CHAPTER 8: WATER

Learning Objectives

As a result of this unit:

- Students will be able to draw multiple interacting water molecules and identify the bonds and atoms
- Students will explain how the molecular structure of the water molecule contributes to the unique properties of water.
- Students will demonstrate an understanding of how much water is available on Earth and how it is distributed.
- Students will be able to compare regional and national responses to water issues.
- Students will be able to explain water-related problems (for example water scarcity, water-borne diseases, water pollution, flooding) from different regions of the world.
- Students will be able to explain how human modifications of natural water systems can be both beneficial and destructive.
- Students will be able to describe solutions to water-related problems.
- Students will be able to read and interpret graphs and charts about water.
- Students will demonstrate knowledge of some of the major regulations related to water in the USA.
- Students will gain a rudimentary understanding of groundwater flow, management and protection.
CHAPTER 8: WATER

This chapter has been adapted from OpenStax (Biology and Concepts in Biology texts), USGS Water Resources, the EPA and The Encyclopedia of Earth

“Whiskey is for drinking. Water is for fighting”

Introduction

Why do scientists spend time looking for water on other planets? Why is water so important? It is because water is essential for life as we know it. Water is one of the more abundant molecules and the one most critical to life on Earth. Approximately 60–70 percent of the human body is made up of water. Without it, life as we know it simply would not exist. The quotation above, which has been attributed to Mark Twain, suggested (by the quote above) that water was extremely important. In recent years, we have seen a rise in conflicts and dispute about water. Fortunately, most of the conflicts have ended up in the courts instead of the battlefields. This chapter is devoted to this precious resource that sustains our planet and its living things.

Chapter outline:

1. Properties of water
   a. hydrogen bonding
   b. Physical state of water
   c. Heat capacity
   d. Heat of Vaporization
   e. Universal Solvent
   f. Cohesion and Adhesion

2. Global Water Distribution and Use
3. The Hydrologic Cycle
4. Components of the Hydrologic Cycle
   a. Atmosphere and precipitation
   b. Rivers and Streams
   c. Lakes, Ponds and reservoirs
   d. Wetlands
   e. Oceans
   f. Groundwater

5. Water Scarcity and Shortage
6. Water Pollution and Quality
   a. Types of water pollution
   b. Sources of water pollution

7. Water Management
   a. Water pollution control
   b. Watershed Management
   c. Regulations

Water

Water is an important commodity for life on Earth and is something we all need in our daily activities. It is referred to by many people as the “essence of life”, “blue gold” and “more precious than oil”. What makes water so important is its unique and special properties. These special properties of water include water’s high heat capacity and heat of vaporization, its ability
to dissolve numerous polar molecules, its cohesive and adhesive properties, and its dissociation into ions that leads to the generation of pH. Understanding these characteristics helps us understand and appreciate its importance in maintaining life on Earth. Before we discuss these properties, we will review the molecular structure of water, which gives rise to these special properties.

**Properties of Water**

A water molecule is composed of one oxygen and two hydrogen atoms that are joined together by polar covalent bonds. Covalent mean that the atoms share electrons, instead of completely giving up electrons to one another. Polar means that the electrons are not shared equally. These polar covalent bonds (Figure 8.1), along with the molecular shape, cause the water molecule to have a slightly positive charge on the hydrogen end and a slightly negative charge on the oxygen side. Water’s charges are generated because oxygen is more electronegative than hydrogen, making it more likely that a shared electron would be found near the oxygen nucleus than the hydrogen nucleus, thus generating the partial negative charge near the oxygen. This gives water molecules their properties of attraction.

![Figure 8.1: Polarity of the water molecule due to the uneven distribution of electrons in its covalent bond. C (From OpenStax Concepts of Biology text)](image)

**Hydrogen Bonds**

Due to water’s polarity, each water molecule attracts other water molecules as oppositely charged ends of the molecules attract each other. When this happens, a weak interaction occurs between the positive hydrogen end from one molecule and the negative oxygen end of another molecule. This interaction is called a hydrogen bond. This hydrogen bonding contributes to the following water’s unique properties.

1. Water is the universal solvent
2. Exists in nature as a solid, liquid, and gas
3. The density of ice is less than liquid water
4. Water has a high surface tension
5. Water has a high heat capacity
6. Water exists as a liquid at room temperature

It is important to note here that even we are only focusing on water in this text book, hydrogen bonding also occurs in other substances that have polar molecules.
Physical State of Water on Earth

Water on Earth can naturally exist as either solid, liquid or gas depending on the prevailing temperature and pressure conditions. The formation of hydrogen bonds (described above) is an important quality of liquid water that is crucial to life as we know it on Earth. As water molecules make hydrogen bonds with each other, liquid water takes on some unique physical and chemical characteristics when compared to other liquids. In liquid water, hydrogen bonds are constantly being formed and broken as the water molecules slide past each other. The energy of the moving water molecules (kinetic energy) is responsible for breaking the bonds. When heat is added to water (increasing temperature), the kinetic energy of the molecules goes up and more bonds are broken. As more heat is added to boiling water, the higher kinetic energy of the water molecules causes the hydrogen bonds to break completely and allow them to escape into the air as water vapor. On the other hand, when the temperature of water is reduced and water freezes, the water molecules form a crystalline structure maintained by hydrogen bonding (since there isn’t enough energy to break the hydrogen bonds). The crystalline structure, ice, has a more open structure than the liquid form of water. The open structure of ice (Figure 8.2) makes ice less dense than liquid water, a phenomenon not seen in the solidification of other liquids.

The lower density of ice, illustrated in Figure 8.2, causes it to float at the surface of liquid water, such as an iceberg in the ocean or ice cubes in a glass of ice water. In lakes and ponds, ice will form on the surface of water creating an insulating barrier that protects animals and plant life that live in the water from freezing. Without this layer of insulating ice, plants and animals living in the water would freeze in the solid block of ice and not survive. The ice crystals that form upon freezing would rupture the delicate membranes essential for the function of living cells, irreversibly damaging them.

Figure 8.2: Hydrogen bonding makes ice less dense than liquid water. The lattice structure water is more condensed (left structure) than that of ice (right structure). The lattice structure of ice makes it less dense than freely flowing molecules of liquid water, enabling ice to float on liquid water. (Image credit: Lynn Yarris, http://www2.lbl.gov/Science-Articles/Archive/sabl/2005/February/water-solid.html)

High Heat Capacity

Water has the highest specific heat capacity of any liquid. Water’s high heat capacity is a property caused by hydrogen bonding among the water molecules. Specific heat is defined as the amount of heat one gram of a substance must absorb or lose to change its temperature by one degree Celsius. For water, this amount is one calorie. It takes water a long time to heat up and a long time to cool down. In fact, the specific heat capacity of water is about five times more than that of sand. This explains why land cools faster than the sea. Due to its high heat capacity, warm
blooded animals use water to disperse heat more evenly and maintain temperature in their bodies: it acts in a similar manner to a car’s cooling system, transporting heat from warm places to cool places, causing the body to maintain a more even temperature.

**Heat of Vaporization**

Water also has a high heat of vaporization, the amount of energy required to change one gram of a liquid substance to a gas. A considerable amount of heat energy (586 calories) is required to accomplish this change in water. This process occurs on the surface of water. As liquid water heats up, hydrogen bonding makes it difficult to separate the liquid water molecules from each other, which is required for it to enter the gas phase (steam). Thus, water acts as a heat sink and requires much more heat to boil than liquids such as ethanol, whose hydrogen bonds are weaker. Eventually, as water reaches its boiling point of 100° Celsius (212° Fahrenheit), the heat can break the hydrogen bonds between the water molecules, and the kinetic energy between the water molecules allows them to escape from the liquid as a gas. Even when below its boiling point, water’s individual molecules acquire enough energy from other water molecules such that some surface water molecules can escape and vaporize: this process is known as evaporation.

Since hydrogen bonds need to be broken for water to evaporate means that a substantial amount of energy is used in the evaporation process. As the water evaporates, energy is taken up by the process, cooling the environment where the evaporation is taking place. In many living organisms, including in humans, the evaporation of sweat, which is 90 percent water, allows the organism to cool so that homeostasis of body temperature can be maintained.

**Water is a Solvent**

Since water is a polar molecule with slightly positive and slightly negative charges, ions and polar molecules can readily dissolve in it. Water is, therefore, referred to as a solvent, because it is capable of dissolving more substances (polar substances) than any other liquid. The charges associated with these molecules will form hydrogen bonds with water, surrounding the particle with water molecules. This is very important as it enables water to dissolve various chemicals and distribute them within living organisms, including taking toxic substances out of living things, and in the environment.

**Water's Cohesive and Adhesive Properties**

Have you ever filled a glass of water to the very top and then slowly added a few more drops? Before it overflows, the water forms a dome-like shape above the rim of the glass (Figure 8.3)
This water can stay above the glass because of its cohesive properties. In cohesion, water molecules are attracted to each other (because of hydrogen bonding), keeping the molecules together at the liquid-gas (water-air) interface, although there is no more room in the glass. Cohesion allows for the development of surface tension, the capacity of a substance to resist rupture when placed under tension or stress. This is also why water forms droplets when placed on a dry surface rather than being flattened out by gravity (Figure 8.4).

Figure 8.3. Water in a glass form a dome shape above the glass due to cohesive forces of attraction among water molecules. Photo Credit: Sam Mutiti

Figure 8.4. Beading up of water due strong cohesive forces between water molecules (Water USGS, right hand photo credit: J Schmidt; National Park Service).

When a steel needle is placed carefully on water it does not sink even though steel is denser (heavier) than the water. Cohesion and surface tension keep the hydrogen bonds of water molecules intact and support the item floating on the top. It is even possible for an insect to “float” on water if it sits gently without breaking the surface tension, as shown in Figure 8.5.
Another important property of water is **adhesion**, or the attraction between water molecules and other molecules. This attraction is sometimes stronger than water’s cohesive forces, especially when water is exposed to charged surfaces such as on the inside of thin glass tubes known as capillary tubes. Adhesion is observed when water “climbs” up the tube placed in a glass of water: notice that the water appears to be higher on the sides of the tube than in the middle. This is because the water molecules are attracted to the charged glass walls of the capillary tube more than they are to each other and, therefore, adhere to it. This type of adhesion is called **capillary action**, and is illustrated in Figure 8.6. This process is also involved in the movement of water and nutrients from the soil around the root systems to other parts of plants above the ground.

**Figure 8.5** The weights of the needle and water strider are pulling the surface downward; at the same time, the surface tension is pulling it up, suspending them on the surface of the water and keeping them from sinking. (Credit: Cory Zanker (left) and Tim Vickers (right))

**Figure 8.6:** Capillary action in a glass tube is caused by the adhesive forces exerted by the internal surface of the glass exceeding the cohesive forces between the water molecules themselves. (Credit: http://moodle.clsd.k12.pa.us/district_videos/Biology/iText/products/0-13-115540-7/ch23/ch23_s5_1.html)
Global Water Distribution and Use

Most of the water on the planet is in oceans and unavailable for human consumption due to its high salinity (Figure 8.7).

![Distribution of Earth's Water](http://water.usgs.gov/edu/earthwherewater.html)

**Figure 8.7**: Graphical representation of available water:
http://water.usgs.gov/edu/earthwherewater.html

Of all the water in the world, only about 0.64% is fresh water that is available for consumption (the other fresh water is locked up in ice). Of this available fresh water, 98.4% is found as groundwater below the surface of the Earth and only 1.4% is surface water in rivers and lakes.

The largest percentage of water withdrawn in the US goes to thermoelectric cooling (Figure 8.8). In some countries, such as Egypt, irrigation accounts for over 70% of water withdrawn. Irrigation is water that is applied by a water system to sustain plant growth. Irrigation also includes water that is used for frost protection, application of chemicals, weed control, field preparation, crop cooling, harvesting, dust suppression, and leaching salts from the root zone.

![2010 withdrawals by category](image)

<table>
<thead>
<tr>
<th>Category</th>
<th>2010 Withdrawals (in million gallons per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public supply</td>
<td>42,000</td>
</tr>
<tr>
<td>Self-supplied domestic</td>
<td>3,600</td>
</tr>
<tr>
<td>Irrigation</td>
<td>115,000</td>
</tr>
<tr>
<td>Livestock</td>
<td>2,000</td>
</tr>
<tr>
<td>Aquaculture</td>
<td>9,420</td>
</tr>
<tr>
<td>Self-supplied industrial</td>
<td>15,900</td>
</tr>
<tr>
<td>Mining</td>
<td>5,320</td>
</tr>
<tr>
<td>Thermoelectric power</td>
<td>161,000</td>
</tr>
</tbody>
</table>

Values do not sum to 355,000 Mgal/d because of independent rounding.
Figure 8.8: Estimated 2010 water withdrawals. Irrigation and thermoelectric power usages account for most water withdrawals. http://water.usgs.gov/watuse/images/category-pages/2010/total-category-pie-2010.png
More water use terminology can be found at: http://water.usgs.gov/watuse/wuglossary.html

The Hydrologic Cycle

The major water reservoirs on Earth are oceans, glaciers, groundwater, rivers, and lakes. Water spends different amounts of time in the various reservoirs. The main factors that control the amount of time water stays in a reservoir are the amount of water in the reservoir and how fast water moves in and out. The hydrologic cycle (water cycle) represents a continuous global cycling of water from one reservoir to another 8.9.

Figure 8.9: The water cycle at the global scale showing water moving through all the major reservoirs, including the ocean reservoir (source https://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-water-cycle).

To gain a deeper appreciation of the water cycle, let us follow a water molecule through the water cycle. Starting in the ocean (an arbitrary starting point) the water molecule can become part of the water that is converted into vapor and enter the atmosphere. Heat energy from the sun, which drives the water cycle, heats water in the oceans and cause evaporation. Evaporation is the process by which water changes from a liquid to a gas or vapor. Evaporation is the primary pathway that water takes from the liquid state back into the water cycle as atmospheric water vapor. Nearly 90% of moisture in the atmosphere comes from evaporation, with the remaining 10% coming from transpiration. Transpiration is the process by which moisture is carried through plants from roots to small pores (stoma) on the underside of leaves, where it changes to
vapor and is released to the atmosphere. Transpiration is essentially evaporation of water from plant leaves. Rising air currents take the vapor up into the atmosphere, along with water from evapotranspiration, which is a combination of water transpired from plants and that evaporated from the soil. The vapor rises into the air where cooler temperatures cause it to condense into clouds. Condensation is the process by which water vapor is converted from gaseous state back into liquid state. Clouds might eventually grow bigger and moist enough to release the water molecule in the form of precipitation. Precipitation is water falling from the clouds in the atmosphere in form of ice (snow, sleet, hail) or liquid (e.g. rain, drizzle). Precipitation that falls as snow can accumulate as ice caps and glaciers.

Did you know that the largest glacier on Earth is the Severny Island ice cap in the Russian Arctic?

Precipitation that falls as liquid usually ends up as surface flow and stream flow. Surface runoff is precipitation which travels over the soil surface to the nearest stream channel. Stream flow is the movement of water in a natural channel, such as a river. Most precipitation falls directly onto the ocean and returns the water molecule back to restart the journey. This is also true for surface runoff, most of the water eventually returns to the ocean via stream flow. This also returns the water molecule back the ocean to start the journey again.

A portion of the water that falls as precipitation can enter lakes where it can evaporate back into the atmosphere, condense, and fall back as precipitation again. Water in the lake can also be taken up by plants and transpired back into the atmosphere. Some of the water that falls as precipitation can infiltrate into the ground and become part of groundwater. Infiltration is the process by which water enters the subsurface by gravitation pull. Some of the water infiltrates into the ground and replenishes aquifers (saturated subsurface rock), which store huge amounts of freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge, and some groundwater finds openings in the land surface and emerges as freshwater springs. Plant roots absorb yet more groundwater to end up as evapotranspiration from the leaves. Over time, though, all this water keeps moving and most of it ends up in the ocean.

Components of the Hydrologic Cycle
Most precipitation falls in the form of rain but there are other forms such as snow, hail, and sleet. Once it runs sufficiently, surface water runoff is generated when the ground is saturated or impervious. Surface water is a major component of the hydrological cycle and one that we interact with very regularly. It includes lakes, wetlands, stormwater runoff (overland flow), ponds, potholes, rivers and streams.

Streams and Rivers
A river forms from water moving from a higher altitude to lower altitude, under the force of gravity. When rain falls on the land, it either evaporates, seeps into the ground or becomes runoff (water running on the surface). When water runs on the land surface it usually converges as it moves towards lower elevation. The converging runoff can concentrate into single channels of conveyance called creeks, stream, or rivers. Usually these start as small rill and rivulets that would join up downhill into larger streams and creeks which can also join up downstream to form even bigger rivers. The streams and rivers that join up to form a larger river are called tributaries, Figure 8.10. The land area drained by a river and all its tributaries is called a watershed or catchment or river basin.
The area adjacent to a river that floods frequently is a called a floodplain. **Floodplains** are areas that rivers use to temporarily store excess water during storm events and frequently contain very fertile soils. This has historically encouraged humans to move into floodplains and use them for agriculture, resulting in a reduction in the capacity of the floodplain to act as temporally storage for excess water during storm events, causing increased damaging flooding downstream. Properly functioning floodplains reduce the negative impacts of floods (by reducing severity of flood), and they assist in filtering stormwater and protecting the water quality of rivers. They also act as areas of recharge for groundwater.

![Figure 8.10: River systems. (A) A river with a small tributary (B) A meandering river with a mature floodplain (C) A satellite image of river system with multiple tributaries (Source USGS)](image)

The US has numerous rivers that run throughout the nation’s landscape. It is estimated that the US has over 200,000 rivers with the Mississippi River being the largest by volume despite it only being the second longest. The Missouri River is the longest river in US. Most states have at least one important river. In Georgia, the main rivers are the Flint, Ochlockonee,
Suwannee, Saint Marys, Satilla, Ogeechee, Altamaha, Oconee, Savannah, Chattahoochee, Tallapoosa, Coosa, Ocmulgee and the Tennessee rivers (Figure 8.11).

Figure 8.11: Major watershed of Georgia representing the main rivers in the state. (Source Georgia Environmental Protection Division: georgiaadoptastream.com)

These rivers are very important for supplying water to the cities and populations of the states. The rivers also contain important biological communities and provide opportunities for recreation such as swimming, fishing, and white water rafting. Rivers are so important and largely control settlement patterns all over the world. Major cities, communities, factories, industries, and power stations are located along rivers. It is, therefore, very important to protect the quality and integrity of rivers all over the world.

Unfortunately, most of the rivers in the world are too polluted to support certain human activities, especially swimming, fishing, and drinking. Close to half of the rivers in the US have been deemed too polluted to support swimming and fishing. A lot of the rivers have also been channelized, dredged, or impounded by dams which have ruined their ability to support a lot of human and biological activities. It is estimated that over 600,000 river miles have been dammed in the US. Benefits of dams to humans include providing a source of water (reservoirs and farms ponds), recreation waters and reducing local flooding. On the other side, dams can also have negative impacts on people and the environment. They can lead to increased severe flooding downstream of the dam, especially during high rain events.

The impoundments can trap stream sediments resulting in reduced sediment supply downstream as well as increased deposition behind the dam. This shift in sediments flow can disrupt and damage aquatic habitats and can increase downstream stream erosion due to lack of sediment supply. The impoundments can also prevent certain aquatic organisms from migrating either upstream or downstream, therefore reducing their range and abilities to survive.
environmental changes as well cutting them off from spawning areas. Construction of dams can also result in displacement of the local people and loss of traditional lands and cultural history. Reservoirs and ponds usually form behind these impoundments.

**Lakes, Reservoirs and ponds:** If water flows to a place that is surrounded by higher land on all sides, a lake will form (Figure 8.12). A lake, pond or reservoir is a body of standing water on the land surface. When people build dams to stop rivers from flowing, the lakes that form are called reservoirs. It is estimated that over 300 million water bodies in the world are lakes, reservoirs, and ponds. Most of the Earth’s lakes (about 60%) are found in Canada. Even though lakes and rivers contain less than 1% of the Earths water, the US gets over two thirds (70%) of its water (for drinking, industry, irrigation, and hydroelectric power generation) from lakes and reservoirs. Lakes are also the cornerstone of the US’s freshwater fishing industry and are the backbone of the nation’s state tourism industries and inland water recreational activities. (http://water.epa.gov/type/lakes/)

**Figure 8.12: Lake Sinclair in Baldwin and Putnam counties (Photo Credits: GCSU Hydrology Research lab)**

**Wetland:** A wetland is an area which is home to standing water for notable parts of the year, has saturated soils for a large part of the year and has plants that require large amounts of water to survive. Wetlands include swamps, marshes, and bogs. Wetlands are identified using three characteristics: soils (water-saturated soils are present), hydrology (shallow water table) and vegetation (wetland plants that are adapted to areas that are saturated with water for long periods of time). Wetlands are very important areas of biological diversity and productivity. These are also important areas where geochemical and biological cycles/processes are consistently taking place. For instance, wetlands are considered as areas of significant carbon sequestration (storage), which impacts global climate change. They also act as filters for storm-water runoff before it enters rivers and lakes.

**Oceans**

As you have probably already guessed, oceans are an important component of the hydrologic cycle because they store majority of all water on Earth (about 95%). Most of the major rivers drain into them. The five oceans covering the surface of the Earth are the Atlantic, Indian, Pacific, Arctic and the Southern Ocean (Figure 8.13).
Approximately 90% of the water that is evaporated into the hydrologic cycle comes from the ocean. Oceans are an important and large part of the hydrologic cycle, with lots biological diversity and many landforms. Did you know that the average depth of the oceans is about 3.6 km with a maximum depth that can exceed 10 kilometers in areas known as ocean trenches? The ocean is also home to many forms of life uniquely adapted to survive in this habitat. Unfortunately, humans have degraded the oceans and their life through pollution, overfishing, carbon dioxide acidification and resource exploitation. Figure 8.14 shows a couple of examples of human impacts on the ocean environment.

Figure 8.14: Trash washed up on the beach (A) and seal tangles up and being struggled by plastic trash in the ocean (B).

From NOAA Libraries
Also watch the video from the Habitable Planet: Oceans Video
vhttp://www.learner.org/courses/envsci/unit/text.php?unit=3&secNum=1

Groundwater

Storage and Flow

Almost 99% of the available fresh water is found below the surface as groundwater. Groundwater is not created by some mysterious processes below ground, but is part of the recycled water in the hydrologic cycle. When precipitation falls, some of the water runs off on the surface while some infiltrates into the ground. Groundwater is replenished when water moves from the surface, through unsaturated rocks or sediment (unsaturated), all the way down the saturated parts (saturated zone) in a process called infiltration and becomes groundwater (Figure 8.15). The top of the saturated portion is called the water table, which is the boundary between saturated and unsaturated zone.

Groundwater is found in aquifers, which are bodies of rock or sediment that store (and yield) large amounts of usable water in their pores. Aquifer productivity is controlled by porosity and permeability. Porosity is the percentage of open space in a rock or sediment body. Permeability is the ability of subsurface material to transmit fluids. Groundwater is found in the saturated zone of a rock body where all pores are filled with water. An important concept is that surface water always moves from higher elevation to lower elevation while groundwater always moves from higher energy (hydraulic head) to lower energy.

Figure 8.15: Model of groundwater system showing the different components of an unconfined groundwater system: http://water.usgs.gov/edu/earthgwaquifer.html

Groundwater will continue to flow until it emerges as a spring, or discharges into surface water bodies on the land or in the ocean. To utilize groundwater, we drill holes (wells) into the ground and pump the water out.
Water Scarcity and Shortage

Water has been identified as one of the major environmental crisis 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 8.16, and 8.17** illustrate this change in water use over time. It is predicted that over the next two decades, the average supply of water per person will drop by a third.

**Figure 8.16:** Trends in fresh and saline water withdrawals in response to population growth (A) surface water withdrawals (B) Groundwater withdrawal trends:
http://water.usgs.gov/edu/wugw.html
Figure 8.17: Both groundwater and surface water withdrawals had increased over time until 1980 when the withdrawals peaked and stabilized.

Water Scarcity and Availability

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 wasted. Tony Allan, the author of Virtual Water, asserts that water follows money. This refers to the fact that rich countries and societies with 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 to build the infrastructure to supply people with safe clean drinking water. Water scarcity is caused by the demand for water being greater than the supply. Scarcity can be defined as either physical scarcity or economic 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 million people around the world are experiencing physical water scarcity. Economic scarcity is a condition where countries lack the financial resources and/or infrastructure to supply their citizens with reliable safe drinking water. About 1.6 billion people are experiencing economic water shortage; most of them live in less industrialized countries. For a lot of 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. A few rich people in these countries get the clean water while the majority of the people who cannot afford to pay for it are left out. Examples of such communities include many villages in Africa, Asia, and South America. Figure 8.18 shows communities in south east Kenya that are experiencing severe water shortages primarily due to lack of infrastructure. Women in these communities must walk long distances to get untreated and contaminated water for drinking and other household needs.
Figure 8.18: Communities in southeast Kenya without ready access to safe drinking water. (A) Groundwater in the area is too salty for consumption. B) Maasai women in Amboseli National Park collecting water from a wetland. (C) Women in Magwede village in SE Kenya walking long distances to get water from a Kiosk. D) 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

Water Quality (pollution)
Water pollution is a major problem facing many of our surface water and groundwater sources. Contamination can both be natural due to geologic or meteorological events and anthropogenic (human causes). Human sources of contamination can be categorized as either point source or nonpoint source. Point-source pollution is water pollution coming from a single point, such as a sewage-outflow pipe. Non-point source (NPS) pollution is pollution discharged over a wide land area such as agricultural runoff and urban stormwater runoff, not from one specific location. Non-point source pollution contamination occurs when rainwater, snowmelt, or
irrigation washes off plowed fields, city streets, or suburban backyards. As this runoff moves across the land surface, it picks up soil particles and pollutants, such as nutrients and pesticides.

Types of Water Pollution

Contamination of water resources comes in the form of chemical, biological, and physical pollution. Chemical pollution includes things such as toxic metals, organic compounds, acidic waters from mining activities and industry, pharmaceuticals and many other chemical compounds from industries and wastewater treatment plants. Another form of chemical pollution is radioactive waste which has a significant potential to cause harm to living things. Most of the radioactive pollution comes from agricultural practices such as tobacco farming, where radioactive phosphate fertilizer is used. Physical pollution includes sediment pollution, trash thrown in the water bodies, thermal and other suspended load. Temperature typically affects the metabolism of aquatic fauna in a negative way and can encourage eutrophication. Biological pollution usually refers to pathogenic bacteria, viruses, and parasitic protozoa. Common pathogenic microbes introduced into natural water bodies are pathogens from untreated sewage or surface runoff from intensive livestock grazing. 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 parasitic and bacterial diseases.

Sources of water pollution

Most of the common inorganic chemical water pollutants are produced by non-point sources, mainly intensive agriculture, and high-density urban areas. Specific inorganic chemicals and their major sources are: ammonium nitrate and a host of related phosphate and nitrogen compounds used in agricultural fertilizers; heavy metals (present in urban runoff and mine tailings area runoff). However, some inorganic contaminants such as chlorine and related derivatives are produced from point sources, ironically employed in water treatment facilities. Moreover, some of the large dischargers of heavy metals to aquatic environments are fixed point industrial plants.

High concentrations of nitrogen (N) and phosphorus (P) in water can cause eutrophication. You are seeing this whenever you notice the greenish tint to the water in our local streams and rivers during low-flow times, or if you have ever seen a green farm pond. These nutrients are primarily coming from:

- treated wastewater (laden with P and N) being dumped into the river from sewage plants,
- agricultural areas where farmers allow livestock direct access to the stream, and
- agricultural areas where there is intense fertilizer application, and from landscapes (homes, gardens, golf courses) with fertilizer runoff.

The N and P act as fertilizers in the water and promote algae blooms. As the algae dies, it is decomposed by aerobic bacteria in the water. These bacteria use up the oxygen in the water and the low dissolved oxygen (DO) levels can results in “fish kills” where large numbers of fish, and other aquatic life, die because of suffocation. The dead zone in the Gulf of Mexico is a huge area of low DO that has a large negative impact on the fishing industry along the Gulf Coast near the mouth of the Mississippi River. The dead zone occurs annually when fertilizers, from farm fields in the Midwest, wash down the Mississippi river.

Improper storage and use of automotive fluids produce common organic chemicals causing water pollution. These chemicals include methanol and ethanol (present in wiper fluid); gasoline and oil compounds such as octane, nonane (overfilling of gasoline tanks); most of these are considered non-point sources since their pathway to watercourses is mainly overland flow.
However, leaking underground and above ground storage tanks can be considered point sources for some of these chemicals, and even more toxic organic compounds such as perchloroethylene. Grease and fats (such as lubrication and restaurant effluent) can be either point or non-point 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.

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. 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 (Figure 8.14). Other common physical objects are timber slash debris, waste paper and cardboard. Finally, power plants and other industrial facilities that use natural water bodies for cooling are the main sources of thermal pollution.

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 are dissolved and may 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 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.

Leakage from septic tanks and/or waste-disposal sites also can contaminate ground water. A septic tank can introduce bacteria to the water, and pesticides and fertilizers that seep into farmed soil can eventually end up in water drawn from a well. Or, a well might have been placed in land that was once used as a garbage or chemical dump site.

**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 reduced DO levels, lower pH (more acidic), higher nutrient levels, more bacteria, and higher temperatures compared to less impacted or pristine sites.

Non-point 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.

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.

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), then 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 program. The regulatory approach has been very successful in controlling and reducing point source pollution, which was the focus of regulations when they were first introduced. 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 is centered on the Clean Water Act (CWA).

Watershed Management

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 a drainage divide. Rainfall that falls in a watershed will generate runoff (if not trapped or infiltrated into groundwater) to that watershed’s outlet. Topographic elevation is used to define a watershed boundary. A focal point of water management plans is the Best Management Practices (BMPs) section. BMPs are designed to consider all of the various uses of water, maximize conservation and minimize pollution.

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 US 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 was created 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.

One of the major water-related regulations in the US is the Clean Water Act (CWA) of 1972. The regulation was very comprehensive with lots of programs and empowered the Environmental Protection Agency (EPA) to create goals, and objective laws for its implementation. The legislation has programs for both point and nonpoint source pollution. One other major piece of regulation governing water was the 1974 Safe Drinking Water Act (SDWA).

In 1974, amended in 1986, the SDWA was enacted to establish standards for many chemical constituents for public water supplied by public water agencies. In the regulations, 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 0 even though many contaminants have MCLs and detection limits in the parts per billion (ppb) range. Some of them (e.g. dioxin) have MCLs in the parts per trillion (ppt). To give you a sense of how small this ppt is, it is the same as 0.4 mm divided by the distance to the moon.

A Closer Look at the Clean Water Act

The 1972 Clean Water Acts was an overhaul of the 1948 Federal Pollution Control Act. The current regulation includes numerous programs for water quality improvement and protection. The EPA works with its federal, state and tribal regulatory partners to monitor and ensure compliance with clean water laws and regulations in order to protect human health and the environment. The Clean Water Act is the primary federal law governing water pollution. One of the objectives of the CWA was to restore and maintain the integrity of the nation’s physical, chemical, and biological waters quality. The ultimate goals of the act are to establish zero pollutant discharge, as well as fishable & swimmable waters in the country. One main component of the CWA is regulations on industrial and municipal discharges into navigable US waters. The act is designed to be a partnership between states and the federal government. The federal government sets the agenda and standards while the state carries out the implementation of the law. States also have the power to set standards that are more stringent than the federal standards if needed. Under the CWA, discharge into US waters is only legal if authorized by a permit. Perpetrators of the law can be punished using administrative, civil, or criminal charges. 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).

The act covers both point sources (discharge from sources such as pipes) and nonpoint sources (pollution from diffuse sources such as stormwater runoff). Point sources are explicitly covered under section 402, 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.

Water in Crisis (case studies)

- You instructor will assign you a specific case study for the course if needed.
Bibliography

Biology and Concepts in Biology texts (OpenStax)


