Chapter 18 – Water Pollution

Key Terms

atmospheric deposition
biological oxygen demand
cultural eutrophication
dissolved oxygen
effluent sewerage
eutrophic
fecal coliforms
nonpoint source
oligotrophic
oxygen sag curve
point source
primary water treatment
red tide
secondary water treatment
tertiary water treatment
total maximum daily loads

Skills

1. Characterize the different types of water pollutants, including their source, environmental impact, and human health effects.
2. Relate sewage treatment and drinking water quality to health, safety, and quality of life.
3. Summarize the quality of water in developed and developing countries.
4. Recall contamination problems associated with groundwater.
5. Identify and describe the major ocean pollutants.
6. Appraise the effectiveness of the Clean Water Act and the Safe Drinking Water Act.

> **Take Note:** You must be familiar with the common water pollutants, their origin and impacts on the environment and human health, as well as ways to remediate the pollutant. For example, one essay question expected students to understand how mercury entered aquatic ecosystems, where the mercury originated, how the mercury could be prevented from entering the ecosystem, and the impacts of bioaccumulation of mercury.

Water Pollution

For generations, Americans dumped toxic chemicals, wastes, solvents, and sewage into rivers and lakes. To protect our waterways, President Nixon signed the Clean Water Act in 1972. The act has been modified several times, but the main goal is to protect surface and groundwater from pollutants. Pollutants are any physical, chemical, or biological changes in water quality that adversely affects living organisms.

Point source pollution is any pollution derived from an easily identifiable source, such as a drain pipe, smoke stack, or factory. Nonpoint source pollution lacks an easily identifiable source. Examples include agricultural runoff, construction site runoff, urban storm runoff, and feedlot runoff. Atmospheric deposition of chemicals may also be considered nonpoint source pollution.

Flowing water systems resist contamination by pollutants because the flowing water tends to dilute and distribute the pollutant. The rate at which the system can clean itself is related to the volume of the river, the rate at which the river flows, and the temperature of the river. A standing water system is far more susceptible to damage because there is no way for the pollutant to flow away.

Take Note: It is imperative that you are familiar with the tests conducted on water to determine water quality. For example, past AP essays have asked students to identify and describe water tests that explain the water quality of a particular body of water. You must be able to differentiate between physical, chemical, and biological water tests and know if those tests are biotic or abiotic.

Water Quality Tests

Numerous tests may be conducted upon water to determine the quality. The turbidity, or cloudiness, of the water will be an indicator of the ability of the algae and emergent vegetation to carry out photosynthesis. The turbidity is increased due to sediment pollution. The color of the water may also play a role. Water that contains a lot of tannins from leaves cause the water to be very dark, and such water is called "black water." Dark water may impair photosynthetic activity. The pH level of water can be taken to determine if the water is too acidic or basic. Extreme pH levels will kill sensitive species. Salinity plays a role in water quality. The levels of magnesium and calcium ions, or the measure of hardness in fresh water, can also be determined. The levels of the inorganic nutrients nitrates and phosphates can be measured to determine water quality. The level of dissolved oxygen (DO) can be measured. The DO levels will determine the animal species capable of surviving in an aquatic ecosystem. The biological oxygen demand, BOD, can be measured as well. The BOD is the amount of oxygen required to sustain an aquatic system. The BOD will rise in the presence of decomposing organic matter (known as oxygen demanding wastes), resulting in a decrease in the DO. Several other factors affect levels of dissolved oxygen. For example, temperature is influential because cold water retains more oxygen than warmer water. Light penetration, turbidity, and color also affect DO because with more light there is more photosynthesis, hence more available oxygen. Turbulence increases the DO levels due to the mixing of atmospheric oxygen into the water. The presence of moderate amounts of submerged vegetation, emergent vegetation, and algae increases the DO.

Analysis of the levels of benthic macroinvertebrates may also be done to determine water quality. In studies of stream benthic macroinvertebrates, mayfly, dobsonfly, and caddisfly larvae are indicative of excellent water quality whereas the presence of blood worms, leeches, and pouch snails are indicative of poor water quality. Many species of fish are sensitive to pollutants or poor water quality and will not be present in contaminated areas. The biodiversity of an area can be assessed to determine if contamination is occurring. Fecal coliform counts may also be made on water sources to determine if fecal contamination is occurring. Fecal coliforms are bacteria such as *Escherichia coli* (*E. coli*), an inhabitant of human intestines. The coliforms are not necessarily dangerous, but their presence indicates contamination with human or animal wastes that may contain pathogenic organisms. Drinking water may not contain any coliforms, and swimming water may not contain more than 200 coliforms in 100 ml of water tested. Beaches, lakes, rivers, and swimming pools are closed if the fecal coliforms exceed safe swimming levels and only reopen when the levels drop to an acceptable amount.

An oxygen sag curve illustrates the changes that occur in a flowing system when oxygen demanding wastes are added. The area upstream of the wastes exhibits good water quality, but when the wastes are added, the DO drops due to the increased BOD, resulting in a dramatic shift in biodiversity. As the water flows, the system slowly recovers back to its original state.

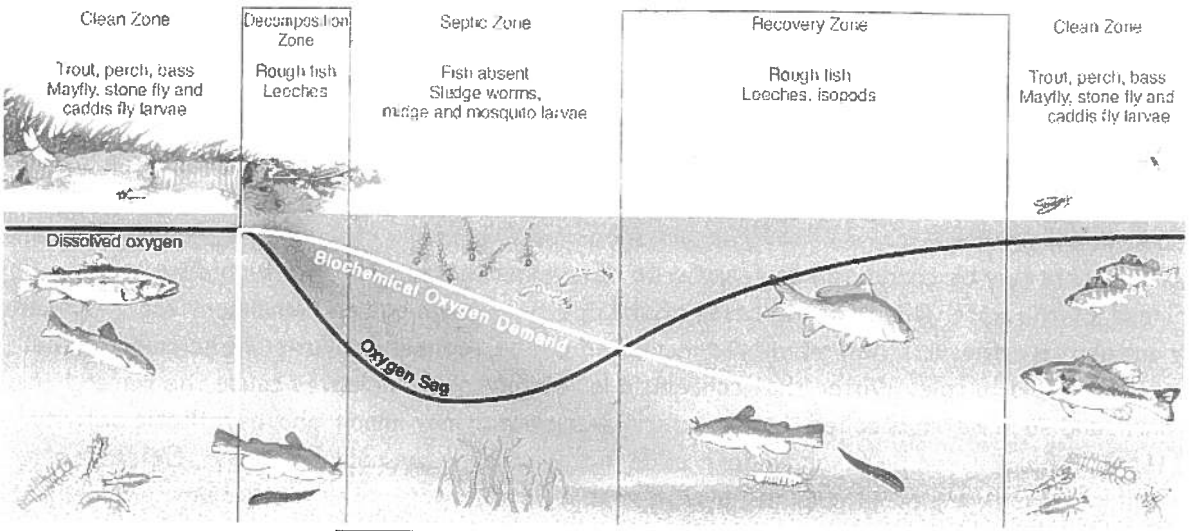

Figure 18.1 Oxygen sag curve

Types of Water Pollutants

Sediment pollution is the greatest pollutant by volume in aquatic systems. The sediment arises primarily from erosion of the land surrounding the water. This erosion may arise from mining, deforestation, rangeland, construction, and agriculture. Sediment may cover gravel where fish lay their eggs and may clog the gills of filter feeders. Sediment increases the turbidity, which impairs photosynthesis.

Pathogenic organisms are the water pollutants that pose the greatest threat to human health. Waterborne diseases include typhoid, cholera, hepatitis A, polio, schistosomiasis, and a variety of dysentery diseases. Mosquitoes that breed in water transmit dengue, malaria, yellow fever, and a variety of encephalitis viruses. Human wastes are the main source of these pathogens, but animal wastes from feedlots or food processing plants may also increase these bacteria in water supplies. In developed countries sewage treatment is readily available, and drinking water is treated to kill pathogens prior to its dispersal to the public. It is estimated that 2.5 billion people lack adequate sanitation in developing countries and over 1 billion lack safe drinking water.

Water can also be contaminated by excessive amounts of nutrients. A body of water low in nutrients is called oligotrophic, and a body of water high in nutrients is called eutrophic. The process of a body of water proceeding from nutrient poor state to a eutrophic state is called eutrophication and is a natural occurrence. When humans exacerbate the rate at which the water becomes eutrophic, it is called cultural eutrophication. Cultural eutrophication is typically caused by excess nutrients from fertilizer runoff or sewage. When excess nutrients are present, they induce an algal bloom. These algae cover the water so thickly that sunlight cannot penetrate to the bottom vegetation and lower algae, which kills them. Their decay, which increases the BOD, consumes oxygen required for aerobic heterotrophs to survive due to the hypoxic state of the water. These animals die, requiring further decay, thus consuming more oxygen in a positive feedback cycle. The sewage contamination also consumes oxygen due to the higher BOD. Another type of algal bloom

associated with runoff is red tide. Red tide is a proliferation of certain species of dinoflagellates. These algae release a toxin lethal to numerous species of fish and has been attributed to killing West Indian Manatees in Florida. The toxin is an irritant to human eyes and respiratory systems. A noted red tide agent, *Pfiesteria piscicida*, even attaches directly to fish and kills them.

Inorganic pollutants are common in aquatic systems. These pollutants include metals, acids, bases, and salts. The heavy metals, including mercury, lead, tin, and cadmium are of great concern as are the super toxic metals selenium and arsenic. The heavy metals are persistent and tend to bioaccumulate and biomagnify. These metals typically arise from mining, mine waste, and smelting. Mercury is added to the atmosphere by coal combustion, incineration, and smelting. Cadmium increases due to mining and smelting. Tin was used on ships as an antifouling agent until its use was banned due to concerns of toxicity. Lead is the heavy metal contaminant that has declined dramatically in the United States since the banning of leaded gasoline, leaded paint, and lead pipes and solder. The maximum legal level of lead in drinking water is 20 ppb.

The nonmetallic salts are dangerous because they are soluble in water. Salts that contain selenium and arsenic build up to dangerous levels in desert ecosystems. Irrigation has increased the salt levels in some areas. In the northern United States, road salt is used to melt ice on bridges and roads. This corrosive salt makes its way into ecosystems.

Acids arise from smelting, metal plating, petroleum distillation, and coal mining (acid mine drainage). Acids also form in the atmosphere from the gases released during fossil fuel combustion. Older soils or soils derived from igneous rock cannot buffer the acid in ecosystems, but limestone and other carbonate rocks have the ability to decrease the impact of acids in aquatic systems. If the pH drops too low, biodiversity is limited to acid-resistant mosses. The acidic conditions also make aluminum more soluble, thus increasing its toxicity.

Synthetic organic chemicals also contaminate aquatic systems. Some of the examples of these chemicals include DDT, dioxins, PCBs, and other chlorinated hydrocarbon chemicals. The two main sources of these chemicals are improper waste disposal and agricultural and urban pesticide runoff.

Thermal pollution, or thermal shock, is due to the heating of water, which is then expelled back into surface water systems. This water is used to cool plants that use steam turbines to generate electricity or to cool other heat-producing industrial processes. The heated water has a negative impact on temperature sensitive species, usually organisms that occupy lower trophic levels. The hotter water also decreases the levels of DO in the water. Larger animals, such as game fish, birds, and manatees, thrive in the warm water effluent from such processes. Water may also increase in temperature when humans remove the existing vegetation from around a body of water. To prevent thermal shock, many power plants have cooling ponds or towers that cool the water prior to being released into natural systems.

Current Water Quality

The Clean Water Act was passed in 1972 and amended in 1977 to decrease pollution in U.S. waters. The act established discharge permits for waste dumping in surface waters. The purpose of the permits was to decrease water pollution from industry or municipal point sources, particularly from

sewage treatment plants. The act also required best practicable control technology and set best available economically achievable technology goals for toxics and other pollutants.

The act allows the EPA to set wastewater standards for industry and set limits on pollutants. The act also has been used to protect wetlands, because it regulates the draining and filling of wetlands. In 1998, the EPA began to focus on watershed quality in order to protect surface water from contamination. States have to identify bodies of water that do not meet goals and develop total maximum daily loads (TMDLs) on each pollutant for each body of water. Future TMDLs will include pollution from acid deposition and background pollutants.

Developing countries and poorly developed countries do not spend money on sewage treatment, and many countries do not adequately provide safe drinking water. As a result, deaths from infectious disease remain high, particularly in the young.

Groundwater Quality

About half of the U.S. drinking water is derived from groundwater. In the past it was believed that percolation of water through soil as it moved into groundwater reserves purified the water. We know now that contaminants frequently remain in water and are therefore even more difficult to treat. Currently in the United States, groundwater may be contaminated by fertilizers and pesticides. Nitrates are extremely dangerous for infants to ingest, as it impairs their ability to carry oxygen. Aging underground storage tanks contaminate groundwater with a variety of chemicals including gasoline. The gasoline additive MTBE promotes complete combustion and therefore reduces CO and VOC emissions from automobile exhaust. Unfortunately MTBE is a suspected carcinogen that readily enters groundwater and does not degrade in the anoxic conditions in an aquifer. Leachate from landfills also enters groundwater if adequate precautions are not taken.

Ocean Pollution

Major contaminants in ocean waters are plastics and oil. Plastics kill organisms directly by wrapping around their bodies or by blocking their digestive systems when ingested. Plastics that are bio- or photodegradable are not as dangerous to marine life because they break down more rapidly than regular plastics. Oil originates naturally from seepage, but also is derived from bilge pumping, oil rigs, tanker accidents, and tank cleaning. Land is also a source of oil because urban runoff contains oil and gasoline. The 1990 London Dumping Convention proposed the Law of the Sea Treaty, which states that industrial waste, tank washing effluent, and plastic trash could not be dumped in the ocean after 1995. There are 64 countries, including the United States, that have agreed to the treaty.

Control of Water Pollution

The most inexpensive way to control water pollution is to prevent it. Many pollutants, such as lead in gasoline and DDT, have been banned due to their toxicity and therefore are no longer a threat to U.S. waterways. Nonpoint sources of pollution are difficult to control. Agriculture runoff contains pesticides, fertilizer, sediment, and animal wastes from feedlots. Urban runoff contains pesticides,

fertilizer, sediment, oil, salts, heavy metals, and pet fecal matter. Construction sites result in sediment pollution. To prevent nonpoint pollution of waterways, best management practices have been developed. For example, animal wastes may be collected in a lagoon and the water passed through a wetland to remove bacteria and excess nutrients prior to discharge into open water. Applying only necessary levels of pesticides and fertilizers will result in decreasing amounts of these materials in runoff. Streets may be swept regularly to prevent trash and oils from entering urban runoff.

The Comprehensive Environmental Response, Compensation, and Liability Act (Superfund Act) and the subsequent Superfund Amendments and Reauthorization Act of 1984 provides funding for cleanup of contaminated abandoned sites that may be affecting water quality.

Sewage Treatment

In many countries with a low-population density, sewage treatment is unnecessary. In areas with high-population densities, treatment is necessary to prevent the transmission of disease. A lack of adequate sanitation in Mexico City, coupled with a burgeoning population, has resulted in fecal snow. Fecal snow is dried human fecal matter that becomes airborne particulate matter. Human feces are often used in developing countries as a source of fertilizer. These feces can carry infectious disease, and thus ingesting fruits and vegetables grown in these areas may be hazardous to one's health. In the U.S. outhouses were common until the 1950s, when septic tank systems and their drainage fields allowed for individual homes to treat wastes without risk of disease or contaminating groundwater.

Septic tanks function by receiving wastes from a household. Oils and grease float to the top and the solids fall to the bottom, where they undergo decomposition. The liquids flow through a series of pipes under the ground and are aerated to kill the usually anaerobic pathogens. The liquids are then taken up by the surrounding soils. The septic tanks must be pumped out occasionally to remove the solids.

Some areas are using effluent sewerage, which has a tank to digest solid waste but instead of using a drainfield for the effluent, the effluent is pumped to a treatment plant. Other areas release wastes directly into a constructed wetland to remove the wastes.

When population densities increase, sewage treatment plants are required to handle the large amount of human wastes. Storm sewers may combine with sanitary sewage forming combined sewer systems. There are two stages that occur in sewage treatment and a third is employed in many areas. The first stage is called primary treatment (Figure 18.2, a). The primary treatment removes the solid portion of the wastes in a mechanical process. The first step is to pass the sewage through grates to removed large debris like rags. A grit tank follows, which allows the large bits of sand and gravel to settle. These grit tanks are important in areas where a combined sewer system is present. The next step is to remove the organic solids separate from the liquid portion by allowing the solids to settle in a settling tank as sludge. Secondary treatment (b) involves removing the dissolved organic components of the wastes using bacteria. Several different methods exist for secondary treatment. The trickling filter bed passes the liquid portion of the waste over a layer of stones covered in bacteria, which degrade the organic material in the wastes. The aeration

tank digestion, also called activated sludge process, mixes the effluent from the primary treatment with bacteria and oxygen to promote decomposition of the wastes. The effluent from the secondary treatment is then disinfected with chlorine, ozone, or UV light to remove bacteria and then released into a nearby waterway.

Tertiary water treatment (c) involves running the secondary treatment effluent through a wetland to remove the excess nutrients such as nitrates and phosphates.

In some areas, the effluent from the secondary treatment is processed a bit farther, then sent out, under pressure, to homes to be used for watering yards. This water is known as reclaimed water and solves several water issues. The reclaimed water does not require effluent entering surface water supplies. It also allows slow recharge of groundwater by allowing the water to trickle through the soil of the lawns on which it is being used. Potable water is not being used to water yards.

The sewage sludge was once dumped into the ocean, but now is incinerated, buried in a landfill, composted, or subjected to further anaerobic digestion to be used as a soil conditioner. Toxins and heavy metals in the sludge determine its final fate, because toxic materials are not suitable as compost or soil conditioners.

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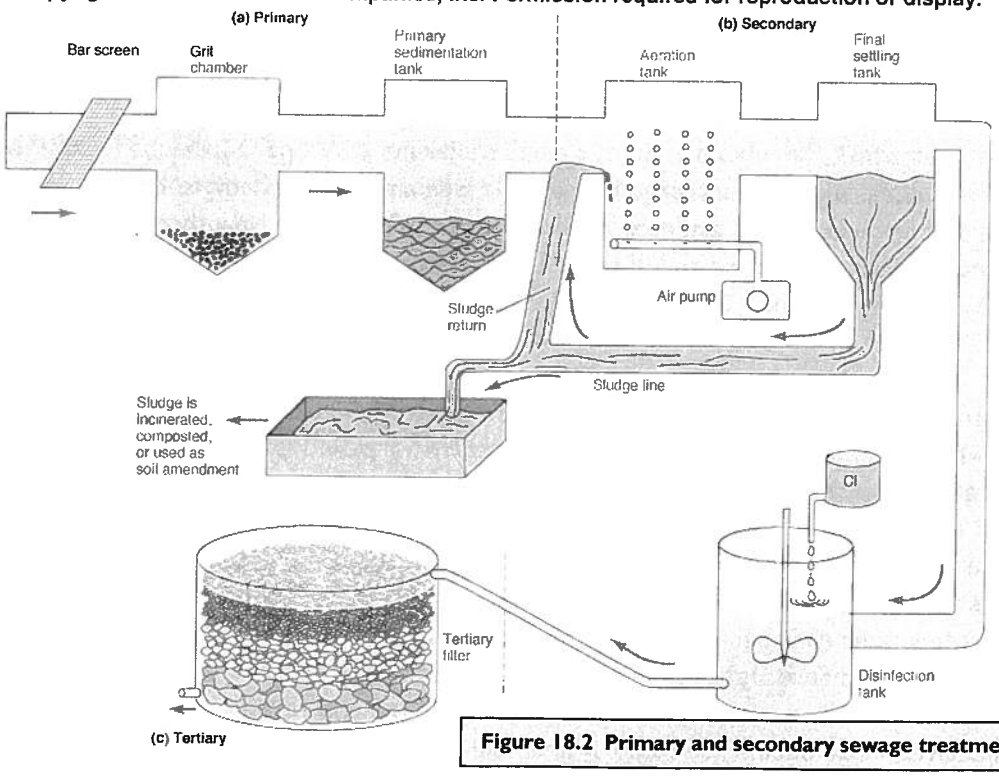


Figure 18.2 Primary and secondary sewage treatment

Potable water

Potable, or drinking, water is managed under the Safe Drinking Water Act, which regulates water quality in commercial and municipal systems. In accordance with the act, the EPA has set maximum contaminant levels for 90 different pollutants in drinking water. To generate potable water, the

first step is to clarify the water by adding coagulants, chemicals that will coagulate dirt and other particles by causing them to stick together and sink. The water is then passed through a filter to remove many of the disease-causing agents. The water is disinfected, usually with chlorine, to ensure the safety of the water. Water may also be disinfected using UV light or ozone. Many areas add fluoride to increase dental heath. The maximum allowable level of fluoride in drinking water is 4 mg/L as established by the EPA.

Chapter 18 Questions

Use the following for questions 1-4.

a. fecal coliforms
b. nitrates
c. atrazine
d. sediment
e. methyl mercury

1. released from combustion of coal; tends to bioaccumulate and biomagnify
2. indicator that human pathogens may be present in aquatic systems
3. broad-leaf herbicide frequently found in surface water and groundwater
4. pollutant that would induce eutrophication

Use the following for questions 5-8.

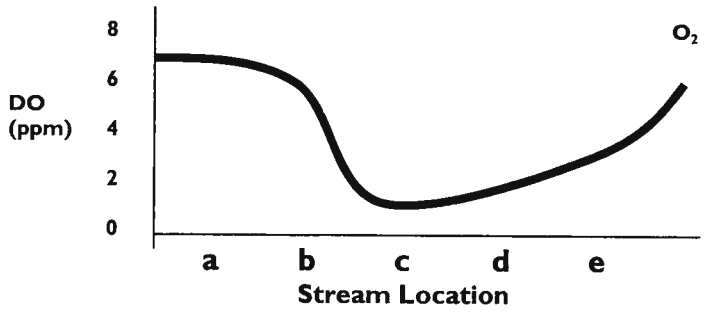
a. Biological Oxygen Demand
b. pH
c. hardness
d. turbidity
e. phosphates

5. measurement increases in the presence of sediment pollution
6. determines the concentration of hydrogen ions in an aquatic system
7. would induce eutrophication in a standing water system
8. increases when decomposition increases

9. Which of the following are biological processes in the treatment of sewage?
   I. primary sewage treatment
   II. secondary sewage treatment
   III. tertiary sewage treatment

a. I only b. II only c. III only d. I and II e. II and III

10. All of the following are point sources of pollution except.
a. heated effluent from a coal power plant cooling system.
b. a steel factory emitting carbon dioxide.
c. rain washing pesticides from a field into a nearby lake.
d. automobile exhaust pipe emitting carbon monoxide.
e. sewage effluent pipe releasing treated wastewater into surface water.



Questions 11-14 refer to the above diagram of an oxygen sag curve due to untreated human sewage.

11. Which location on the diagram indicates the highest biological oxygen demand?
12. Which location would you expect to find midgefly larvae, blackfly larvae, pouch snails, and leeches?
13. Which location would represent the introduction of untreated human sewage?
14. Which parameters would you expect to be increased at point c?

I. temperature
II. turbidity
III. pH

a. I only b. II only c. III only d. I and II e. I, II, and III

15. Feedlots contribute which of the following to surface water?

I. sediment pollution
II. fecal coliforms
III. nitrates

a. I only b. II only c. III only d. I and II e. I, II, and III

16. All of the following are persistent organic pollutants except
a. polychlorinated biphenyls. b. DDT. c. dioxins.
d. organochlorine pesticides. e. nitrates.

17. Acidification in ecosystems can arise from all of the following except
a. surface water flowing through abandoned coal mines.
b. urban runoff containing high levels of salts entering surface water systems.
c. nitrogen oxides from automobile exhaust forming nitric acid in the atmosphere.
d. sulfur dioxide from coal burning power plants forming sulfuric acid in the atmosphere.
e. rain carrying sulfur from mine tailings into surface water.

18. Nitrate levels in water are addressed by which of the following legislative acts?
    I. Safe Drinking Water Act
    II. Clean Water Act
    III. Superfund Act
a. I only b. II only c. I and II d. II and III e. I, II, and III

19. Which of the following contaminants were found in groundwater once lead was banned from gasoline?
a. mercury b. MTBE c. DDT d. nitrates e. N_2O

20. All of the following are used in the United States to dispose of sewage sludge except
a. ocean dumping. b. incineration. c. treatment to become soil conditioner.
d. compost. e. land fill burial.

Chapter 18 Answers

1. e. Methyl mercury is released from combustion of coal, and it bioaccumulates and biomagnifies.
2. a. Fecal coliforms indicate that human pathogens may be present in aquatic systems.
3. c. Atrazine is the broad-leaf herbicide frequently found in surface water and groundwater.
4. b. Nitrates, along with phosphates, are pollutants that would induce eutrophication.
5. d. Turbidity is a measurement of the cloudiness of water and therefore would increase in the presence of sediment pollution.
6. b. pH measures the concentration of hydrogen ions in an aquatic system. pH is the negative logarithm of the hydrogen ion concentration. For example, pH of 4 has an H^+ concentration of 1×10^{-4}.
7. e. Phosphates could induce eutrophication in a standing water system.
8. a. The Biological Oxygen Demand increases when decomposition increases due to the increased need for oxygen for decay.
9. e. Secondary and tertiary treatments are biological processes in the treatment of sewage. Primary treatment is a physical process.
10. c. Rain washing pesticides from a field into a nearby lake is nonpoint pollution.
11. c. The BOD is highest where the DO is the lowest because a high biological oxygen demand results in low DO.
12. c. Midgefly larvae, blackfly larvae, pouch snails, and leeches are indicative of poor water quality and would be expected at point c.
13. b. The DO begins to drop, then drops dramatically at point c, indicative of high levels of oxygen demanding wastes.
14. d. Temperature and turbidity tend to increase with high levels of oxygen demanding wastes.
15. e. Feedlots contribute sediments, coliforms, and nitrates to surface water.
16. e. Nitrates are inorganic.
17. b. Salts do not contribute to acidification.
18. c. The Superfund Act refers to cleanup of hazardous waste sites, not nitrate pollution.
19. b. MTBE began to be used as an oxygenate in fuel once lead was banned and began appearing in water supplies.
20. a. Ocean dumping is illegal in the United States.