *Learn More: Fracking and Water Quality*).

Learn More: Fracking and Water Quality

Over the past couple of decades, there has been rapid development and growth in the use of an oil- and gas-drilling technique known as hydraulic fracturing, or fracking. Fracking allows oil and gas companies to remove these fuels from oil shale rock formations that previously were not considered viable for exploitation (see Section 7.4). In fracking, liquids mixed with sand (collectively known as fracking fluid) are pumped into oil shale deposits under extremely high pressures. This fractures and cracks the shale formations while the sand keeps the cracks open just enough to allow the oil and gas to begin to flow to the surface.

In theory, fracking should not have much of an impact on groundwater, since shale deposits are located far below the surface and well below the water table and aquifers that homes and municipalities draw drinking water from. However, the fracking process creates a number of opportunities for groundwater contamination, and there is growing evidence that this process has been impacting water quality in regions of the country where fracking is widespread (including Pennsylvania, Wyoming, and Colorado). For example, leaks of fracking fluid from the drill hole have been documented, as well as leaks of contaminated water that "flows back" (known as flowback water) to the surface. Likewise, poor management and handling of fracking fluid and flowback water at the well site can lead to spills and seepage of these fluids into groundwater deposits.

The oil and gas industry has adamantly denied a link between fracking activities and changes in water quality, while a major 2016 EPA report found that fracking could impact water quality under "certain conditions" if the process is not managed properly. Nevertheless, as fracking has grown in importance throughout the United States, and as well operations have aged, the number of reports of water-quality impact from fracking activities has also grown.

More information on the links between fracking and water quality can be found at these sites:

- https://www.epa.gov/hfstudy
- https://www.bbc.com/news/uk-37578189
- https://e360.yale.edu/features/as_fracking_booms_growing_concerns_about_wastewater
- http://worldwater.org/wp-content/uploads/2013/07/ww8-ch4-fracking.pdf

There is also growing concern over groundwater contamination by a class of chemicals known as per- and polyfluorinated alkyl substances, or PFAS. PFAS are used in a number of products, including firefighting foam and waterproofing materials, and exposure to them has been linked to various forms of cancer, pregnancy complications and low birth weights, liver damage, thyroid disease, asthma, and reduced fertility. PFAS pollution is especially problematic on dozens of military bases around the country due to heavy use there in firefighting operations. The Union of Concerned Scientists (2018) reports that of 131 military sites tested for PFAS in their groundwater used for drinking, only 1 was within the safe limit. Forty-three sites had drinking water with PFAS levels that were 1 to 100 times over the safe limit, and 87 sites had PFAS levels more than 100 times greater than the safe limit.

Managing Point Source Pollution

"Will this prescription interact with the meds already in my drinking water?

Aaron Bacall/Cartoon Collections

Overall, serious water pollution problems from point sources like factories have become much less of a problem in countries like the United States due to laws and regulations. The U.S. **Clean Water Act (CWA)**, which was first passed in 1972, makes it illegal for a factory or another point source to dump any pollutant in a waterway without a permit. The CWA also sets standards for industrial wastewater management, places restrictions on wetland destruction or conversion, and provides funding mechanisms for upgrading municipal wastewater treatment plants. One interesting provision of the CWA allows individual citizens and environmental groups to monitor and report to the federal government cases in which CWA standards are not being met. This has led to the formation of hundreds of volunteer water-quality monitoring groups across the country that regularly test and report on water-quality conditions in their area. Soon after the CWA was passed, the **Safe Drinking Water Act (SDWA)** was enacted in 1974. The SDWA required that the EPA set specific standards for allowable levels of chemicals in water and mandated that local water authorities monitor and report on drinking water quality in their jurisdictions.

While the CWA and the SDWA have both resulted in dramatic improvements in water quality in the United States since the 1970s, there remain significant challenges with water pollution, particularly from nonpoint sources. (If you're interested in the quality of your own local water supply, check out *Close to Home: Assessing Local Drinking Water*.) The remainder of this chapter will focus on additional approaches both to conserve water and manage demand, as well as on further ways in which water quality can be protected. This includes a discussion of water conservation and management in Section 5.6 and the role that forests play in protecting water supplies in Section 5.7.

Close to Home: Assessing Local Drinking Water

The Flint water crisis began in 2014 when the city of Flint, Michigan, changed its public water sources from the Detroit River and Lake Huron to the Flint River. During the transition, the city mismanaged how it was treating its water, and pipelines began releasing large amounts of lead into the public water supply. More than 100,000 residents were exposed to high levels of this heavy metal neurotoxin, including 6,000 to 12,000 children who may suffer from lifelong health challenges as a result. A federal state of emergency was declared in 2016, and ever since, officials have been scrambling to fix the problem.

The Flint water crisis demonstrates the high stakes involved with protecting public water supplies. It also highlights the importance of regular water monitoring. In this feature box, we will learn about some regulations that protect our water supplies. We will also take a closer look at where our drinking water comes from and determine if it is safe to drink.

The SDWA of 1974 requires the mandatory monitoring of public water supplies throughout the United States. Local water authorities must test drinking water for microorganisms, disinfectants, and chemical pollutants like lead on an annual basis and publish their findings in documents called Consumer Confidence Reports (CCRs). These reports provide background information on local water systems as well as the detailed monitoring information of specific pollutants. Table 5.4 is an excerpt from a 2017 CCR for Meadville, Pennsylvania.

Table 5.4: Excerpted 2017 water test results for Meadville, Pennsylvania

Contaminant	Action level	MCLG	90th percentile value	Units	Sample date	# of sites above AL of total sites	Violation	Sources of contamination
Lead	15	0	2	ppb	06/01/16	0 out of 30 sites	No	Corrosion of household plumbing; erosion of natural deposits
Copper	1.3	1.3	0.5	ppm	06/01/16	0 out of 30 sites	No	Corrosion of household plumbing; erosion of natural deposits; leaching from wood preservatives

Source: From "2017 Annual Water Quality Report," by Meadville Area Water Authority, 2017 (https://meadvillepawater.govoffice3.com/vertical/Sites/%7BEB63EC2C-4A5A-4CE9-8231-28BBB646C55F%7D/uploads/2017_Consumer_Confidence_Report.pdf).

(continued)

Close to Home: Assessing Local Drinking Water *(continued)*

This section of Meadville's CCR presents the results of lead and copper monitoring. Three columns, in particular, provide important information about the safety of this drinking water. First, there is the maximum contaminant level goal (MCLG) for each pollutant. Depending on the type of pollutant being measured, these values might also be called a maximum residual disinfectant level goal (MRDLG). When pollutant levels are below these values, there is no known risk to human health.

You may also notice the column providing an action level (AL) for each pollutant. This value represents the enforceable standard for drinking water. In other words, the EPA requires water authorities to take action when measurements exceed these levels. These levels may also be listed on CCRs as maximum contaminant levels (MCLs) or a maximum residual disinfectant levels (MRDLs). In general, these values are set as close to MCLGs and MRDLGs as possible while taking technology and cost limitations into consideration.

Finally, the column labeled "# of sites above AL of total sites" tells us how many of the locations sampled by the water authority exceeded the upper limits set by the government. Luckily for the folks in Meadville, none of these sites appeared to have excessive amounts of lead or copper.

Now that you have a better understanding of what drinking water information is available and what it means, see if you can find a CCR for your location. You can often find them on the Internet by using "Consumer Confidence Report" and the name of your hometown as search terms. You can also obtain this information by reaching out to your local water authority. By reading the CCR for your hometown, you will learn a little bit more about where your water comes from and whether there are any contamination issues you should be concerned about.

5.6 Water Conservation and Management

Throughout the 20th century, the primary approach to meeting growing water needs and demand was to build more dams, reservoirs, pipelines, and water treatment plants. The basic idea was to deliver high-quality water to all end users and to eliminate wastewater. The result was a highly centralized and industrial-scale approach to meeting water demand, one that placed a large amount of political and economic power in the hands of water utilities.

Peter Gleick, a water scientist and cofounder of the Pacific Institute, has labeled this approach the **hard path for water** because of its focus on physical infrastructure and water supply projects. While Gleick acknowledges that hard path approaches have brought economic and health benefits over the past 100-plus years, he argues that now is the time for a new approach to water management. This new approach, a **soft path for water**, is meant to complement and build on the success of established hard path infrastructure. But rather than building new water supply and distribution systems, the soft path focuses on improving efficiency and helping local communities take control of their own water needs (Gleick, 2010; Pacific Institute Staff, 2013).

Characteristics of the Soft Path

Gleick distinguishes the soft path for water from the hard path in a few different ways. First, the soft path focuses on meeting the water-related *needs* of people, not just a certain level of supply. People need water to clean clothes, irrigate crops, and shower, and if we can help them find a way to do these things with less water, we should. For example, washing machines that use half the water to wash clothes or irrigation systems that require one third of the water to support crops are still allowing home owners and farmers to achieve the desired outcome at a lower cost.

Second, the soft path pays more attention to *matching* water quality to specific end uses. For example, water for irrigation or certain industrial uses does not have to be of the same quality as water we use for drinking or bathing. As a result, soft path approaches often involve finding ways to reuse water more than once before treating it, such as by diverting gray water—relatively clean water from sinks and showers—to water plants or flush toilets.

Third, the soft path emphasizes smaller, *decentralized* solutions to water management issues. Rather than invest massive amounts of scarce capital in new water supply systems, these funds could be used to pay for hundreds of smaller scale initiatives at the local level that save just as much or more water. For example, many water utilities promote and even make available, at low cost or no cost, water-conserving devices (such as low-flow showerheads and rain barrels) and products to their customers.

Fourth, the soft path recognizes that water is as essential to the health of *natural systems* as it is to human society. Therefore, soft path approaches seek to work with nature rather than trying to engineer or work against it. This is precisely what New York City did when it invested in the water purifying ecosystems in its water supply region.

Examples of the Soft Path

Soft path approaches to water management are becoming more common as opportunities to develop new water supplies dwindle and as the cost of hard path approaches continues to rise. In the 1970s Orange County, California, was one of the first locations in the United States to experiment with treated wastewater reuse. At the time, the Orange County Water District was pumping water out of its main aquifer faster than it could recharge, and as a result salt water from the nearby Pacific Ocean was seeping into the aquifer. The water district also imported water from the Colorado River and the Sierra Nevada mountain range, but that supply was limited and costly. A decision was made to take municipal wastewater—the water left over after sewage is treated—and pump it into holding ponds directly above the municipal aquifer. This wastewater slowly seeps into the aquifer below, which helps maintain water levels and supply. Because soil can naturally filter any remaining contaminants from the water, this approach also maintains the quality of Orange County's main aquifer. Orange County's wastewater-to-drinking-water facility (known as the Groundwater Replenishment System) is now the world's largest, and with an upcoming expansion scheduled to begin in late 2019, it will provide close to 500 million liters (130 million gallons) of drinking water a day and meet 40% of the district's overall demand.

Learn More: Orange County's Soft Path Approach

More information about the innovative groundwater replenishment system in Orange County, California, can be found here.

- https://www.ocwd.com/what-we-do/water-reuse
- https://www.ocwd.com/gwrs

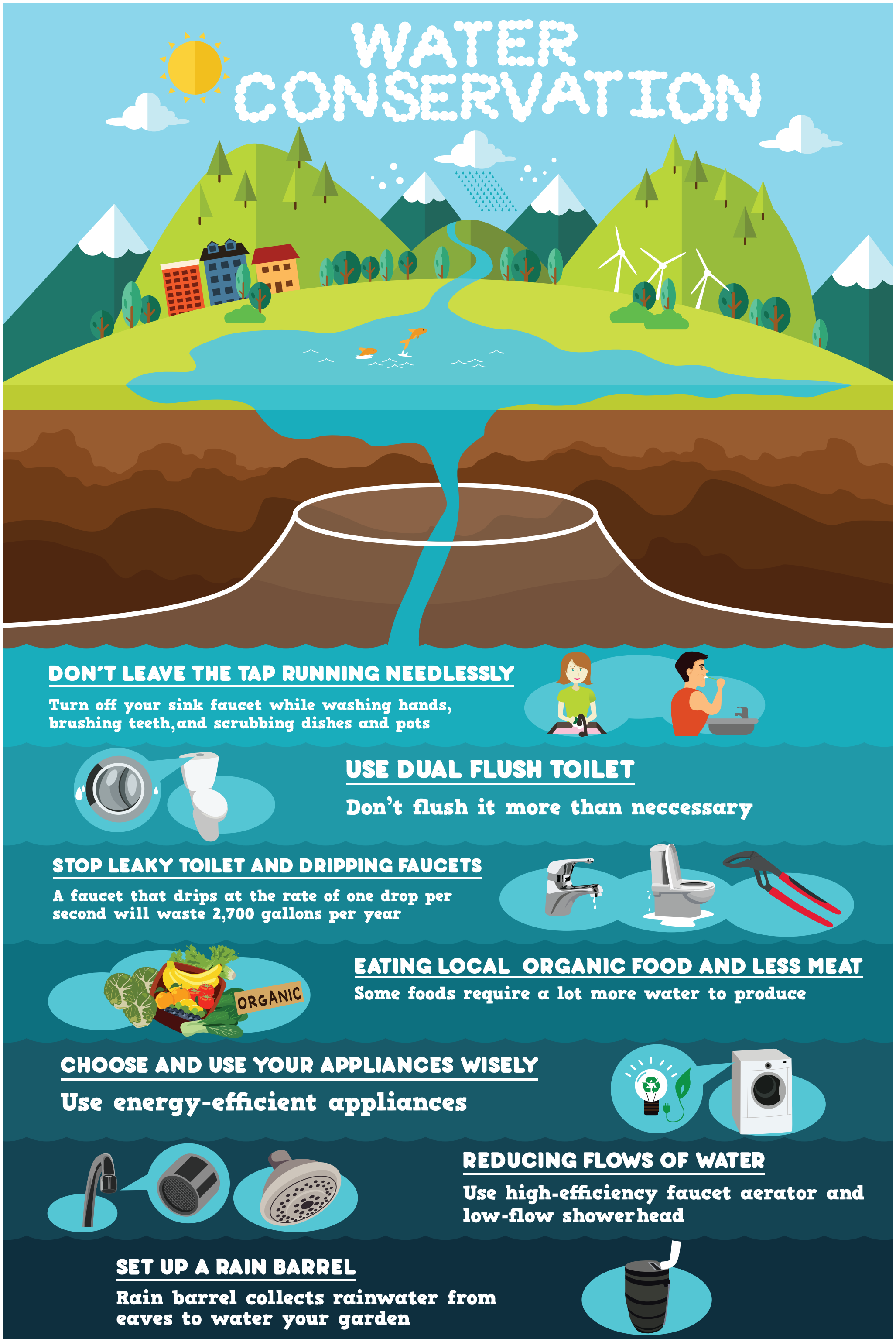
In addition to wastewater reuse, local water authorities are adopting other soft path approaches. For example, Los Angeles and other cities in Southern California used to try to prevent flooding by building concrete drainage channels to carry storm water straight to the ocean. Today these cities are making changes to road surfaces, city parks, and other built-up areas to slow storm water runoff and increase rates of recharge to underground aquifers. These are examples of the soft path approach of working with nature.

Cities in the eastern United States that have older water distribution systems are increasing efforts aimed at leak detection and repair. The WRI estimates that up to 50% of all the water "captured" by water supply systems in the United States is lost to evaporation, leaks, and inefficient use. Basic investments in leak detection and repair can cut these losses dramatically and save water districts and their customers millions of dollars. Elsewhere, especially in drought-prone regions of the Southwest, water districts are working with local residents to help them cut water use for landscaping, bathing, toilets, and other purposes (see Figure 5.8). It costs the water district less to help a customer cut water demand than it does for the water district to increase water supply.

Given that agriculture is the single biggest user of water globally, improving water use efficiency in this sector is an important part of the soft path approach. The most basic and inefficient form of crop irrigation is known as *flood irrigation*. This involves pumping water from a river or underground aquifer and allowing it to flow across a farm field. Likewise, *spray irrigation* uses large-scale sprinklers to spray large amounts of water on a field. Both methods lose as much as half the water they spread through evaporation and runoff. Far more efficient methods for crop irrigation are available and have come into wider use in recent years as farmers become more aware of water supply challenges. Low-energy, precision application sprinklers, drip irrigation systems, and center-pivot, low-pressure sprinklers all deliver 80% to 95% of the water used to the plants where they need it. Small-scale farmers in developing countries are also increasingly returning to water conservation practices and approaches that were once more common. These include rainwater harvesting and the construction of simple "check dams" built across water channels to slow runoff and increase water infiltration to aquifers. Even small improvements in the efficiency of water use in agriculture can go a long way to help free up water supplies for thirsty cities like Cape Town, South Africa.

Figure 5.8: Water efficiency tips

Where else can you save water?



Source: Adapted from artisticco/iStock/Getty Images Plus

Soft path approaches to meeting water demand represent a move toward *integrated water resources management* (IWRM). IWRM looks at issues of water supply and water demand holistically and in an integrated manner, rather than treating them as separate matters to be addressed by different agencies and organizations. What soft path approaches and IWRM have in common is that they tend to put more emphasis on *local solutions* to *local challenges*, rather than relying, for example, on the construction of new dams hundreds of miles away to meet water supply shortages. Given the increasing challenge of meeting world water needs in a time of rising populations and global climate change, such local approaches may be the best option for avoiding severe water shortages and conflict.

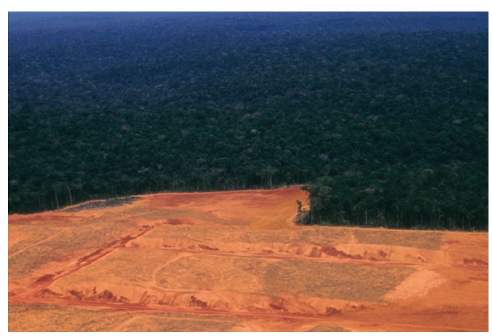
The final section of this chapter shifts to a focus on the role of forests and forest ecosystems in maintaining both water quantity and water quality. As we saw with the example of New York City's water system, forested ecosystems help replenish water sources and purify water as it enters reservoirs, rivers, and streams.

5.7 Forests and Water Management

It may seem odd to have a section on forests in a chapter on water, but effective forest management plays a critical role in good water management. Forests provide ecosystem functions and services that affect *both* water quality and water quantity. In a sense, forests are a form of *natural infrastructure* that can be just as important—or even more important—to water quality and quantity as the physical infrastructure of dams, pipelines, and water treatment plants.

Maintaining Water Quantity

As rains fall and snow melts, forests help slow the rate at which water runs off the surface. Tree roots and dead branches and leaves on the ground intercept water and hold it, allowing it to slowly seep into the ground. Some of this water recharges underground aquifers, while the rest is slowly released into nearby streams and rivers. Experiments at the Hubbard Brook Experimental Forest in New Hampshire and at other locations have been designed to measure what happens to stream flow when forests are cleared (Franz, 2016). In one experiment after another, water runoff and stream flow increased dramatically after trees were removed, resulting in a stream flow pattern that spikes immediately after rains or snow melt (increasing the risk of floods) and then drops dramatically soon after. In contrast, when forests are intact, water from rains and snow melt is released slowly to underground aquifers and nearby streams, and stream flow patterns are more steady and reliable. In fact, it's typically the case that even after weeks of no rain or precipitation, forest streams are still flowing with significant volumes of water.



iStock/Thinkstock

Cleared forest land—such as the deforestation in the Amazon shown here—can create sediment loading in nearby streams and rivers, creating water-quality issues for communities farther downstream.

Maintaining Water Quality

In addition to maintaining water quantity, forests also help maintain water quality. The Hubbard Brook experiments have shown that water running off cleared forest land is high in nitrates and other pollutants and does not meet clean drinking water standards. Clearing forests also increases soil erosion and "sediment-loading" of streams and rivers, increasing the costs of water treatment for downstream communities. In contrast, intact forests help prevent soil erosion and can also help trap and hold other pollutants and contaminants before they can enter nearby waters. This is why riparian buffers—discussed in Section 5.5—are so important to water quality.

The example of New York City's water system at the start of this chapter helps illustrate the importance of forests in good water management. Another example comes from Rio de Janeiro in Brazil, site of the 2016 Summer Olympics. Rio operates the world's largest water treatment plant to provide clean water to its 6.3 million residents. However, this treatment facility is facing operating challenges due to deforestation that is occurring upstream from the city. The deforestation is increasing rates of soil erosion and leading to increased sediment in the water as it reaches Rio's reservoirs. Like New York, Rio is approaching this challenge not by constructing more or better water treatment plants but by going to the *source* of the problem in upstream watersheds. The strategy is to restore and maintain upstream forested areas, an approach that will save the city an estimated $79 million in water treatment costs annually while also improving water quality (Ozment & Feltran-Barbieri, 2018).

Maintaining the Global Water Cycle

In addition to their direct and immediate impact on water quality and quantity in *nearby* ecosystems, we are also becoming more aware of the critical role that forests play in maintaining the *global* water cycle. Trees and other plants perform the ecosystem service of drawing water from the soil and releasing it to the atmosphere as water vapor through transpiration. This process has been summed up beautifully by environmental journalist Fred Pearce (2018a):

> *Every tree in the forest is a fountain, sucking water out of the ground through its roots and releasing water vapor into the atmosphere through pores in its foliage. In their billions, they create giant rivers of water in the air—rivers that form clouds and create rainfall hundreds or even thousands of miles away.* (para. 1)

Those "giant rivers of water in the air" are disrupted through deforestation, especially large-scale tropical deforestation. Deforestation in the Amazon basin could disrupt precipitation patterns and agriculture in China and central Asia thousands of miles away.

As a result, any discussion of effective and sustainable water management should also include ideas for sustainable forest management. In forested, tropical regions of South America, Africa, and Southeast Asia, this often involves efforts at **community-based forest management**. Rather than fencing off forests as a means of protecting them, these programs work with local communities to help them derive a livelihood from the forests while also managing them sustainably. Rain forest–certified coffee, chocolate, and other products are examples of items that can be produced in a way that maintains the ecological integrity and ecosystem services of forested regions.

Bringing It All Together

It's somewhat remarkable that water is so essential to human life yet many of us barely even think of it. We turn on the tap or shower, flush the toilet, and consume water-intensive fruits and vegetables with barely a thought to where that water came from or where it goes after we use it. This is partly a function of where and how we live. For example, where this book's authors live in northwestern Pennsylvania, it seems like sometimes there is *too much* water. As a result, it can be hard to appreciate notions of water as "scarce" or "precious." In contrast, residents of places like California and Cape Town, South Africa, who have lived through years of crippling drought and water shortages, are more likely to pay closer attention to their own water use patterns. Even more so, a woman or young girl in a water-scarce or water-stressed region of the developing world will be acutely aware of the value of water if she has to walk long distances every day to acquire it.

Despite an evolving awareness and growing evidence of the challenges of meeting water demands in a time of population growth and global climate change, we are still largely approaching water and forest management in ways that are problematic. Hard path approaches that dominated water management throughout the 20th century are bumping up against physical, financial, and ecological limits. Soft path approaches are becoming more widely adopted but perhaps not as quickly as needed. A more rapid move toward soft path and integrated water resource management approaches is called for, one that looks at issues of water supply, demand, access and human rights, ecosystem management, and transboundary political cooperation as interconnected rather than separate.

While this chapter dealt with that small portion of the planet's water that is fresh, the next chapter will examine the challenges of sustaining the oceans that cover over 70% of the Earth's surface. We will see, perhaps not surprisingly, that some of the same issues that make management of freshwater resources a challenge also apply to the oceans. We'll also see that a growing awareness of the importance of oceans to all life is driving innovative approaches to sustaining this remarkable and vast resource.

Additional Resources

Global Water Use and Demand

The *Yale Environment 360* website features an excellent five-part series, "Crisis on the Colorado," that examines the threats to the Colorado River system and the communities that depend on its water.

- https://e360.yale.edu/series/crisis-on-the-colorado

National Public Radio featured a series of stories called "Stories From the Water Front" that focused on communities struggling with water supply and water-quality issues.

- https://www.npr.org/series/646816049/stories-from-the-water-front

There are a number of interesting TED Talks on water shortages. Here are some good examples.

- Balsher Singh Sindhu: Are We Running Out of Clean Water?: https://www.youtube.com/watch?v=OCzYdNSJF-k
- Anu Sridharan: When Will I Get My Water Next?: https://www.youtube.com/watch?v=LUXgG6xFNi4
- Kala Fleming: Easing Water Scarcity by Understanding When and Where It Flows: https://www.youtube.com/watch?v=78kzzMySOvw

The World Resources Institute is an excellent source for information on global water issues.

- https://www.wri.org/our-work/topics/water

The New York Times has a stunning video essay on how global warming is causing glaciers to retreat in central Asia and what that will mean for local water supply.

- https://www.nytimes.com/interactive/2019/04/17/climate/melting-glaciers-globally.html

Water and Global Politics

The issue of water shortages and the possibility of conflict between nations over water supplies is growing in importance. These sources take a look at potential cases of water conflict and what might be done to avoid them.

- https://e360.yale.edu/features/mideast_water_wars_in_iraq_a_battle_for_control_of_water
- http://worldwater.org/wp-content/uploads/2013/07/www8-water-conflict-events-trends-analysis.pdf
- http://worldwater.org/wp-content/uploads/2013/07/ww8-ch1-us-water-policy.pdf
- https://www.wri.org/blog/2018/11/un-security-council-examines-connection-between-water-risk-and-political-conflict

Water Quality

In a humorous TED Talk, Rose George talks about the issue of a basic, sanitary toilet and the implications for water quality.

- https://www.youtube.com/watch?v=ZmSF9gVz9pg

Water Conservation and Management

In this TED Talk, Lana Mazahreh talks about water conservation lessons learned while growing up in Jordan.

- https://www.youtube.com/watch?v=nLB8A—QdHc

As water shortages become more widespread and severe, there is increasing interest in the idea of developing "toilet-to-tap" schemes that would purify and reuse water from toilets and other water washed down the drain. This water is variously known as "gray water" if it's from sinks or showers and "brown water" or "black water" if it's from toilets. As much as people are taken aback by the idea of "toilet-to-tap," plans are underway to do just that in cities around the world, including San Diego, California.

- https://www.mnn.com/lifestyle/recycling/blogs/taste-recycled-waste-water
- https://sites.sandiego.edu/sdpollutiontrackers/2018/05/09/toilet-to-tap-not-as-horrendous-as-youd-think
- https://www.kusi.com/toilet-tap-moving-ahead-san-diego?
- http://www.bbc.com/future/story/20160105-why-we-will-all-one-day-drink-recycled-wastewater?
- https://www.sciencedaily.com/releases/2018/03/180313084219.htm
- https://www.pureblue.org/post/toilet-to-tap

Forests and Water Management

The connection between forests and water is the focus of these sites.

- https://www.americanforests.org/blog/the-important-relationship-between-forests-and-water
- http://www.fao.org/3/a1598e/a1598e02.htm
- https://www.srs.fs.usda.gov/cifs/research/forests-and-water

Key Terms

aquifer An area of permeable rock and sediment from which water can be extracted.

Clean Water Act (CWA) U.S. legislation passed in 1972 that makes it illegal for a factory or another point source to dump any pollutant in a waterway without a permit.

community-based forest management Programs that work with local communities to help them derive a livelihood from forests while managing them sustainably.

consumptive use An extractive use of water that involves withdrawing the water and using it without returning it to its source.

ecosystem management In the case of water, an approach that focuses on maintaining water quality at the source rather than cleaning it at its destination.

evapotranspiration The process of evaporation and transpiration together.

extractive uses The ways water is used in which it is physically removed from its source.

hard path for water A term coined by water scientist Peter Gleick for the traditional, centralized, and industrial-scale water management approach. It typically involves building distant dams, reservoirs, pipelines, and water treatment plants.

hydrologic cycle The movement of water between the planet's surface, atmosphere, soil, oceans, and living organisms. Also known as the water cycle.

infiltration The process by which water sinks slowly down through the soil.

instream uses The ways water is used in which it is *not* removed from its source.

nonconsumptive use An extractive use of water that involves withdrawing the water and returning it to its source.

nonpoint sources Indirect and diffuse sources of water pollutants.

point sources Stationary and fixed sources of water pollutants.

reliable surface runoff Freshwater runoff that is readily accessible for human use and consumption.

riparian buffer A vegetated strip of land alongside a stream or river.

Safe Drinking Water Act (SDWA) U.S. legislation passed in 1974 that requires that the EPA set specific standards for allowable levels of chemicals in water and mandates that local water authorities monitor and report on drinking water quality in their jurisdictions.

saltwater intrusion The movement of saltwater into freshwater aquifers.

soft path for water A term coined by water scientist Peter Gleick for an alternative approach to water management. It emphasizes improving efficiency and local solutions over building new water supply and distribution systems.

surface water Water on the surface of the Earth, found in rivers, wetlands, lakes, or reservoirs.

virtual water The water required to produce a product or item before it reaches the consumer. Also known as *embodied water*.

water scarcity A physical lack of water.

watershed An area of land where sources of water (streams, creeks) flow together to a single destination.

water stress A lack of accessible or affordable clean water.

water table A depth below ground where soil and rock are completely saturated with water.