Chapter Six

Physical and Chemical Characteristics of the Lakes

As we have begun to see, the Great Lakes ecosystem is a very complex unit in which many different components are constantly operating and influencing the Great Lakes Basin ecosystem. For all of those animals, plants, fungi and microorganisms that live directly in the water of the five Great Lakes, existence is totally dependent upon the physical and chemical environment in which they live and the biological community of which they are a part. In order for us to better understand the whole large ecosystem of the basin, we need to understand how this environment of the five Great Lakes is put together, and how its functioning impacts upon those things that live in the environment.

Within the science of biology, there are many specialties. The specialty that deals with the interactions of organisms and their environments is known as ecology. Within ecology, the study of freshwater environments, especially lakes, and the interactions of the organisms that live in lakes, is known as *limnology*. Limnology is a word that was derived from the Greek word for pool or lake, *limne* and the Greek word *logos*, which means the study of. In this chapter we will examine some aspects of the limnological environment of the Great Lakes and in Chapter Seven we will examine selected aspects of its community of living things. ★

Physical Characteristics of Deep Lakes

A number of features distinguish lakes from terrestrial ecosystems. First, of course, the environment of a lake is always wet. Secondly, lakes respond more slowly to changes in temperature than do terrestrial ecosystems, and thirdly, lakes have obvious borders. It is not at all hard to tell where the lake stops and a different ecosystem begins. In contrast, consider the situation where one type of terrestrial ecosystem meets another, for example where a field meets a forest. Here there is a gradual change from the open field dominated by low-growing plants to a forest dominated by tall trees.

Within a lake there are distinct, specialized zones and sharp transitions from one condition to another. Because these are typical of all deep lakes, they apply directly to the Great Lakes. Near the shore, water is shallow. There may be rooted plants growing with stems or leaves extended above the water. There may be organic material accumulated in the sediments and the water can be rich with algae, invertebrates and small fish. This shallow-water zone around the edge of a lake is known as the *littoral zone* (Figure 6-1). In the littoral zone water is usually warmer than in the deeper parts of the lake, and wave action tends to stir up sediments from the bottom, adding cloudiness to the water that is already cloudier due to the presence of tiny algae and invertebrates. Around the edges of smaller lakes, the presence of rooted plants marks the littoral zone, however, in the Great Lakes, there usually are few rooted plants except near river mouths or coastal wetlands. The absence of these plants in Great Lakes water is due to the lack of adequate amounts of mineral elements such as nitrogen, phosphorus and potassium which are necessary to support the growth of the plants.

The deeper water, which includes all of the lake except the littoral zone, is too deep to support rooted plants. Vertically, this deeper water is divided into two zones, the *limnetic zone* and the *profundal zone* (Figure 6-1). The limnetic zone exists between the surface of the water and the depth to which light penetrates. This depth, the *light compensation level,* marks the beginning of the profundal zone where light no longer penetrates. That zone extends to the bottom of the lake. Obviously in a lake with very clean, clear water the limnetic zone is much deeper than in one having cloudy or muddy water. Many microscopic and near-microscopic algae and animals live in the limnetic zone where they are fed upon by larger animals and fish. These tiny, suspended organisms are known collectively as *plankton*, the algae being *phytoplankton*, and the animals or animal-like organisms, *zooplankton*. The profundal zone, on the other hand, cannot support photosynthetic organisms such as the algae. The animals that live in this zone depend upon dead organic materials that drift down to them from the limnetic zone above. Since water absorbs light, however, and particles in the water absorb and reflect light, in large lakes such as the Great Lakes, the greater part of the deep water is occupied by profundal zone. The water of the Great Lakes is generally very clear away from the shore; the limnetic zone is usually quite a bit deeper than in most smaller, inland lakes where the water is usually cloudier.

At the bottom of both the littoral and profundal zones is the region of the lake in which sediments accumulate, known as the *benthic zone* (Figure 6-1). These sediments may consist primarily of mineral materials such as gravel, sand, silt and clay, or they may include a great deal of dead organic matter. In the latter case, the sediments are often seen as organic muck. In the benthic zone of the littoral zone, sufficient light penetrates to support photosynthesis. Here are found algae, including diatoms and green algae, which grow attached to rocks and similar objects. Such algae are known as *periphyton.* Because no photosynthesis is occurring in the benthic zone at the bottom of a profundal zone, the water there is most often very low in oxygen and only animals, fungi and bacteria that can tolerate low oxygen conditions are able to survive. Away from the river mouths and coastal wetlands, the benthic zones of the Great Lakes have little organic matter in contrast to the organic ooze normally found at the bottoms of bays and inland lakes. Lacking the organic matter as a food source, the numbers and kinds of living things in the benthic zone of the Great Lakes are few.

Water Temperature

Water, as a chemical, is a very special substance. It has several unique properties which are directly related to temperature, that is, water responds differently than most other substances. Water has a very high specific heat. This refers to the amount of heat it takes to raise the temperature of one gram of water, one degree Celsius. The specific heat of water is one gram-calorie (gcal); that is, it takes one gcal of heat to raise one gram of water one degree Celsius. Only ammonia has a higher value. The net effect of this high specific heat is that it takes a lot of heat energy to make water warmer. For animals and plants, changes in water temperature of a lake during the day are not nearly so great as they are in terrestrial ecosystems where the temperature can fluctuate many degrees in 24 hours.

In addition, water has a high latent heat of fusion (80 gcal), the amount of heat energy required to change one gram of ice to one gram of liquid water without changing the temperature. Conversely, it's the amount of heat which must be given off by one gram of liquid water in order to change to one gram of ice. Water has the highest known latent heat of evaporation, the amount of energy required to change one gram of liquid water to one gram of water vapor without changing the temperature. It is 536 gcal.

Most substances have their greatest density (a gram occupies the least space) when in the solid state. Water, however, is most dense at 4 C (39.2° F), just slightly above the temperature of freezing. Because ice, at 0 C, is less dense than liquid water, it floats. If ice were denser than liquid water, lakes would freeze from the bottom up and fish would be trapped on top of the ice instead of surviving the winter in the water under the ice.

Because water is able to absorb and hold a great deal of heat, and because heat does not move rapidly through water and become evenly distributed, the water in lakes tends to be *thermally stratified*, that is, composed of layers at different temperatures. As the sun shines on the lake surface, the water at the surface is first warmed, and only slowly does the heat penetrate to the lower levels of the lake. The net effect of these phenomena is that lakes in temperate regions of the world have water of different temperatures at different depths. Warmer water, being less dense than cooler water stays near the surface, while the cooler water sinks and stays nearer the bottom. Two distinct layers form, the upper layer of warmer water is the *epilimnion* and the lower layer of cooler water is the *hypolimnion*. As summer progresses and the water of the epilimnion absorbs more and more heat, becoming warmer and less dense, it tends to circulate within the epilimnion but does not mix with the hypolimnion. At the depth where the two thermal layers meet there is a sharp change in temperature over a distance of only a few feet. This zone of rapid temperature change is the *thermocline*; in the Great Lakes it can a have a thickness of only 12 to 15 feet through which the temperature may drop 20 or more degrees Fahrenheit (Figure 6-2). Even in the summer, the water at the bottom is near 4 C (39.2° F) in the deepest parts of the Great Lakes, except Lake Erie which may get warmer in its shallower western basin. In Chapter Four we discussed internal seiches within the Great Lakes. The tilting referred to there is a tilting at the level of the thermocline which can result in the upward movement of cold hypolimnetic water to near the surface at the shoreline.

In a lake, the depths of the light compensation level and the thermocline do not necessarily correspond. In cloudy water, for instance, the light compensation level can be higher in the water. However, in the clear waters of most parts of the Great Lakes, the two often occur at similar depths.

As summer ends and fall begins, the temperature conditions of a lake undergo a dramatic change. The days become shorter, and the angle of incidence (the angle at which the sun's rays strike the earth's surface) becomes lower, together reducing the daily input of heat into the water. Eventually, more heat is lost at night by re-radiation than is gained during the day, and the water at the surface cools. As the season progresses into fall, the cooling continues. Since cool water is denser than warmer water, this now cool surface water sinks and the warmer water from below rises to take its place. Such a pattern of cooling continues until the entire epilimnion has cooled to the temperature of the hypolimnion. The water of the epilimnion continues to cool and as it does the denser water circulates down into the hypolimnion and the water of the hypolimnion circulates upward and is cooled. The overall mixing of the water from the upper parts of the lake with that of the lower parts is know as the *fall overturn*. This mixing can be triggered by even gentle wind blowing across the lake. Eventually, in the Great Lakes, the water will be a uniform 4 C from surface to bottom.

As winter begins, cooling of the surface water continues below 4 C. This now cooler water is less dense that 4 C-water and so will stay on the top. Eventually the surface water cools to 0 C and forms a layer of ice. The result is winter thermal stratification in which the surface water (ice at 0 C) is cooler than the layer of water (liquid at or just below 4 C) below. During the winter, as additional heat is lost from the lake, the layer of ice becomes thicker.

At the end of winter, the process of cooling of the lake is reversed with the surface warming from 0 C to 4 C. When the water is uniform temperature from top to bottom, *spring overturn* occurs, once again mixing the water from top to bottom in the lake. Spring warming of the water leads over several weeks to the formation of a warm epilimnion above a cool hypolimnion and eventually the thermal stratification of summer is established. Limnologists refer to lakes that undergo two overturns a year as *dimictic lakes* (two mixings). All of the Great Lakes are dimictic, although, among them, there are definite differences in the maximum surface temperature reached in the summer. Lake Erie, being shallow and located in the southern part of the basin, gets much warmer (mean summer surface temperature of 22 - 23 C) than does Lake Superior (mean summer surface temperature of 16 C) with its much greater depth, greater volume of water and its location in the north of the basin. Lakes Michigan, Huron and Ontario have mean summer surface temperatures ranging between 21 - 22 C in the south to 18 - 19 in the north. ( )

Fall and spring overturns of lakes are vitally important in determining the chemical properties of the lake. During the summer, nutrients in the form of dead organic matter slowly sink to the bottom. A variety of zooplankton, bacteria and fungi digest that organic matter as an energy source, and in the process, oxygen becomes depleted in the hypolimnion. With fall overturn, oxygen-rich water is brought to the bottom of the lake and nutrient-rich water is brought back up to the surface. The spring overturn again brings up nutrient-rich water and carries oxygen-laden water to the bottom. In inland lakes, often we can observe a "spring bloom" when the water becomes rich with algae, giving it a greenish cast. This occurs because the nutrients that were brought up by the spring overturn have stimulated rapid growth of algae. Spring bloom is less likely to be seen in the Great Lakes, except perhaps Lake Erie, because of the low nutrient levels in the water and the great volume of water in which they are diluted. There is no doubt, however, that there is increased growth of algae in these lakes in the spring.

Oxygen

Oxygen is added to the water of a lake by two primary means: photosynthesis and mixing from the atmosphere. The phytoplankton of the limnetic zone carry on photosynthesis and thereby contributing oxygen to the water. However how much photosynthesis occurs, and thus how much oxygen is added to the water, is determined by how much light penetrates the water, to what depth the light penetrates, how mineral-rich is the water, and the water temperature.

Water and air only mix at the surface where oxygen is dissolved into the water at the interface between water and air. Wave action due to strong winds increases the movement of water and thus more oxygen gets dissolved into the water. The fetch, wind speed and duration of the wind all determine wave size and as a result they also determine the amount of oxygen added to the water by this mechanism. In both cases, the addition of oxygen to water is limited to the limnetic zone. Since the water of deep lakes is thermally stratified, during the summer months, there is no addition of oxygen to the water of the hypolimnion from the epilimnion. The thermocline is a very effective barrier to mixing.

The animals, fungi and bacteria which live in the hypolimnion need oxygen in order to survive. As they use up the available oxygen from the water, those oxygen levels can become critically low. Some animals have special adaptations which permit them to survive in deep water that is low in oxygen. In the Great Lakes, in bays and near river mouths, where there is organic matter for them to eat, one finds animals such as bloodworms. Bloodworms technically are not worms, but actually are the larvae of a kind of fly. The name bloodworm comes from the fact that these larvae are bright, blood red, a result of the very high amounts of hemoglobin in their bodies. Hemoglobin is the blood pigment that picks up and holds oxygen. The high levels of hemoglobin means that these animals are very efficient at extracting oxygen from the water and holding it, they can live in the low-oxygen water of the benthic zone where relatively few other invertebrates or vertebrates can survive. Since they can swim from hypolimnion to epilimnion, fish distribute themselves according to the amount of oxygen dissolved in the water. During spring those, such as trout and salmon that need highly-oxygenated water, can be found in the lake from near the surface to the bottom. As summer progresses, and oxygen is used up in the hypolimnion, these fish will move up into the epilimnion. Only those fish, such as bass, that can tolerate lower-oxygen conditions will be found in the hypolimnion late in the summer.

Turbidity

Limnologists refer to the degree of cloudiness of water as *turbidity*. The turbidity of water has direct impacts on the depth to which light penetrates, the amount of oxygen dissolved, and even the temperature of the water of a lake--those physical characteristics of a lake discussed above. Turbidity results from particles being suspended in the water. These particles can be mineral, especially clay and silt, or they can be either living or dead organisms. In all three cases, these particles interfere with the passage of light through water. Some of that interference comes about because light strikes the particles and is scattered or reflected away. Other portions of the light are absorbed by the particles. In the case of living phytoplankton, the photosynthetically-active wavelengths of light, especially blue and red, are absorbed and used in the process of photosynthesis. One effect of the scattering and absorption associated with increasing turbidity is to cause the water to appear progressively less blue and more green and then finally, brown. In water with high turbidity, most of the light striking the water will be absorbed, scattered or reflected back to the sky, and only a little will penetrate to any distance. Since little light penetrates, photosynthesis is limited to that shallow layer in which there is sufficient light intensity, and thus the oxygen being released into the water is limited to that layer. A very simple way to measure the turbidity of water is to use a device called a Secchi disk, which is a flat, weighted disk painted alternately white and black. The disk is lowered into the water and the depth at which it can no longer be seen is recorded as the Secchi depth. The Secchi depth is multiplied by 2.7 giving the depth at below which there is insufficient light to support photosynthesis.

The particles in turbid water also absorb heat, much of which will be retained raising the temperature of the water higher than water of low turbidity. Most of the time, the water of the Great Lakes, except in bays and near river mouths, is clear and clean, having very low turbidity. Thus light penetrates to great depths. The water is oxygenated by those phytoplankton present, and little heating of the water is achieved from heat being absorbed by particles in suspension.

Leaves contain a group of chemicals called tannins which are biproducts of the life processes of the plant. These chemicals are brown in color and, when the leaves decay, are dissolved in water, thereby giving the water a brownish color. Tributary streams that run through forests often are quite brown in color. The huge volume of water in the Great Lakes dilutes the tannins that flow into the lakes and, except for near river mouths, evidence of these water-coloring chemicals is not seen.

Dissolved Minerals

All living things require certain chemical elements in order to make the organic compounds of which they are composed. The list of those needed by plants is easy to remember: C HOPKNS CaFe Mg (C. Hopkins Cafe, mighty good) for the elements carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron and magnesium which are needed in relatively large quantities and MoB CuMn Zn (Mob comes in) for the elements molybednum, boron, copper, manganese and zinc which also are necessary, but only in very tiny amounts. The algae that constitute the phytoplankton of the Great Lakes need all of these elements as well as chlorine, and they get them from the water in which they live.

Carbon is derived from the gas carbon dioxide (CO_2) which dissolves in the water and which the plants use in photosynthesis. Carbon dioxide is released into the water as a result of the cellular respiration of all living things, including those living in the lake. In addition, some CO_2 is dissolved in the water, like oxygen, from the atmosphere.

Hydrogen is one of the two elements that make up water. Its source is obvious, again taken in during photosynthesis. The oxygen needed is present, as we discussed earlier, as the gas dissolved in water. Nitrogen also is a gas, making up 78% of the atmosphere. However, most living things cannot use gaseous nitrogen but must have nitrogen in a combined form such as the nitrate ion (NO_3^-) or the ammonium ion (NH_4^+). These ionic forms of nitrogen are introduced into the water by the decay of dead animals and plants and by certain types of bacteria and cyanobacteria (blue-green algae) which have the ability to convert gaseous nitrogen to one of the ionic forms.

Elemental chlorine is also a gas, but in solution it is present as chloride ions (Cl^-) that are released from various minerals such as table salt ($NaCl$). All of the other elements listed are metallic elements which are dissolved from rocks and minerals either on the bottom of the lake or they can be washed into the Great Lake from anywhere in the basin. They may be dissolved in the water in elemental ionic form such as potassium (K^+) or iron (Fe^{2+}), or they may be in combined ionic form such as phosphate (PO_4^{3+}).

The relative amounts of dissolved mineral elements are quite small in the waters of the Great Lakes. The result is that only limited numbers of phytoplankton live in the water, carry on photosynthesis and provide a food supply for the zooplankton and larger animals. Waters of inland lakes and rivers have much higher levels of these elements and they support much greater numbers of rooted plants, phytoplankton, zooplankton and larger animals per cubic meter of water. Since these inland sources drain into the Great Lakes through the rivers, concentration of minerals is greatest in and near the mouths of those rivers.

Salinity is a chemical property of bodies of water directly related to levels of dissolved minerals, especially common table salt, sodium chloride ($NaCl$). Although living things need only extremely small amounts of the two elements that make up salt, they can be strongly affected by the levels of these in the water. The waters of the Great Lakes have very low naturally-occurring levels of salinity. However, one of the consequences of human habitation in the Great Lakes ecosystem is increased salinity in the lakes. Thousands of tons of salt are spread on the roads of the basin each winter. Melted snow and rain runoff carry this salt into the rivers and ultimately into the Great Lakes. That, and other sources of salt, are causing a gradual increase in salinity (Figure 6-3), thereby changing the character of the Great Lakes.

Often we hear the water of the Great Lakes region described as being "hard." Hardness of water is a measure of the amounts of calcium and magnesium salts found dissolved in the water. These two elements are usually found as combined forms as carbonates, sulfates, chlorides and nitrates (Wetzel, 1975). As discussed in Chapter Three, except for Lake Superior, the basins of the five Great Lakes are primarily composed of limestones which add large amounts of calcium to the water of the lakes. Thus the water can be relatively hard. An interesting relationship exists between hardness and carbon dioxide levels in water. The pH of water is determined by the relative concentration of hydrogen ions (H^+) in the water. Hydrogen combines with hydroxyl ions (OH^-) forming water (H_2O). Lake or river water with a high concentration of hydrogen ions is acidic, having a pH below 7. In water with a high level of hydroxyl ions, any free hydrogen ions are immediately tied up by the hydroxyl ions, giving a low concentration of free hydrogen ions in the water. Water with low concentrations of hydrogen ions is alkaline, or basic, and has a pH above 7. Carbon dioxide when it is dissolved in water chemically combines with water molecules to form carbonic acid: $CO_2 + H_2O \rightarrow H_2CO_3$. Hydrogen ions freely dissociate from the carbonic acid producing free hydrogen ions that lower the pH and bicarbonate ions: $H_2CO_3 \rightarrow H^+ + HCO_3^-$. Bicarbonate ions in turn dissociate forming carbonate ions: $HCO_3^- \rightarrow H^+ + CO_3^{2-}$. At pH <5, CO_2 predominates in the water, between pH 7 and 9, HCO_3^- predominates, and at pH

> 9.5 CO_3^{2-} predominates (Wetzel, 1975). If, as in the case of the Great Lakes, natural carbonates are common in the water from minerals in the soil and rocks of the drainage basin, the carbonic acid formed helps to dissolve limestone releasing calcium, forming calcium bicarbonate, $Ca(HCO_3)_2$. Since calcium bicarbonate is relatively soluble in water, Ca^{2+} and HCO_3^- ions are now free in the Great Lakes. Normally, $HCO_3^- + H_2O \rightarrow H_2CO_3 + OH^-$ and the presence of OH^- ions raises the pH (Wetzel, 1975). The consequence of all of this is that the Great Lakes have pH's in the range of 8 to 8.5 because, with the exception of Lake Superior, the rocks of their drainage basins are high in calcium.

Eutrophication

All lakes undergo a sequence of events that leads to their ultimate filling in, converting them from open water to wetland and finally to terrestrial environments. This process is known as *eutrophication* or aging of a lake. Over time, nutrients and sediments from the surrounding upland areas are carried into lakes, accumulating in the water and on the bottom. Over long periods of time, the lake becomes shallower and its physical and chemical characteristics change, until a lake no longer exists.

When the Wisconsin glacier had melted from the Great Lakes basin, it left behind numerous large and small depressions which filled with water from the melted glacier and from precipitation. The bottoms of these lakes may have been rock or they may have been gravel or sand. After a period of time, silt in the water would have settled out leaving the water very clear, that is, having very low turbidity. The amount of dissolved oxygen in the water was high because it was being added to the water by wave action and there were very few animals, fungi and bacteria in the water using oxygen. There were very few algae or rooted plants because the necessary mineral elements were present in very low amounts. With very limited growth of algae and plants, the food supply for tiny invertebrates and fish was very limited and so their numbers were also very small. Such a lake with a mineral bottom, clear water that is high in oxygen, low in CO_2, low in mineral nutrients and low in living things, is called an *oligotrophic* lake. The name comes from two Greek words, *oligo* which means scant or little and *trophic* which refers to nourishment. Thus an oligotrophic lake has very little nourishment available (a lake with little feeding) and extreme limits are placed upon the numbers and kinds of organisms that can live there.

In ecology we use the term trophic level to refer to one of the series of steps in a food chain. At the base of each food chain are green plants or algae which undergo photosynthesis. That chemical energy is passed along from trophic level to trophic level, each of which is made up of animals, fungi or bacteria which, unlike plants, cannot make their own food. In an oligotrophic lake there are only poorly-defined or non-existent food chains and their trophic levels.

Lakes fill the lowest places in the landscape. When it rains, runoff water picks up and transports soil and organic material such as dead leaves, twigs, seeds, fruits, manure and feathers into small streams or directly into lakes. The small streams empty into larger streams or rivers which carry the soil and organic material to lakes such as the Great Lakes. Trees and shrubs living at the edge of lakes shed their leaves and seeds which fall into the water. Waterfowl land on the lake in search of food or nesting sites and leave behind feces and feathers. As these organic materials are decayed by fungi and bacteria, the mineral nutrients tied up in them are released into the water. Inorganic substances in rocks and minerals dissolve and are released into the water. Insoluble inorganic materials (sand and silt) settle to the bottom where they accumulate. Organic sediments settle out as well and also accumulate on the bottom. Over time, the sediments become deeper, and the water becomes shallower. The mineral nutrients which are now more abundant in the water support the growth of algae, both phytoplankton and periphyton. This process of accumulation of mineral nutrients in the water and the buildup of sediments on the bottom of a lake is known as *eutrophication.*

The suffix *eu* means true, and is used in this case to mean the presence of true nutrition or the presence of food chains with true trophic levels. The process of eutrophication is the development of the capability to support food chains. The environment of an oligotrophic lake usually changes very slowly. Over hundreds, thousands or, as in the case of the Great Lakes, tens of thousands of years, eutrophication progresses. Gradually, the oligotrophic lake with its clear, oxygen-rich and nutrient-poor water will become slightly turbid, the dissolved oxygen level will decline and the level of dissolved nutrients will increase. As more phytoplankton and periphyton grow in the water, they will be food for zooplankton whose numbers will begin to increase. The numbers of those zooplankton eventually will become great enough to support larger invertebrates and small fish. As eutrophication continues, larger fish will also be able to find adequate amounts of food and they too will become established.

As sediments buildup around the edges of the lake, an ecological succession, of the sort that occurs on sand dune, as described in Chapter Four, takes place in the water. Eventually flowering plants, including water-weed *(Elodea)* and coontail (*Ceratophyllum*), floating submerged in the water, will become established along with the algae. These now become a food source for small animals. Later, the sediments will have become deep enough, thereby making the water shallower, and plants with roots in the mud at the bottom and leaves floating on the water will grow. These include water lilies (*Nymphaea* and *Nuphar*), pondweeds (*Potamogeton*) and pickerel-weed (*Pontederia*). Those floating-leaved plants in turn contribute more organic sediments and trap inorganic sediments around them and the water becomes even shallower. Eventually a new group of plants will become established; these have their roots in the mud at the bottom and have leaves that emerge into the air above the surface of the water. The grasses and grasslike plants of coastal marshes, described in Chapter Five, are examples of these. Wetland shrubs will colonize when the water is even shallower and then eventually the region that was once open water at the edge of a lake will be dry land supporting a forest of trees.

A lake, in which eutrophication has progressed to the point that bands of emergent plants, floating-leaved plants and floating, submerged plants are apparent around the edge, is described as being an *eutrophic* lake. The environment of an eutrophic lake is characterized by having a lake bottom with sediments containing dead organic matter, the water is turbid and light does not penetrate as deeply as in an oligotrophic lake of similar depth, and the amount of dissolved oxygen in the water is less. The amounts of dissolved mineral nutrients and dissolved CO_2 are greater than in a comparable oligotrophic lake.

The numbers of phytoplankton and zooplankton are much higher in the eutrophic lake, and there are numerous larger invertebrates and fish. An oligotrophic lake does not turn immediately into an eutrophic lake, instead there is a long series of slow changes. A lake which is no longer oligotrophic, but has not yet reached the stage of eutrophic is referred to as being *mesotrophic* (meso means middle or mid-way).

This series of events, eutrophication, leading to the gradual filling in of lakes can be seen as the edge of the lake moves closer and closer towards the lake's center. This filling in from the shoreline will continue until the entire lake is filled in. The time required for a particular lake to fill in depends upon many factors including water depth, total surface area of the lake, steepness of the slopes around the lake, type of soil composing the upland regions drained by the lake, the richness of the soil of the uplands, the amount of annual precipitation, the type of terrestrial vegetation growing on the uplands and the level of human activities in the uplands around the lake. Very large lakes, including the Great Lakes, undergo certain of the changes associated with eutrophication just as surely as do smaller lakes. However, the Great Lakes are very deep and contain vast quantities of water, much of which stays very cold through the summer. Therefore, under natural conditions, these lakes age differently than smaller lakes. Mineral nutrients are diluted throughout the huge volumes of water. There is a great reservoir of oxygen dissolved in the water, and only a minimal use of it by animals. The volume of the lakes is so tremendous that sediments that wash into the lakes have little impact. Thus these resist the aging of eutrophication much more so that do smaller inland lakes.

By the 1960's, it had become apparent to ecologists that Lake Erie was showing clear signs of eutrophication (Milway, 1968). Some people have described the situation by saying that during 15 years in the 1950's and 1960's Lake Erie had undergone the eutrophic changes that should normally have taken 15,000 years. Why did such remarkable aging show up in Lake Erie, but was not evident in the four other Great Lakes? The answer is really quite simple. Lake Erie, of the five Great Lakes, is the shallowest and smallest, and it is surrounded by the heaviest concentration of human activity. Milway (1968) estimated that at that time there was an annual input of 136,000,000 kilograms of nitrogen and 29,000,000 kilograms of phosphates into Lake Erie. Of that latter figure, he estimated that 80% (23,200,000 kilograms) of the phosphates were being retained in the lake. The sources of these nutrients which stimulate the growth of phytoplankton, periphyton, floating-submerged plants, floating-leaved plants and emergent plants are runoff from farm fields in southern Ontario, southeastern Michigan, northern Ohio, northwestern Pennsylvania, western New York, and the effluent from sewage treatment facilities in all of the major cities which are located on the lake. For comparison, Milway (1968) indicates that in the much larger Lake Michigan in 1963 only 75,500,000 kilograms of nitrogen were input and 6,650,000 kilograms of phosphates were retained in the lake. Although the inputs into Lake Michigan are significantly less than those into Lake Erie, even they have had measurable effects (Ayers, 1968), especially in southern Lake Michigan where there is the greatest concentration of human activity in the areas of metropolitan Chicago, metropolitan Milwaukee and southwestern Michigan.