Chapter 8:
Water Challenges and Solutions

Water in Copenhagen, Denmark being used for recreation and transportation. Photo by A.R. VandeVoort (2013).

Learning Objectives

By the end of this chapter, students will be able to:

1. Differentiate between physical water scarcity and economic water scarcity and give examples of both.
2. Describe various sources of water pollution (point-source and nonpoint-source) and forms of water pollution (chemical, physical, biological), and be able to sort water pollution examples into these categories
3. Give examples of groundwater pollution and some unique challenges associated with identifying and remediating it
4. Describe solutions to water-related problems, including watershed management
5. Demonstrate knowledge of some of the major regulations related to water in the USA, including the Clean Water Act and the Safe Drinking Water Act
6. Describe components of water quality and tools that researchers use to assess it

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8.1 Introduction

As described in Chapter 7, water is an essential commodity for human life and survival. We need to consume it to stay alive and use it to clean our food, utensils, clothes, bodies, and surroundings to prevent disease. Unfortunately, this same water is responsible for about 80% of all diseases in developing countries (Annan, 2003) and over three million deaths a year globally. Here in the United States, **waterborne diseases** sicken over 7 million people each year (US CDC, 2025). It is therefore very important that we understand why water is vital and at the same time can cause so much harm. This chapter is devoted to the availability and quality of water. **Water quality** will be defined as the physical, chemical and biological properties of water that impact its intended use. This definition recognizes that quality designations of any given water body can vary depending on what purpose it is serving. A single water body may have different quality designations depending on the intended uses. For instance, water considered good quality for fishing is not necessarily good for swimming or drinking. It is for this reason that different regulations and standards have been created for the different water uses. These standards are created to ensure that there is no water shortage due to mismanagement, overuse, and contamination.

8.2 Access to Water Resources

Access to safe water has been identified as one of the major environmental crises facing the world today. More than one billion people in the world lack access to clean drinking water. The demand for water has grown at a very fast pace in response to the rate of global population growth. **Figures 8.1** illustrates this change in water use over time in across the world. In the year 1900, when our global population was approximately 1.6 billion people, the global freshwater withdrawals were approximately 671 billion m^3. Compare this to the year 2014, when our global population had grown to approximately 7.2 billion people and our global freshwater withdrawals were close to 4 trillion m^3. Based on this information, our water demand per person has also increased during this time period, from 419 m^3 per person annually in the year 1900 to 556 m^3 per person annually in the year 2014. For reference, there are about 264 US gallons in each cubic meter.

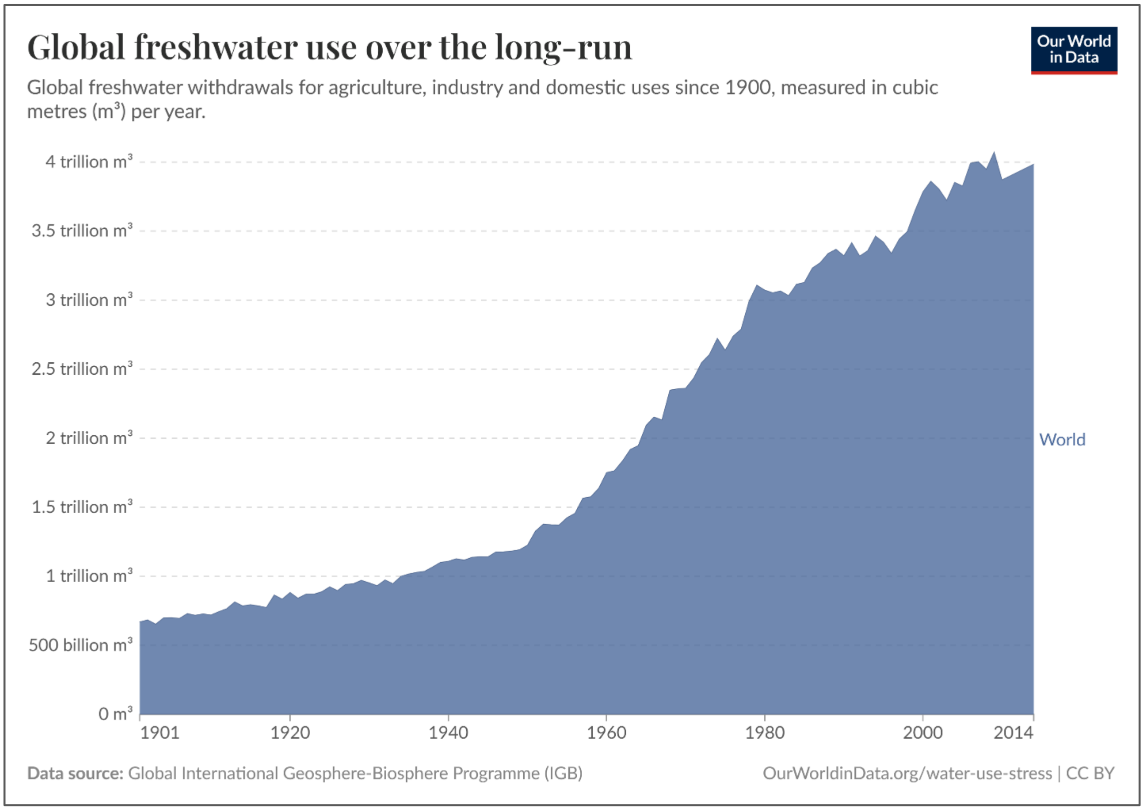

Figure 8.1: Freshwater withdrawals worldwide. 4 trillion m^3 = 10.56 trillion gallons. Source: Our World in Data

Both **groundwater** and **surface water** withdrawals had increased over time until 1980 when the withdrawals peaked and stabilized. Water withdrawals in the US show a major divide between the western and eastern parts of the country. The western part withdraws most of the water for agriculture, as these are the farm areas while eastern half withdraws most of its water for **thermoelectric cooling** and industry (**Figure 8.2**). Thermoelectric cooling, where water is used to regulate the heat produced in steam turbine powerplants, is defined as a **non-consumptive** use of water because very little water is lost in the process and it is returned almost immediately to its source reservoir. In contrast, consumptive uses of water (such as **irrigation**, public supply, and most industrial uses) remove water from its source and make it unavailable for immediate reuse. Consumptive uses of water impact physical water supplies more significantly than non-consumptive uses.

The states of California and Texas combine to account for over 20% of all water withdrawn. In fact, California consumes more water than is available within the state and is therefore forced to get water from the other states. Despite this deficiency almost everyone in California has access to clean and safe drinking water. Contrast this to Lusaka, the capital city of Zambia, which has more water available than is withdrawn but more than a third of its population has no access to safe drinking water.

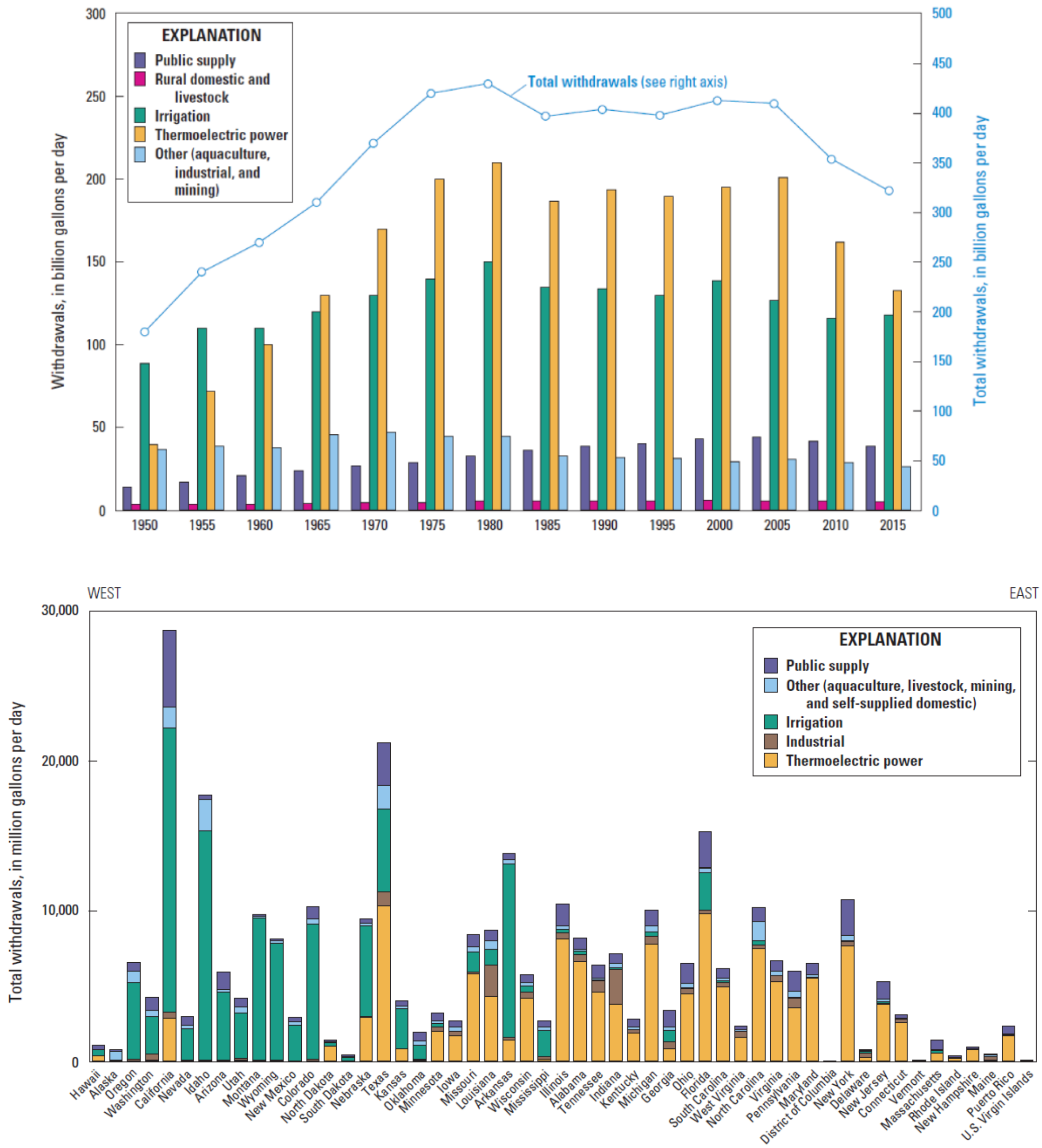

Figure 8.2. Water withdrawals in the United States by sector. Upper figure: all United States withdrawals from 1950-2015. Lower figure: 2015 withdrawals in 2015 by state, arranged from west to east. 300 billion gallons = 1.14 billion m^3. **Source**: USGS.

Test your knowledge…

Water usage

1. *Give examples of consumptive and non-consumptive uses of water. Which water use do you think is most impactful on our freshwater reservoirs worldwide and why?*
2. *How have water withdrawals changed over time globally and within the United States? What are some reasons for this?*
3. *In Figure 8.2, compare water withdrawals in the state of Georgia with those in the state of California. What might account for the substantial differences between these two states?*

8.2.1 Water Scarcity

There is enough fresh water on Earth to supply every human being with enough drinking water. The main problem we face with regards to water is that it is unevenly distributed, polluted, mismanaged, and/or wasted. Tony Allan, the author of "*Virtual Water*", asserts that water follows money. This refers to the fact that rich countries and societies with more money and affluence have more access to safe drinking water even when they live in regions without much water. It also means that areas with large supplies of water can still have water scarcity if they lack the financial resources and infrastructure to supply people with clean and safe drinking water. Water scarcity is caused by the demand for water or a certain quality being greater than the supply. Scarcity can be defined as either **physical water scarcity** or **economic water scarcity**.

Physical water scarcity is a situation where there is an actual shortage of water, regardless of quality or infrastructure. It is estimated that about 1.2 billion people around the world are experiencing physical water scarcity (Molden et al. 2007). Physical water scarcity is most common in arid environments or in places of significant water overuse. In these regions, water demand and/or usage exceeds opportunities for water resources to replenish naturally through the water cycle such as precipitation and groundwater recharge. These conditions are notable in regions such as North Africa and West and Central Asia.

Economic water scarcity is a condition where countries lack the financial resources and/or infrastructure to supply their citizens with reliable safe drinking water. The fraction of people across the globe impacted by economic water scarcity continues to increase. By 2030, about 1.6 billion people will experience economic water scarcity, most of them living in less industrialized countries (United Nations, 2022). For many places in the world, scarcity is a transient condition that can be reduced or eliminated by installing the right infrastructure.

The major problem in less industrialized countries is the lack of political, financial, and physical structures to provide water to everyone. Commonly, a few rich people in these countries will have access to clean water, while the majority of people cannot afford to pay for it and are left out. Examples of such communities include many villages in Africa, Asia, and South America. **Figure 8.3** shows communities in southeast Kenya facing severe water shortages primarily due to lack of infrastructure coupled with physical scarcity. People in these communities, often women and children, must walk long distances to get untreated and contaminated water for drinking and other household needs (Mutiti et al. 2010).

Figure 8.3: Communities in southeast Kenya without easy access to safe drinking water. (top left) Groundwater in the area is too salty for consumption. (top right) Maasai women in Amboseli National Park collecting water from a wetland. (bottom left) Women in Magwede village in SE Kenya walking long distances to get water from a Kiosk. (bottom right) Children collecting water in Bungule Village from a water kiosk that is only open for about an hour every day. *Photo credit: Jonathan Levy, Sam Mutiti and Christine Mutiti*

8.3 Water Pollution

8.3.1 Pollution Sources

Water pollution is a major problem facing many of our surface and ground water sources. Contamination can occur naturally due to geologic or meteorological events, as well as through **anthropogenic** (human-created) causes. Anthropogenic sources of contamination are commonly called pollution events and can be categorized as either point-source or nonpoint-source. **Point-source pollution** is water pollution coming from a single, identifiable location. This is sometimes referred to as "end-of-pipe" pollution, because the most common way for point-source pollution to enter a surface water body is as **effluent** from a factory or sewage treatment plant that exits the facility through a pipe, as shown in **Figure 8.4**.

Nonpoint-source pollution comes from a wide area such as agricultural or urban lands, not from one specific location. This pollution is typically carried by **surface runoff** through the **watershed** and into the receiving surface water body. Review **Chapter 7** of this text for more information about watersheds and the water cycle. Nonpoint-source pollution contamination occurs when rainwater, snowmelt, or irrigation washes off agricultural fields, city streets, or suburban backyards and carries pollutants into local water sources. As this runoff moves across the land surface, it picks up soil particles and pollutants, such as nutrients, metals, pathogens, and pesticides. Additional sources of nonpoint-source pollution include faulty or poorly maintained septic systems and atmospheric deposition. Since the passage of the Clean Water Act in 1972 (see **Section 8.5.1**), nonpoint-source pollution is the most common form of surface water pollution in the United States.

Figure 8.4. **Left**: Discharge pipe on Monterey Bay Beach, Orange County, California showing an example of point-source water pollution. Image by Dick Rowan (1970), US Environmental Protection Agency. **Right**: Surface runoff into Bateswood Lake, England. Runoff commonly carries nonpoint-source water pollution with it, including fertilizers, pesticides, and/or sediments. Image credit Jonathan Hutchins (2013).

Test your knowledge…

Point-source and nonpoint-source pollution

Sort the following examples in either the point-source or nonpoint-source category and provide your reasoning for each:

1. *The BP Gulf oil spill of 2010*
2. *Sediment pollution in nearby lakes following a rainstorm*
3. *The Kingston TVA Coal Ash Spill of 2008*
4. *Improperly-treated wastewater treatment plant effluent*
5. *Pesticide runoff from a local golf course*

8.3.2 Forms of Water Pollution

Water pollution from both point-sources and nonpoint-sources comes in a variety of forms: chemical, biological, and physical pollution. **Chemical pollution** adds chemicals to or changes the chemistry of the receiving water body. Examples include toxic metals, organic compounds, acidic waters from mining activities and industry, pharmaceuticals, nutrients from fertilizers, and many other chemical compounds from industries and wastewater treatment plants. Another form of chemical pollution is radioactive waste which has significant potential to cause harm to living things. Much of the radioactive pollution comes from the processing of radioactive phosphate fertilizer (US EPA, 2025).

Physical pollution includes sediment pollution, trash thrown in the water bodies, and other additions of suspended particles to water bodies. Additionally, **thermal pollution** is a form of physical pollution that occurs when the temperature of the water is artificially changed. High temperatures typically increase chemical and biological reactions, including the metabolism of aquatic. This process can exacerbate eutrophic conditions described in Section 8.3.2.1.

Biological pollution refers to the addition of pathogenic microorganisms, including bacteria, viruses, and parasitic protozoa to water bodies. These are often introduced to natural water bodies from untreated sewage or surface runoff from intensive livestock agriculture. Biological pollution is a common cause of illness and death in less industrialized countries where population density, water scarcity and inadequate sewage treatment combine to cause widespread waterborne diseases.

8.3.2.1 Chemical Pollution

Most of the common **inorganic** chemical water pollutants come from nonpoint-sources, mainly intensive agriculture, and activities from urban areas. Of particular concern is **nutrient pollution** resulting from the overuse of chemical fertilizers in agriculture and lawn maintenance. Specifically, fertilizer chemicals such as ammonium nitrate (NH_4NO_3) and diammonium phosphate ($(NH_4)_2HPO_4$) contain water-soluble nitrogen (N) and phosphorus (P). These elements (N and P) are the most common **limiting nutrients** to the growth of land plants, aquatic plants, and algae. Therefore, while adding more N and P in the form of fertilizers to a farm or lawn encourages desired plants to grow, runoff of N and P to surface water bodies can cause harmful algal blooms. High concentrations of N and P in water causes the condition known as **eutrophication**. While fertilizer-based agricultural runoff is the most common cause of eutrophic conditions, N and P can also come from runoff from lawns, runoff from livestock areas, or from point-sources such as untreated or poorly-treated wastewater.

Increased supply of limiting nutrients into an aquatic system leads to alterations of the local ecosystem, starting with the photosynthetic organisms. A locally-abundant growth of algae is called an **algal bloom**. Algal blooms can be natural events and nearly all algae are capable of experiencing blooms. However, eutrophic conditions resulting from nutrient pollution makes these events much more frequent. You may observe algal blooms in your local environment, characterized by a greenish tint to the water in your local streams and rivers during low-flow times (**Figure 8.5**). Another common observation, particularly in late summer, are green farm ponds.

Figure 8.5: Images from Lake Sinclair, Georgia, United States. **Left image**: recreational area with expected accumulation of algae under normal conditions; **Right image**: an algal bloom resulting in water clarity loss as measured with a **Secchi disk**. Photos credit Kalina Manoylov.

Cyanobacteria (blue-green algae) are not always harmful, but some species can produce toxins under certain environmental conditions. These events are becoming more frequent in coastal areas of the United States. Harmful algal blooms are encouraged by prolonged sunlight in summer, high surface water temperatures, and when water stays stagnant in the presence of fertilizer runoff from the surrounding areas. When a bloom occurs, it can be difficult to identify whether it is toxic. Toxic algal blooms commonly cause fish kills (**Figure 8.6**). Additionally, toxic algal blooms can be dangerous to humans and other animals, including pets and livestock.

Figure 8.6: Eutrophic conditions. **Left image**: Visible algal bloom in Minnewashta Lake, Iowa, United States, photo credit: Kalina Manoylov; **Right image**: Fish kill resulting from algal bloom, photo credit Jennifer L. Graham at USGS.

Following any algal bloom, whether toxic substances were produced or not, the algae eventually use up the available N and P in the system and subsequently die. Once the algae die, they are decomposed by **aerobic** bacteria in the water. These bacteria consume the **dissolved oxygen** (DO) in the water as part of their metabolism. Dissolved oxygen is an essential component of water quality for natural surface water ecosystems. Most fish require at least 5-6 mg/L (equivalent to 5-6 **parts per million** [ppm]) DO for their livelihood. Low DO levels can result in **fish kills** where large numbers of fish, and other aquatic life, die because of suffocation (**Figure 8.6** and **Figure 8.7**).

The Gulf of Mexico experiences a phenomenon called a "dead zone" annually as the result of eutrophication from nutrient pollution. Each year, a huge area of extremely low DO (less than 2 ppm, defined as **anoxic**) occurs in this water body, and it has a large negative impact on the fishing industry along the Gulf Coast near the mouth of the Mississippi River **(Figure 8.7).** The Mississippi River is the largest river and largest watershed in North America. It drains the majority of the farmland in the Midwest and Great Plains regions of the United States, which amount to approximately 3.7 million acres (1.5 million hectares) of farmland (NASA, 2016). This includes some of the most agriculturally-productive land on Earth, much of which is managed under intensive, industrial agriculture. This agricultural system requires significant use of fertilizers, pesticides and irrigation. The dead zone occurs annually when fertilizers, from this agriculture, run off into Mississippi River and eventually deposit into the Gulf of Mexico (**Figure 8.8**).

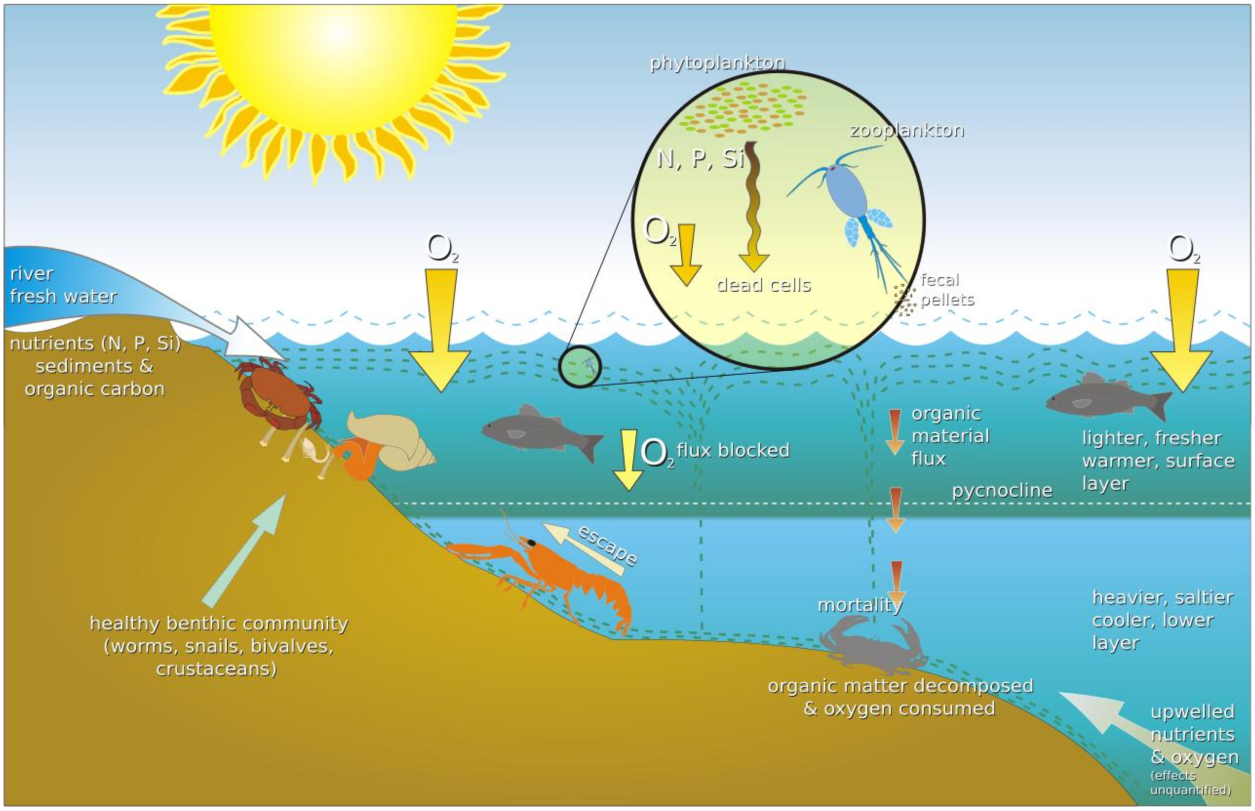

Figure 8.7: Eutrophication process leading to algal (**phytoplankton**) blooms in ocean environments as the result of nutrient pollution (especially N and P) from runoff carried by river water. This also causes eventual algal death and decay, which results in a decrease in dissolved oxygen (O_2) in the surface ocean environment. Image credit: Hans Hillewaert (2007), US EPA.

Test your knowledge…

Put the following actions in the ***correct order*** *as they would appear in a eutrophication event resulting in a fish kill:*

a) Fish kill
b) Algae death and decomposition
c) Fertilizer runoff to a surface water body
d) Algal bloom
e) Dissolved oxygen depletion

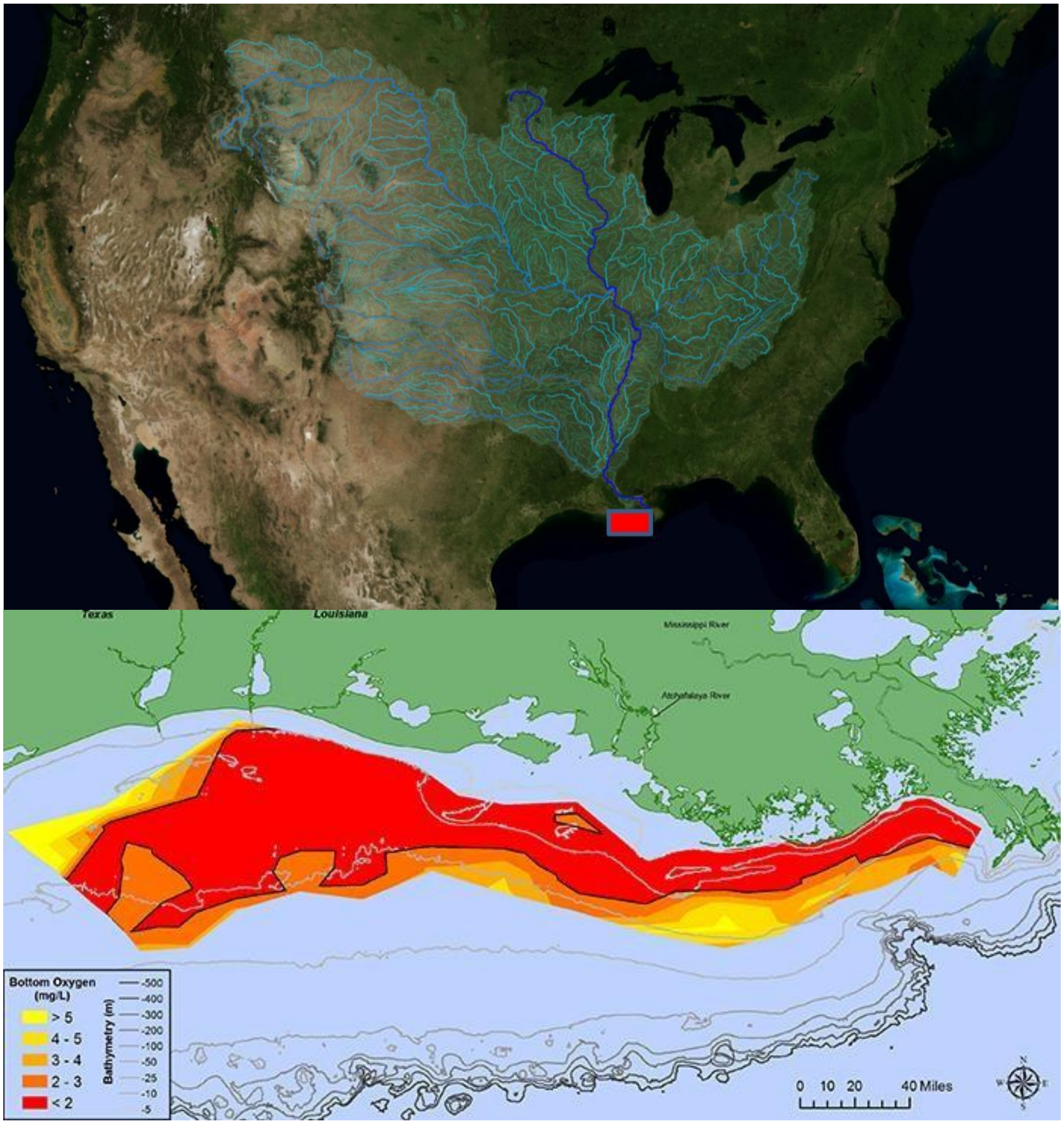

Figure 8.8: The dead zone in the Gulf of Mexico 2017, **Top photo**: Showing the watershed of the Mississippi river (Image source: NASA). **Bottom image**: oxygen levels in the Gulf of Mexico. (Image Source: NOAA)

Besides nutrient pollution, additional inorganic chemicals also impact water quality. Some contaminants, such as **chlorine** and related derivatives, are produced from point-sources, ironically employed in water treatment facilities. Chlorine is frequently use as a final disinfectant to treated wastewater before it is released to surface water bodies. This decreases the potential for biological pollution resulting from wastewater effluent, however, it also affects aquatic ecosystems. Moreover, some of the large dischargers of toxic metals to aquatic environments are fixed-point industrial plants or powerplants. Metals of particular concern include: lead (Pb), mercury (Hg), arsenic

(As), and hexavalent chromium (Cr^{6+}). **Table 8.1** shows a summary of some common chemical pollutants and their sources.

Table 8.1: Forms of chemical pollution and their common sources, both anthropogenic and natural

Chemical water pollutant	Common sources
Heavy metals: lead (Pb), chromium (Cr), zinc (Zn), arsenic (As), cadmium (Cd), mercury (Hg), selenium (Se), etc.	*Anthropogenic*: mining, industry, coal-fired powerplants *Natural*: rock weathering
Nutrients: ammonium (NH_4^+), nitrate (NO_3^-), phosphate ($H_2PO_4^-$)	*Anthropogenic*: agriculture (fertilizers, compost, livestock yards), lawn/turf maintenance, wastewater treatment *Natural*: decomposition of organic matter
Other inorganic chemicals: carbonate (CO_3^{2-}), fluoride (F^-), sulfate (SO_4^{2-}), sodium (Na^+), calcium (Ca^{2+}), chlorine (Cl)	*Anthropogenic*: fertilizers, wastewater treatment, drinking water treatment, mining, industry *Natural*: decomposition of organic matter, rock weathering, atmospheric dissolution
Pharmaceuticals: most commonly carbamazepine (antidepressant), and pain relievers (diclofenac, ibuprofen, and acetaminophen); also antibiotics, caffeine, and blood pressure medication	*Anthropogenic*: improper disposal, pharmaceutical manufacturing, wastewater treatment, hospital waste *No natural sources*
Pesticides: including glyphosate, atrazine, chlordane, DDT, etc.	*Anthropogenic*: agriculture, lawn/turf maintenance, pest control *No natural sources*
Petroleum-derivatives: octane, nonane, various hydrocarbons	*Anthropogenic*: urban runoff (gas stations, maintenance shops, car lots, etc.), powerplants, industry, mining, hydraulic fracturing *No natural sources*
Other organic compounds: benzene, xylene, phenols, trichloroethylene, dioxin, etc.	*Anthropogenic*: industry, powerplants, electrical transformers, gas stations *Natural*: volcanoes, forest fires
Radioactive isotopes	*Anthropogenic*: uranium mining, nuclear waste, medical waste, phosphate fertilizer processing *Natural*: radioactive rock weathering

Organic chemicals can also pollute our surface water bodies. Petroleum-based chemicals are a major component here (**Figure 8.9**). Improper storage and use of automotive fluids produce common organic chemicals causing water pollution. These chemicals include methanol and ethanol (present in wiper fluid) and gasoline and oil compounds such as octane, nonane (overfilling of gasoline tanks). Most of these chemicals enter surface water from urban runoff, and are considered nonpoint sources since their pathway to water sources is mainly overland flow. However, point source pollution of petroleum-based organic chemicals can also occur from leaking underground and above-ground storage tanks. Additionally, these storage tanks can also leach toxic organic compounds such as perchloroethylene. Grease and fats from lubrication and restaurant effluent can be either point or nonpoint-sources depending upon whether the restaurant releases grease into the wastewater collection system (point-source) or disposes of such organics on the exterior ground surface or transports to large landfills.

Agricultural runoff also provides us with nonpoint-source organic pollutants in the form of **pesticides**. Some harmful organic pesticides have been banned in the United States due to their impacts on human and environmental health. These include numerous organochlorides such as dichlorodiphenyltrichloroethane (DDT), dieldrin, aldrin, toxaphene, heptachlor, and chlordane. The influential 1962 book *Silent Spring* by Rachel Carson is credited with raising public awareness about the impacts of these chemicals. However, many organic pesticides that impact human and/or environmental health are still widely used, including glyphosate, atrazine, neonicotinoids, and pyrethroids. These enter our surface water bodies through agricultural runoff.

Figure 8.9 Petroleum-based urban runoff in Mercer County, New Jersey, United States. Source: Famartin (2024).

8.3.2.2 Physical Surface Water Pollution

The most significant **physical pollutant** is excess sediment in runoff from agricultural plots, clear-cut forests, improperly graded slopes, urban streets, and other poorly managed lands (especially when steep slopes or lands near streams are involved). In most non-arid temperate and tropical ecosystems, bare soil is rare in nature. Exposed areas of soil are naturally overtaken by vegetation through the process of **ecological succession**. When soil is poorly managed in these areas, either through over-farming, over-grazing, clear-cutting, or other forms of land clearing, it becomes highly susceptible to erosion. **Erosion** occurs when soil particles leave the terrestrial environments from which they originated and enter another ecosystem, often a surface water body. Erosion harms both the terrestrial ecosystem, which now has fewer soil resources, and the surface water body, which now has sediment pollution. These soil particles can also carry with them other forms of pollution, including chemical pollutants (nutrients, organic compounds, etc.) and biological pollutants (e.g., pathogens).

Other physical pollutants include a variety of plastic refuse products such as packaging materials; the most pernicious of these items are ring shaped objects that can trap or strangle fish and other aquatic fauna in our rivers, lakes and oceans. Oceans house many forms of living things that are uniquely adapted to survive in these habitats. Unfortunately, humans have degraded oceans through pollution, overfishing, carbon dioxide acidification (see **Chapter 6**) and resource exploitation. Other common physical objects are timber slash debris, wastepaper, and cardboard. **Figure 8.10** shows a couple of examples of human impacts on the ocean environment.

Figure 8.10: Left image: Trash washed up on the beach; **right image**: a seal is tangled up and being strangled by plastic trash in the ocean until a diver intervenes. Photo Credit: NOAA Libraries

Finally, powerplants and other industrial facilities that use natural water bodies for cooling (including thermoelectric cooling) can cause thermal pollution (**Figure 8.11**) in surface water by increasing its temperature. Thermal pollution can change the ecology of the water bodies and harm living things. The warm water discharged is usually only used for cooling in the plant and does not contain other contaminants.

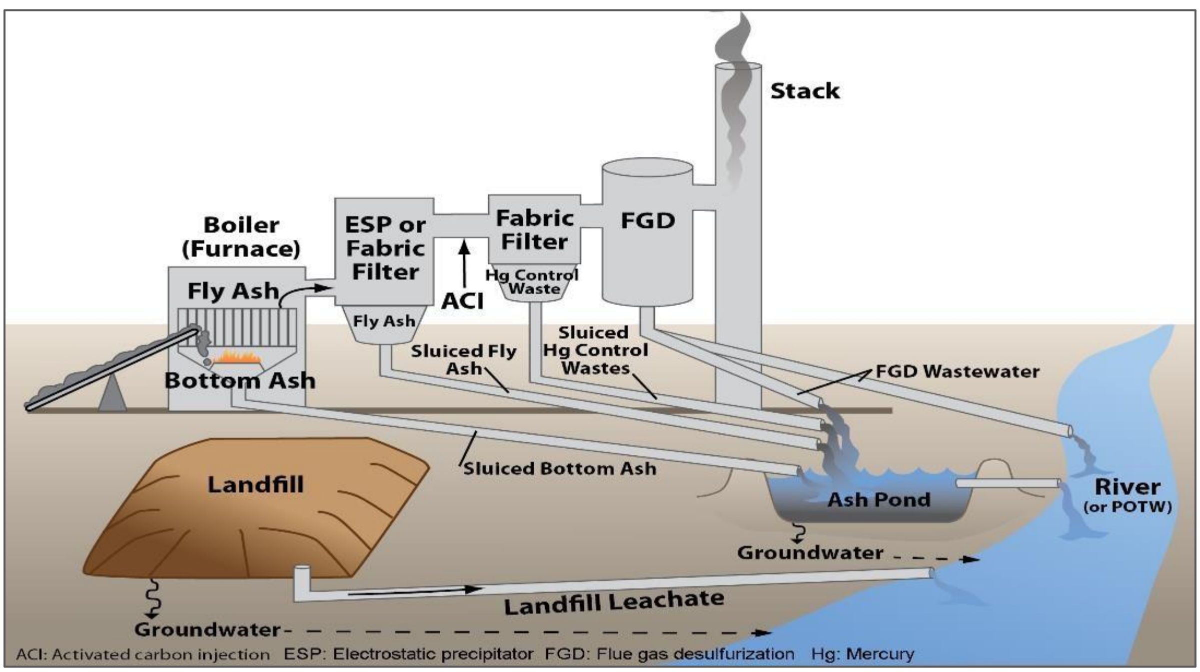

Figure 8.11: Schematic of the plant causing thermal pollution (Credit: USEPA)

8.3.2.3 Biological Pollution

Common biological pollutants include pathogenic microorganisms such bacteria, viruses, protozoa, and helminths. The most frequently encountered bacteria are

Escherichia coli (*E. coli*), *Shigella*, *Vibrio cholerae*, *Campylobacter,* and species of the genus *Salmonella* (which variously cause typhoid fever and food-borne illnesses). Common viral pollutants include the Norwalk virus, Enteroviruses, Adenoviruses and Hepatitis A and E, while protozoans are dominated by *Giardia*, and species in the genus *Cryptosporidium*. All these are fecal-oral route parasites often transmitted as water pollutants and are associated with inadequate sanitation. They originate from various sources that include sewage treatment facilities, animal fecal waste, leaky septic tanks, and recreational areas such as swimming pools. In addition, we also have parasitic worms (helminths) and amoeba (protist *Entamoeba histolytica*) that live inside animal digestive systems for part of their life cycle that are partially spread as water pollutants, with an estimated three billion people currently affected globally. These parasites are transmitted into the water by direct contact of human fecal matter.

While both human waste and animal waste are common sources of biological pollution resulting in waterborne diseases, human waste is the most significant and dangerous source of biological pollution to drinking water.

Test your knowledge…

Consider the following pollution events, and describe whether they caused chemical, physical, and/or biological pollution. Note: some events cause more than one type!

1. *A sewer pipe ruptures causing human waste to enter a creek*
2. *Runoff enters a river from a concentrated animal feedlot operation (CAFO) that contains animal waste (including pathogens and nutrients), pharmaceuticals, and sediment*
3. *The Exxon Valdez oil tanker spill of 1989 released 11 million gallons of crude oil into Prince William Sound, Alaska*

8.3.3 Groundwater Pollution

Surface water is not the only water source that can get contaminated by the pollutants previously discussed in this chapter. Groundwater can also become contaminated from both natural and anthropogenic sources of pollution. Naturally occurring contaminants are present in the rocks and sediments. As groundwater flows through sediments, metals such as iron and manganese may dissolve and later be found in high concentrations in the water. Industrial discharges, urban activities, agriculture, groundwater withdrawal, and disposal of waste all can affect groundwater quality. Contaminants from leaking fuel tanks (**Figure 8.12**) or fuel or toxic chemical spills may enter the groundwater and contaminate the aquifer. Pesticides and fertilizers applied to lawns and crops can accumulate and migrate to the **water table**.

Human waste is commonly stored underground in **septic tanks**, especially in remote areas without access to municipal sewer lines. According to the US Environmental Protection Agency, over 60 million Americans use septic systems for their wastewater disposal. While properly-maintained septic systems are safe for humans and the environment, old or poorly-maintained systems have the potential to leak. Leakage from septic tanks and other waste-disposal sites also can contaminate ground water as well**.** A septic tank can introduce pathogens and other forms of biological pollution to the water. Many citizens who use septic systems for their wastewater disposal also use private well water (sourced from groundwater) for their household supply. This water is not subject to the protections of the Safe Drinking Water Act, discussed later in this chapter.

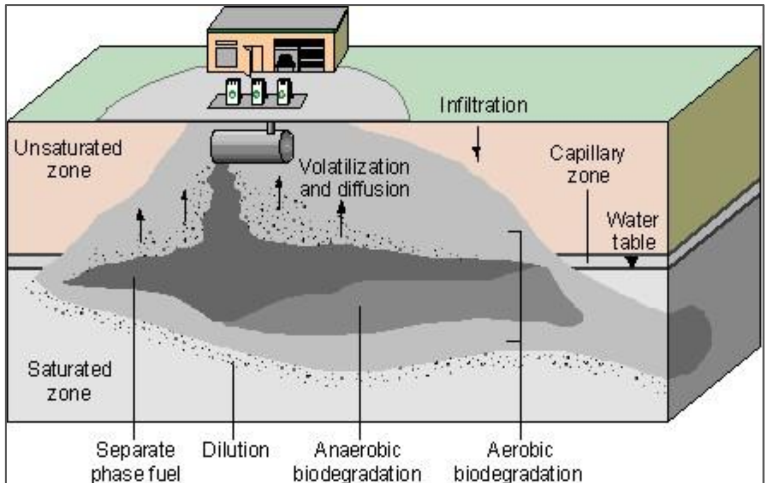

Figure 8.12: Contaminated groundwater from a leaky fuel storage tank (Image Credit: USGS)

8.4 Water Management

Pollution control begins with testing and monitoring of water quality. Water quality is usually monitored using easy to measure indicators such as pH, specific conductance (commonly referred to as conductivity), temperature, fecal and total coliform bacteria, dissolved oxygen, macroinvertebrates, and algae. Polluted sites typically have lower DO levels, lower pH (more acidic), higher nutrient levels, more bacteria, and higher temperatures compared to less-impacted or pristine sites.

Nonpoint-source control relates mostly to land management practices in the fields of agriculture, mining and urban design and sanitation. Agricultural practices leading to the greatest improvement of sediment control include: contour grading, avoidance of bare soils in rainy and windy conditions, polyculture farming resulting in greater vegetative cover, and increasing fallow periods. Minimization of fertilizer, pesticide and herbicide runoff is best accomplished by reducing the quantities of these materials, as well as applying fertilizers during periods of low precipitation. Other techniques include avoiding of highly water soluble pesticides and herbicides, and use of materials that have the most rapid decay times to benign substances. Additionally, the use of **buffer zones** near agricultural lands (**Figure 8.13**) can reduce the amount of chemical, physical, and biological pollution that reaches nearby surface water bodies.

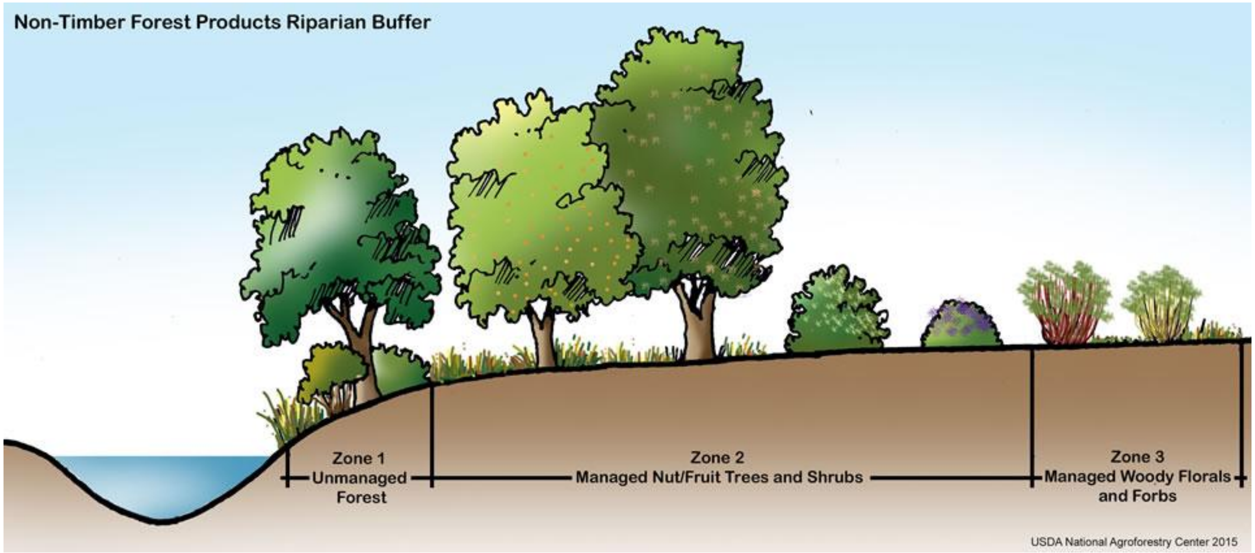

Figure 8.13. A riparian buffer zone used in agroforestry to minimize agricultural impacts on nearby surface water. Notice the unmanaged forest in Zone 1 of this image, closest to the river. The plants in this area serve to absorb nutrient pollution, while their roots also hold soil particles, preventing erosion. Source: USDA National Agroforestry Center.

Test your knowledge…

Explain why a buffer zone works particularly well in agricultural environments to protect surface water quality.

***Further connection**: Consider your knowledge of the water cycle from Chapter 7. Since a buffer zone also slows water down before entering the creek, it provides additional benefits as well. Identify how these might benefit human populations.*

Mines and quarries also require significant water management protocols. The main water pollutants associated with mines and quarries are aqueous slurries of minute rock particles, which result from rainfall scouring exposed soils and also from rock washing and grading activities. Runoff from metal mines and ore recovery plants is typically contaminated by the minerals present in the native rock formations. Control of this runoff is chiefly achieved by preventing rapid runoff and designing mining operations that avoid tailings either on steep slopes or near streams. Without proper runoff controls in place, water from active and abandoned mines can become acidic and produce what's called **acid mine drainage** (AMD). This is runoff with low pH and high concentrations of iron and other heavy metals that are harmful to aquatic life. For more information on the impacts of mining and AMD, see Chapter 3.

In the case of urban stormwater control, good urban planning and design can minimize stormwater runoff. By reducing impermeable surfaces (pavement that doesn't allow water through), cities can reduce the amount of surface water runoff the carries pollutants into surface water and causes flooding. Additionally, the use of native plant and xeriscape techniques reduces water use and water runoff, and minimizes the need for pesticides and nutrients. Regarding street maintenance, a periodic use of street sweeping can reduce the sediment, chemical and rubbish load into the storm sewer system

The two common approaches to water management fall under either voluntary programs or the regulatory programs. The regulatory approach has been very successful in controlling and reducing point-source pollution, which was the focus of early water management regulations. Voluntary programs, together with new amendments to regulations, have had great success in increasing conservation and reducing diffuse nonpoint-source pollution. One of the most widely used voluntary programs is **Watershed Management** while the regulatory approach in the United States is centered on the Clean Water Act (CWA).

The watershed management approach recognizes that water contamination problems are complex and not localized to a section of a river. Water pollution problems are caused by multiple activities within the watershed and, therefore, require holistic approaches in the entire watershed. A **watershed** (drainage basin or catchment) is an area of land that drains to a single outlet and is separated from other watersheds by topographic features that create a drainage divide. Precipitation that falls in a watershed will generate runoff (if not trapped or infiltrated into groundwater) to that watershed's outlet. Topography (elevation) is used to define a watershed boundary. A focal point of water management plans is the **Best Management Practices** (BMPs). BMPs are designed to consider all of the various uses of water, maximize conservation and minimize pollution.

8.5 The Regulatory Approach

Water management through policy and laws seeks to clean up polluted water, prevent further pollution and apply punitive measures for polluters. In the United States water-related regulations go as far back as 1899 with the **Rivers and Harbors Act**, also known as the Refuse Act that prohibited the dumping of solid waste and obstruction of waterways. This regulation, however, did not include waste flowing from streets and sewers. In 1948, another regulation, the **Federal Water Pollution Act** (which is the basis of the Clean Water Act) was enacted. This regulation covered contamination from sewage outfalls. It served to reduce contamination of both interstate groundwater and surface waters. Through this regulation funding was made available to states and local governments for water quality management.

8.5.1 The Clean Water Act

The current most significant regulation on the environmental quality and pollution prevention of surface water in the United States is the **Clean Water Act** (CWA) of 1972. This regulation empowered the Environmental Protection Agency (EPA) to create goals, and objective laws for its implementation, and was an overhaul of the 1948 Federal Water Pollution Control Act. The legislation has programs for both point and nonpoint-source pollution. The Clean Water Act made it illegal to discharge pollutants into surface water bodies without a permit. Many people credit the **Cuyahoga River** fires with inspiring the creating of the Clean Water Act. Severely impacted by point-source industrial pollution, the Cuyahoga River in Ohio caught fire several times between the late 1800s and the 1960s.

The goal of the Clean Water Act is to “restore and maintain the chemical, physical, and biological integrity of the Nation’s waters.” The ultimate goals of the act are to establish zero pollutant discharge, as well as fishable and swimmable waters in the United States. One main component of the CWA is regulations on industrial and municipal discharges into navigable United States waters. The act was designed to be a partnership between states and the federal government. The EPA works with its federal, state and tribal regulatory partners to monitor and ensure compliance with clean water laws and regulations to protect human and environmental health. The federal government sets the agenda and standards while states carry out the implementation and enforcement of the law. States also have the power to set standards that are more stringent than the federal standards if needed. In the state of Georgia, the Environmental Protection Division provides these functions.

Under the CWA, point-source discharge into United States waters is only legal if authorized by a permit. Violators of the law can be punished using administrative, civil, or criminal charges. Point-sources discharges are covered under section 402, the **National Pollutant Discharge Elimination System** (NPDES). This section requires industries and municipalities to get permits from the EPA before discharging into US waters. The permits require the use of control technology to reduce and prevent pollution. The second component of the act is providing funding for constructing municipal waste water treatment plants and other projects to improve water quality (Title II and Title VI).

Test your knowledge…

How does the Clean Water Act in the United States work? Review the following questions:

1. *Are states allowed to have different regulatory standards than the federal government? Why or why not?*
2. *True or false: absolutely no point source discharges are allowed to US waters since the passage of the CWA in 1972*
3. *Which of the following water sources are covered under the CWA:*
    a. *Rivers including the Mississippi River and the Chattahoochee River*
    b. *Lakes including Lake Michigan and Lake Sinclair*
    c. *Groundwater aquifers*
    d. *Municipal drinking water*
    e. *Small, seasonal wetlands*

8.5.2 The Safe Drinking Water Act

The major piece of legislation governing the safety of drinking water in the United States is the 1974 **Safe Drinking Water Act** (SDWA). In 1974, and amended in 1986, the SDWA was enacted to establish standards for many chemical constituents for public water supplied by water agencies. In the regulation, **maximum contaminant level goals** (MCLG), which are non-enforceable and **maximum contaminant levels** (MCLs) that are enforceable where created. MCLG are what would be ideal and desirable, while MCL are what should be attained in any drinking water supplied by a public municipal agency. For any carcinogen, the MCLG is zero even though many contaminants have MCLs and detection limits in the **parts per billion** (ppb) range. Some (e.g. dioxin) have MCLs in the **parts per trillion** (ppt) range. To give you a sense of how small this *ppt* is, it is approximately the same as 0.4 mm divided into 348,470 km (238,900 miles) which is the distance from Earth to the moon.

The Safe Drinking Water Act covers a wide range of contaminants, including microorganisms, disinfectants, disinfection byproducts, inorganic chemicals, organic chemicals, and radionuclides. For a full list of all of the MCLG and MCL standards, visit the EPA website.

One important aspect of the SDWA is that it covers **municipal drinking water** in the United States. This is sometimes referred to as "city water," as is the water that comes from drinking water treatment plants, through municipal water lines, and into the fixtures of homes, schools, and businesses within that municipality. Some drinking water in the United States is **not** covered by the SWDA, including the household water for homes with their own private wells. According to the US EPA, approximately 15% of the US population (about 43 million people) rely on private wells for their drinking water. For these individuals, the water quality is the responsibility of the property owner. It is recommended that private well owners test their water quality annually. University Extension Services and state health departments can often assist homeowners with water quality testing. Additionally, **bottled water** in the United States is also not covered by the SDWA. Instead, bottled water is regulated as a food by the Food and Drug Administration (FDA).

8.6 Water Quality Assessment

Assessing water quality is essential for understanding the safety and suitability of water for various uses, including drinking, agriculture, and industry. This process involves measuring key physical, chemical, and biological parameters that indicate the health of a water source. These are physical, chemical or biological parameters that typically have a set maximum (or minimum) standard that is used as a bench mark for determining whether the quality of the water is good or poor. These standards are a set of measurable or observable characteristics that are established by a recognizable body (agency or authority) such as the World Health Organization, any national, state, local or tribal environmental protection agency, or the government. In the U.S. for example, the EPA sets the standards. These authorities use the scientific method to decide what the safe limits are for different contaminants. They also constantly keep testing/monitoring and continually adjust the standards as more data (evidence) becomes available.

Table 8.2 lists common water quality parameters along with the methods used to test them. Below are brief descriptions of selected measurement methods/techniques.

- **Colorimetry**: measuring the amount of specific wavelengths of light that can pass through a liquid corresponding to its intensity of color. Color changes are induced through chemical reactions that produce color based the concentration of the chemical of interest. These can use either a colorimeter such as Hach Colorimeter or Spectrophotometer**.**
- **Stoichiometry**: reacting chemicals together and using titrations to determine the neutral point of either the acid or the base
- **Ion specific electrodes**: measuring the potential between two electrodes to determine concentrations of specific ions. The electrodes can be single ion

handheld probe or multi-parameter hand instruments such as, Extech meters and YSI multi-parameter systems.

- **Chromatography**: physically separating solutes and suspended substances in a liquid based on their adsorption and absorption characteristics

Table 8.2: Water Quality Assessment

Parameter	Measurement Method/Instrument
pH	Ion electrode (handheld probe)
Alkalinity	stoichiometry
Carbonate	Colorimeter, chromatography, stoichiometry
Nitrate	Colorimeter, chromatography, stoichiometry
Phosphate	Colorimeter, chromatography, stoichiometry
Acidity	stoichiometry
Biochemical Oxygen Demand (BOD)	stoichiometry, ion electrode (handheld probe)
Temperature	Ion electrode (handheld probe)
Algae	Microscope, ion electrode (handheld probe)
Macroinvertebrates	Visual identification
Bacteria	Agar and plate count
Chlorophyll A	Handheld probe, colorimeter
Specific Conductance	Ion electrode (handheld probe)
Total Dissolved Solids (TDS)	Ion electrode (handheld probe)

End of Chapter Review

1. What does the global freshwater use trend shown in Figures 8.1 appear to correlate with over time?
2. Explain the trends shown in the Figure 8.2 (focus on periods of increase, stabilization and decline, and why they happened)
3. Which states have the highest total water withdrawals in Figure 8.2, and what is the primary category contributing to these withdrawals?
4. Fully explain the differences in water scarcity issues between highly industrialized countries and less industrialized countries. Why do these differences exist?
5. Explain and justify the best water management for less industrialized countries.
6. What is major type of ocean pollution and how can we prevent it?
7. What are some of the reasons why not everyone in Lusaka (with abundant natural water resources) has access to clean and safe drinking water while California (with limited natural water supplies) has safe clean water accessible to all its residents?
8. What are practical ways to prevent toxic algal blooms?

9. Discuss some of the parameters and pollutants that would you look for in water to distinguish between mining and sewage treatment sources of pollution
10. How can agricultural practices be modified to reduce water consumption?
11. Based on your understanding of the water management strategies provided in this text and other sources of your choice, discuss a situation where a regulatory approach would be more effective than the watershed management approach.
12. Evaluate the effectiveness of desalination as a long-term solution for water scarcity.
13. Should water be considered a human right or a commodity? Justify your answer.
14. Find out which of the equipment listed in Table 8.2 your school owns (make a list)
15. Using USGS and EPA sources make discuss why it is important to measure and monitor each of the following water quality parameters:
    a. pH
    b. Specific conductance
    c. Dissolved Oxygen
    d. Temperature
    e. Macroinvertebrates

Resources

- Allan, Tony. (2011). *Virtual Water: Tackling the Threat to Our Planet's Most Precious Resource*. I.B. Tauris. Print
- Annon, Kofi (2003). Message to the United Nations by Secretary-General Kofi Annon for World Environment Day: https://press.un.org/en/2003/sgsm8707.doc.htm
- Brooks, Kenneth M., Ffolliott, Pete, F. and Magner, Joseph, A. (2012) *Hydrology & Management of Watersheds*, 4th Edition. Hoboken, New Jersey: Wiley-Blackwell. Print
- Carson, Rachel. (1962). *Silent Spring*. Houghton Mifflin. Print.
- Cech, Thomas V. (2009). *Principles of Water Resources: History, Development, Management, and Policy*, 3rd Edition. Wiley and Sons Inc. Print
- Clausen, C. John. (2018). *Introduction to water resources*. Long Grove, Illinois. Waveland Press, Inc. Print.
- Fetter, C.W. Jr. *Applied Hydrogeology*, 4th Edition. (2000). Upper Saddle River, New Jersey: Prentice Hall. Print
- Hendriks, Martin R. (2010). *Introduction to Physical Hydrology*. Oxford: Oxford University Press. Print
- Hogan, C. (2014). Water pollution. Retrieved from http://www.eoearth.org/view/article/51cbef2a7896bb431f69cd56

- Leiter, M., Levy, J., Mutiti, S., Boardman, M., Wojnar, A., and Deka, H. (2012). Drinking water quality in the Mount Kasigau region of Kenya: a source to point-of-use assessment. *Environmental Earth Sciences* 68:1-12. https://doi.org/10.1007/s12665-012-1698-8
- Manning, John C. Manning. (1996) *Principles of applied hydrology* 3rd, Edition. Upper Saddle River, New Jersey: Prentice Hall. Print.
- Molden, D., C. de Fraiture, and F. Rijsberman. 2007. Water Scarcity: The Food Factor. *Issues in Science and Technology*. 23(4): 39-48.
- Mutiti, S., Levy, J., Mutiti, C., & Gaturu, N. U. S. (2010). Assessing ground water development potential using Landsat imagery. *Groundwater*, 48(2), 295-305.
- Perlman, Howard. (2015). The USGS Water Science School. 2015. http://water.usgs.gov/edu/wusw.html.
- Sipes, James L. (2010). *Sustainable Solutions for Water Resources*. Hoboken, New Jersey: John Wiley and Sons Inc. Print.
- United Nations. (2022). The Sustainable Development Goals Report: https://unstats.un.org/sdgs/report/2022/The-Sustainable-Development-Goals-Report-2022.pdf
- US Centers for Disease Control and Prevention. (2025). Waterborne Disease in the United States: https://www.cdc.gov/healthy-water-data/waterborne-disease-in-us/index.html
- US Environmental Protection Agency. (2025). Radioactive Material from Fertilizer Production: https://www.epa.gov/radtown/radioactive-material-fertilizer-production
- US Environmental Protection Agency. (2025). Safe Drinking Water Act (SDWA): https://www.epa.gov/sdwa
- US Environmental Protection Agency. (1972). Summary of the Clean Water Act. 33 U.S.C. §1251 et seq. https://www.epa.gov/laws-regulations/summary-clean-water-act
- US Geological Survey: Water Resources Mission Area. (2025): https://www.usgs.gov/mission-areas/water-resources

Terms

Acid mine drainage
Aerobic
Algal bloom
Alkalinity

Anoxic
Anthropogenic
Best Management Practices
Biological pollution
Bottled water
Buffer zone
Chemical pollution
Chlorine
Chromatography
Clean Water Act of 1972
Colorimetry
Consumptive water use
Cuyahoga River
Cyanobacteria
Dissolved oxygen
Ecological succession
Economic water scarcity
Effluent
Erosion
Eutrophication
Federal Water Pollution Act of 1948
Fish kill
Groundwater
Inorganic chemical
Ion-specific electrode
Irrigation
Limiting nutrient
Maximum contaminant level (MCL)
Maximum contaminant level goal (MCLG)
Municipal drinking water
National Pollutant Discharge Elimination System (NPDES)
Nitrogen
Non-consumptive water use
Nonpoint-source pollution
Nutrient pollution
Parts per billion
Parts per million
Parts per trillion
Pesticides
pH
Phosphorus
Physical pollution
Physical water scarcity
Point-source pollution
Rivers and Harbors Act of 1899
Safe Drinking Water Act of 1974
Secchi disk
Septic tank
Specific conductance
Stoichiometry
Surface runoff
Surface water
Thermal pollution
Thermoelectric cooling
Total dissolved solids (TDS)
Water quality
Water table
Waterborne diseases
Watershed
Watershed management