Bacteria

Bacteria are among the simplest, smallest, and most abundant organisms on earth. Bacteria are "procaryotic" organisms- a term which indicates a cellular structure lacking an organized nucleus and nuclear membrane. Instead of containing genetic information stored on several chromosomes, bacteria contain a single strand of DNA. These organisms reproduce by binary fission, which occurs when a single cell divides to form two new cells called daughter cells. Each daughter cell contains an exact copy of the genetic information contained in the parent cell. The process continues with each daughter cell giving rise to a generation of two new cells. The generation time is the time required for a given population to double in size. This time can be as short as 20 minutes for some bacteria species (e.g., *Escherichia coli*).

While the vast majority of bacteria are not harmful, certain types of bacteria cause disease in humans and animals. Examples of waterborne diseases caused by bacteria are: cholera, dysentery, shigellosis and typhoid fever. During the London cholera epidemics of 1853-1854, Dr. John Snow observed that nearly everyone who became ill obtained their drinking water from a specific well into which a cesspool was leaking. Those who became ill either drank water from the well or came into contact with fecally contaminated material while tending those already sick.

Concerns about bacterial contamination of surface waters led to the development of analytical methods to measure the presence of waterborne bacteria. Since 1880, coliform bacteria have been used to assess the quality of water and the likelihood of pathogens being present. Although several of the coliform bacteria are not usually pathogenic themselves, they serve as an indicator of potential bacterial pathogen contamination. It is generally much simpler, quicker, and safer to analyze for these organisms than for the individual pathogens that may be present. Fecal coliforms are the coliform bacteria that originate specifically from the intestinal tract of warm-blooded animals (e.g, humans beavers, racoons, etc.). They are cultured in a special growth media and incubated at 44.5^{o} C.

The first U.S. standards for drinking water, established by the Public Health Service in 1914, were based on coliform evaluations. It was reasoned that the greatest source of human pathogens in water was from human waste. Each day, the average human excretes billions of coliform bacteria. These bacteria are present whether people are ill or healthy. Monitoring for coliform bacteria was designed to prevent outbreaks of enteric diseases, rather than to detect the presence of specific pathogens. Today, coliform bacteria concentrations are determined using methods specified by the Environmental Protection Agency (EPA) and *Standard Methods for the Examination of Water and Wastewater* (AWWA, APHA, and WEF, 20th ed., 1998).

Bacteria sources

Human sources of bacteria can enter water via either point or nonpoint sources of contamination. Point sources are those that are readily identifiable and typically discharge water through a system of pipes. Sewered communities may not have enough capacity to treat the extremely large volume of water sometimes experienced after heavy rainfalls. At such times, treatment facilities may need to bypass some of the wastewater. During bypass or other overflow events, bacteria-laden water is discharged directly into the surface water as either sanitary sewer overflow (SSO) or as combined sewer overflow (CSO). Power outages and flooding can also contribute to the discharge of untreated wastewater.

Illicit connections to storm sewers are a source of bacteria in surface waters, even during dry periods. A connection to a storm sewer is "illicit" when the wastewater requires treatment prior to discharge and should be routed to the sanitary sewer. Only storm water and certain permitted discharges (e.g. clear noncontact cooling water) should be discharged to a storm sewer.

Nonpoint sources are those that originate over a more widespread area and can be more difficult to trace back to a definite starting point. Failed on-site wastewater disposal systems (septic systems) in residential or rural areas can contribute large numbers of coliforms and other bacteria to surface water and groundwater.

Animal sources of bacteria are often from nonpoint sources of contamination. Concentrated animal feeding operations, however, are often point source dischargers. Agricultural sources of bacteria include livestock excrement from barnyards, pastures, rangelands, feedlots, and uncontolled manure storage areas. Storm water runoff from residential, rural, and urban areas can transport waste material from domestic pets and wildlife into surface waters. Land application of manure and sewage sludge can also result in water contamination, which is why states require permits, waste utilization plans, or other forms of regulatory compliance. Bacteria from both human and animal sources can cause disease in humans.

Bacteria-laden water can either leach into groundwater and seep, via subsurface flow, into surface waters or rise to the surface and be transported by overland flow. Bacteria in overland flow can be transported freely or within organic particles. Overland flow is the most direct route for bacteria transport to surface waters. Underground transport is less direct, because the movement of water and bacteria is impeded by soil porosity and permeability constraints.

Water Quality Standards for Bacteria

Rule 62 of the Michigan Water Quality Standards (Part 4 of Act 451) limits the concentration of microorganisms in surface waters of the state and surface water discharges. Waters of the state which are protected for total body contact recreation must meet limits of 130 *Escherichia coli* (*E. coli*) per 100 milliliters (ml) water as a 30-day average and 300 *E. coli* per 100 ml water at any time. The limit for waters of the state which are protected for partial body contact recreation is 1000 *E. coli* per 100 ml water.

Discharges containing treated or untreated human sewage shall not contain more than 200 fecal coliform bacteria per 100 ml water as a monthly average and 400 fecal coliform bacteria per 100 ml water as a 7-day average. For infectious organisms which are not addressed by Rule 62, The Department of Environmental Quality has the authority to set limits on a case-by-case basis to assure that designated uses are protected.

Bacteria Effluent Limitations in NPDES Permits

Wastewater treatment plants which discharge to waters of the state are required to monitor for fecal coliform bacteria on a frequent basis and must comply with the limits of 200 fecal coliform bacteria per 100 ml water as a monthly average and 400 fecal coliform bacteria per 100 ml water as a 7-day average. Other types of facilites may also receive monitoring requirements and/or limits for fecal coliform bacteria. Limits are necessary if there is a potential for bacteria in the facility's discharge to cause waterborne disease or nuisance conditions.

Bacteria numbers can be effectively reduced by disinfection procedures including chlorination and ozonation. If chlorine is used for disinfection, the treated wastewater must be dechlorinated prior to discharge to protect fish and other aquatic life.

Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand, or BOD, is a measure of the quantity of oxygen consumed by microorganisms during the decomposition of organic matter. BOD is the most commonly used parameter for determining the oxygen demand on the receiving water of a municipal or industrial discharge. BOD can also be used to evaluate the efficiency of treatment processes, and is an indirect measure of biodegradable organic compounds in water.

Imagine a leaf falling into a stream. The leaf, which is composed of organic matter, is readily degraded by a variety of microorganisms inhabiting the stream. Aerobic (oxygen requiring) bacteria and fungi use oxygen as they break down the components of the leaf into simpler, more stable end products such as carbon dioxide, water, phosphate and nitrate. As oxygen is consumed by the organisms, the level of dissolved oxygen in the stream begins to decrease

Water can hold only a limited supply of dissolved oxygen and it comes from only two sources- diffusion from the atmosphere at the air/water interface, and as a byproduct of photosynthesis. Photosynthetic organisms, such as plants and algae, produce oxygen when there is a sufficient light source. During times of insufficient light, these same organisms consume oxygen. These organisms are responsible for the diurnal (daily) cycle of dissolved oxygen levels in lakes and streams.

If elevated levels of BOD lower the concentration of dissolved oxygen in a water body, there is a potential for profound effects on the water body itself, and the resident aquatic life. When the dissolved oxygen concentration falls below 5 milligrams per liter (mg/l), species intolerant of low oxygen levels become stressed. The lower the oxygen concentration, the greater the stress. Eventually, species sensitive to low dissolved oxygen levels are replaced by species that are more tolerant of adverse conditions, significantly reducing the diversity of aquatic life in a given body of water. If dissolved oxygen levels fall below 2 mg/l for more than even a few hours, fish kills can result. At levels below 1 mg/l, anaerobic bacteria (which live in habitats devoid of oxygen) replace the aerobic bacteria. As the anaerobic bacteria break down organic matter, foul-smelling hydrogen sulfide can be produced.

BOD is typically divided into two parts- carbonaceous oxygen demand and nitrogenous oxygen demand. Carbonaceous biochemical oxygen demand (CBOD) is the result of the breakdown of organic molecules such a cellulose and sugars into carbon dioxide and water. Nitrogenous oxygen demand is the result of the breakdown of proteins. Proteins contain sugars linked to nitrogen. After the nitrogen is "broken off" a sugar molecule, it is usually in the form of ammonia, which is readily converted to nitrate in the environment. The conversion of ammonia to nitrate requires more than four times the amount of oxygen as the conversion of an equal amount of sugar to carbon dioxide and water.

When nutrients such as nitrate and phosphate are released into the water, growth of aquatic plants is stimulated. Eventually, the increase in plant growth leads to an increase in plant decay and a greater "swing" in the diurnal dissolved oxygen level. The result is an increase in microbial populations, higher levels of BOD, and increased oxygen demand from the photosynthetic organisms during the dark hours. This results in a reduction in dissolved oxygen concentrations, especially during the early morning hours just before dawn.

In addition to natural sources of BOD, such as leaf fall from vegetation near the water's edge, aquatic plants, and drainage from organically rich areas like swamps and bogs, there are also anthropogenic (human) sources of organic matter. If these sources have identifiable points of discharge, they are called point sources. The major point sources, which may contribute high levels of BOD, include wastewater treatment facilities, pulp and paper mills, and meat and food processing plants.

Organic matter also comes from sources that are not easily identifiable, known as nonpoint sources. Typical nonpoint sources include agricultural runoff, urban runoff, and livestock operations. Both point and nonpoint sources can contribute significantly to the oxygen demand in a lake or stream if not properly regulated and controlled.

Performing the test for BOD requires significant time and commitment for preparation and analysis. The entire process requires five days, with data collection and evaluation occurring on the last day. Samples are initially seeded with microorganisms and saturated with oxygen (Some samples, such as those from sanitary wastewater treatment plants, contain natural populations of microorganisms and do not need to be seeded.). The sample is placed in an environment suitable for bacterial growth (an incubator at 20^{o} Celsius with no light source to eliminate the possibility of photosynthesis). Conditions are designed so that oxygen will be consumed by the microorganisms. Quality controls, standards and dilutions are also run to test for accuracy and precision. The difference in initial DO readings (prior to incubation) and final DO readings (after 5 days of incubation) is used to determine the initial BOD concentration of the sample. This is referred to as a BOD_5 measurement. Similarly, carbonaceous biochemical oxygen test performed using a 5-day incubation is referred to as a $CBOD_5$ test.

Water Quality Standards for BOD

Although there are no Michigan Water Quality Standards pertaining directly to BOD, effluent limitations for BOD must be restrictive enough to insure that the receiving water will meet Michigan Water Quality Standards for dissolved oxygen.

Rule 64 of the Michigan Water Quality Standards (Part 4 of Act 451) includes minimum concentrations of dissolved oxygen that must be met in surface waters of the state. This rule states that surface waters designated as coldwater fisheries must meet a minimum dissolved oxygen standard of 7 mg/l, while surface waters protected for warmwater fish and aquatic life must meet a minimum dissolved oxygen standard of 5 mg/l.

Biochemical Oxygen Demand Limitations in NPDES Permits

Typically, $CBOD_5$ limits are placed in NPDES permits for all facilities which have the potential to contribute significant quantities of oxygen consuming substances to waters of the state. These limits are developed in direct correlation with limits for ammonia nitrogen and dissolved oxygen. The nitrogenous oxygen demand is computed separately because of the difference in oxygen demand (as explained above) and because the rate of oxygen consumption over time varies from carbonaceous oxygen demand. Ammonia is further considered separately because in sufficient levels (dependant upon several variables) it can also be toxic to living organisms.

In determining $CBOD_5$ limits, stream modelers use computer models which simulate actual stream conditions. Model inputs include the flow of the receiving stream, the quantity of water to be discharged, the decay rate for the particular type of wastewater, the stream's slope, and temperature. Other upstream or downstream dischargers are also considered in the model. The modeler determines maximum limits for $CBOD_5$ and ammonia nitrogen and minimum limits for dissolved oxygen. These limits are selected to insure that Water Quality Standards for dissolved oxygen are met in the receiving water.

Dissolved Oxygen

Dissolved oxygen (DO) refers to the volume of oxygen that is contained in water. Oxygen enters the water as rooted aquatic plants and algae undergo photosynthesis, and as oxygen is transferred across the air-water interface. The amount of oxygen that can be held by the water depends on the water temperature, salinity, and pressure. Gas solubility increases with decreasing temperature (colder water holds more oxygen). Gas solubility increases with decreasing salinity (freshwater holds more oxygen than does saltwater). Both the partial pressure and the degree of saturation of oxygen will change with altitude . Finally, gas solubility decreases as pressure decreases. Thus, the amount of oxygen absorbed in water decreases as altitude increases because of the decrease in relative pressure.

Once absorbed, oxygen is either incorporated throughout the water body via internal currents or is lost from the system. Flowing water is more likely to have high dissolved oxygen levels compared to stagnant water because the water movement at the air-water interface increases the surface area available to absorb the oxygen. In flowing water, oxygen-rich water at the surface is constantly being replaced by water containing less oxygen as a result of turbulence, creating a greater potential for exchange of oxygen across the air-water interface. Because stagnant water undergoes less internal mixing, the upper layer of oxygen-rich water tends to stay at the surface, resulting in lower dissolved oxygen levels throughout the water column. Oxygen losses readily occur when water temperatures rise, when plants and animals respire (breathe), and when aerobic microorganisms decompose organic matter.

Oxygen levels are also affected by the diurnal (daily) cycle. Plants, such as rooted aquatic plants and algae produce excess oxygen during the daylight hours when they are photosynthesizing. During the dark hours they must use oxygen for life processes.

Dissolved oxygen may play a large role in the survival of aquatic life in temperate lakes and reservoirs during the summer months, due to a phenomenon called stratification (the formation of layers). Seasonal stratification occurs as a result of water's temperature-dependent density. As water temperatures increase, the density decreases. Thus, the sun-warmed water will remain at the surface of the water body (forming the epilimnion), while the more dense, cooler water sinks to the bottom (hypolimnion). The layer of rapid temperature change separating the two layers is called the thermocline.

At the beginning of the summer, the hypolimnion of the lake will contain more dissolved oxygen because colder water holds more oxygen than warmer water. However, as time progresses, an increased number of dead organisms from the epilimnion sink to the bottom and are broken down by microorganisms. Continued microbial decomposition eventually results in an oxygen-deficient hypolimnion. If the lake has high concentrations of nutrients, this process may be accelerated. When the growth rate of microorganisms is not limited by a specific nutrient, such as phosphorus, the dissolved oxygen in the lake could be depleted before the summer's end.

Microbes play a key role in the loss of oxygen from surface waters. Microbes use oxygen as energy to break down long-chained organic molecules into simpler, more stable end-products such as carbon dioxide, water, phosphate and nitrate. As the organic molecules are broken down by microbes, oxygen is removed from the system and must be replaced by exchange at the air-water interface.

Each step above results in consumption of dissolved oxygen. If high levels of organic matter are present in a water, microbes may use all available oxygen. This does not mean, however, that the removal of microbes from the ecosystem would solve this problem. Although microbes are responsible for decreasing levels of dissolved oxygen, they play a very important role in the aquatic ecosystem. If dead matter is not broken down it will "pile up," much as leaves would if they were not broken down each year.

The introduction of excess organic matter may result in a depletion of oxygen from an aquatic system. Prolonged exposure to low dissolved oxygen levels (less than 5 to 6 mg/l oxygen) may not directly kill an organism, but will increase its susceptibility to other environmental stresses. Exposure to less than 30% saturation (less than 2 mg/l oxygen) for one to four days may kill most of the aquatic life in a system.

If all oxygen is depleted, aerobic (oxygen-consuming) decomposition ceases and further organic breakdown is accomplished anaerobically. Anaerobic microorganisms obtain energy from oxygen bound to other molecules such as nitrates and sulfates. The oxygen-free conditions result in the mobilization of many otherwise insoluble compounds. As sulfate compounds break down, the water may smell like rotten eggs.

Low dissolved oxygen levels may occur during warm, stagnant conditions that prevent mixing. In addition, high natural organic levels will often cause a depletion of dissolved oxygen.

Water Quality Standards for Dissolved Oxygen

Rule 64 of the Michigan Water Quality Standards (Part 4 of Act 451) includes minimum concentrations of dissolved oxygen which must be met in surface waters of the state. This rule states that surface waters designated as coldwater fisheries must meet a minimum dissolved oxygen standard of 7 mg/l, while surface waters protected for warmwater fish and aquatic life must meet a minimum dissolved oxygen standard of 5 mg/l.

Dissolved Oxygen Limitations in NPDES Permits

Dissolved oxygen limits are placed in many NPDES permits, to ensure that the minimum levels are met. These limits are developed along with limits for biochemical oxygen demand (BOD) and ammonia nitrogen. BOD is the measure of the oxygen needed to degrade organics in the water column. Ammonia is of concern because it is converted to nitrate (a nitrogen-oxygen compound) by bacteria in the water column, a process which results in the consumption of oxygen. By insuring that levels of BOD and ammonia nitrogen are sufficiently low, and levels of dissolved oxygen are sufficiently high, these limits together play an important role in protecting our surface waters.

Dissolved oxygen limits are commonly placed in permits for discharges which have the potential to exert an oxygen demand. These types of discharges include effluent from wastewater treatment plants, food processing and manufacturing operations and landfills. Dissolved oxygen limits are not necessary for all permits, such as discharges of clear noncontact cooling water, where levels of dissolved oxygen are expected to be high.

Treatment plants can keep levels of dissolved oxygen in their effluent high by proper aeration. This is accomplished by adding bubbles of oxygen, or running the water over rocks or "steps" to increase the transfer of oxygen across the air-water interface.

pH

Water (H_20) contains both hydrogen (H+) and hydroxyl (OH-) ions. The pH of water is a measurement of the concentration of H+ ions, using a scale that ranges from 0 to 14. A pH of 7 is considered "neutral", since concentrations of H+ and OH- ions are equal. Liquids or substances with pH measurements below 7 are considered "acidic", and contain more H+ ions than OH- ions. Those with pH measurements above 7 are considered "basic" or "alkaline," and contain more OH- ions than H+ ions. For every one unit change in pH, there is approximately a ten-fold change in acidity or alkalinity. Therefore, a pH of 4 is 10 times more acidic than a pH of 5. Similarly, a pH of 9 is 10 times more alkaline than a pH of 8 and 100 times more alkaline than a pH of 7. Pure deionized water is neutral, with a pH of 7.

Natural water usually has a pH between 6.5 and 8.5. While there are natural variations in pH, many pH variations are due to human influences. Fossil fuel combustion products, especially automobile and coal-fired power plant emissions, contain nitrogen oxides and sulfur dioxide, which are converted to nitric acid and sulfuric acid in the atmosphere. When these acids combine with moisture in the atmosphere, they fall to earth as acid rain or acid snow. In some parts of the United States, especially the Northeast, acid rain has resulted in lakes and streams becoming acidic, resulting in conditions which are harmful to aquatic life. The problems associated with acid rain are lessened if limestone is present, since it is alkaline and neutralizes the acidity of the water.

Most aquatic plants and animals are adapted to a specific pH range, and natural populations may be harmed by water that is too acidic or alkaline. Immature stages of aquatic insects and young fish are extremely sensitive to pH values below 5. Even microorganisms which live in the bottom sediment and decompose organic debris cannot live in conditions which are too acidic. In very acidic waters, metals which are normally bound to organic matter and sediment are released into the water. Many of these metals can be toxic to fish and humans. Below a pH of about 4.5, all fish die.

Water Quality Standards for pH

Rule 53 of the Michigan Water Quality Standards (Part 4 of Act 451) states that the hydogen ion concentration expressed as pH shall be maintained within the range of 6.5 to 9.0 in all waters of the state.

Effluent Limitations for pH in NPDES Permits

Wastewater treatment plants and most industrial facilities which discharge to waters of the state are required to monitor for pH on a frequent basis. Limits are usually 6.5 as a daily minimum and 9.0 as a daily maximum. Limits for pH are not necessary for all permits, such as discharges of clear noncontact cooling water, which are expected to have pH levels between 6.5 and 9.0 without treatment.

Phosphorus

Phosphorus (P) is an essential nutrient for all life forms, and is the eleventh-most abundant mineral in the earth's crust. In surface waters, phosphorus is usually present as phosphate (PO_4-P). Phosphorus is needed for plant growth and is required for many metabolic reactions in plants and animals. Organic phosphorus is a part of living plants and animals, their by-products, and their remains. Generally, phosphorus is the limiting nutrient in freshwater aquatic systems. That is, if all phosphorus is used, plant growth will cease, no matter how much nitrogen is available.

Phosphorus typically functions as the "growth-limiting" factor because it is usually present in very low concentrations. The natural scarcity of phosphorus can be explained by its attraction to organic matter and soil particles. Any unattached or "free" phosphorus is quickly removed from the aquatic system by algae and larger aquatic plants. Excessive concentrations of phosphorus can quickly cause extensive growth of aquatic plants and algal blooms. Several detrimental consequences may result.

Excessive algae and plant growth can lead to depletion of the oxygen that is dissolved in the water. Water can hold only a limited supply of dissolved oxygen (DO) and it comes from only two sources- diffusion from the atmosphere and as a byproduct of photosynthesis. Excessive growth leads to depletion of DO because of nighttime respiration by living algae and plants and because of the bacterial decomposition of dead algae/plant material. Depletion of DO adversely affects many animal population and can cause fish kills.

In addition to low DO problems, excessive plant growth can increase the pH of the water because plants and algae remove dissolved carbon dioxide from the water during photosynthesis, thus altering the carbonic acid-carbonate balance. Because plants and algae provide food and habitat to animals, the relative abundance of species affects the composition of the animal community. Drinking water supplies may experience taste and odor problems, and the costs of treating drinking water can increase.

Finally, high nutrient concentrations interfere with recreation and aesthetic enjoyment of water resources by causing reduced water clarity, unpleasant swimming conditions, objectionable odors, blooms of toxic and nontoxic organisms, interference with boating, and "polluted appearances." The economic implications are significant for many communities.

Phosphorus may accumulate in bottom sediment, both in deposited clays and silts and deposited organic matter. In such cases, phosphorus and other nutrients may be released from the sediment in the future. This results in an internal phosphorus loading. Because of this phenomenon, a reduction in phosphorus inputs may not be effective in reducing algal blooms for a number of years.

Phosphorus enters surface waters from both point and nonpoint sources. The primary point source of phosphorus is sewage treatment plants. A normal adult excretes 1.3 - 1.5 g of phosphorus per day. Additional phosphorus originates from the use of industrial products, such as toothpaste, detergents, pharmaceuticals, and food-treating compounds. Primary treatment removes only 10% of the phosphorus in the waste stream; secondary treatment removes only 30%. Tertiary treatment is required to remove additional phosphorus from the water. The amount of additional phosphorus that can be removed varies with the success of the treatment technologies used. Available technologies include biological removal and chemical precipitation.

Nonpoint sources of phosphorus include both natural and human sources. Natural sources include 1) phosphate deposits and phosphate-rich rocks which release phosphorus during weathering, erosion, and leaching, and 2) sediments in lakes and reservoirs which release phosphorus during seasonal overturns. The primary human nonpoint sources of phosphorus include runoff from 1) land areas being mined for phosphate deposits, 2) agricultural areas, and 3) urban/residential areas.

Because phosphorus has a strong affinity for soil, little dissolved phosphorus will be transported in runoff. Instead, the eroded sediments from mining and agricultural areas carry the adsorbed phosphorus to the water body. An additional source is the overboard discharge of phosphorus-containing sewage by boats.

Phosphate itself does not have adverse health effects. However, phosphate levels greater than 1.0 may interfere with coagulation in water treatment plants. As a result, organic particles that harbor microorganisms may not be completely removed.

Water Quality Standards for Phosphorus

Rule 60 of the Michigan Water Quality Standards (Part 4 of Act 451) limits phosphorus concentrations in point source discharges to 1 mg/l of total phosphorus as a monthly average. The rule states that other limits may be placed in permits when deemed necessary. The rule also requires that nutrients be limited as necessary to prevent excessive growth of aquatic plants, fungi or bacteria, which could impair designated uses of the surface water.

Phosphorus Limitations in NPDES Permits

Phosphorus limits are placed in NPDES permits for all discharges which have the potential to contain significant quantities of phosphorus. The limit of 1 mg/l is contained in permits for discharges to surface waters which do not have substantial problems with high levels of nutrients. More stringent limits are required for discharges to surface waters which are very sensitive to nutrient inputs. Many of these surface waters are in developed areas with substantial point source and nonpoint source phosphorus inputs. In such areas, a waste load allocation may be necessary. The DEQ must determine the total amount of phosphorus (in pounds per day) which can be assimilated into the particular surface water. The DEQ then works with the dischargers to decide on appropriate phosphorus limits for each permit, without exceeding the total assimilative capacity of the surface water.

Temperature

Thermal pollution occurs when humans change the temperature of a body of water. The most common point source of thermal pollution is cooling water, which is used to cool machinery. Thermal pollution may also be caused by stormwater runoff from warm surfaces such as streets and parking lots. Soil erosion is another cause, since it can cause cloudy conditions in a water body. Cloudy water absorbs the sun's rays, resulting in a rise in water temperature. Thermal pollution may even be caused by the removal of trees and vegetation which normally shade the water body.

Thermal pollution can result in significant changes to the aquatic environment. Most aquatic organisms are adapted to survive within a specific temperature range. As temperatures increase, cold water species, such as trout and stonefly nymphs, may be replaced by warmwater species, like carp and dragonfly nymphs. Thermal pollution may also increase the extent to which fish are vulnerable to toxic compounds, parasites, and disease. If temperatures reach extremes of heat or cold, few organisms will survive.

In addition to thermal pollutions' direct effects on aquatic life, there are numerous indirect effects. Thermal pollution results in lowered levels of dissolved oxygen, since cooler water can hold more oxygen than warmer water. Low dissolved oxygen levels will cause oxygen-sensitive species to die.

Photosynthesis and plant growth increase with higher water temperatures, resulting in more plants. When these plants die, they are decomposed by bacteria that consume oxygen. This can result in a further drop in dissolved oxygen levels.

The metabolic rate of fish and aquatic organisms also increases with increasing water temperatures, and additional oxygen is required for respiration. Life cycles of aquatic insects may speed up in response to higher water temperatures. Animals that feed on these insects may be harmed, especially birds that depend on aquatic insects emerging at specific times during their migratory flights.

Water Quality Standards for Temperature

Rules 69 through 75 of the Michigan Water Quality Standards (Part 4 of Act 451) specify temperature standards which must be met in the Great Lakes and connecting waters, inland lakes, and rivers, streams and impoundments. The rules state that the Great Lakes and connecting waters and inland lakes shall not receive a heat load which increases the temperature of the receiving water more than 3 degrees Fahrenheit above the existing natural water temperature (after mixing with the receiving water). Rivers, streams and impoundments shall not receive a heat load which increases the temperature of the receiving water more than 2 degrees Fahrenheit for coldwater fisheries, and 5 degrees Fahrenheit for warmwater fisheries.

These waters shall not receive a heat load which increases the temperature of the receiving water above monthly maximum temperatures (after mixing). Monthly maximum temperatures for each water body or grouping of water bodies are listed in the rules.

The rules state that inland lakes shall not receive a heat load which would increase the temperature of the hypolimnion (the dense, cooler layer of water at the bottom of a lake) or decrease its volume. Further provisions protect migrating salmon populations, stating that warmwater rivers and inland lakes serving as principal migratory routes shall not receive a heat load which may adversely affect salmonid migration.

Effluent Limitations for Temperature in NPDES Permits

Temperature limits are necessary if a facility's effluent has the potential to raise the temperature of the receiving water above acceptable levels. Limits are often needed for facilities discharging noncontact cooling water. Effluent monitoring may be required to gain more information about a facility's effluent.

Total Suspended Solids

Total suspended solids (TSS) include all particles suspended in water which will not pass through a filter. Suspended solids are present in sanitary wastewater and many types of industrial wastewater. There are also nonpoint sources of suspended solids, such as soil erosion from agricultural and construction sites.

As levels of TSS increase, a water body begins to lose its ability to support a diversity of aquatic life. Suspended solids absorb heat from sunlight, which increases water temperature and subsequently decreases levels of dissolved oxygen (warmer water holds less oxygen than cooler water). Some cold water species, such as trout and stoneflies, are especially sensitive to changes in dissolved oxygen. Photosynthesis also decreases, since less light penetrates the water. As less oxygen is produced by plants and algae, there is a further drop in dissolved oxygen levels.

TSS can also destroy fish habitat because suspended solids settle to the bottom and can eventually blanket the river bed. Suspended solids can smother the eggs of fish and aquatic insects, and can suffocate newly-hatched insect larvae. Suspended solids can also harm fish directly by clogging gills, reducing growth rates, and lowering resistance to disease. Changes to the aquatic environment may result in a diminished food sources, and increased difficulties in finding food. Natural movements and migrations of aquatic populations may be disrupted.

For point sources, adequate treatment is necessary to insure that suspended solids are not present at levels of concern in waters of the state. Treatment typically consists of settling prior to discharge of the wastewater. Settling allows solids to sink to the bottom, where they can be removed. Some types of wastewaters, such as noncontact cooling water, are naturally low in suspended solids and do not require treatment.

For nonpoint sources, control measures should be implemented to reduce loadings of suspended solids to streams, rivers and lakes. Farming practices such as no-till minimize soil erosion and help protect water quality. For construction sites, controls such as silt fences and sedimentation basins are designed to prevent eroding soils from reaching surface waters. In urban areas, storm water retention ponds or a regular schedule of street sweeping may be effective in reducing the quantity of suspended solids in storm water run-off.

Water Quality Standards for Total Suspended Solids

Rule 50 of the Michigan Water Quality Standards (Part 4 of Act 451) states that waters of the state shall not have any of the following unnatural physical properties in quantities which are or may become injurious to any designated use: turbidity, color, oil films, floating solids, foam, settleable solids, suspended solids, and deposits. This kind of rule, which does not establish a numeric level, is known as a "narrative standard."

Most people consider water with a TSS concentration less than 20 mg/l to be clear.   Water with TSS levels between 40 and 80 mg/l tends to appear cloudy, while water with concentrations over 150 mg/l usually appears dirty. The nature of the particles that comprise the suspended solids may cause these numbers to vary.

Regulation of Total Suspended Solids in NPDES Permits

Michigan's rules do not contain numerical limits for total suspended solids. The permit writer must take the "narrative standard" into consideration when deciding on appropriate limits.

In addition, the permit writer must also apply treatment technology based effluent limits when appropriate. The U.S. Environmental Protection Agency has promulgated treatment technology based limits for total suspended solids for municipal wastewater treatment plants and many industrial categories. Municipal wastewater treatment plants must provide treatment to meet TSS limits of 30 mg/l as a monthly average and 45 mg/l as a 7-day average. Some industrial categories have treatment technology based concentration limits. Others have production-based loading limits, which are expressed in lbs/day or lbs/year.

Federal treatment techology based limits do not exist for certain industries and for non-municipal wastewater treatment. In the absence of federal categorical standards, permit limits are derived based on best professional judgment.