Chapter 19

Case Study: America's "First River": A Success Story in Progress
This case study is an overview of the Hudson River's history with toxic pollutants. Even though the river was at the center of the development of the United States, it was seriously polluted to the point of fishing and swimming bans and a designation as a Superfund site. Recent court decisions have led to an attempted cleanup of the Hudson River, and it is counted as a victory for water cleanup and environmental justice.

WATER POLLUTION AND TREATMENT

19.1 WATER POLLUTION

Water pollution consists of a degradation of water quality to the point that traditional uses and/or desirable life forms are threatened. Pollutants can be **physical**, such as sediment, **chemical**, such as PCBs, or **biological**, such as viruses and bacteria. Obtaining clean, disease-free water for drinking is the major health problem facing a large proportion of humans.

The US Environmental Protection Agency sets allowable levels of pollutants in water, but these are subject to controversy, such as the one that arose regarding arsenic levels in drinking water during the Clinton/Bush presidential transition.

19.2 BIOCHEMICAL OXYGEN DEMAND (BOD)

BOD, also called the **biological oxygen demand**, is the amount of oxygen consumed by microorganisms in water in a fixed amount of time, typically 5 days (BOD_5). BOD is caused by the respiration of bacteria that are consuming organic matter, so BOD is proportional to the organic matter in the water. Sources of organic matter may be natural, such as decaying plant matter, or may be from anthropogenic sources such as agriculture and sewage runoff. The resulting BODs along a stream lead to classifications of **pollution zone**, **active decomposition zone**, and **recovery zone** as one moves downstream from a source.

When BOD is high, the oxygen concentration in the water can be reduced to levels that are too low for many fish species and other organisms. An oxygen level below 5 mg/L is considered the threshold for a pollution alert by the EPA. High BOD is a frequent cause of fish kills.

19.3 NUTRIENTS

Nitrogen and phosphorus are the most important, because they are often limiting nutrients in water system. Fertilizers and sewage effluent (including detergent) are rich sources of both.

● Eutrophication

Levels of nutrient loading can reach such high levels that algal populations explode. As the algal populations crash, the decomposition of their remains produces a high BOD that robs the water of oxygen. Thus, the nitrogen and phosphorus are not directly toxic, but cause a cascade of effects that end in mortality, an example of the **ecosystem effect**. The biological term for this is **eutrophication**.

Eutrophication is a natural and normally very slow process in lakes, and passes through predictable stages: **oligotrophic**, **mesotrophic**, and **eutrophic** as nutrient levels rise. The term **cultural eutrophication** describes the accelerated process caused by people. The solution to cultural eutrophication is to prevent excessive nutrient loadings. This is more easily accomplished when dealing with **point sources** of nutrients than with

non-point sources. To repair the damage is harder - it involves removing any additional contributions of nutrients and may require dredging.

19.4 WATERBORNE DISEASE

The importance of waterborne disease has been recognized for well over a century, since a cholera outbreak in London was traced to a public well on Broad Street in 1854. The generic term for waterborne disease is **fecal-oral**, or 'toilet to mouth' disease, because of the common mode of infection. Waterborne disease is common in undeveloped nations, where water treatment is not advanced. Even in the United States, which has advanced water and sewage treatment, occasional can outbreaks occur. In 1993, there was an outbreak of *Cryptosporidium* in drinking water that affected 400,000 people in Milwaukee.

● Fecal Coliform Bacteria

It is difficult to test for and monitor the multitude of disease organisms (ranging from viruses to protozoans), but the **fecal coliform tes**t is considered a relatively quick test of fecal contamination. Fecal coliforms (such as *Escherichia coli*) are bacteria that usually live in the digestive system of mammals, and are generally harmless, but when they are detected in water, ~~then~~ there is the possibility that disease organisms spread through fecal matter are also present. In cases of suspected pollution, genetic testing can be done to precisely identify contaminants and whether humans are the source.

Standards are used that recognize different levels of hazard depending on the concentrations of coliforms. Drinking water standards are most strict (no coliforms permitted), ranging up to concentrations at which swimming or boating is not allowed.

19.5 OIL

Oil is discharged into water in bilge water from tankers, from oil spills, and from the runoff from roadways, which collect the oil leaks from our vehicles. One of the best known oil spills was caused by the grounding of the oil tanker *Exxon Valdez* in Prince William Sound, Alaska, one of the most pristine marine environments in the world. The 11 million gallons of spilled oil killed 13% of the harbor seals, 28% of the otters, and 100,000-645,000 sea birds. The volatile fractions of oil are highly toxic and can cause cancer. Only about 14% of the spilled oil was recovered. Fortunately oil is biodegradable, but the long term effects are unknown. The resulting damage from the *Deepwater Horizon* drilling rig oil spill in the Gulf of Mexico, the largest ever at 205 million gallons, is still being evaluated.

19.6 SEDIMENT

Sediment eroding from agricultural landscapes and construction sites is another serious pollution problem. Excessive sediment loads can easily smother the benthic fauna and flora (incl. submerged aquatic vegetation) in a stream or lake. Construction sites use erosion controls around their sites to reduce the impact. The erosion from fields can be reduced by using no-till agriculture and other means, and buffer zones of natural vegetation around streams can reduce the sediment as well as the nutrient loads.

19.7 ACID MINE DRAINAGE

Acid mine drainage occurs when precipitation percolates through mines, especially coal mines, or mine tailings rich in sulfidic minerals such as pyrite. The sulfides are oxidized by oxygen in the water or air to produce sulfuric acid (H_2SO_4). The acidic (and often orange) water then drains into nearby lakes and streams. The effects on local ecosystems can be extremely severe. Various techniques are being used to try to prevent this water from reaching sensitive areas.

19.8 SURFACE-WATER POLLUTION

Pollution of surface and ground water occurs in many ways from numerous sources. Generally sources can be categorized as either **point-source** or **non-point source** pollutants. Point-source pollutants are theoretically more easy to deal with. Non-point sources, particularly from agriculture, are major water quality problems and require a broader approach.

● Reducing Surface-Water Pollution

Two main strategies are to **reduce production** of pollutants and/or to **treat contaminated water** before discharge. In the U.S. and other developed nations there is a growing list of success stories about rivers that have been greatly improved by implementing pollution control of point sources. The Potomac River was once so polluted that is was dangerous to swim in. The Cuyahoga River in Cleveland, which ignited in flames in 1969, today is cleaner and is no longer flammable. Treatment of water by high tech means such as the use of **nano particles** has great promise, as does use of plants and soil in **bioengineered** landscapes.

Urban-runoff naturalization attempts to confine waters from urban areas and direct it into the ground or to treatment plants.

19.9 GROUNDWATER POLLUTION

About ½ of the people in the U.S. depend on **groundwater** as a source of drinking water. Groundwater has a low turnover time, so pollution of groundwater is difficult to rectify when it occurs. Some US groundwater is still fairly clean, but it is suspected that most of the 175,000 US waste disposal sites are leaking contaminants that are migrating into groundwater resources. The hazard level depends on concentration and toxicity of the pollutant and the degree to which people are exposed.

● Principles of Groundwater Pollution: An Example

Contamination of groundwater by toxic chemicals must be cleaned by pumping followed by treatment processes that are expensive, time consuming, and may require removal of hazardous waste. Gasoline tanks are an important success story in regard to changes in policy about how they are permitted, made, and handled. **Bioremediation** can be used in conjunction with pump and treat, or by directly injecting nutrients into the groundwater that would stimulate microbes to consume the toxins. This is often effective when the pollutants are organic toxins that microbes can degrade.

There are several questions that must be considered regarding groundwater contamination and cleanup, such as whether the contaminant mixes with water, floats on it, or sinks beneath it; the permeability and retention time of the substrate; the degree of aeration of the substrate; and the rate of movement.

19.10 WASTEWATER TREATMENT

Wastewater treatment is designed to prevent eutrophication in discharge areas as well as the spread of disease. Wastewater is generally composed of anything that leaves the house or industry as sewage, including human waste as well as water from clothes and dish washing.

● Septic-Tank Disposal Systems

Septic tanks are one form of home waste treatment. The waste flows into a tank where the solids settle, and the liquid flows into a drain field. The grass is normally greener over the drain field! There are usually regulations about where septic tanks can be used and their design, particularly when there are withdrawal wells in the vicinity. Periodically they must be cleaned by a commercial service that sends out a truck, euphemistically called a honey wagon, to pump out the tank. Septic tanks are common in rural or outlying suburban areas where the population density is low. They can cause problems when used around lakes and streams because of the leachate.

In home treatment of waste is practiced in some countries using a device called a **composting toilet**. The waste accumulates in a holding bin, it is composted there and makes a rich fertilizer. Modern design and ventilation prevent bad smell.

● Wastewater Treatment Plants
Urban areas centralize wastewater treatment by sewers that deliver raw sewage, often with the aid of lift stations, to a **wastewater treatment plant**. Their main function is to reduce BOD and the potential for discharge to cause disease.

A problem that faces many wastewater systems is the effect of storm water runoff.
Sewers often pick up storm water, which raises the volume of water entering the plant. After a big storm, raw sewage can pour into a river. For example in New Haven, CT, after a rainstorm, undigested corn from the sewage treatment plant is all over the mud flats in the harbor (the birds love it).

Students may wish to discuss the multitude of toxins that enter the waste stream such as used motor oil, heavy metals, paint solvents, pharmaceuticals, and mercury compounds, in short, everything that anyone disposes of down the drain or in some cases down the storm sewer.

● Primary Treatment
Primary treatment removes sewage solids by screening and settling. Often sand that has leaked into the sewage pipes can be a problem at this step and requires a separate removal.

● Secondary Treatment
Secondary treatment is a biological process that removes much of the dissolved organic matter and BOD along with some of the nitrogen via denitrification. In the **activated sludge** process, bacteria and protists are employed in aerobic processes to convert the organics to inorganics. Some sludge is always kept as a living culture for the next round of digestion. Excess sludge is commonly composted, spread on fields, given to farmers, etc..

● Advanced Wastewater Treatment
Advanced treatment involves various techniques such as sand filters to further reduce BOD and/or other potential pollutants.

● Chlorine Treatment
Chlorination of discharged wastewater is an effective way to remove pathogens but may contribute to the formation of toxins in the discharge area. Shock chlorination followed by chlorine removal can be practiced so that chlorine residues dumped into natural waters is minimized.

19.11 LAND APPLICATION OF WASTEWATER

Land application is yet another method of treating domestic wastewater. This is practiced in some areas of the U.S. and is the common means of water treatment in the Netherlands and elsewhere. In theory, it is a method of recycling the waste and nutrients back into an ecosystem, such as an agricultural ecosystem. In the Netherlands, wastewater is pumped into sand dunes where a natural filtering and biological treatment occurs, and the water is recycled back into the ground water which is used for human consumption. In rural China the waste is often used to generate methane, which is used for cooking, and is recycled back onto the agricultural fields from which the nutrients originated.

● Wastewater and Wetlands
Wastewater may be applied to either natural or constructed wetlands. This approach is useful for dealing with municipal wastewater from treatment plants and many types of contaminated industrial wastewater.

● Louisiana Coastal Wetlands
Wetland areas are highly suitable for use as advanced treatment after secondary treatment at a plant. If applied judiciously, the discharge improves plant growth. This technique also saves a great deal of money.

● Phoenix, Arizona: Constructed Wetlands
Constructed wetlands in arid areas can be used not only for treatment but as groundwater recharge zones.

19.12 WATER REUSE

Inadvertent water reuse is common and occurs when water is withdrawn, used, treated and returned to the source. Subsequent use is possible, as when water is taken from a river by a municipality and returned, only to be used again by a city downstream. Inadequate treatment of discharged waters can cause trouble further down the chain of use.

Indirect reuse results form a deliberate plan and implementation, as when wastewater is treated and recycled back into the source water for reuse.

Direct reuse occurs when treated wastewater is piped directly from a treatment plant to the next user as *reclaimed water*. There is little direct reuse of water for human consumption; most is used for other purposes such as watering golf courses.

Domestic wastewater from the laundry and sinks, termed **gray water**, can be used for watering lawns or washing cars. Some rural homes with septic systems maintain a *gray water tank* that is separate from the *black water tank*.

Chapter 19
Study Questions

1. Do you think outbreaks of waterborne diseases will be more common or less common in the future? Why? Where are outbreaks most likely to occur?

Ans: As human populations continue to grow the risk of waterborne disease outbreaks will increase. The primary water-pollution problem in the world today is the lack of clean drinking water. Each year, particularly in less-developed countries, several billion people are exposed to waterborne diseases whose effects vary in severity from an upset stomach to death. Outbreaks of waterborne diseases continue to be a threat even in developed countries.

2. What was learned from the *Exxon Valdez* oil spill that might help reduce the number of future spills and their environmental impact?

Ans: The *Exxon Valdez* spill produced an environmental shock that resulted in passage of the Oil Pollution Act of 1990 and a renewed evaluation of cleanup technology

3. What is meant by the term *water pollution*, and what are several major processes that contribute to water pollution?

Ans: Water pollution refers to degradation of water quality. In defining pollution, we generally look at the intended use of the water, how far the water departs from the norm, its effects on public health, or its ecological impacts. Water pollutants include heavy metals, sediment, certain radioactive isotopes, heat, fecal coliform bacteria, phosphorus, nitrogen, sodium, and other useful (even necessary) elements, as well as certain pathogenic bacteria and viruses. All segments of society—urban, rural, industrial, agricultural, and military—may contribute to the problem of water pollution.

4. Compare and contrast point and nonpoint sources of water pollution. Which is easier to treat, and why?

Ans: Point sources are distinct and confined sites that empty into streams or rivers. In general, point source pollutants from industries are controlled through on-site treatment or disposal and are regulated by permit. Nonpoint sources, such as runoff, are diffused and intermittent and are influenced by factors such as land use, climate, hydrology, topography, native vegetation, and geology. Nonpoint sources are difficult to monitor and control.

5. What is the two fold effect of sediment pollution?

Ans: Sediment pollution is a twofold problem: It results from erosion, which depletes a land resource (soil) at its site of origin and it reduces the quality of the water resource it enters.

6. In the summer, you buy a house with a septic system that appears to function properly. In the winter, effluent discharges at the surface. What could be the environmental cause of the problem? How could the problem be alleviated?

Ans: The most common causes are failure to pump out the septic tank when it is full of solids, and poor soil drainage, which allows the effluent to rise to the surface in wet weather. When a septic-tank drain field does fail, pollution of groundwater and surface water may result. Solutions to septic-system problems include siting septic tanks on well-drained soils, making sure systems are large enough, and practicing proper maintenance.

7. Describe the major steps in wastewater treatment (primary, secondary, advanced). Can natural ecosystems perform any of these functions? Which ones?

Ans: Primary treatment of raw sewage begins as it enters the plant from the municipal sewer line and first passes through a series of screens to remove large floating organic material. The sewage next enters the "grit chamber," where sand, small stones and grit are removed and disposed of. From there, it goes to the primary sedimentation tank, where particulate matter settles out to form sludge. Secondary treatment involves activated sludge, it uses living organisms—mostly bacteria. In this procedure, the wastewater from the primary sedimentation tank enters the aeration tank where it is mixed with air (pumped in) and with some of the sludge from the final sedimentation tank. The sludge contains aerobic bacteria that consume organic material (BOD) in the waste. The wastewater then enters the final sedimentation tank, where sludge settles out. Advanced treatments are specifically designed treatments, such as sand filters, carbon filters, and chemicals applied to assist in the removal process of specific pollutants. At a slower rate natural ecosystems could digest the sludge and consume organic material.

8. How does water that drains from coal mines become contaminated with sulfuric acid? Why is this an important environmental problem?

Ans: Coal and the rocks containing coal are often associated with a mineral known as fool's gold or pyrite (FeS_2), which is iron sulfide. When the pyrite comes into contact with oxygen and water, it weathers. A product of the chemical weathering is sulfuric acid. The acid is produced when surface water or shallow groundwater runs through or moves into and out of mines or tailings. If the acidic water runs off to a natural stream, pond, or lake, significant pollution and ecological damage may result. The acidic water is toxic to the plants and animals of an aquatic ecosystem; it damages biological productivity, and fish and other aquatic life may die. Acidic water can also seep into and pollute groundwater.

9. What is eutrophication, and why is it an ecosystem effect?

Ans: Eutrophication is the process by which a body of water develops a high concentration of nutrients, such as nitrogen and phosphorus .The nutrients increase the growth of aquatic plants in general, as well as production of photosynthetic blue-green bacteria and algae. The bacteria and algae die, and as they decompose, BOD increases, reducing the water's oxygen content, sometimes to the point where other organisms, such as fish, will die. They die not from phosphorus poisoning but from a chain of events that started with the input of phosphorus and affected the whole ecosystem. This is what we call an ecosystem effect.