Chapter 8

Water Resources

Water Compartments and the Water Cycle

The Water Cycle

Water on earth circulates through different global water compartments, or places for storage, driven by solar heating and gravity. Energy from the sun evaporates water from oceans, inland bodies of water, leaves, and soil, then moves through the air as vapor. If the water vapor cools or decreases in pressure by moving to a higher altitude, the liquid water precipitates as rain or snow. If the rain lands on terrestrial ecosystems, it enters a river as runoff or infiltrates into the ground and enters the groundwater.

Water Compartments and the Availability of Fresh Water

The following chart identifies the percent of water on earth in each water compartment and the approximate length of time that water remains in that water compartment.

Table 8.1 Location of Water in Earth's Compartments

Water Compartment	% of Global Water Supply	Average Residence Time
Ocean	97.60	3,000–30,000 yrs.
Ice and snow	2.07	1–16,000 yrs.
Groundwater to 1 km	0.28	days – 1,000s of yrs.
Soil, animals, plant moisture	0.010	weeks
Lakes and reservoirs	0.009	1–100 yrs.
Saline lakes, inland seas	0.007	10–1,000 yrs.
Atmosphere	0.001	8–10 days
Swamps and marshes	0.003	months to years
Rivers and streams	0.0001	10–30 days

The fresh water that we use for all our needs comes predominantly from lakes, reservoirs, rivers, and groundwater. However, as the above chart shows, the combined percent of all freshwater that is available from these sources represents less than one-third of one percent of the global water supply.

Groundwater

As water is absorbed into the ground and moves downward, it eventually reaches an impervious layer of rock and forms an **aquifer**. The type of aquifer that is charged by percolation from above is called an *unconfined aquifer*. The upper boundary of an unconfined aquifer is called the *water table*. A *confined aquifer* is sandwiched between two layers of impermeable rock, and is also known as an *artesian well*. Confined aquifers are charged in *recharge zones* where the geologic layer of the sandwiched, porous rock absorbs water directly.

The water in aquifers is available for use by drilling a well. If too many wells are drilled, the aquifer will *subside*, and perhaps form a dip in water level around the well called a *cone of depression*. If this occurs near the coast, where an aquifer empties underwater, saltwater will diffuse up the aquifer. If a well near the coast uses water from the aquifer faster than it can be replaced from the freshwater uphill source, saltwater will be drawn toward the well and may make it unusable; this is called *saltwater intrusion*. As the water from an intruded well becomes more brackish, or saltier, a user may be tempted to use the water for irrigation. Doing so will leave a salt film, called *salinization*, on plants and soil that will eventually destroy the plants and degrade the land.

Geography and Rainfall

Rain Shadows

Trade winds tend to bring water vapor-laden air inland from the coasts. If there are mountains near the coast, the air must rise up the mountain in order to pass over it. As the air rises, both pressure and temperature drop and contribute to water vapor precipitating first into clouds, and then as rain or snow. By the time the air passes over the mountain, it is much drier. As the air descends on the other side, the air becomes more pressurized and warms ($PV = nRT$). The area on the downwind, or leeward, side of the mountain is then both drier and warmer than the air on the windward side of the mountain. The drier, warmer side is called a rain shadow.

For example, the Sierra Mountains in California capture considerable moisture in the form of snow as the air rises on the Pacific Ocean side of the mountains. On the downwind, or leeward, side of the range, the air descends into the much drier state of Nevada. The air is hottest in the zone where it has descended the most and reached the lowest altitude on the North American continent, Death Valley. Similarly, the rising Pacific air drops considerable moisture as it climbs the Olympic Mountains in Washington State. So much moisture falls that a temperate rain forest has formed between the mountains and the coast.

Desert Belts

Atmospheric convection cells create rising and falling air masses. The air pressure is lower where the air rises, and greater where the air descends. In the same way that descending high pressure air causes an arid rain shadow, it can also cause warm, dry zones at latitudes that experience descending air masses. Chapter Three described how air loses moisture and is heated and expands in the equatorial region, then moves north and south to descend at about 23 degrees from the equator. These zones are called the **Tropic of Cancer** in the north and the **Tropic of Capricorn** in the south. As the air descends, it comes under pressure and warms ($PV = nRT$), causing hot dry air in these regions. Because of this, these latitudes contain the largest deserts on each continent: Gobi in Asia, Kalahi in South Africa, Great Sandy Desert in Australia, and the Sahara in North Africa.

Trends in Water Use

Geography

In addition to latitude, varied rainfall and river locations lead some regions to have more water resources than others. For example, agriculture is limited in Kuwait, but this small energy-rich country obtains most of its water through *desalinization* of sea water through *reverse osmosis* plants, a very energy-intensive process.

Water use per person typically increases as countries develop. As each person uses more energy and manufactured goods in a culture of consumerism, both direct and indirect water use climbs. Currently, the United States uses about 1,300 gallons of water per day per person while Haiti uses about 30 gallons per day per person.

Water Use

Water is used by three general segments of society: municipal/residential, industrial, and agricultural. Although water use trends vary from country to country, the following chart gives approximate worldwide water use trends. Notice that the agricultural segment uses by far the most water.

Table 8.2 Water Use by Different Sectors in American Society

Water User	Percent of All Water Used
Municipal/residential	7%
Industrial	21%
Paper/pulp	10%
Wood/lumber	6%
Mining/oil/gas/chemical	3%
All other	2%
Agricultural	72%

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Residential Water Use

As the following chart suggests, most residences use water primarily to wash away waste and water lawns; only a small portion (2%) is used for cooking and drinking.

Table 8.3 Residential Water Use Pattern in the United States

Water Use	Percent of All Water Used
Lawns and gardens	29%
Toilet	29%
Bathing	23%
Laundry	11%
Dishes	6%
Drinking, cooking	2%

Industrial Water Use

While it is clear when water is used directly by the average consumer, it is less clear when water is used indirectly. For example, we know we use a lot of water if we leave the sprinkler running, but we might be less sure about the amount of water that goes into the different foods we eat. A Sunday newspaper for a major metropolitan area requires nearly 300 gallons of water to be produced. Paper and pulp activities are the largest industrial water users. When we reduce paper use, or recycle paper, we are also conserving fresh water.

Agricultural Water Use

More water is used for agriculture than for any other sector. Many farmers are switching to low-use methods of irrigation. For example, instead of using large rotating sprinklers that lose most of the water to evaporation, some crops allow for the conversion to drip irrigation, which allows most of the water to go directly onto the plant and less is lost to evaporation. As world population increases, many regions may have to consider switching to less water-intensive crops. For example, wheat uses less water than potatoes. California, a state that struggles with having enough water resources, is the nation's largest producer of rice, the grain that demands the most water.

Managing Water Resources

Lock and Dam Projects

The Ohio River spans several states in the American Midwest. Along the river are 19 lock and dam combinations, 7 of which are also hydroelectric facilities, all built by the Army Corps of Engineers nearly 50 years ago. The combination of locks and dams allows large vessels to navigate up and down the river; in particular, it allows coal barges to cheaply transport coal from Pennsylvania and Kentucky downstream to the 47 coal-fired power plants along the river. In addition to navigability, the lock and dam system helps control flooding. However, some would argue that the increased channelization of the river has reduced wetlands along the bank, and thereby decreased the river's ability to flood without doing severe damage.

The lock and dam system has provided power and cheap transportation for industry and economic development. However, the power plants have caused thermal pollution in the water and the emissions are responsible for acid rain, mercury deposition, and high ozone levels in the area.

Hydroelectric Dam/Reservoir Projects

The Hoover Dam was built on the Colorado River in the 1930s. By allowing the river to back up behind it and form the immense Lake Mead, the Hoover Dam is able to control flooding downstream and produce a very large amount of power. However, the dam is over 700 feet high, and an adjacent lock to allow boats or fish to pass by is unreasonable. Therefore, one of the consequences is that fish are no longer able to pass through the dammed portion of the river.

In the Northwest along the Columbia and lower Snake rivers, many are advocating that the hydroelectric dams be breached—or broken open—to allow salmon to pass through and refurbish declining upstream populations. While these dams produce about 5% of the northwest's power needs, many feel that it would be better for business to pay more for power and allow the salmon to survive. As is the case with Lake Mead and the Hoover Dam, the Snake River dams create large reservoirs that are used for recreation and flood control.

In these type of projects, regional governments must weigh trade-offs between environmental and cultural costs (backed up waters often flood important cultural sites), and economic or recreational benefits.

Water Diversion Projects

In ancient Rome, the aqueducts that brought fresh water from the north into the city were a hallmark of Roman ingenuity and convenience. Moving water to areas of heavy use is still a big challenge and poses severe environmental consequences.

The Aral Sea in the former Soviet Union was used as a source of water and diverted to croplands to the south to grow cotton. However, so much water was diverted that the size of the inland sea diminished, causing local fishing villages to lose their income, and exposing vast, salty shores. Local winds blow the salt to nearby villages and increase respiratory illness. As a final insult, the briny water used for irrigation deposited salt in the soil (called salinization) surrounding the cotton and spoiling the land, which now requires even more water from an unidentified source to cleanse it. This water diversion plan turned into a cultural debacle, an air pollution problem that causes illness, and a soil conservation issue.

The California Water Project similarly used aqueducts to bring water from the Sacramento River near San Francisco Bay south 350 miles through hot, arid terrain and over a mountain range so that it could be used by communities in the Los Angeles area. A second portion of the project diverted runoff from the eastern slope of the Sierras with a similar aqueduct. While Los Angeles has been able to use more water, the mountain runoff was not able to enter its ancestral target, Mono Lake. As a result, Mono Lake has become an American Aral Sea: pillars of salt speckle the shore and a much smaller, brackish lake remains. Aside from the political conflicts this project has ignited between northern and southern California, there are severe health effects for the airborne salt from Mono Lake.

Steps Toward Water Conservation

Watershed Management

Clayton County, Georgia, developed a technique to supply more people with its limited water supply. The county implemented an innovative plan to use pine forests in the area to treat waste water, which would enter the groundwater and flow into the town's reservoir. From that point, the water would be treated, used again, and remain in the local hydrologic cycle. Such watershed management has helped communities use the local geography to clean and recycle water.

River Bank Management

After the Mississippi floods in the 1990s, many flooded areas remained open to allow the river to overflow, recharge groundwater, and supply local wetlands. A river with adjacent wetlands and less channelization tends to be cleaner and flow more steadily, with less flooding. See Case Studies in Chapter Nine for a story about planning for the levees of the Mississippi.

Reduce the Use of Water-intensive Products

If it really takes 280 gallons to produce a Sunday paper, perhaps reading the news from the Internet or listening to a radio would provide the same service. Water resources can be saved by purchasing fewer water intensive products. Paper recycling reduces the largest industrial user of fresh water.

Low Flow Utilities

Take shorter showers, or put a flow reducer on the shower head. Consider a low-flow toilet; some use less than half the water of traditional toilets. Some homes and public areas have installed composting toilets that use no water at all. As long as the waste is highly oxygenated, it does not smell. That would entirely eliminate our largest use of domestic water.

Decreased Spoilage

The most prevalent form of stream and river pollution is siltation. This can be reduced by limiting the runoff from construction sites, or other places where the land has been opened. Putting recharge zones in parking lots will reduce the speed and forcefulness of runoff after rains, and less silt will enter local creeks.

Water Pollution

Point Source vs. Nonpoint Source Pollutants

Point source pollutants discharge pollution from specific points, or locations. For example, drain pipes, sewer outfalls, and industrial drains are all considered point sources. Conversely, **nonpoint sources** of water pollution come from sources that are not limited to a discreet, identifiable location. For example, rain runoff in a city washes sediment, oils, and heavy metals into local streams and rivers, but it does not come from any one source. Pesticides entering the groundwater come from many fields; it is difficult to identify a single source. Acid rain is caused from reactions that occur in the atmosphere, then travel many miles before polluting a stream or river and is a major nonpoint source pollutant.

Types of Pollutants

Pathogens

Chapter Six identifies a sampling of pathogenic organisms, many of which are waterborne. Pathogenic pollution is the form of water pollution that poses the highest threat to human health. Most of these pathogens come either from a microbe contained in the life cycle of an insect or water organism, or from improperly treated human waste. Bacterial pathogens include those which cause cholera, dysentery, enteritis, and typhoid. Human coliform bacteria, such as *E. coli* and *giardia*—a protozoan—cause a severe intestinal reaction, but they do not cause death.

Viral pathogens cause Hepatitis A and polio. Schistosomiasis is one of the most prevalent aquatic pathogens and is caused by an animal (the blood fluke). Schistosomiasis has drastically increased in countries that have built very large water projects. The slower-moving impounded water allows the growth of small snails, which are the vectors for the fluke.

Oxygen-demanding Wastes

The addition of nutrients, such as nitrates and phosphates, or human waste will help certain types of algae to grow. Once the algae blooms, decomposing organisms break down the algal bodies and use up oxygen, which makes it difficult for organisms that undergo respiration to live. Therefore, anything that encourages the growth of algae robs a waterway of essential oxygen.

The **Biological Oxygen Demand** (BOD) is a good estimate of the load of oxygen-consuming organisms in a stream or river. The *Dissolved Oxygen* (DO) is a direct measure of the oxygen available for organisms in the water. When an oxygen-demanding waste is discarded into a river or stream, the levels of DO drop downstream and create *oxygen sag*. As the oxygen levels drop, so does the diversity and abundance of oxygen-demanding organisms. The *decomposition zone* is immediately downstream from the discharge, and will contain organisms like leeches and trash fish (such as catfish). The next zone is the *septic zone*, where the lowest DO exists (often as low as 2 ppm). Fish will not survive in the septic zone, and only highly tolerant organisms, such as worms and mosquito larvae, are hardy enough to exist.

As the water moves downstream, the natural turbulence in the water helps replenish dissolved oxygen in the water. The colder the water, the more easily oxygen will dissolve. After the septic zone, the *recovery zone* represents that area where the DO goes back to pre-discharge levels (usually about 8–10 ppm). When the water has fully recovered, the *clean zone* will once again be able to support sensitive, oxygen-demanding organisms, such as mayfly, stonefly, and cadisfly larvae. Like lakes, rivers that have clear water and low biological productivity are **oligotrophic**. **Eutrophic** rivers are nutrient-rich and carry a higher BOD.

Inorganic Wastes

There are two general types of inorganic wastes: suspended particles and dissolved ions—of which acid deposition is one type.

Suspended Particles

Suspended particles are undissolved solids, such as small objects and sediment, that spoil waterways. Sediment that has washed into a stream or river from runoff or erosion is responsible for spoiling more waterways than any other type of water pollution. Sediment spoils the water for drinking, and can cover or clog organisms that need a free flow of water or exposure to sunlight in order to survive. *Turbidity* is a measure of biotic and abiotic suspended solids, and is measured by determining the depth at which a black and white pattern on a secchi disk is still visible.

Dissolved Ions

Dissolve ions come from ionic compounds that dissolve in water (as described in Chapter Two). The most common problematic dissolved ions include heavy metal ions, calcium ions, iron ions, sulfide ions, chloride ions, and acidic hydrogen ions.

Heavy Metal Ions

Most heavy metal ions are toxic; some are extremely toxic. Mercury, lead, cadmium, and nickel can be fatal in the parts-per-million range. Metal ions already exist in their simplest form, so they do not break down further; therefore, they are extremely persistent. One of the most famous cases of metal poisoning occurred in Minamata, Japan, where residents ate fish that had ingested mercury and then metabolized it to form the more toxic methylmercury. Methylmercury poisoning caused birth defects and permanent brain damage. Methylmercury poisoning is now called **Minamata disease**.

The most prevalent form of metal ion water pollution exists as water passes through old plumbing and leaches out lead that was used for solder in incoming pipes and joints in waste pipes. Even if a particular household does not receive a dangerous dose, constant low levels of pollution can build up in the environment and cause illness somewhere else.

Calcium Ions

Calcium ions spoil the water by combining with soap to decrease its cleaning ability and create a bothersome film. Calcium ions can also precipitate with other ions inside appliances to form a calciferous crust that may eventually destroy the appliance. For these reasons, many families use a water softener to replace the calcium ions with sodium ions so that appliances and soap work better. The drawback to this practice is that the sodium in the water—like eating too much table salt—can increase the incidence of hypertension in some people.

Iron and Sulfide Ions

These ions are often found in areas where water is pumped from mineral-rich aquifers. Sulfide ions give water a rotten-egg smell, but can be removed with carbon filters. Iron ions affect the taste of water and can be harmful at high concentrations.

Chloride Ions

Chloride ions enter the water as runoff from salted roads and industrial processes. If combined with organic material, such as particulate material from sewage treatment facilities, the resulting compounds may be carcinogenic.

Acid Deposition

Acid runoff is perhaps the most damaging type of dissolved ion pollution. (Chapter Two outlined the definitions of acids and pH.) Acid deposition results from acid rain (Chapter Seven) or from runoff that has filtered through soil that contains acidic material, such as mine tailings. Acid deposition threatens the stable pH that aquatic organisms need in order to survive. The aquatic larval stages of insects are more sensitive to fluctuating pH; severe damage to these ecologically important organisms can result with a slight drop in pH.

Toxic Organic Wastes

Organic toxics can come from either natural or anthropogenic sources. One natural source of organic toxins is red tide, which is caused by the dinoflagellate *Pfiesteria piscicida*. Blooms of this organism are caused by nutrient wastes reaching marine pelagic environments. This microorganism can attack fish and be toxic to humans who eat the fish. The resulting disease is called paralytic shellfish poisoning.

Some artificially developed organic compounds represent the most toxic substances known; pollution of water by these compounds presents a serious threat to human and nonhuman life. Pesticides that wash off agricultural and residential land are one of the most prevalent culprits. Organic wastes that leach out of dumps or corroded fuel tanks into the groundwater often end up in streams and rivers. Dioxins, a type of toxin that is produced from burning trash, can rain down upon lakes and streams; exposure to dioxin at very low levels—a few parts per quadrillion—can lead to cancer and birth defects.

Thermal Pollution

Cool water is able to dissolve more oxygen, which can then be used by aquatic organisms. As water heats up, less oxygen can dissolve in the water. When power plants use river water to cool steam after it has passed through a turbine, then the cooling water is returned to a river a few degrees warmer and the river has a lowered DO. In metropolitan areas, thermal pollution is most pronounced when it occurs alongside nutrient pollution, both of which decrease the DO of a river or stream.

Wastewater Treatment

Pre-use Water Treatment

Before water is used by a municipality, it is generally filtered, flocculated, re-filtered, and disinfected.

Filtration and Re-filtration

Water is drawn through filters that contain gravel and sand of various diameters. At the end stage, carbon filters are used to remove the smallest particles and improve taste.

Flocculation

Aluminum sulfate may be added to water to bind small particles together so that they may be more easily filtered out.

Disinfection

Before entering the water supply system, water is frequently disinfected with chlorine, ozone, or ultraviolet light.

Wastewater Treatment

Primary Treatment

Primary treatment removes large particles through filtration, and then allows bacteria to partially digest carbon and nitrogen wastes in large settling tanks. However, this does not entirely degrade the carbon into methane, or the ammonia/nitrogen into atmospheric nitrogen, and pathogens or toxins may still exist in the water. Primary treatment is fundamentally a filtration and settling process.

Secondary Treatment

Secondary treatment holds the waste for a longer time in conditions that are favorable to bacterial digestion of the carbon and nitrogen wastes. The carbon-rich sludge tends to settle in the initial pond and can be removed to be digested by anaerobic methane-producing bacteria. The methane has a pungent odor, but it can be burned off or used as an energy source to operate the treatment facility.

The nitrogen-rich solution is skimmed off and sprayed over high surface area substrate to promote aerobic, or oxygen-using, bacteria growth. These bacteria will add oxygen to the ammonia form of nitrogen and convert it to nitrate ions. The carbon and nitrogen consuming bacteria can be easily filtered off before the waste is discharged. This solid waste is called sludge, and presents a major disposal problem for many metropolitan areas. Also, the nitrates remain in the water and, if left untreated, will lead to decreasing the available dissolved oxygen in the water after being discharged.

Pathogens can be killed by exposing the effluent to chlorine, UV light, or ozone before discharge. Secondary treatment removes the greatest percentage of waste and pathogens, but it does not remove nutrient or toxic wastes.

Tertiary Treatment

Tertiary treatment can involve many methods to remove nitrates, phosphates, and industrial pollutants. Nitrates and phosphates are fertilizers and can be removed by sprinkling the water on trees or fields, or running the water through marshes so the plants assimilate the nutrients. Exposing the water to denitrifying bacteria will convert nitrates into nitrogen gas. Passing the water between electrically charged plates will remove charged particles. Reverse osmosis will remove all dissolved and undissolved particles, but it is very energy intensive.

Tertiary treatment may also involve specific chemical treatment to disinfect the water or remove toxic wastes, depending on the needs of a community, but this is very expensive.

Removal of Toxic Wastes

Toxic wastes can be removed by physical, chemical, or biological methods, or some combination of those three.

Physical methods include vaporization (air stripping), filtration (especially using carbon, or reverse osmosis), UV oxidation/disinfection, or washing. For example, an underground oil spill can be remediated by using an air stripping method, which passes warm air through the ground to vaporize most of the oil fractions and allow them to rise to the surface of the ground.

Reverse osmosis is a common type of filtration that is able to remove suspended and dissolved particles and pathogens from water. This process uses energy to press water through layers of filters with microscopic pores. It is used on a small scale in homes and hospitals for water purification. On a large scale, it is a costly method of deriving fresh water from the ocean.

Chemical methods include acid neutralization, oxidation, reduction, precipitation, chelation, or hydrolysis. For example, chelation uses large molecules to combine with dissolved heavy metal ions so they may be more easily filtered from polluted water.

Biological methods often involved bioremediation. It may involve constructing wetlands, which have a natural filtering effect and use up nutrients that may otherwise cause a drop in dissolved oxygen. Duckweed can remove a large amount of organic nutrients from water. Duckweed lagoons are able to treat sewage at a fraction of the cost of traditional sewage treatment plants; then the duckweed can be harvested and fed to animals.

One noted example of bioremediation: After the *Exxon Valdez* oil spill in Alaskan waters, all the best artificial efforts were not as effective as allowing bacteria to digest the oil coating the coastal areas.

The Clean Water Act

The **Clean Water Act of 1972** was passed to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." This bill is one of the top five most important environmental legislative acts; it involves the following major objects:

1. Make all waters "fishable and swimmable."
2. Require discharge permits of major polluters.
3. Identify toxic pollutants and require the use of the best practical technology (BPT) to remove those pollutants.
4. Set goals for best available technology (BAT) to be developed in the future.

Water Pollution Control

Other than treatment, the best way to clean our waterways is to not pollute them in the first place. The following actions help avoid pollution altogether, but they involve expensive trade-offs that countries and local governments are rarely willing to make.

Reduce Emission of Sulfur and Nitrogen Oxides

These emissions come from point sources (power plants) and nonpoint sources (automobiles). This would reduce acid deposition of our waterways.

Modify Agricultural Practices

Reducing pesticide, nutrient, and sediment runoff will vastly improve the quality of our waterways. Using land practices that decrease runoff, or farming practices that reduce the need for water, pesticides, and fertilizers, would significantly increase available fresh water supplies. Golf courses use large amounts of fertilizer and weed control chemicals, and feedlots that produce nutrient, hormonal, and antibiotic waste also need to limit and/or treat runoff.

Treat Waste at Industrial Point Sources

If wastes are treated before it enters municipal sewage systems, those systems will not be overloaded. Municipal treatment facilities are not equipped to treat specialized industrial waste.

Separate Storm Runoff from Septic Treatment

Heavy rains can overwhelm wastewater treatment facilities and cause untreated waste to enter waterways.

Decrease Silt Runoff

Our largest water pollution problem could be solved if communities devote holding ponds that allow silt to settle before entering streams and rivers. However, numerous nonpoint sources would continue to exist from urban areas, parking lots, and construction sites. Using permeable pavers instead of asphalt or cement would allow water to soak into the groundwater and prevent silt from flowing into streams.

Seal landfills to prevent toxic substances from entering groundwater.

Stop ocean dumping of garbage or cleaning the bilges of large ships.

Reverse River Channelization

Wetlands adjacent to streams and rivers filter toxins and silt out of the water, decrease the flow of the river, and provide a buffer zone that decreases flooding.

When a river is engineered to be in a long, straight channel instead of winding through wetlands, all of these benefits are eliminated.

Case Summaries

Oxygen Demand on the Chattahoochee River

Principles mentioned in this case:

- **Combined effect of thermal and nutrient pollution**
- **Regional competition for water**

The Chattahoochee River flows through metropolitan Atlanta on its way to the Gulf of Mexico. It is the major source of water for domestic and industrial needs for this growing area. The water is in high demand as a repository for treated sewage, fresh water source, and coolant for power plants. However, local sewage treatment facilities must coordinate with regional power utilities in order to keep the dissolved oxygen in the river within acceptable levels.

As the population of Atlanta has increased, so has the burden of treated sewage. As a result, a major downstream coal-fire power plant must now reduce its use of river water as a coolant and must build large, unsightly cooling towers that will accomplish the same amount of cooling with less water. This is an example of how population growth puts increased stress on water resources.

The Diminishing Everglades

Principles mentioned in this case:

- **The effects of groundwater depletion on local ecology**
- **Toxic wastes and endangered species**
- **Channelization**
- **Restoring wetlands**

Steady use of Florida groundwater and ever-increasing diversion of water has reduced the high water table in and around the famed Everglades National Park. Steady development north of the park has converted many thousands of acres of wetland that previously drained into the Everglades into residential and farming uses. Not only does this decrease the flow of water into the Everglades, but runoff from these developed areas sends nutrient and toxic wastes into the Everglades, which also threatens the endangered species protected by the park.

One portion of the solution may lie with the "re-twisting" of the Kissimmee River, which was turned into a straight channel several years ago to promote navigation. Restoring the oxbow, circuitous nature of the river will revitalize former wetlands along its banks, which will in turn remove nutrients from the water before it reaches the Everglades.

The Ogallala Aquifer: A Hidden Treasure Dries Up

Principles mentioned in this case:

- **Water resource management**
- **Anatomy of an aquifer**
- **Subsidence**

The Ogallala aquifer is the largest aquifer in North America; it lies underneath the Central Plains states of Oklahoma, Kansas, Colorado, Nebraska, South Dakota, New Mexico, and parts of Texas. It ranges from dozens of feet to over 1,300-feet thick, and provides the water for America's "breadbasket."

Farmers and municipalities began to pump water from the Ogallala about 100 years ago, but use of the aquifer usually surpasses its ability to recharge itself. Some are concerned because it took millions of years to accumulate the water in Ogallala's porous rock, but all that water is being used within just a few generations. Careful attention is now being paid to use and recharge rates, water table levels, and groundwater pollution that spoils the aquifer.

The Gulf Hypoxic Zone: Symptom of a Larger Problem?

Principles mentioned in this case:

- **Oxygen-demanding wastes**
- **Relationship between global health and regional misuse**

The Mississippi River is the third-largest river in the world. It flows for approximately 2,300 miles, provides 23% of the nation's drinking water, and drains 40% of the United States. However, the mighty river also carries an enormous load of toxic waste—particularly agricultural waste. That waste continues to concentrate as the river approaches the Gulf of Mexico. Now there is a large zone in the Gulf—about 20,000 square kilometers, about the size of the state of Massachusetts—that is dead and cannot support life. The dead zone is hypoxic, which means that there is no oxygen in the water.

The Gulf hypoxic zone is a massive example of the consequence of oxygen-demanding waste mentioned in this chapter. Nutrient waste is emitted into a waterway. Algae populations bloom. Decomposer populations that feed off the algae then bloom—using up the oxygen in the water.

The Mississippi not only carries the bulk of the nation's water, but also a large proportion of the country's fertilizer runoff. Since the development of the United States, the land that drains into the Mississippi has steadily been converted from vast prairies to feedlots and croplands. The nitrates and phosphates that are produced on these farms run off into the Mississippi and ultimately create the hypoxic zone in the Gulf of Mexico. An estimated 56% of the nutrient pollution enters the river above the Ohio River confluence. Iowa alone contributes an estimated 51 million tons of animal waste per year to the river.

Compounding the effect is the increased channelization of the great river. (See Case Studies, Chapter Nine.) The vast wetlands that used to assimilate the pollutants of the river have been turned into agricultural lands—which instead of assimilating runoff fertilizer, only contribute more.

When this happens in a stream, the natural mixing and turbulence of the stream helps to dissolve more oxygen into the water; the stream has a chance to recover. However, the Gulf water does not experience enough mixing, and the hypoxic zone only increases. The shrimp fisheries in the Gulf must entirely avoid the hypoxic zone, which has pushed shrimp populations further from shore—requiring more energy to procure them.

As the river moves along, the water becomes increasingly polluted. Near the mouth of the river, there is considerable poverty. To some people the mismanagement of the Mississippi becomes an issue of social justice.

As a family in Baltimore or Newark or whatever city sits at the table to have dinner, they probably do not think about the consequences to people and the environment for growing that food in America's Breadbasket.

The Three Gorges Project: The Largest Dam Project in the World

Principles mentioned in this case:

- **Effects of a large water project**
- **Social justice of community displacement**
- **External costs**

The Three Gorges area along the Yangtze River is the construction site for what will be the largest hydroelectric dam in the world. It will span a mile-long canyon and rise 575 feet above the Yangtze. Its reservoir will extend 350 miles upstream, and it will produce a behemoth 18,000 megawatts of electricity with 26 turbines. The project is scheduled to be completed in 2009.

However, the environmental and social cost is commensurate with the size of the project. It will displace nearly 2 million people, many of whom have no place to go. The Chinese government's web site reports that about 850,000 people will need to be resettled, and they are doing so happily because of a generous re-settlement stipend. However, interviews of indigenous villagers by human rights organizations suggest that relocation stipends are being embezzled, and villagers are being sent to jail if they ask too many questions.

The Chinese government feels that electrical power is critical to continued development in the country that contains over one-sixth of the world's population. The dam will also help prevent flooding along a river famous for catastrophic floods.

Land Resources