DRINKING WATER

Understanding the Science and Policy behind a Critical Resource

National Academy of Sciences
National Academy of Engineering
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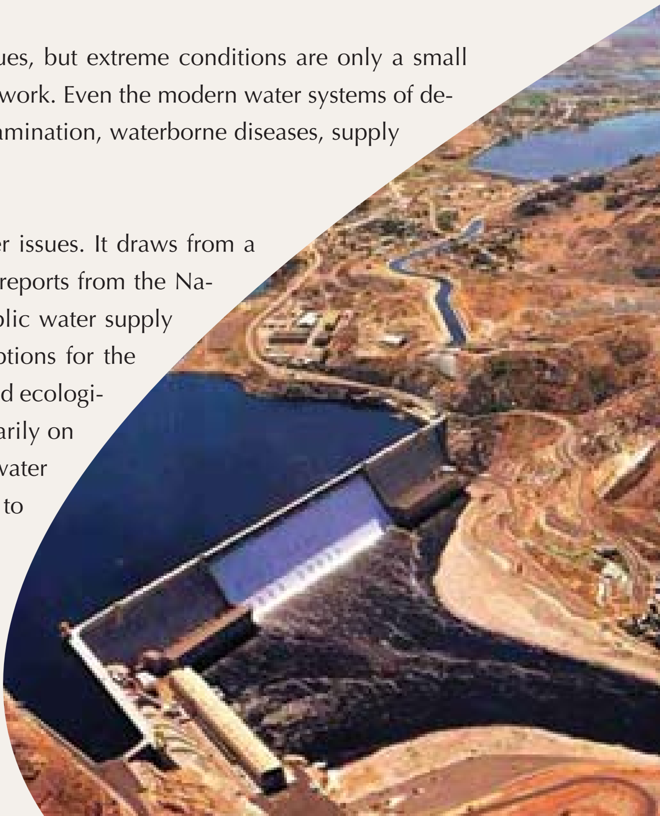
Water is one of those things that people usually take for granted—until it is either gone or unsuitable to drink. In 2007, residents in the southeastern United States were forced to take notice of water when extreme drought swept across the region. With no rain clouds on the horizon for months on end, lawns were shriveling and long-standing reservoirs were being sucked dry. Restaurants began using paper plates to avoid having to wash dishes. In Athens, Georgia, fans at the University of Georgia's homecoming football game were asked not to flush the toilets: stadium attendants were even hired to moderate flushing in a desperate effort to save water. It was the southeast's most extreme drought on record.

Water is a limited resource, the demands for which are fast increasing. Populations in some U.S. cities, like Las Vegas, Nevada, and Phoenix, Arizona, for instance, are expanding at a rate of thousands per month. The result is that water managers must struggle to keep taps flowing without compromising water supplies for future generations.

In the United States, a virtual army of people—utility workers, scientists and engineers, government officials, and many others—work around the clock to provide safe and clean drinking water to America's homes and businesses. Their efforts affect many aspects of society, from the health of individuals and ecosystems to the health of the nation's economy.

Droughts bring increased media attention to water issues, but extreme conditions are only a small part of the problems water managers encounter in their work. Even the modern water systems of developed nations face such challenges as chemical contamination, waterborne diseases, supply shortages, and deteriorating, outdated infrastructures.

This booklet provides an introduction to drinking water issues. It draws from a body of independent, peer-reviewed expert consensus reports from the National Research Council to provide an overview of public water supply and demand, water management and conservation, options for the government and the private sector, and the economic and ecological aspects of drinking water. The booklet focuses primarily on issues in the United States; references to international water issues are generally used for comparison purposes or to illustrate certain issues in greater depth.

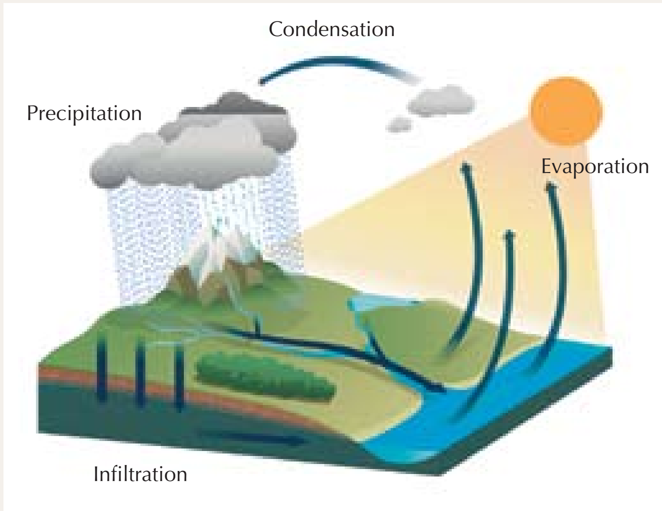


The Grand Coulee Dam on the Columbia River in Washington State.
Image courtesy of the U.S. Department of the Interior.

WHERE DOES DRINKING WATER COME FROM?

Although water covers about 70 percent of the Earth, less than 1 percent is available as freshwater for human use. The vast majority of the water on this "blue planet" is found in the ocean, too salty to drink and unfit for many other applications. Of the freshwater available on Earth, about two-thirds is frozen in ice caps and glaciers, which leaves only a small fraction accessible for human use.

Surface water—such as that in lakes, reservoirs, rivers, and streams—is the primary water source for humans. *Groundwater*—that is, water underground in aquifers (highly permeable rocks, soil, and sand)—can be extracted through wells or found as springs. Technically speaking, groundwater resources exceed salt-free surface water on Earth, but humans use surface water more often because it is easier to access in large quantities.



Earth's water cycle. Solar energy heats surfaces, causing water vapor to rise into the atmosphere through evaporation. There, it condenses into droplets and forms clouds. Water returns to the surface through precipitation as rain or snow. There, it evaporates, flows into rivers, lakes, or the ocean, or sinks through the ground, infiltrating underground aquifers.
Image courtesy of the Marian Koshland Science Museum.

Each part of the United States faces unique challenges in meeting drinking water demands. Individual households and small towns may be served sufficiently by groundwater from wells or springs, whereas large cities tend to use surface water and centralized water treatment and distribution systems.

Image courtesy of the National Aeronautics & Space Administration.

Processing and Treatment

Human or animal wastes, industrial chemicals, pharmaceuticals, and other types of pollutants sometimes contaminate water from rivers, lakes, underground aquifers, and other sources. Fortunately, engineers and scientists have developed innovative solutions to make water potable (safe to drink).

Conventional surface water treatment plants in most developed countries follow this sequence of processes:

- Coagulation: After screening out large objects from the water, coagulant chemicals are added to cause suspended particles to clump together.
- Sedimentation: Water moves into quiet sedimentation basins where sediments settle out.
- Filtration: Water is filtered through sand, membranes, or other materials.
- Disinfection: Chemical additives, ozone, or ultraviolet light are used for disinfection. Other chemicals or processes may also be used to eliminate specific contaminants, to prevent corrosion of the distribution system, or to prevent tooth decay.

Although this treatment sequence produces water that meets legal water quality standards, some people also choose to use additional water purification devices in their homes to improve the water's color, taste, or hardness, or to remove other constituents.

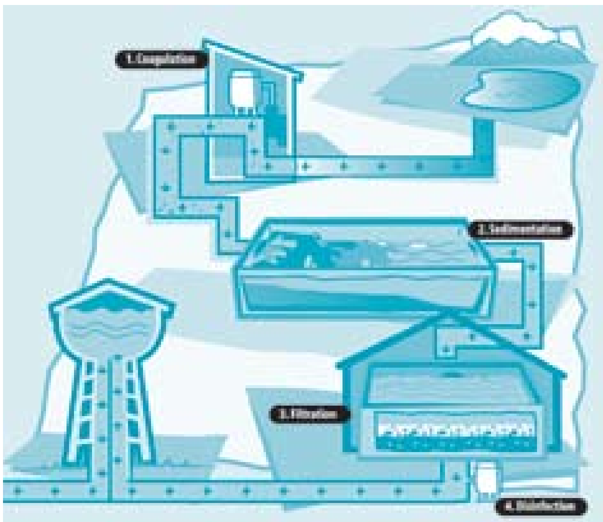


Image courtesy of the American Chemistry Council's Chlorine Chemistry Division and borrowed from www.americanchemistry.com/s_chlorine.

FLUORIDE IN DRINKING WATER

In the early 1900s, a medical doctor named Frederick McKay noticed that children living near the Pike's Peak region of Colorado had teeth with mottled stains but fewer cavities than other children did. Decades of research ultimately revealed that these effects were caused by naturally occurring fluoride in the water supply. Fluoride can enter water supplies from natural sources, such as runoff from fluoride-containing rocks and soils, through the use of certain chemicals, or through industrial discharges and emissions.

By the middle of the 20th century, various U.S. municipalities had begun to add fluoride to water to help prevent tooth decay. Fluoridation of drinking water was named one of the ten Great Public Health Achievements in the 20th Century by the Centers for Disease Control and Prevention (CDC) for its role in the decline in tooth decay during the second half of the 1900s.

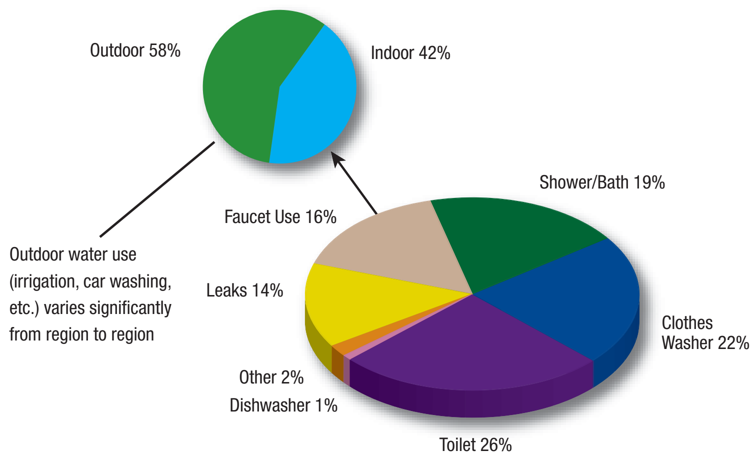
In places where fluoride is artificially added to water, the fluoride concentration is kept at a safe level between 0.7 and 1.2 mg/L. For communities with naturally fluoridated water, however, maintaining optimal fluoride concentrations can be challenging. Studies in the early 1990s revealed that of the approximately 10 million Americans with naturally fluoridated public water supplies, around 200,000 had fluoride concentrations at or exceeding 4 mg/L (the maximum concentration allowed under U.S. Environmental Protection Agency (EPA) standards). At this concentration, approximately 10 percent of children experience severe enamel fluorosis, which has effects ranging from mild tooth discoloration ("mottling") to severe staining, loss of enamel, and pitting.[1]

From Treatment to Tap: Distribution Systems

People in the United States are fortunate to have sophisticated water distribution systems that provide constant access to water at household taps. Maintaining this distribution system, however, constitutes a major challenge because of the sheer amount of physical infrastructure involved: nearly 1 million miles of pipes and countless pumps, valves, storage tanks, reservoirs, meters, fittings, and other hydraulic equipment!

Historically, water systems have been given a low priority in municipal budgets; it is largely due to this fact that some water utilities have put off upgrading and replacing their old infrastructure for so long. As a result, many water delivery pipes in the United States will soon reach the end of their life expectancy.

The cost of water to users typically reflects only the expenses of water capture, transmission, treatment, and delivery. But as more and more systems are in need of replacement, municipalities are finding that these costs can be substantial. Prices for water may have to be raised to pay for needed repairs and replacements.[2]



Residential uses of water in the United States (typically 200 gallons per day per household).
Data from Mayer, et al. Residential End Uses of Water, 1999.

MANAGING A CRITICAL RESOURCE

From dealing with dwindling water supplies to monitoring contaminants in public drinking water, water management and regulation efforts involve nearly 20 federal agencies and thousands of regional, state, and city entities. As the nation's water challenges increase in complexity, more agencies and stakeholders may become involved. Protecting the safety and reliability of America's taps is a large and important challenge—and one that the general public does not understand very well.

Factors Affecting Water Supply

Water may seem to be a stable resource in places where it appears whenever one turns on the tap. In reality, however, water supplies—especially those that depend on surface water—vary dramatically with the seasons, weather patterns, and long-term shifts in climate. Precipitation (rain, snow, sleet, hail, frost, and dew) produces much of the world's drinking water. But precipitation ranges from less than 4 inches per year to more than 160 inches per year in different regions of the United States.

Drought

So little rain fell in the midwestern United States in the 1930s that parched topsoil was literally carried away by the wind. The drought caused sun-blocking dust storms so severe that they were called "black blizzards" and contributed to the destruction of hundreds of millions of acres of previously fertile agricultural land. Spanning across 70 percent of the country and lasting nearly a decade in some places, the "Dust Bowl" drought compounded the effects of the Great Depression and led millions to flee the Midwest. It is considered to be one of the most catastrophic weather events in U.S. history.

Drought isn't limited to occasional catastrophic events or the famously dry American southwest. In the past five years alone, drought conditions have been recorded in nearly every region of the United States. Drought is a unique type of natural disaster in that it seldom has a spectacular or sudden onset. Damage inflicted by drought usually occurs subtly over a span of months to years instead of minutes to days. Unfortunately, few areas are immune to drought.

The catastrophic "Dust Bowl" drought of the 1930s destroyed agricultural land and caused severe dust storms like this one in Stratford, Texas. Image courtesy of the National Oceanic and Atmospheric Administration (NOAA) George E. Marsh Album.

Average annual precipitation across the United States, in inches. Precipitation produces much of the world's drinking water, but precipitation levels range widely in different areas and seasons. Image courtesy of the U.S. National Atlas.

The key to adequate drought management lies in pre-drought preparation. Measures that managers can take to protect against the effects of drought include, among others, increasing water storage, developing a good water system maintenance program, periodically evaluating emergency water sources, establishing a plan for managing water demands, and building public information programs.[3]

Climate Change

The Earth's climate is changing and its atmosphere is warming. What might this mean for freshwater resources?

- *Rising water demands.* Hotter summers mean thirstier people and plants. Temperature increases will likely contribute to higher water demands. In addition, more evaporation from reservoirs and irrigated farmland will lead to faster depletion of water supplies.

- *Increased drought.* Scientific evidence suggests that rising temperatures in the southwestern United States will reduce river flows and contribute to an increased severity, frequency, and duration of droughts.

- *Seasonal supply reductions.* Many utilities depend on winter snowpack to store water and then gradually release it through snowmelt during spring and summer. Warmer temperatures will accelerate snowmelt, causing the bulk of the runoff to occur earlier—before crops can use the water—and potentially increasing water storage needs in these areas.

Severe drought in 2007 left what is normally a pond outside Nicholasville, Kentucky, nothing but dry, cracked ground. Image courtesy of the Lane Report; photo by Andy Olsen.

Mandating water-conserving landscaping was one measure Tucson, Arizona, has taken to reduce its water use.

- *Long-term water supply reductions.* Many communities depend on seasonal water runoff from glaciers. Although shrinking glaciers create higher runoff (and thus more water) in the short term, the longer-term disappearance of glaciers threatens this important water resource.[4]

Getting Every Last Drop

Water is a finite resource, yet demands for it are rapidly increasing. The residents of Tucson, Arizona are well aware of this: Tucson receives just 12 inches of rain per year and sees an influx of thousands of new residents each month. To help preserve its dwindling groundwater supply, the city began implementing a series of water-conservation measures in the 1970s. These efforts, which included public education, improving infrastructure to reduce leakage, mandating water-conserving landscaping, and even employing "water cops" to crack down on water waste, have helped drop the city's per capita potable water use

New Science to Inform Water Management in the Southwest

The Colorado River provides water for tens of millions of people from San Diego, California, to Denver, Colorado. Although gauges have continuously monitored the river's flow for more than a hundred years, scientists didn't know until recently how recorded flows compared with the river's longer-term history.

Tree rings offer insight into the Colorado River basin's hydrologic history. Image courtesy of Connie Woodhouse.

Using tree-ring analysis, scientists are now able to estimate Colorado River flows dating back to the 15th century. These estimates show that extended droughts are an integral part of the basin's climate and suggest that stream-flow measurements over the past 100 years may offer an overly optimistic forecast of future water availability. Given the severity of the droughts indicated by the reconstructed river history, future droughts may be even worse than those of the past century.

Analyses have revealed that the Colorado River Compact of 1922, which governs water allocations between the upper and lower Colorado River basins, was based on a short record of relatively high flows. This means that the water allocations already exceed the mean annual flows in the Colorado River; any future decreases in the river's flow would make the situation even more serious for the region's water users.[5]

The residual ring (white) around the top of Lake Powell makes apparent the dramatic decline in water level. Image courtesy of Brad Udall, University of Colorado.

FIVE STEPS TO WATER CONSERVATION

A variety of practices and technologies—from the low-tech to the high-tech—can help stretch limited water supplies. Here are just a few:

- *Reduce leaks*. From the individual household faucet or toilet to municipal water distribution pipes, repairing or replacing leaking water infrastructure can save water—and money.

- *Install low-flow fixtures*. Water-conserving toilets, showerheads, and faucets, which are now required by building code in many areas, can reduce domestic water use by 50 percent or more.

- *Change water-wasting habits at home*. Small habit changes such as running the dishwasher or washing machine only for full loads or taking shorter showers can, over time, mean big water savings.

- *Use water-saving landscaping techniques*. Some primary water-conserving landscaping techniques (also known as xeriscape landscape principles) include grouping plants with similar water needs together, limiting water-guzzling lawns, using drought-tolerant plants, and irrigating efficiently.

- *Irrigate crops more efficiently*. Conserving the amount of water used to irrigate crops benefits everyone: farmers spend less money on water, and more water is available for other purposes. Advanced techniques can help farmers monitor the precise level of moisture in soil and alter their irrigation practices to limit overall water use. In an approach called deficit irrigation, for example, irrigation is reduced at noncritical times but crops are properly watered at critical flowering and fruiting stages.

Improperly aimed sprinklers often waste a lot of water by allowing it to run off onto sidewalks and into storm drains.
Image courtesy of City of Santa Cruz Water Department.

from 205 gallons per day in 1973 to 163 gallons per day today. That 42-gallon reduction is widely celebrated as a successful water conservation achievement. But expanding populations in Tucson and other cities continue to increase urban water demands, making conservation efforts essential components of water management.

Water Storage

Thinking about your local reservoir may conjure visions of water sports, fishing, or picnicking, but reservoirs serve a much more vital purpose. Reservoirs, or man-made lakes, are typically created by building dams across rivers (some also occur naturally). Reservoirs even out the fluctuations in a water supply by storing water when it is abundant and releasing it later, especially when a water supply diminishes during drought.

Water towers, a familiar sight along nearly every highway in America, help to make sure that water deliveries remain relatively constant even during peak water use times. Their main purpose, however, is to elevate the water level high enough to supply adequate water pressure throughout a distribution system.

As demand for water increases, so does the need for new reservoirs. But a number of factors—including high evaporation rates, damage to fish and ecosystems, and decreasing availability of land for dam construction—have made building additional dams less desirable.

An alternative approach, *managed underground storage*, involves capturing water from a source, storing it in an underground aquifer, and then pumping it back up through wells for use. Managed underground storage systems do not require the requisition of large amounts of land that

Underground storage wells like this one offer an alternative approach to building more dams and reservoirs for water storage.
Image courtesy of Andy Terrey, City of Phoenix.

surface reservoirs do, and loss of water through evaporation is not a problem. Nevertheless, underground storage does pose some challenges. Among them are the generally high costs of design, construction, and monitoring, and the potential for contamination from chemical reactions between the water and aquifer materials.[6]

Water Recycling

Water recycling, also called water reuse or reclamation, can be either direct or indirect. In *direct potable reuse*, wastewater is used for drinking purposes directly after treatment. Direct potable reuse is not used for large-scale public water systems in the United States.

In *indirect potable reuse*, treated wastewater is discharged and mixed into a lake, a river, or groundwater before being extracted and treated again for use. Unlike direct potable reuse, indirect potable reuse is now fairly common, especially in the southwestern United States. For example, Orange County, California, recently completed a state-of-the-art water purification system to augment its drinking water supply with recycled wastewater, creating a virtually "drought-proof" water supply for millions of individuals.[7]

A UV-light purification system, part of Orange County's new recycled wastewater treatment facility.
Image courtesy of Orange County Water District.

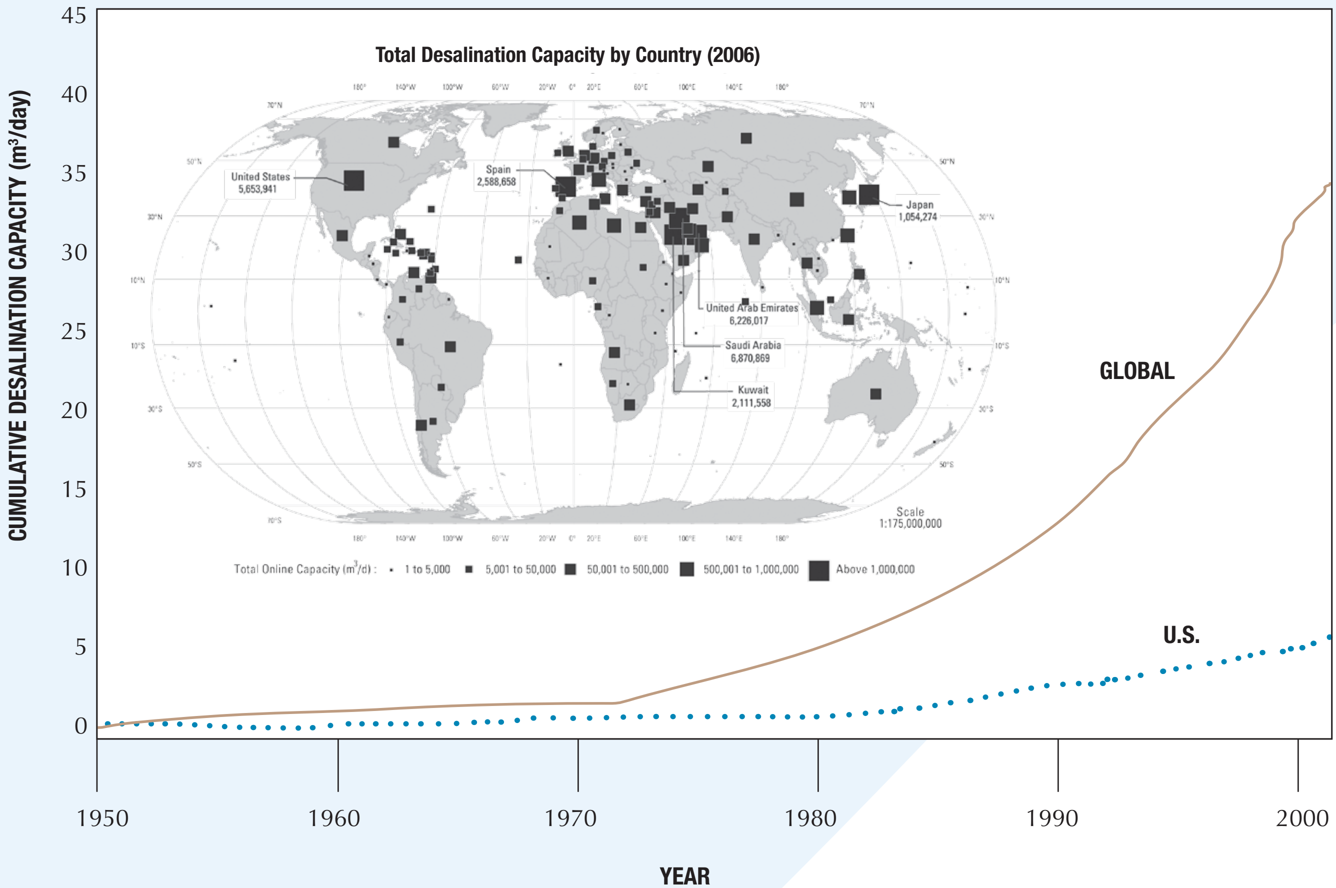


Image @ International Mapping Associates.

Recycled water is commonly used to irrigate parks and golf courses. Such recycling cuts down on the amount of high quality water extracted for non-potable purposes, thus helping to conserve the best freshwater resources for drinking.

Desalination

Another option for augmenting water supplies is a process called desalination. During desalination, salt and other dissolved solids are removed from seawater or brackish groundwater. The worldwide desalination capacity has approximately doubled since 1995: today, the world's operational desalination capacity is more than 10,000 million gallons per day, equal to about 0.3 percent of total freshwater use. That capacity continues to grow steadily. Nearly half of the current global desalination capacity is located in the Middle East, with the remaining capacity distributed throughout North America, Europe, and Asia.

Although their total combined capacity is estimated at less than 0.4 percent of total U.S. water use, desalination plants have been built in every state in the United States. Nearly half of the plants are small facilities built for specific industrial needs. Florida, California, Texas, and Arizona currently have the greatest installed desalination capacity.

Until recently, the cost of desalination was prohibitively expensive in many areas. Advances in membranes and reverse-osmosis technologies, however, have significantly reduced the costs of producing desalinated water. Meanwhile, the costs of other alternatives for augmenting water supplies have continued to rise, making desalination more attractive in a relative sense.

Like many other water management options, desalination has potential environmental implications that need careful consideration. For example, seawater intake mechanisms can harm marine life, and energy use by desalination plants can mean increased greenhouse gas emissions. One of the biggest concerns is the ecological impact of discharging the salt concentrates that are produced in the desalination process. Yet the cost of discharging salt concentrates in an environmentally sustainable manner can be prohibitively expensive where low-cost waste management options are not available.[8]

The Columbia River.
Image courtesy of the U.S. Forest Service.

Competing Uses: The Columbia River Story

For thousands of years, Washington State's Columbia River salmon runs were among the most prolific on Earth. Unfortunately, dams and hydroelectric power plants, commercial fishing operations, logging, irrigated agriculture, and human population growth have altered the river's flows. As a result of degrading salmon habitat, some of the area's native salmon populations are now listed as threatened or endangered under the federal Endangered Species Act.

How can the Columbia River's resources be managed to serve both people and fish? State officials and others have faced difficult decisions as they struggle to satisfy competing demands from the federal government, environmental groups, cities and towns, farmers, and Native American tribes who rely on the river's water. The river continues to offer potential for economic development: according to one calculation, withdrawing a million-acre feet of water (about 0.5 percent of the river's annual flow) for irrigation would create 18,000 jobs and annual revenues of approximately $850 million. However, even a relatively small withdrawal of water could have a negative effect on the area's threatened and endangered salmon.

Ultimately, the state decided to focus its efforts on developing new ways to store the river's water and improve the efficiency of existing storage facilities. Under the state's plan, one of every three gallons of water made newly available through this process would be set aside for protection of the salmon.

Elements of the Columbia River story echo throughout watersheds across the country. Allocating water resources to satisfy competing demands often requires effective communication among stakeholders, thorough analysis of the watershed's hydrological conditions, and creative and innovative solutions.[9]

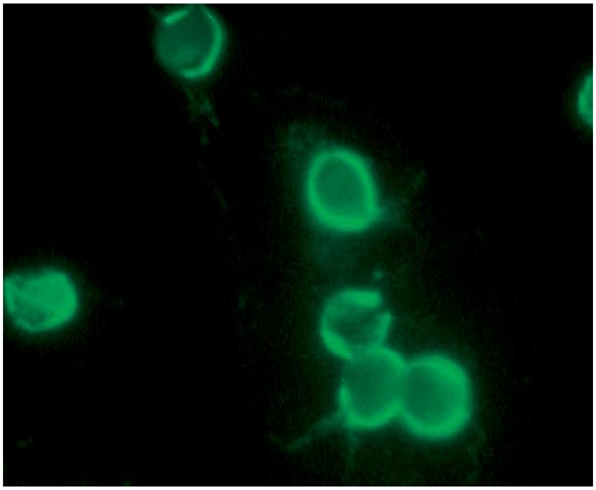
SOMETHING IN THE WATER? WATER AND PUBLIC HEALTH

Water plays an essential role in sanitation and public health. But while it helps to keep people, homes, and cities clean, water itself can also carry harmful microbial or chemical contaminants. In the United States, many water quality regulations help to ensure that drinking water is adequately treated, monitored, and managed to protect public health. Nevertheless, some microbial and chemical contaminants still pose a threat.

Microbial Threats

During a two-week period in the spring of 1993, an estimated 403,000 people in Milwaukee, Wisconsin, became ill with stomach cramps, diarrhea, fever, and vomiting. The culprit: a microscopic parasite called *Cryptosporidium parvum* that had been insufficiently filtered from much of the city's water supply. Affecting more than a quarter of the city's residents and contributing to more than a hundred deaths, it was one of the largest documented waterborne disease outbreaks in modern U.S. history. The malfunctioning treatment plant was shut down following the outbreak, but the event stands as a reminder of the critically important role of effective water treatment.

Many waterborne diseases, including dysentery, typhoid, and cholera, have been virtually eradicated in the United States. Some waterborne bacteria, however—among them *Legionella, Campylobacter,* nontyphoid *Salmonella*, and pathogenic *Escherichia coli*—still cause illnesses. The CDC estimates that waterborne *Legionella* causes 8,000



***Cryptosporidium parvum*, the bacteria behind a major waterborne disease outbreak in Milwaukee, Wisconsin.**
Image courtesy of the EPA; photo by H. D. A. Lindquist.

to 18,000 illnesses each year in the United States. *Legionella*, the cause of Legionnaires' disease (discovered when an outbreak occurred at a Philadelphia convention of the American Legion in 1976), thrives in warm water. When inhaled through contaminated mist or vapor (for example, during showering), it causes pneumonia-like symptoms.

For more than 100 years, U.S. public health officials have relied on indicator organisms, coliform bacteria (found in the feces of humans and other animals), to detect microbial contamination in drinking water. Coliform tests are relatively inexpensive and widely used to test water for contamination.

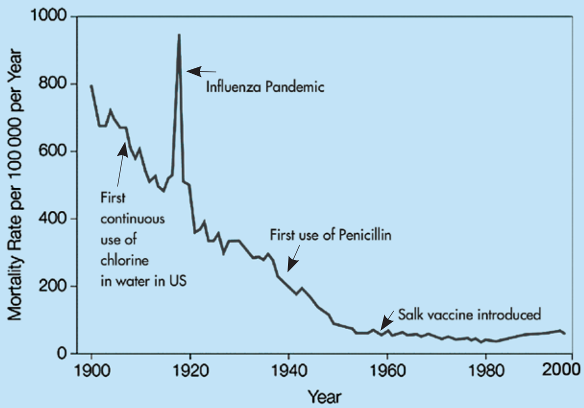
However, the use of bacterial indicators does not always protect against other potentially harmful pathogens, such as viruses and single-celled organisms called protozoa (including *Cryptosporidium parvum*). Some of these pathogens survive in water much longer than coliform bacteria

CHLORINE

Chlorine has been used routinely in U.S. public water systems for 100 years. Chlorine not only kills bacteria in the water at the treatment plant but also continues to disinfect all the way to the consumer's tap. When hurricanes Katrina and Rita struck the Gulf Coast in 2005, chlorinated disinfectants for sanitizing drinking water were among the critical emergency supplies that relief agencies brought in to help affected residents.

Disinfection by-products, which result from interactions between chlorinated disinfectants and naturally occurring organic matter in water, pose potential health problems in the liver, kidneys, or central nervous system, as well as an increased risk of cancer. Both chlorine and disinfection by-products are regulated by the EPA to protect public health.

Alternatives to chlorine disinfection include ozone and ultraviolet radiation; however, these approaches disinfect water only at the site of treatment, not throughout the distribution system. As a result, communities that use ozone or ultraviolet disinfection may add chlorine, or chlorine plus ammonia, as a final "secondary disinfectant" to provide protection throughout the distribution system.



Deaths from infectious disease have declined sharply since utilities began using chlorine to disinfect drinking water.
Image courtesy of the Marian Koshland Science Museum.

ADDRESSING ARSENIC POISONING IN BANGLADESH

Cupful by cupful, many people in Bangladesh are slowly being poisoned by their drinking water. Arsenic, a toxic chemical element, is found in the water of tens of millions of Bangladeshis at concentrations 10 to 50 times what is considered safe.

The contaminated water comes from tube wells that extract groundwater; arsenic has dissolved into the groundwater from natural sources. Bangladesh switched from using surface water to using groundwater relatively recently due to high levels of microbial contamination in surface water sources. Arsenic poisoning leads to several types of cancer and may also be linked to diabetes, respiratory and cardiovascular ailments, and birth defects.[11] (Natural sources of arsenic exist in the United States, but regulations set by the EPA make sure that arsenic concentrations in public sources of drinking water are kept well below harmful levels.)

To help address the serious public health problem arsenic poses in Bangladesh and other developing countries, the National Academy of Engineering held an engineering contest in 2007 to find a sustainable and economical water treatment system for arsenic-contaminated groundwater. The creators of the winning systems were awarded up to $1,000,000 (supported by The Grainger Foundation) for their innovative designs. The winning systems were required to be affordable, robust, reliable, easy to maintain, socially acceptable, and environmentally friendly. With further development and deployment in arsenic-affected areas, these new water treatment systems could well save lives.

Dr. Abul Hussam won the 2007 Grainger Challenge Prize for his method for treating arsenic-contaminated groundwater.
Image courtesy of Evan Cantwell, George Mason University.

A chemist at Sandia National Laboratories observes a new high-tech unattended water sensor, which constantly monitors water for biological pathogens including biotoxins, bacteria, viruses, and protozoa.
Image courtesy of Sandia National Laboratories.

do, so a negative coliform test may not indicate an uncontaminated water sample. Scientists are at work to develop fast, sensitive, and inexpensive tests that look for other microbial contamination indicators in addition to coliform bacteria. Scientists have also called for expanding population health studies of waterborne disease outbreaks to better assess the sources of microbial contamination and prevent future outbreaks.[10]

Chemical Contaminants

A large array of synthetic organic chemicals have been released into the environment, and from there these chemicals can eventually find their way into drinking water supplies. Herbicides, pesticides, pharmaceuticals, antibiotics, industrial pollutants, and radioactive materials all present potential health threats in drinking water. Although these contaminants can be harmful, they are

often present in drinking water at such a low concentration that they do not pose a health risk to consumers. The EPA is responsible for determining the highest acceptable concentrations of these contaminants in drinking water.

Lead

In the mid-1990s, the District of Columbia Water and Sewer Authority (WASA) increased the dose of chlorine in Washington's water to better control microbial contamination. Later, WASA switched from using free chlorine to chloramines for final disinfection in order to lower the amount of potentially harmful disinfection by-products in the water.

Unfortunately, a serious unintended consequence of these changes—which were, ironically, implemented to protect public health—was later discovered. Increased concentrations of free chlorine, combined with pH variations and the conversion to chloramines, had started a chemical reaction that caused lead from the city's and customers' pipes to leach into the water at consumers' taps. In 2002, more than 10 percent of sampled taps in residences in the nation's capital revealed lead contamination of up to 75 parts per billion—five *times* the EPA standard.

To comply with the Lead and Copper Rule of the Safe Drinking Water Act, Washington's water utility has taken several actions to address the city's lead contamination problems. First, it replaced 5,500 lead service lines in 2004–2005 and committed to replacing the public portion of all lead service lines by 2015. Homeowners were encouraged to replace lead pipes on their own property. Second, since August 2004, water treatment plants have been adding *orthophosphate*, a corrosion inhibitor, to the

drinking water. This tasteless, odorless, food-grade additive can form a protective coating inside pipes, decreasing the amount of lead that leaches into the water from lead service lines and home plumbing systems.

The District of Columbia is not alone in facing problems with lead-contaminated drinking water. Prior to 1986, plumbing systems in most homes in America were built of copper pipes soldered together with lead. Unless the water chemistry is carefully controlled, lead can leach into tap water.

The EPA recommends that homeowners who suspect that there may be lead in their water have their water tested by a certified laboratory. Ingesting high levels of lead can cause delayed physical or mental development in infants and children, as well as kidney problems or high blood pressure in adults. The EPA estimates that 10 to 20 percent of lead exposure comes from contaminated drinking water; the majority of that contamination is caused by corroded pipes in homes and buildings.

Gasoline and Other Organic Contaminants

Petroleum hydrocarbons, including gasoline and other fuel oils, can enter groundwater through spills on the surface, leaking pipes or underground storage tanks, or intentional liquid waste disposal operations.

Chlorinated solvents, a family of chemicals used in some industrial processes and household consumer products, can also contaminate drinking water. Chlorinated solvents can be found in drain and oven cleaners, shoe polish, household degreasers, waxes, and pesticides. These solvents are also used in the aerospace and electronics industries, in dry cleaning products, and in some wood manufacturing processes. In 2006, the USGS reported on a study in which one in ten samples of drinking water across 12 states was found to contain trace concentrations of chlorinated solvents.

Cleaning up sites contaminated by petroleum hydrocarbons or the chemicals in chlorinated solvents can be challenging and expensive. One of the most promising approaches, *bioremediation*, involves the use of biological agents, such as bacteria or plants, to break down contaminants. Oil seeps occur naturally in some areas; as a result, some organisms have evolved enzymes to degrade oil and related substances. Bioremediation technologies try to encourage the growth of such organisms in water contaminated by petroleum hydrocarbons.

A geologist notes the spilled contents of a storage tank overturned during hurricanes Katrina and Rita in 2005.
Image courtesy of the Aquifer Evaluation & Protection Section, Louisiana Department of Environmental Quality.

Removing chlorinated solvents, on the other hand, presents a greater challenge. Because most chlorinated solvents are man-made, few organisms have the enzymes needed to degrade these chemicals. An additional challenge is how these contaminants behave in groundwater: while petroleum hydrocarbons tend to float, chlorinated solvents sink down to the bottom of an aquifer or into the bedrock that underlies it.[12]

BOTTLED OR TAP?

Americans spent an estimated $16 billion on bottled water in 2007, guzzling a billion bottles each week. As bottled water becomes ever more popular—either because of its convenience or because people perceive it to be safer—many wonder: Is bottled water actually better than tap?

Some blind taste tests have given mixed results, with tasters often unable to tell the difference between tap and bottled water. Water quality standards are roughly comparable between the two, although some (including the Government Accountability Office) have criticized the methods used for testing the quality of bottled water. One key difference between bottled and tap water is that while most tap water contains fluoride to prevent tooth decay, bottled water generally does not.

Bottled water also costs *several thousand times* as much as tap water. Much of this markup goes into producing the bottle itself, as well as marketing and transportation costs. Producing all those bottles also comes with environmental consequences. The materials and processes used to make plastics and transport the products consume energy resources and can release pollutants into air and water. Furthermore, the used plastic bottles are often dumped into landfills rather than being recycled.

Because of water treatment processes, it is generally safe to drink tap water in every town and city in the United States. Some municipalities, such as New York City, have even launched advertising campaigns to increase trust in the city's water and decrease residents' use of bottled water.

WHO IS IN CHARGE OF AMERICA'S TAPS? THE REGULATORY FRAMEWORK

Who is in charge of making sure that drinking water is safe and free of harmful chemicals? Who makes decisions about curtailing water usage if water is in short supply? Who determines the price of drinking water?

The framework for regulating the nation's drinking water extends across local, state, regional, and federal levels and consists of federal agencies, congressional mandates, state regulations, local municipalities, and private organizations.

The Safe Drinking Water Act

Passed by Congress in 1974, the Safe Drinking Water Act was the first federal law mandating drinking-water standards for all public water systems, and it remains a cornerstone of the nation's drinking water standards. Under the act, the EPA is charged with setting water quality standards for particular contaminants (such as arsenic or mercury) in public water systems.

The act has been amended since 1974 to set goals for additional contaminant standards. Examples of regulations set under the Safe Drinking Water Act include a Total Coliform Rule that sets goals for the presence of total coliform bacteria in drinking water, and a Lead and Copper Rule that aims to reduce the levels of these metals at the tap. Currently, 87 chemicals, disinfectants and disinfection by-products, radioactive chemicals, and microorganisms are monitored for compliance with EPA standards. To keep the list of agents sampled for compliance purposes up-to-date, the EPA publishes a list every five years of unregulated chemical and microbial contaminants that are known or anticipated to occur in public water systems. These agents are then evaluated to determine whether they should be regulated.

A USGS scientist measures the water level in a monitoring well. The framework for regulating drinking water includes many federal agencies, state regulations, local municipalities, and private organizations.
Image courtesy of the USGS.

The EPA regulates approximately 160,000 drinking water systems, which supply water to 90 percent of Americans. The vast majority of EPA-regulated water systems are very small, serving between 25 and 500 people, but almost half of the U.S. population is served by just a few hundred large public water systems. The EPA does not regulate drinking water wells that serve fewer than 25 people, although some state and local governments do set rules to protect users of such wells.

The EPA's headquarters in Washington, D.C. The agency sets water quality standards for particular contaminants in public water systems.
Image courtesy of the EPA.

The Role of States

The Safe Drinking Water Act authorizes states and tribes to assume the primary responsibility for oversight and enforcement of regulations for public water systems. At a minimum, public water systems must meet federal standards, but states can also impose additional regulations. There are many different state-level arrangements for regulating drinking water.

In general, environmental regulation and drinking water quality regulation are the responsibility of state departments of health or environment, along with the EPA. The financial regulation of private water service providers, especially the setting of user water rates, is often the responsibility of regulators such as public utility commissions. However, public water systems set their own rates. In general, state regulations also establish plumbing codes and determine how distribution systems are designed, constructed, operated, and maintained.

Day-to-Day Operations

Most of the responsibilities for daily operations of water utility systems are at the municipal or community level. The major goal of the utility is to supply water of an acceptable quantity and quality, under constant pressure, at all times. Water utility managers must consider issues of public health and safety, pricing, employee training and relations, customer service, and public relations.

A number of voluntary programs help water utilities improve distribution systems and produce water quality beyond the minimum requirements established by law. These programs include accreditation standards, water safety plans, and personnel training programs.

Information about the quality of your area's drinking water and water source can be found at http://www.epa.gov/safewater/dwinfo.

Economics and Financing

The cost of delivering water to the tap reflects the water's extraction, treatment, and distribution; however, water prices often do not reflect the full cost of these activities. As mentioned earlier in the section "Distribution Systems," a large number of the nation's water delivery infrastructures are approaching the end of their life expectancy. Pressing needs to replace and repair aging infrastructure are likely to put increasing strain on underfunded water utilities and may even result in increasing pressure to raise water rates.

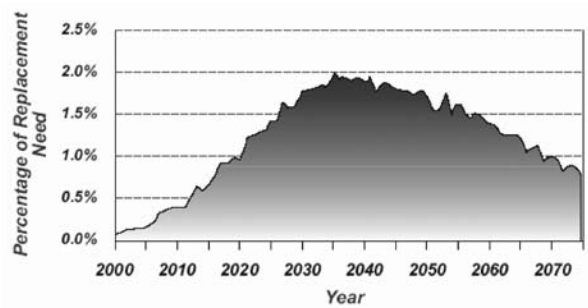
The EPA recently estimated that the 53,000 community water systems and 21,400 not-for-profit noncommunity water systems (including schools and churches) in the United States will need to invest $276.8 billion between 2003 and 2023 to upgrade or replace aging infrastructure and equipment.

Given the projected costs of infrastructure improvements and additions, and the financial challenges of running a water utility, water managers are considering options to improve water system operations. Among those options are programs to improve performance of publicly owned drinking water systems and plans for privatizing various water utility responsibilities and assets.

Privatization

Private companies formed the early water utilities in the United States. As cities expanded ever more rapidly, more of them developed publicly owned water systems. Although today publicly owned systems account for more than 90 percent of all U.S. water production, many public water utilities are again considering some form of privatization, which can encompass a wide variety of water utility operations, management, and ownership arrangements. For example, a publicly owned water utility may outsource laboratory work, meter reading, or supplying chemicals. Or, it may contract with a private company to design and build or operate and maintain water treatment plants. In the most complete form of privatization, a water utility is sold outright to a private company.

There is no inherent reason why either the public or the private sector should be preferred; however, each type of ownership faces its own unique constraints and incentives. For example, privately owned and operated water utilities may be less tied to local politics and could have more flexibility. On the other hand, public systems may be more responsive to public input and more amenable to conservation and long-term resource management objectives. Continued public ownership and operation is the



Projected annual replacement needs for water distribution infrastructure, 2000–2075. Many water delivery pipes in the United States will soon reach the end of their life expectancy. Water utilities are entering an era during which they must make substantial investments in pipe repair and replacement.
Image courtesy of the EPA.

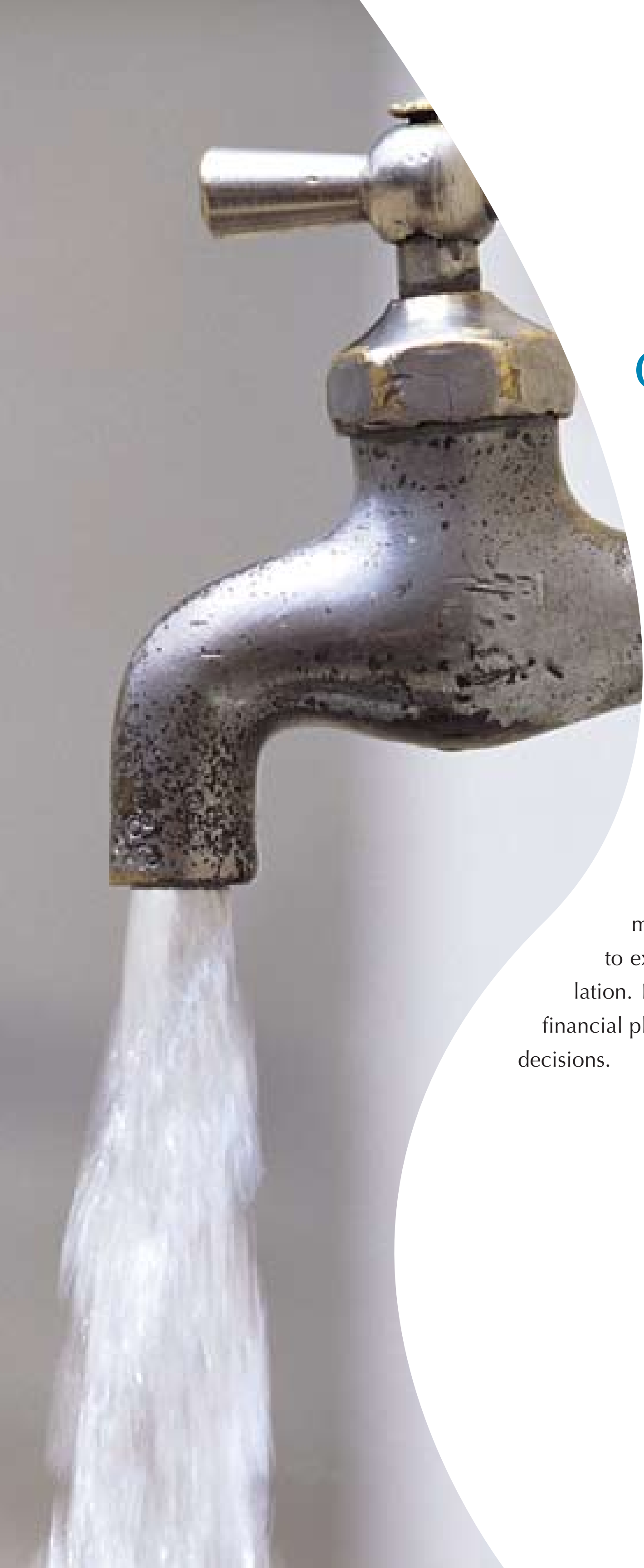
The world's freshwater supplies are under increasing pressure to provide for both human and ecosystem needs.

New York has long enjoyed high quality water from the Catskill Mountains watershed, which provides approximately 90 percent of New York City's drinking water. Unfortunately, increased housing developments and septic systems in the watershed, combined with the impacts of agriculture, have caused water quality to deteriorate. By the late 1990s, New York City managers had two choices: build a filtration plant at an estimated cost of up to $6 billion, or take steps to protect its major watershed. Ultimately, managers decided to protect the watershed at a total projected investment of about $1 to $1.5 billion. If successful, New York's watershed-based management approach could serve as a prototype for other urban water managers.[14]

most likely future for the majority of water utilities, but many people believe that the existence of private alternatives and the possibility of privatization have helped improve the performance of public water utilities.[13]

Water and the Environment

The world's freshwater supplies are under increasing pressure to provide for both human and ecosystem needs. When a city builds a new dam, the resulting artificial lake impacts aquatic species above the dam and along the river. Discharging untreated wastewater into an ecosystem can affect species downstream. Draining a wetland area leaves the watershed more vulnerable to erosion and flooding.



CONCLUSIONS

The value of our water cannot be overestimated. The United States is fortunate to enjoy sophisticated public systems that provide clean, reliable water—a resource critical to our health and quality of life. The United States possesses some of the world's most extensive water treatment and distribution networks. The result of sizable past investments, these systems stand as assets of considerable value and are considered to be one of the greatest public health achievements in the nation's history.

The ability for public drinking water systems in the United States to continue to meet demands over the coming decades cannot be taken for granted. Critical water infrastructure is aging in many places and will require significant investments in research, management and planning, and repair and replacement. These investments are needed in order to sustain as well as to expand current operations to keep up with a growing U.S. population. Protecting water supplies for sustainable use requires research, financial planning, communication, innovative solutions, and sound policy decisions.

For More Information

This booklet is based on expert consensus reports from the National Research Council of the National Academies. For more information on the issues discussed in this booklet, please refer to the following reports, which can be purchased or read free online at www.nap.edu.

[1] *Fluoride in Drinking Water: A Scientific Review of EPA's Standards* (2006)

[2] *Drinking Water Distribution Systems: Assessing and Reducing Risks* (2006)

[3] *Drought Management and Its Impact on Public Water Systems* (1986)

[4] *Colorado River Basin Water Management* (2007)

[5] *Ibid*

[6] *Prospects for Managed Underground Storage of Recoverable Water* (2007)

[7] *Issues in Potable Reuse* (1998)

[8] *Desalination: A National Perspective* (2008)

[9] *Managing the Columbia River: Instream Flows, Water Withdrawals, and Salmon Survival* (2004)

[10] *Indicators for Waterborne Pathogens* (2004)

[11] *Arsenic in Drinking Water* (2001)

[12] *Contaminants in the Subsurface: Source Zone Assessment and Remediation* (2004); *Groundwater and Soil Cleanup: Improving Management of Persistent Contaminants* (1999)

[13] *Privatization of Water Services in the United States* (2002)

[14] *Watershed Management for Potable Water Supply: Assessing the New York City Strategy* (2000)

EXPERT CONSENSUS REPORTS

For further reading, please see the following selected reports:

- *Improving the Nation's Water Security: Opportunities for Research* (2007)
- *Regional Cooperation for Water Quality Improvement in Southwestern Pennsylvania* (2005)
- *Confronting the Nation's Water Problems: The Role of Research* (2004)
- *Estimating Water Use in the United States: A New Paradigm for the National Water-Use Information Program* (2002)
- *Envisioning the Agenda for Water Resources Research in the Twenty-First Century* (2001)
- *Safe Water From Every Tap: Improving Water Service to Small Communities* (1997)

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Below right: Image courtesy of UNICEFF/HQ04-04008/Christine Nesbitt.

WATER INFORMATION CENTER

The National Academies' Water Information Center is an online resource designed to assist the work of water scientists, engineers, managers, policymakers, and students throughout the world. The site makes it easy to navigate more than 100 peer-reviewed reports on water-related topics from the National Research Council. For more information, see http://water.nationalacademies.org.

SAFE DRINKING WATER IS ESSENTIAL

Over 1 billion people lack access to safe drinking water worldwide. The National Academies have developed an interactive online "Technologies Decision Tool" to help people in developing countries explore cost-effective options for water treatment. It is available in the online exhibit "Safe Drinking Water Is Essential" at http://www.drinking-water.org.

http://water.nationalacademies.org

The United States is fortunate to enjoy sophisticated public drinking water systems that provide clean, reliable water—a resource critical to our health and quality of life. But the ability for these drinking water systems to continue to meet increasing water demands over the coming decades cannot be taken for granted. This booklet draws from a body of independent, peer-reviewed expert consensus reports from the National Research Council to provide an introduction to the scientific and policy aspects of keeping America's taps flowing.

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