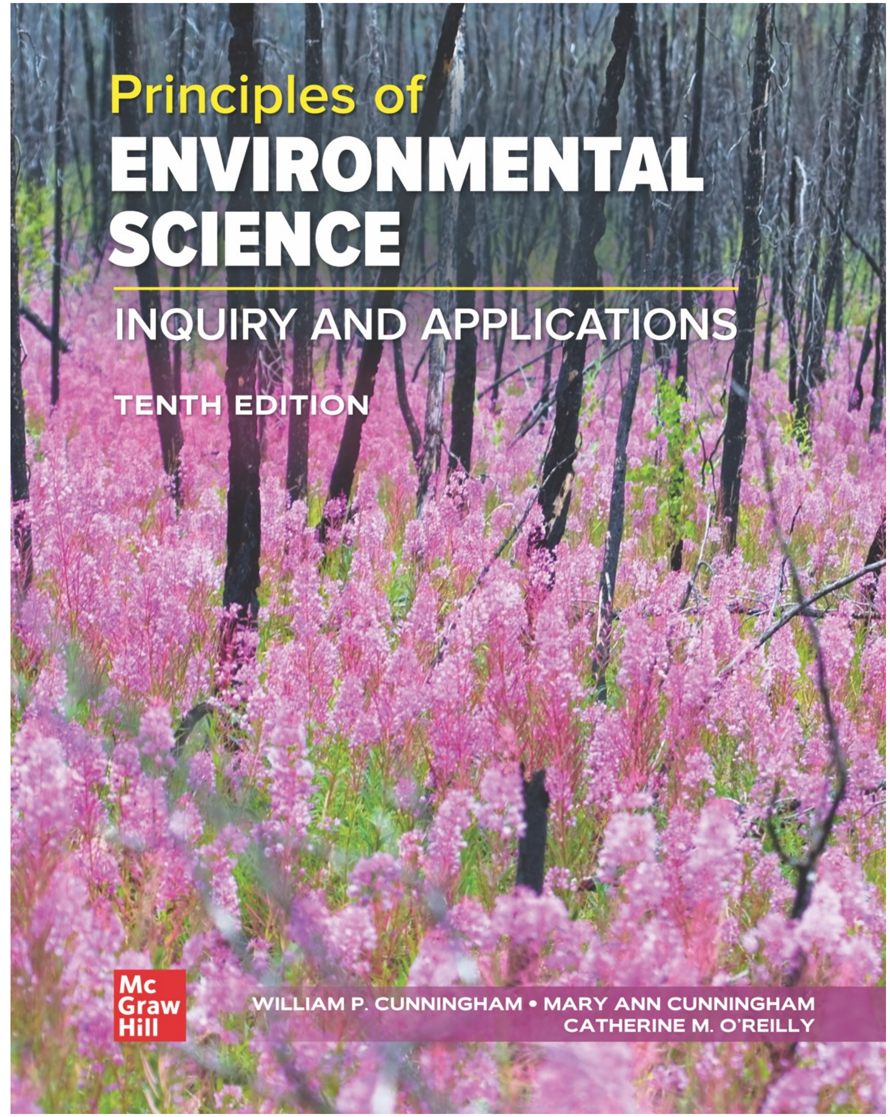
Because learning changes everything.®

Chapter 11 Lecture Outline



Learning Outcomes

After studying this chapter, you should be able to answer the following questions:

- Where does our water come from? How do we use it?
- Where and why do water shortages occur?
- How can we increase water supplies? What are some costs of these methods?
- How can *you conserve water?*
- What is *water pollution*? What are its sources and effects?
- Why are sewage treatment and clean water important in developing countries?
- How can we control water pollution?

I tell you gentlemen; you are piling up a heritage of conflict and litigation of water rights, for there is not sufficient water to supply the land.

–John Wesley Powell

CASE STUDY:
The Quest to Rescue Lake Erie

11.1 Water Resources

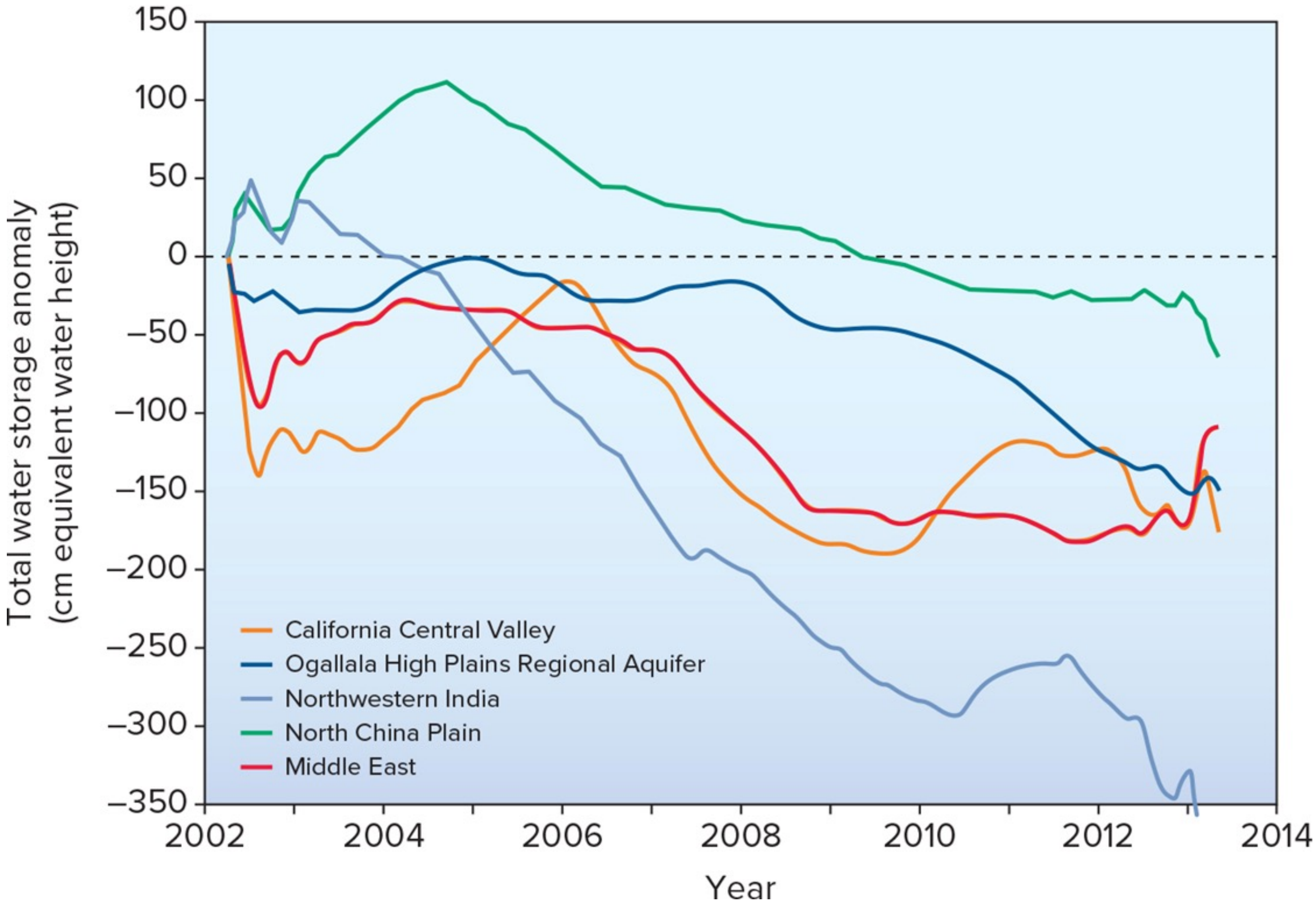
Water is essential for life.

Water dissolves nutrients and distributes them to cells, regulates body temperature, supports structures, and removes waste products. About 60% of your body is water.

You could survive for weeks without food but only a few days without water.

Water also is needed for agriculture, industry, transportation, and a host of other human uses. In short, clean freshwater is one of our most vital natural resources.

Water Resources—Withdrawals



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Source: Famiglietti. J. S., “The Global Groundwater Crisis,” *Nature Climate Change*, vol. 49, 2014, 945–948.

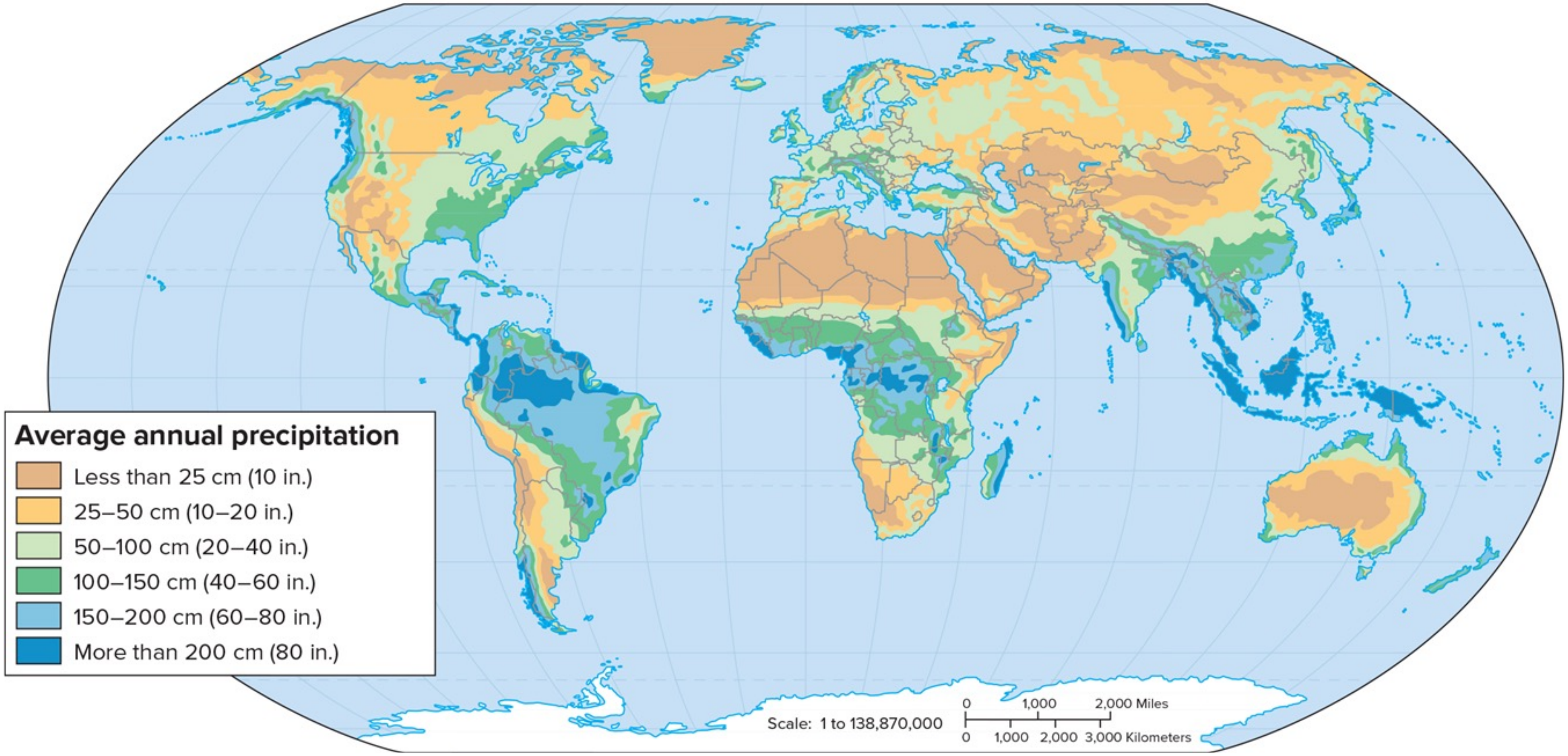
The Hydrologic Cycle Constantly Redistributes Water

Water cycles endlessly through the environment.

This water evaporates from moist surfaces, falls as rain or snow, passes through living organisms, and returns to the ocean in a process known as the **hydrologic cycle**.

Solar energy drives the hydrologic cycle by evaporating surface water which becomes rain and snow. Because water and sunlight are unevenly distributed around the globe, water resources are very uneven.

There Is an Uneven Distribution of Water Resources



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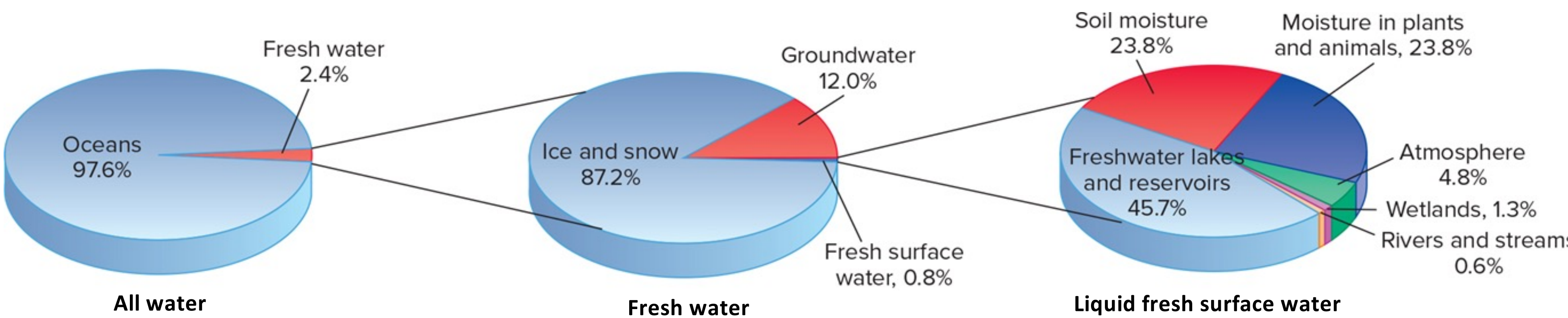
Water Resources



The distribution of water is often described in terms of interacting compartments in which water resides.

Nearly all the world's water is in the oceans.

Only about 0.02 percent of the world's water is in a form accessible to us and to other organisms that rely on fresh water.

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Glaciers, Ice, and Snow Contain Most Surface, Fresh Water

Of the 2.4% of all water that is fresh, nearly 90% is tied up in glaciers, ice caps, and snowfields.

Although most of this ice is located in Antarctica, Greenland, and the floating ice cap in the Arctic, alpine glaciers and snowfields supply water to billions of people.

Climate change is shrinking glaciers and snowfields nearly everywhere. In Asia, the Tibetan glaciers that supply water to major rivers and drinking water for 3 billion people are shrinking rapidly.

Glaciers and Snow Fields Provide Fresh Water to Many

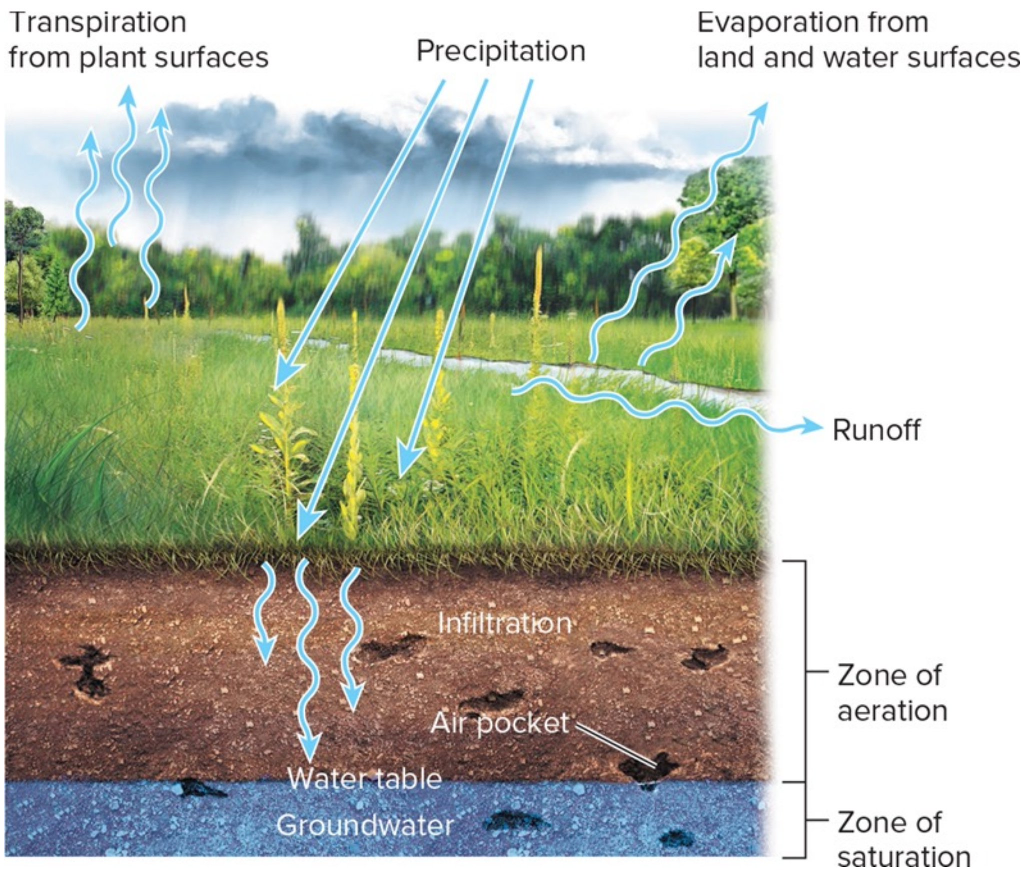
©William P. Cunningham

Groundwater Stores Large Resources

Originating as precipitation that percolates into layers of soil and rock, groundwater makes up the largest compartment of liquid, fresh water.

The groundwater within 1 kilometer of the surface is more than 100 times the volume of all the freshwater lakes, rivers, and reservoirs combined.

Groundwater Zones



Zone of aeration

- Shallow layer of soil containing both air and water.

Zone of saturation

- Lower soil layer with pores filled with water.

Water table

- Top of zone of saturation that supplies most wells.

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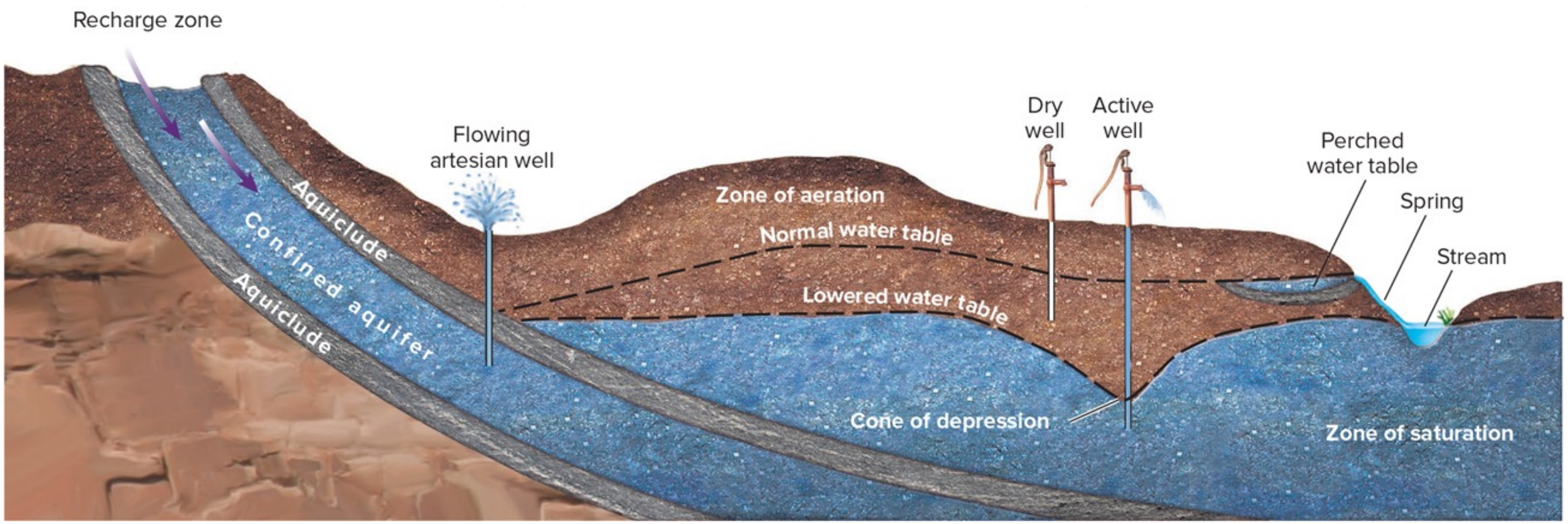
Geological Layers that Contain Water Are Called Aquifers



Aquifers may consist of porous layers of sand or gravel or of cracked or porous rock. Below an aquifer, relatively impermeable layers of rock or clay keep water from seeping out at the bottom.

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Rivers, Lakes, and Wetlands Cycle Quickly

The 16 largest rivers in the world carry nearly half of all surface runoff on Earth, and a large fraction of that occurs in a single river, the Amazon, which carries nearly as much water as the next seven biggest rivers together.

Lakes contain nearly 100 times as much water as all rivers and streams combined, but much of this water is in a few of the world's largest lakes.

Wetlands—bogs, swamps, wet meadows, and marshes—play a vital and often unappreciated role in the hydrologic cycle.

The Atmosphere Is One of the Smallest Compartments

The atmosphere contains only 0.001% of the total water supply, but it is the most important mechanism for redistributing water around the world.

An individual water molecule resides in the atmosphere for about 10 days, on average.

Some water evaporates and falls within hours.

Water can also travel halfway around the world before it falls, replenishing streams and aquifers on land.

11.2 How Much Water Do We Use?

Perhaps more than any other environmental factor, the availability of water determines the location and activities of human beings on Earth.

Water supplies are resources that are replenished regularly—mainly surface water and shallow groundwater.

Water is a renewable resource, but renewal takes time. The rate at which we now use water makes it essential that we protect and conserve local water supplies.

Renewable water is most plentiful in the tropics, where rainfall is heavy, and large land masses.

Water Has Always Been Key to Survival

Mieszko9/Shutterstock

We Use Water for Many Purposes

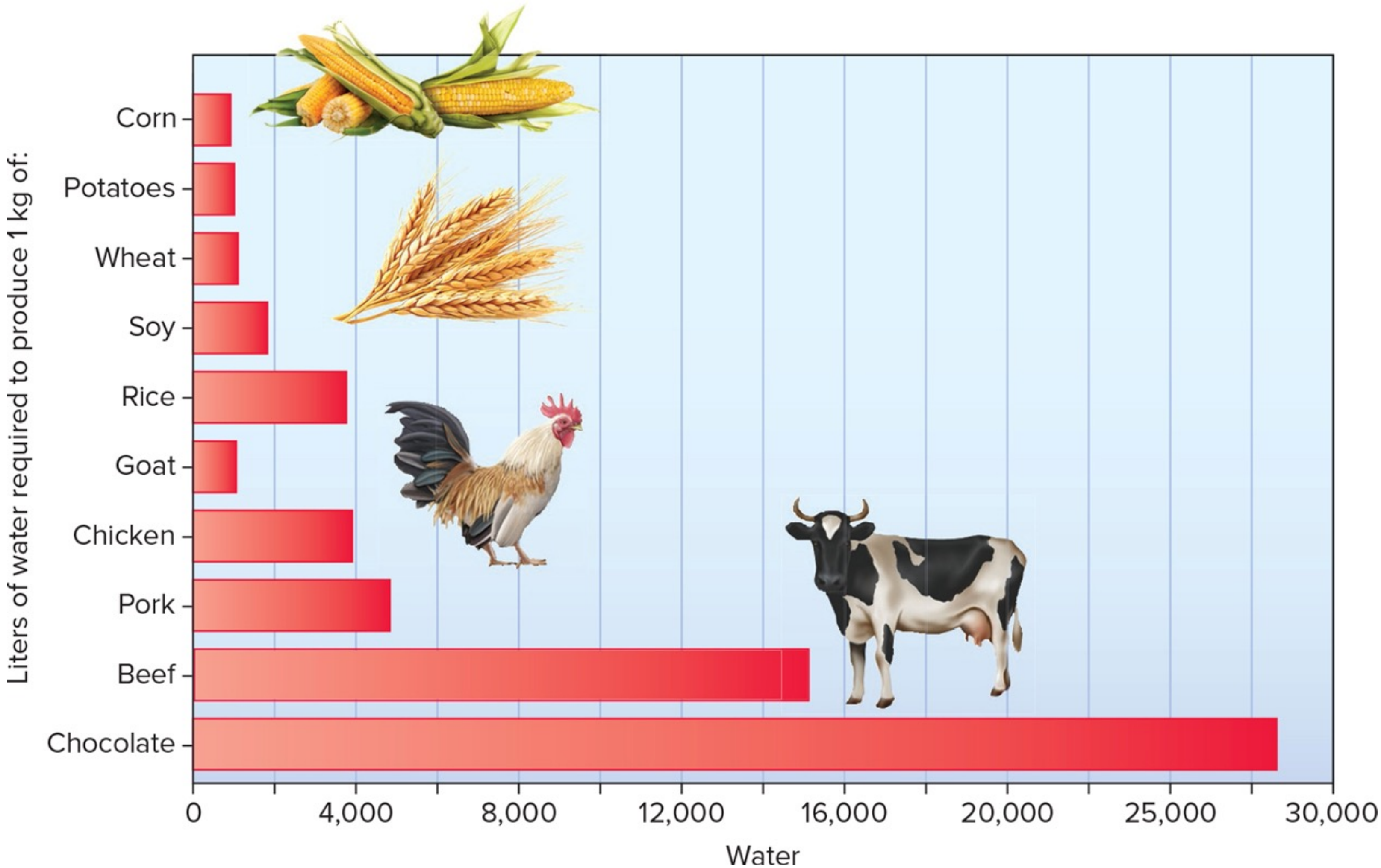
Water withdrawal is the total amount of water taken from a water body.

Worldwide, agriculture claims about 70% of total water withdrawal and that use is increasing.

Raising a kilogram of grain fed beef takes more than 15,000 liters of water whereas raising goats requires at least 90 percent less water.

Rice cultivation (which generally occurs in wet paddies) takes about three times as much water as raising potatoes or wheat.

Water Usage in Food Production



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Industrial and Domestic Uses Tend to Be Far Lower Than Agricultural Use

Some European countries use 70% of water for industry; less-industrialized countries use as little as 5%.

Cooling water for power plants is by far the largest single industrial use of water, typically accounting for 50 to 75% of industrial withdrawal.

A rapidly growing demand for water is for biofuel production. It currently takes 4 to 5 liters of water to produce 1 liter of ethanol.

Water shortages may limit a switch to biofuels.

Domestic Water Use Accounts for Only About 6% of World Water Use

Domestic use includes water for drinking, cooking, and washing.

The amount of water used per household varies enormously.

The United Nations reports that people in developed countries consume on average, about 10 times more water daily than those in developing nations.

Poorer countries can’t afford the infrastructure to obtain and deliver water to citizens.

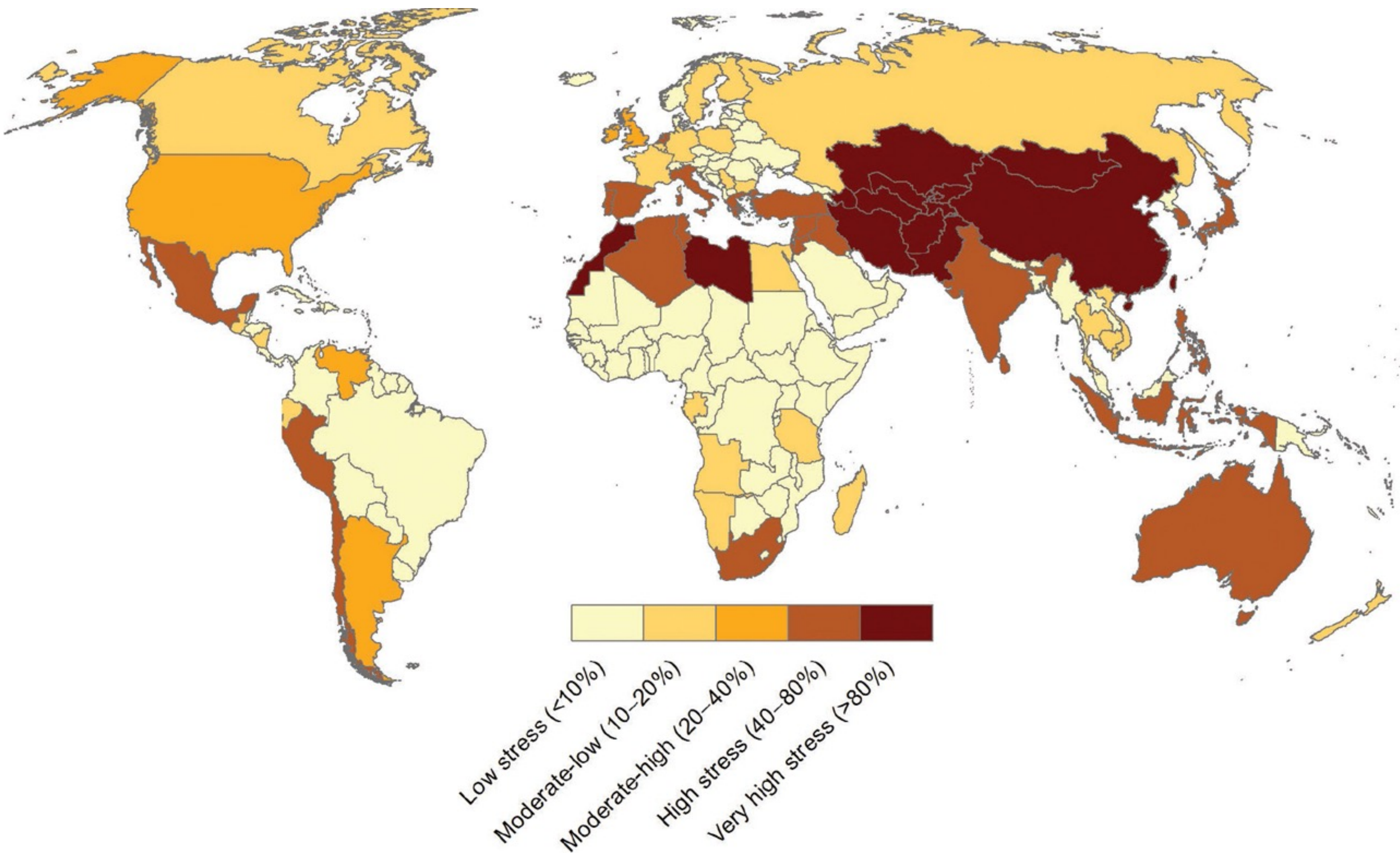
11.3 Dealing with Water Scarcity

The World Health Organization considers an average of 1,000 $meters^3$ (264,000 gallons) per person per year to be a necessary amount of water for modern domestic, industrial, and agricultural uses.

About a third of the world's current population lives in countries where water supplies don't meet everyone's minimum essential water needs.

The biggest problems in water stress and scarcity at a human level occur in Africa and Asia where rainfall is low and poor countries can't afford to adapt.

Water Stress Varies Geographically



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Source: Data from the World Resources Institute.

Many People Lack Access to Clean Water

More than two-thirds of the world's households have to fetch water from outside the home.

This is heavy work, done mainly by women and children and sometimes taking several hours a day.

Improved public systems bring many benefits to these poor families.

Living in an Age of Thirst

In general, a drought is an extended period of consistently below average precipitation that has a substantial impact on ecosystems, agriculture, and economies.

Droughts are often cyclic and land-use practices exacerbate their effects.

In the United States, the worst drought--so far--in economic and social terms, was in the 1930s when dry years and poor soil conservation resulted in the “dust bowl”.

Duration of Droughts Varies

The dust bowl of the 1930s, for example, only lasted about six years, but the megadroughts that destroyed the Anasazi cultures in the twelfth and thirteenth centuries lasted 25 to 50 years.

Groundwater Supplies Are Being Depleted

Groundwater provides nearly 40% of the fresh water for agricultural and domestic use in the United States.

In many areas of the United States, groundwater is being withdrawn from aquifers faster than natural recharge can replace it.

Water withdrawal also allows aquifers to collapse. **Subsidence**, or sinking of the ground surface, follows.

Another consequence of aquifer depletion is **saltwater intrusion**.

Subsidence Caused by Groundwater

A photo taken in 1977 showing subsidence caused by groundwater pumping in California's San Joaquin Valley.

The 1925 sign indicates the ground level in that year.

Source: Dick Ireland, USGS

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Diversion Projects Redistribute Water

Dams and canals are a foundation of civilization because they store and redistribute water for farms and cities. Many great civilizations have been organized around large-scale canal systems.

More than half of the world's 227 largest rivers have been dammed or diverted.

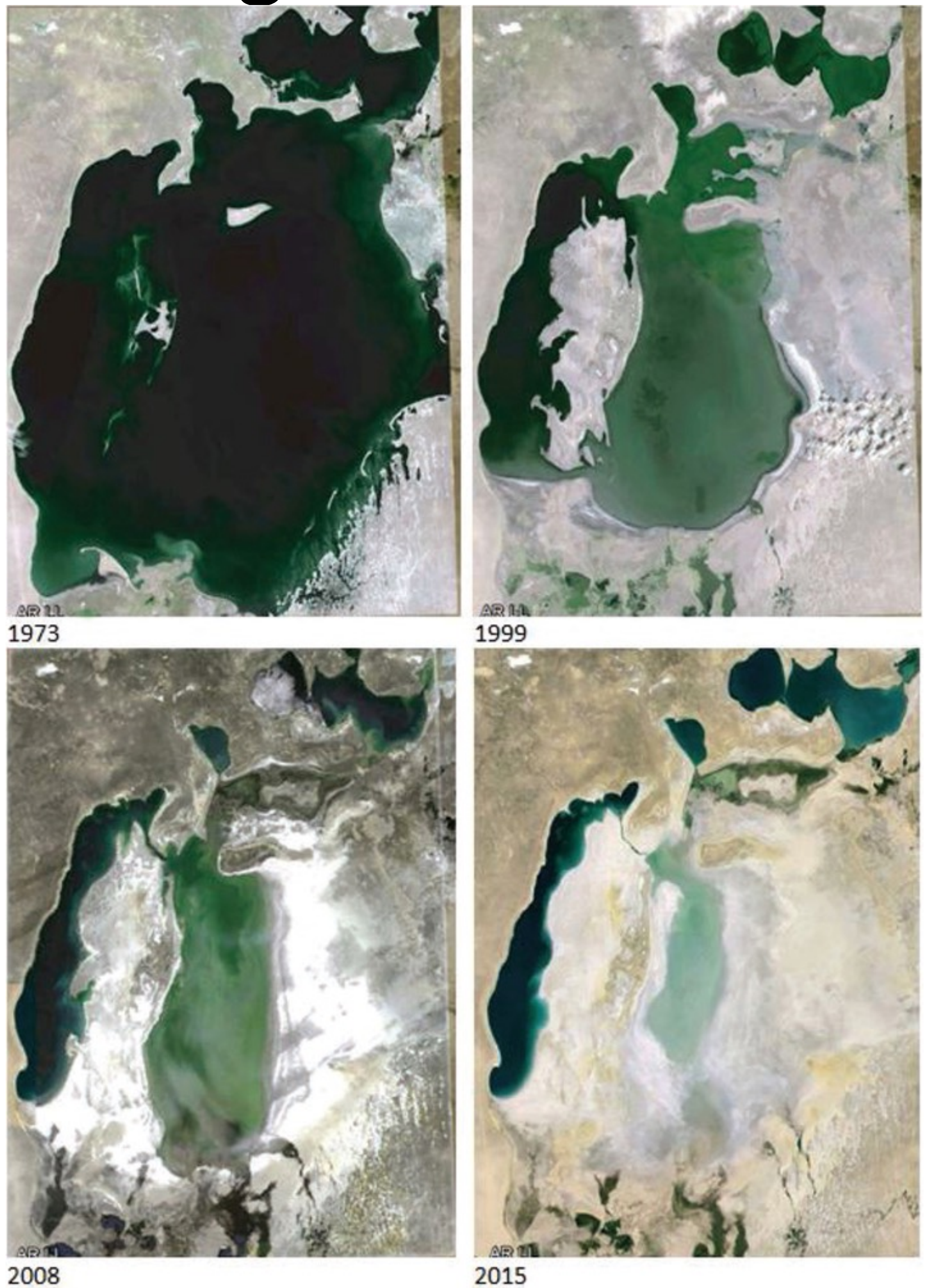
The 3 Gorges Dam, the largest water diversion project in the world, is now being built in China.

One of the most disastrous diversions in world history is that of the Aral Sea.

Hoover Dam Near Las Vegas

Source: USDA, NRCS, photo by Lynn Betts

Changes in the Aral Sea



Access the text alternative for slide images. Source: USGS Earth Resources Observation and Science (EROS) Center

Questions of Justice Often Surround Dam Projects

International Rivers, an environmental and human rights organization, reports that dam projects have forced more than 23 million people from their homes and land, and many are still suffering the impacts of dislocation, years after it occurred.

There is increasing concern that big dams in seismically active areas can trigger earthquakes.

Would You Fight for Water?

Fortune magazine wrote “water will be to the 21st century what oil was to the 20th.”

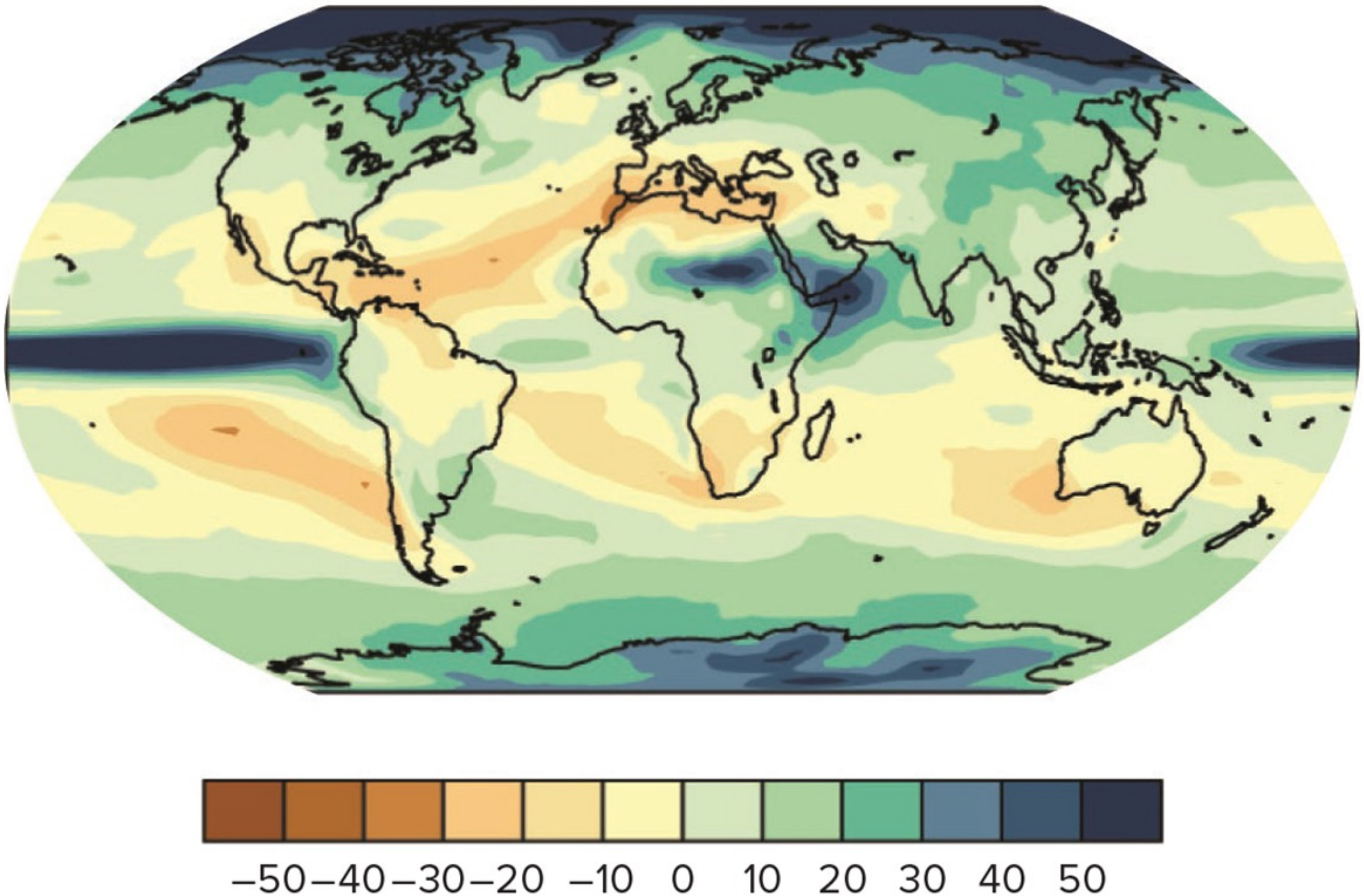
Skirmishes—if not outright warfare—over insufficient water have already occurred.

In Kenya, for instance, nomadic tribes have fought over dwindling water and grazing.

An underlying cause of the genocide now occurring in the Darfur region of Sudan is water scarcity.

There have been at least 37 military confrontations in the past 50 years in which water has been a factor.

Changes in Precipitation for 2081–2100 (relative to 1986–2005)



Percentage change in precipitation

Access the text alternative for slide images.

Source: IPCC Climate Change 2014 Synthesis Report, Summary for Policymakers, Figure SPM.7, 12.

Water Conservation and Management

Watershed management and conservation are often more economical and environmentally sound ways to prevent flood damage and store water for future use than building huge dams and reservoirs.

A **watershed,** or catchment, is all the land drained by a stream or river.

It has long been recognized that retaining vegetation and groundcover in a watershed helps hold back rainwater and lessens downstream floods.

Everyone Can Help Conserve Water

We could probably save as much as half of the water we now use for domestic purposes without great sacrifice or serious changes in our lifestyles.

Simple steps, such as taking shorter showers, fixing leaks, and washing cars, dishes, and clothes as efficiently as possible, can go a long way.

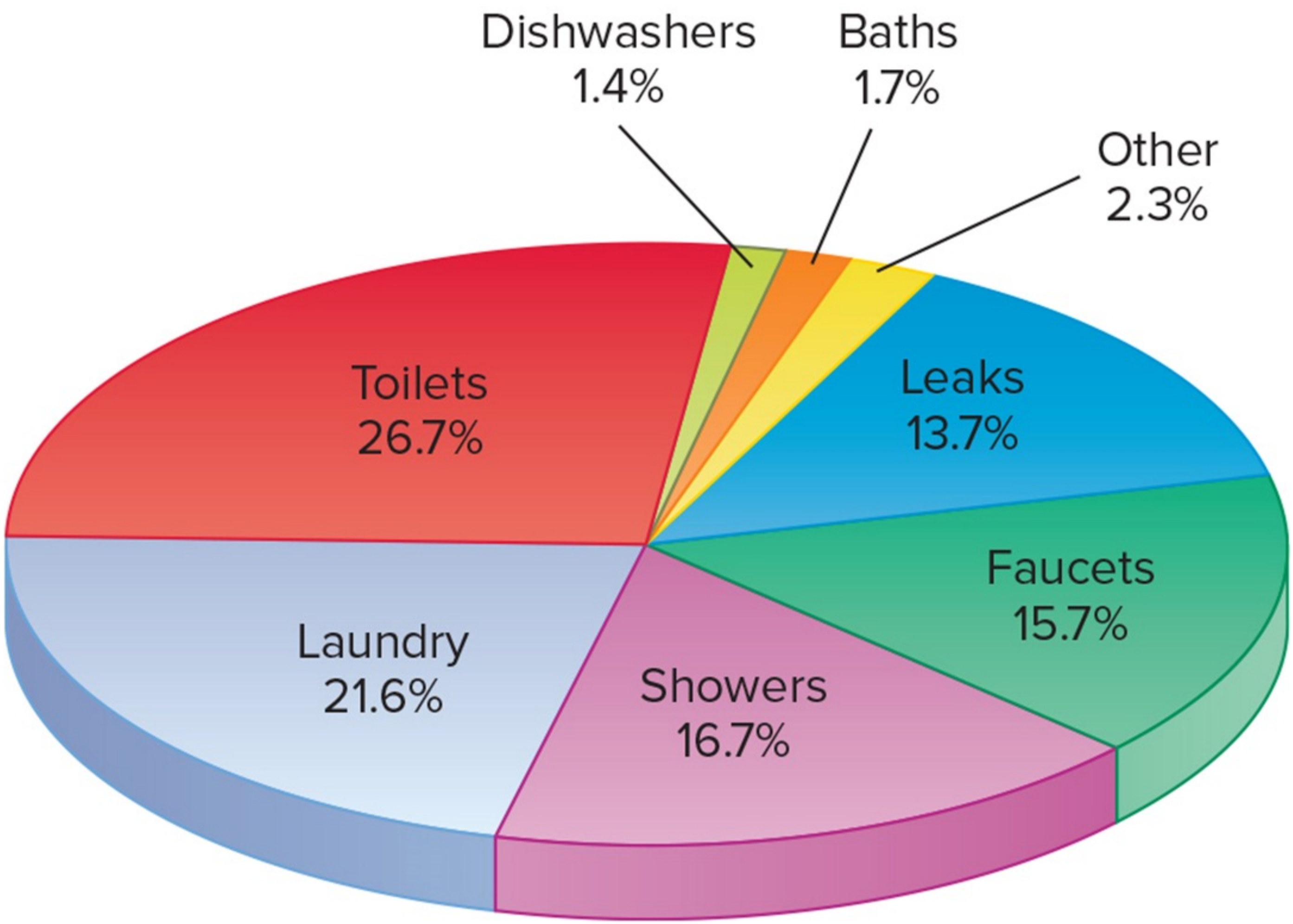
Water-conserving appliances, such as low-volume showerheads and efficient dishwashers, can reduce water consumption greatly.

Planting Native Vegetation Saves Water

Planting native vegetation can be both ecologically sound and aesthetically pleasing.

Las Vegas is paying residents to replace turf with natural vegetation. They have even asked golf courses to rip up fairways.

Toilets Are Our Greatest Domestic Water User



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Source: Data from the American Water Works Association, 2010.

What Can You Do?

Don’t flush every time you use the toilet.

Take shorter showers and shower instead of taking baths.

Put a brick or full water bottle in your toilet tank to reduce the volume of water in each flush.

Use water-conserving appliances: low-flow showers, low-flush toilets, and aerated faucets.

Gray water (recycled from other uses) could be used for flushing, but installing separate plumbing systems is expensive.

Efficiency Is Reducing Water Use in Many Areas

Growing recognition that water is a precious and finite resource has encouraged conservation.

Despite a growing population, the U.S. is now saving some 38 million gal per day compared with per capita consumption rates of 30 years ago.

New requirements for water-efficient fixtures in many cities help conserve water on the home front.

Pricing may effect our water usage. Water from stressed Lake Mead costs 33 cents per $meters^3$ Las Vegas while in Atlanta it costs $3!

11.4 Water Pollutants

Any physical, biological, or chemical change in water quality that adversely affects living organisms or makes water unsuitable for desired uses can be considered **pollution**.

There are natural sources of water contamination, such as poison springs, oil seeps, and sedimentation from erosion.

However, here we'll focus primarily on human-caused changes that affect water quality or usability.

Pollution Includes Point Sources and Nonpoint Sources

Point sources discharge pollution from specific locations, such as drain pipes, ditches, or sewer outfalls such as factories, power plants, sewage treatment plants, underground coal mines, and oil wells.

Nonpoint sources have no specific location where they discharge into a particular body of water, including runoff from farm fields and feedlots, golf courses, lawns and gardens, construction sites, logging areas, roads, streets, and parking lots.

Point Source Pollution

pingphuket/Shutterstock

Biological Pollution Includes Pathogens and Waste

The most serious water pollutants in terms of human health worldwide are **pathogenic** (disease-causing) organisms.

Among the most important waterborne diseases are typhoid, cholera, bacterial and amoebic dysentery, enteritis, polio, infectious hepatitis, and schistosomiasis.

If any **coliform bacteria** are present in a water sample, infectious pathogens are usually assumed to be present also.

Biological Oxygen Demand

Oxygen is removed from water by respiration and chemical processes that consume oxygen.

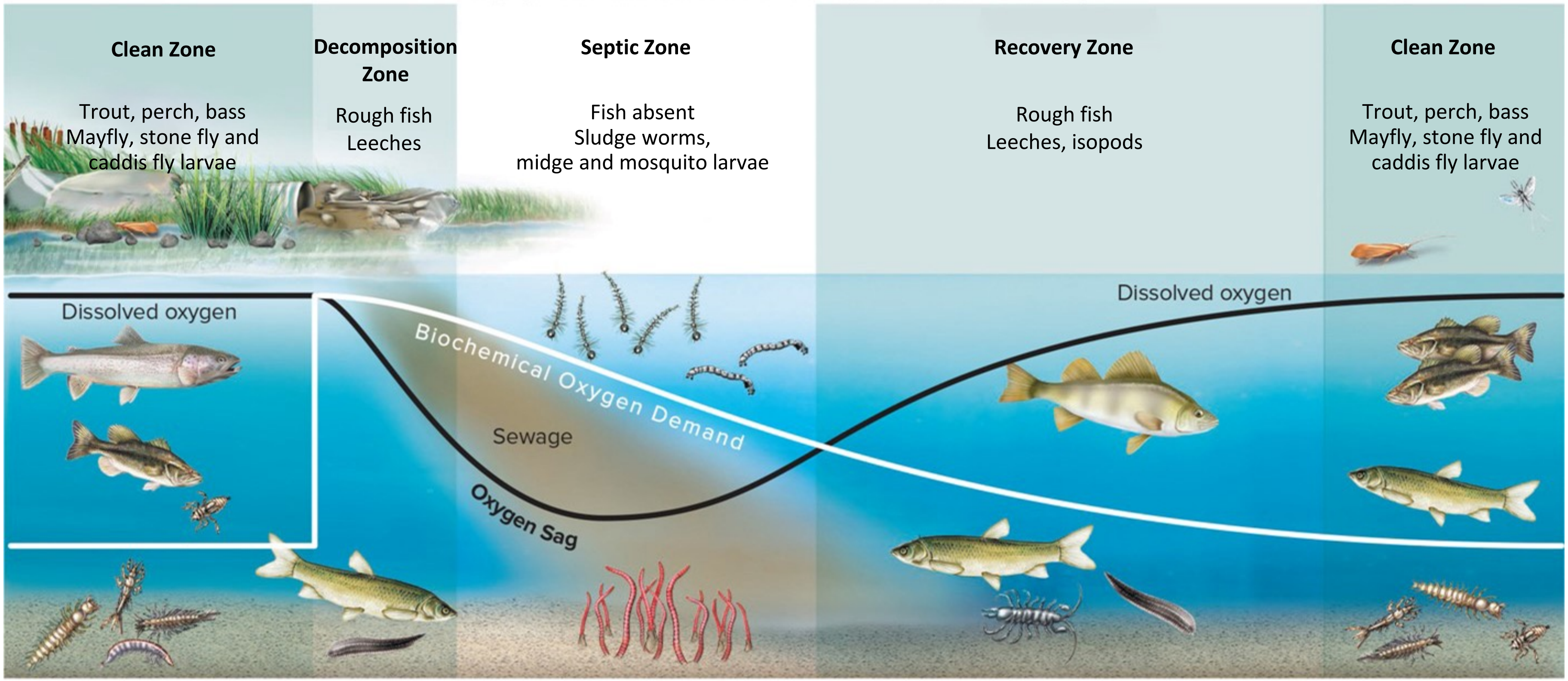
Because oxygen is so important in water, **dissolved oxygen (DO)** levels are often measured to compare water quality in different places.

Organic materials, such as sewage or paper pulp, in water increase oxygen consumption by decomposers.

Biochemical oxygen demand (BOD), is the amount of dissolved oxygen consumed by aquatic microorganisms.

Chemical oxygen demand (COD) is a measure of all organic matter in water.

Oxygen Sag



Dissolved oxygen levels (parts per million): 0 to 2 parts per million | 2 to 5 parts per million | 5 to 10 parts per million

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Plant Nutrients and Cultural Eutrophication

Rivers and lakes that have clear water and low biological productivity are said to be **oligotrophic** (*oligo = little; trophic = nutrition).*

Eutrophic *(eu = trophic ; well-nourished)* waters are rich in organisms and organic materials.

Eutrophic Lake

©William P. Cunningham

Eutrophication Can Also Occur in Marine Ecosystems

Partially enclosed seas, such as the Black, Baltic, and Mediterranean Seas, tend to be in especially susceptible to eutrophication.

Effluents from nearby large cities may be dumped untreated into the sea. Beach pollution, fish kills, and contaminated shellfish result. Extensive “dead zones” often form where rivers dump nutrients into estuaries and shallow seas.

Excessive nutrients support blooms of these deadly aquatic microorganisms like red tides.

Inorganic Pollutants Include Metals, Salts, and Acids

Some toxic inorganic chemicals are naturally released into water from weathering of rocks but humans can accelerate this process by our actions.

Among the chemicals of greatest concern are heavy metals, such as mercury, lead, tin, and cadmium.

Such heavy metals are highly persistent, they accumulate in food chains and effect humans.

Mercury, released from incinerators and coal-burning power plants, is the most widespread toxic metal contaminant in North America.

Organic Chemicals Include Pesticides and Industrial Substances

The two principal sources of toxic organic chemicals in water are:

- Improper disposal of industrial and household wastes.
- Pesticide runoff from farm fields, forests, roadsides, golf courses, and private lawns.

Bottled Water Is Not Better

It has become trendy to drink bottled water. Every year, Americans buy about 28 billion bottles of water at a cost of about $15 billion with the mistaken belief that it's safer than tap water.

About one-quarter of all bottled water in the United States is simply reprocessed municipal water, and much of the rest is drawn from groundwater aquifers, which may or may not be safe.

A recent survey of bottled water in China found that two-thirds of the samples tested had dangerous levels of pathogens and toxins.

Sediment and Heat Also Degrade Water

Sediment is a natural part of river systems. Sediment fertilizes floodplains and creates fertile deltas, but human activities, chiefly farming and urbanization, greatly increase sediment loads in rivers.

Thermal pollution, usually effluent from cooling systems of power plants or other industries, alters water temperature. Raising water temperatures from normal levels can adversely affect water quality and aquatic life.

Sediment Can Degrade Water

Silt and sediment are considered the largest source of water pollution in the United States.

NASA-GSFC

Remaining Problems

The greatest impediments to achieving national goals in water quality in both the United States and Canada are sediment, nutrients, and pathogens, especially from nonpoint discharges of pollutants.

About 3/4 of the water pollution in the U.S. comes from soil erosion, fallout of air pollutants, and surface runoff from urban areas, farm fields, and feedlots.

11.5 Persistent Challenges

Developing countries often have serious water pollution

Despite the fall of the Iron Curtain in 1989, parts of Russia, along with the Balkans and Central Asia, remain extremely polluted.

It's estimated that 70% of China's surface water is unsafe for human consumption, and that the water in ½ the country's major rivers is so contaminated that it's unsuited for any use.

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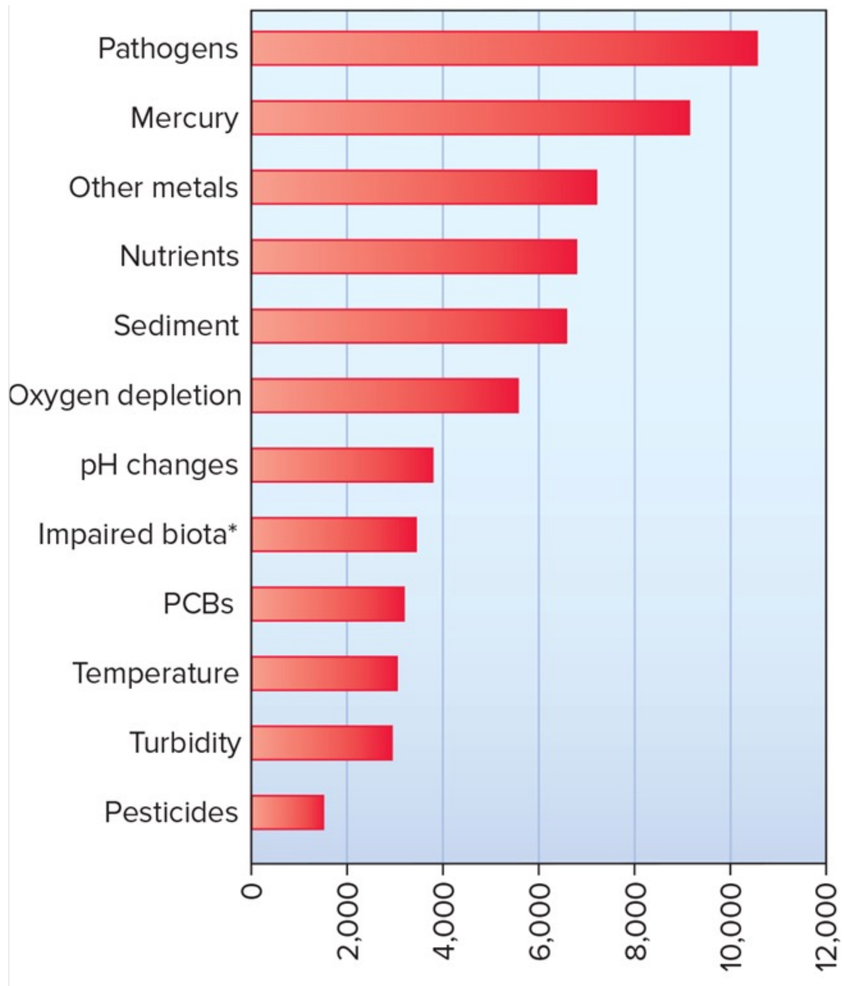
Leading Causes of Surface Water Impairment



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Source: Data from EPA, 2009.

Ditches Serve as an Open Sewer in Haiti

Robert Nickelesberg/Getty Images

Groundwater Is Especially Hard to Clean Up

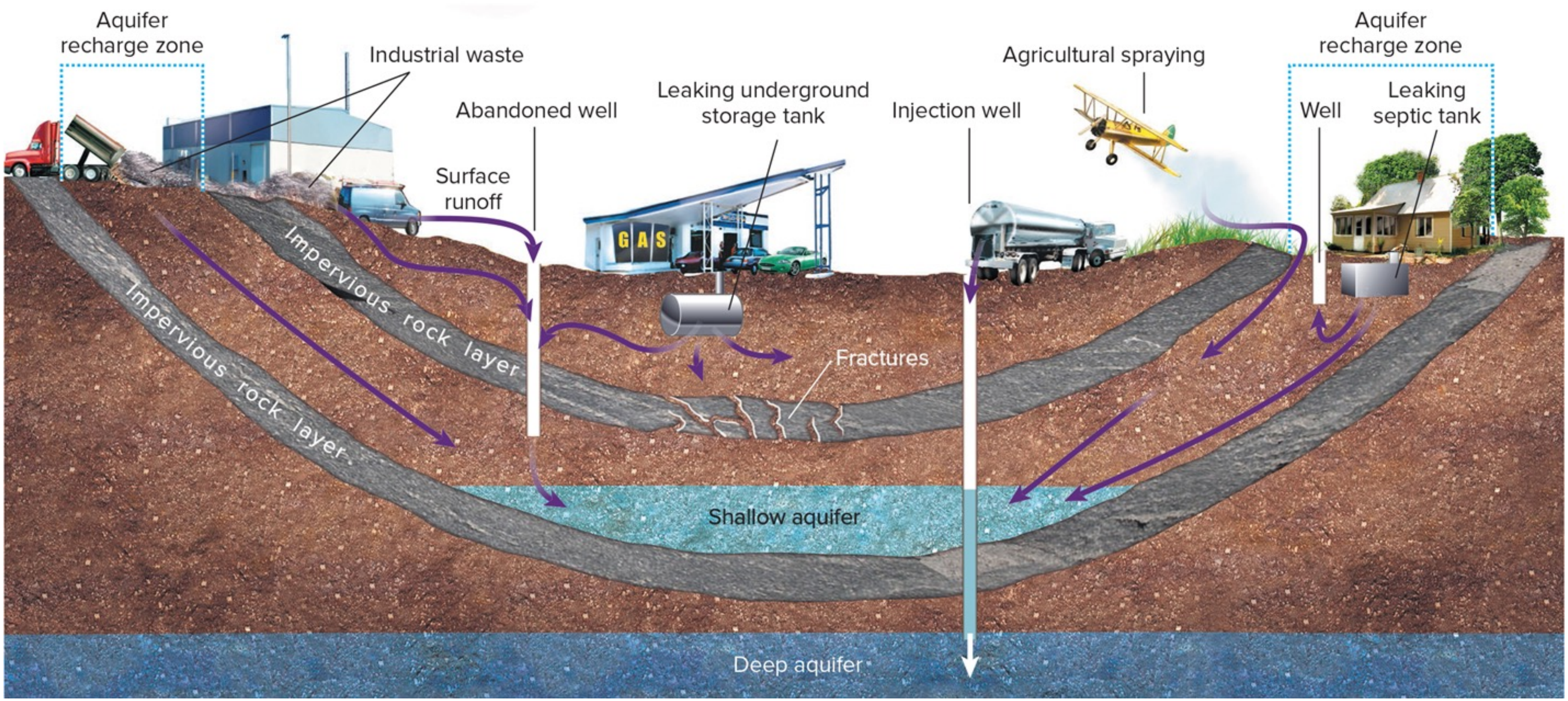
About ½ of the people in the United States, including 95% of those in rural areas, depend on underground aquifers for their drinking water.

This vital resource is threatened in many areas by overuse and pollution and by a wide variety of industrial, agricultural, and domestic contaminants.

The EPA estimates that 1.2 trillion gallons of contaminated water seep into the ground in the U.S.

When deep underground aquifers are contaminated, it is possible, but expensive, to pump water out of aquifers, clean it, and then pump it back.

Sources of Groundwater Pollution



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Ocean Pollution Has Few Controls

Coastal bays, estuaries, shoals, and reefs are often overwhelmed by pollution.

Dead zones and poisonous algal blooms are increasingly widespread. Toxic chemicals, heavy metals, oil, sediment, affect some of the most attractive and productive ocean regions.

Discarded plastic flotsam and jetsam are becoming a ubiquitous mark of human impact on the oceans.

6 million metric tons of plastic are tossed from ships every year into the ocean, where they ensnare and choke seabirds, mammals, and even fish.

Plastics Can Be Deadly to Marine Life

Source: Pally/Alamy Stock Photo;

11.6 Water Treatment and Remediation

The cheapest and most effective way to reduce pollution is to avoid producing it or releasing it in the first place.

Eliminating lead from gasoline has resulted in a widespread and significant decrease in the amount of lead in U.S. surface waters.

Industry can reduce pollution by recycling or reclaiming materials that otherwise might be discarded in the waste stream. Using this approach, companies can extract valuable metals and chemicals and sell them, instead of releasing them as toxic contaminants into the water system.

Nonpoint Sources Are Often Harder to Control Than Point Sources

Farmers have long contributed a huge share of water pollution, including sediment, fertilizers, and pesticides that flow from fields.

In urban areas, reducing waste that enters storm sewers is essential.

The tremendous challenge of managing these sources is seen in Chesapeake Bay.

Nutrient pollution had degraded the bay but implementation of pollution prevention measures and planting of sea grasses and wetlands has helped.

How Do We Treat Municipal Waste?

Under natural conditions, water purification occurs constantly in soils and water. The high population densities of cities, however, produce much more waste than natural systems can process.

Most developed countries require that cities and towns build municipal water treatment systems to purify the human and household waste.

Most rural households use septic systems, which allow solids to settle in a tank, where bacteria decompose them.

Municipal Treatment Has Three Levels of Quality

Sanitary engineers have developed ingenious and effective municipal wastewater treatment systems:

- **Primary Treatment** physically separates large solids from the waste stream with screens and settling tanks.
- **Secondary Treatment** uses aerobic bacteria to break down dissolved organic compounds.
- **Tertiary Treatment** removes dissolved metals and nutrients, especially nitrates and phosphates.

Municipal Wastewater Treatment

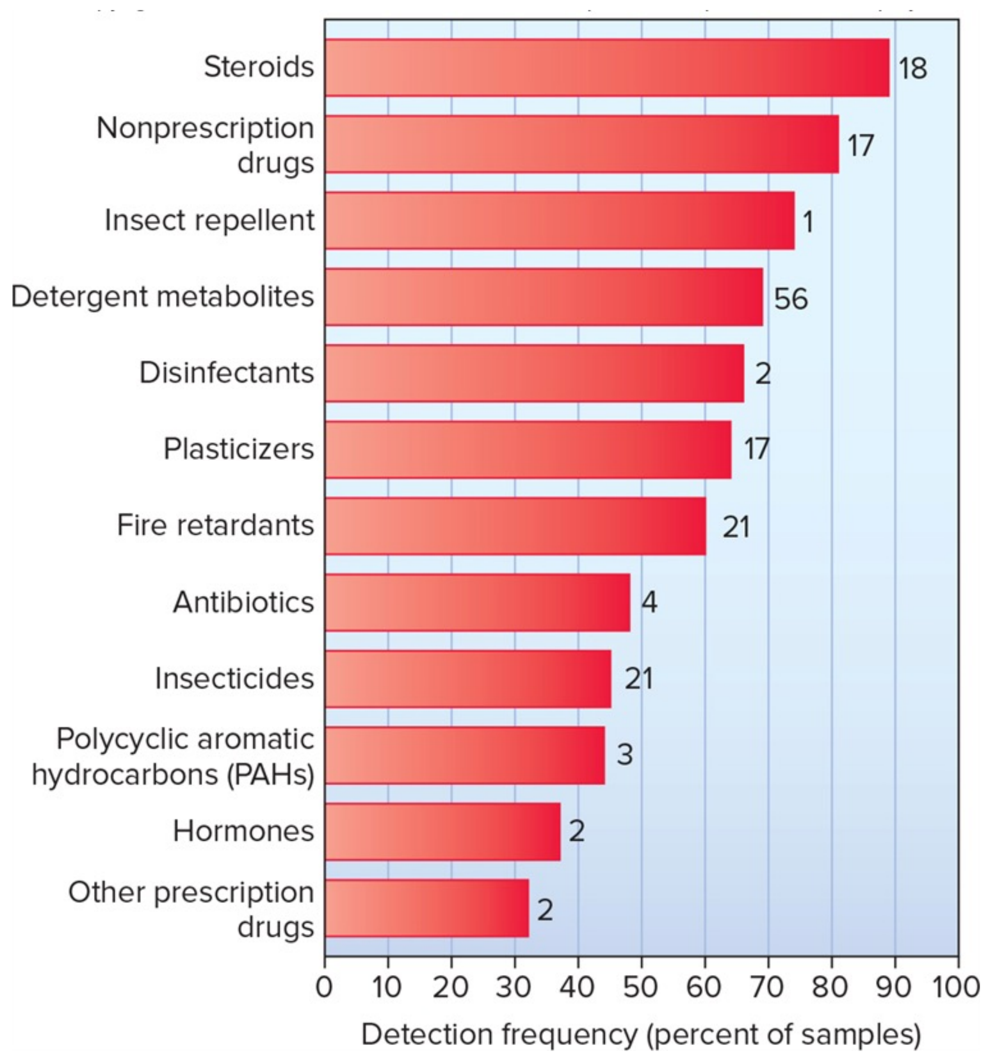
Steve Allen/Brand X Pictures/Alamy Stock Photo

Conventional Treatment Misses New Pollutants

In 2002, the USGS released the first-ever study of pharmaceuticals and hormones in streams. Scientists sampled 130 streams, looking for 95 contaminants, including antibiotics, natural and synthetic hormones, detergents, plasticizers, insecticides, and fire retardants. All these substance were found in low concentrations.

What are the effects of these widely used chemicals on our environment or on people consuming the water? Nobody knows.

Unusual Pollutants Are Now Being Detected in Surface Waters



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Alternative Waste Treatment Systems Exist

Cedar Grove Cheese Factory has built a "**Living Machine",** a sequence of tanks, bacteria, algae, and small artificial wetlands.

This system converts factory effluent to nearly pure water and wetland flowers.

Cedar Grove Cheese Inc.

Remediation Can Involve Containment, Extraction, or Biological Treatment

Often, living organisms can clean contaminated water effectively and inexpensively. We call this **bioremediation.**

Restored wetlands, for instance, along stream banks or lake margins can effectively filter out sediment and remove pollutants.

Some plants are very efficient at taking up heavy metals and organic contaminants. Bioremediation offers exciting and inexpensive alternatives to conventional clean-up.

11.7 Legal Protections for Water 1

Water pollution control has been among the most broadly popular and effective of all environmental legislation in the United States.

- It has not been without controversy, however.

Some of the most important water legislation in the United States are described in Table 11.4.

11.7 Legal Protections for Water 2

TABLE 11.4 Some Important Water Quality Legislation

Federal Water Pollution Control Act (1972). Establishes uniform nationwide controls for each category of major polluting industries.

Marine Protection Research and Sanctuaries Act (1972). Regulates ocean dumping and established sanctuaries for protection of endangered marine species.

Ports and Waterways Safety Act (1972). Regulates oil transport and the operation of oil-handling facilities.

Safe Drinking Water Act (1974). Requires minimum safety standards for every community water supply. Among the contaminants regulated are bacteria, nitrates, arsenic, barium, cadmium, chromium, fluoride, lead, mercury, silver, and pesticides; radioactivity and turbidity also are regulated. This act also contains provisions to protect groundwater aquifers.

Resource Conservation and Recovery Act (RCRA) (1976). Regulates the storage, shipping, processing, and disposal of hazardous wastes and sets limits on the sewering of toxic chemicals.

Toxic Substances Control Act (TOSCA) (1976). Categorizes toxic and hazardous substances, establishes a research program, and regulates the use and disposal of poisonous chemicals.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (1980) and *Superfund Amendments and Reauthorization Act (SARA) (1984).* Provide for sealing, excavation, or remediation of toxic and hazardous waste dumps.

Clean Water Act (1985) (amending the 1972 Water Pollution Control Act). Sets as a national goal the attainment of "fishable and swimmable" quality for all surface waters in the United States.

London Dumping Convention (1972). Calls for an end to all ocean dumping of industrial wastes, tank-washing effluents, and plastic trash. The United States is a signatory to this international convention.

The 1972 Clean Water Act Protects Our Water

The 1972 Clean Water Act established a National Pollution Discharge Elimination System (NPDES), which requires an easily revoked permit for any industry, municipality, or other entity dumping wastes in surface waters.

The permit requires disclosure of what is being dumped and gives regulators valuable data and evidence for litigation.

The Clean Water Act Was Ambitious, Popular, and Largely Successful

Passage of the U.S. Clean Water Act of 1972 was a bold, bipartisan step that made clean water a national priority.

Along with the Endangered Species Act and the Clean Air Act, this is one of the most significant and effective pieces of environmental legislation ever passed by the U.S. Congress.

The ambitious goal of the Clean Water Act was to return all U.S. surface waters to “fishable and swimmable” conditions.

Areas of Progress

As a consequence, only about 10% of our water pollution now comes from industrial and municipal point sources.

One of the biggest improvements has been in sewage treatment. Nearly everyone in urban areas is now served by municipal sewage systems, and no major city discharges raw sewage into a river or lake except as overflow during heavy rainstorms.

Impaired Rivers in the U.S.

©William P. Cunningham

Take-Away Points

Water is a precious resource. As human populations grow, water is likely to become even more scarce in the future.

Conflicts over water rights are becoming more common between countries that share water.

U.S. Federal, state, and local pollution controls have greatly improved our water quality in most places.

In rapidly developing countries, such as China and India, water pollution remains a serious threat.

Constructed wetlands for ecological sewage treatment provide low-tech, inexpensive ways to reduce pollution.

Because learning changes everything.®

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