A LAKE MANAGEMENT PRIMER FOR NON-SCIENTISTS

Second Edition

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Berryman & Henigar

FOREWORD

A LAKE MANAGEMENT PRIMER FOR NON-SCIENTISTS was originally developed and published on January 13, 1998 by the Environmental Resources Management Division, Pinellas County Department of Environmental Management, authored by Donald D. Moores. The second edition was prepared to update some of the content to reflect the current state of knowledge, and to correct some typographical errors.

The primer was originally conceived as a handout to be used in conjunction with a workshop that was offered to non-scientists attending the Florida Lake Management Society (FLMS) and North American Lake Management Society (NALMS) conferences, in hopes of arming the attendees against the use of scientific jargon by conference presenters. The primer is also used in conjunction with a separate document entitled *Glossary of Lake Management Terms Used by Scientists to Confuse Non-Scientists*.

Acknowledgments are due to Lisa Baltus and Nancy Page, Pinellas County Government, for graphics design. Chris Holdren, U.S. Bureau of Mines and Reclamation, provided technical collaboration and peer review.

TABLE OF CONTENTS

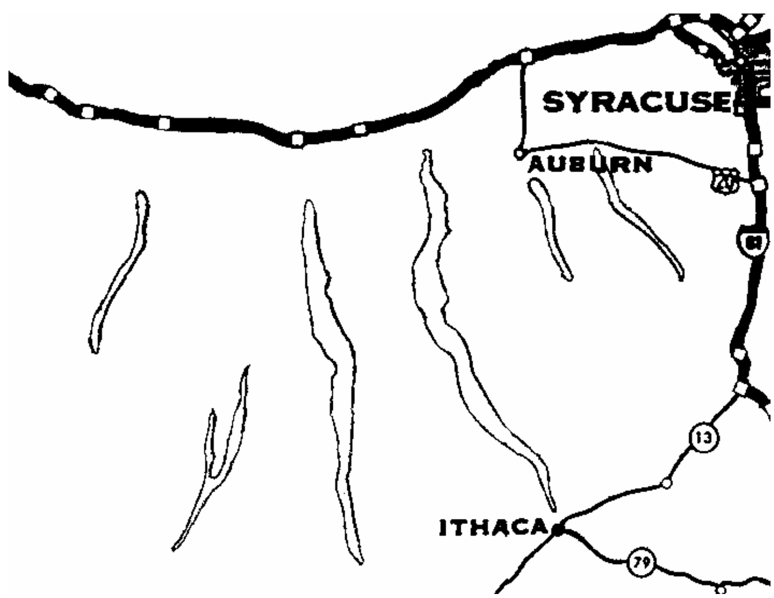
A LAKE MANAGEMENT PRIMER FOR NON-SCIENTISTS

What is a lake? What is the difference between a lake and a pond?

You might think these are silly questions, but the two terms are often confusing to people.

Basically there isn't any difference between a lake and a pond except for size; a lake is a big hole in the ground filled with water. A pond is a smaller hole.

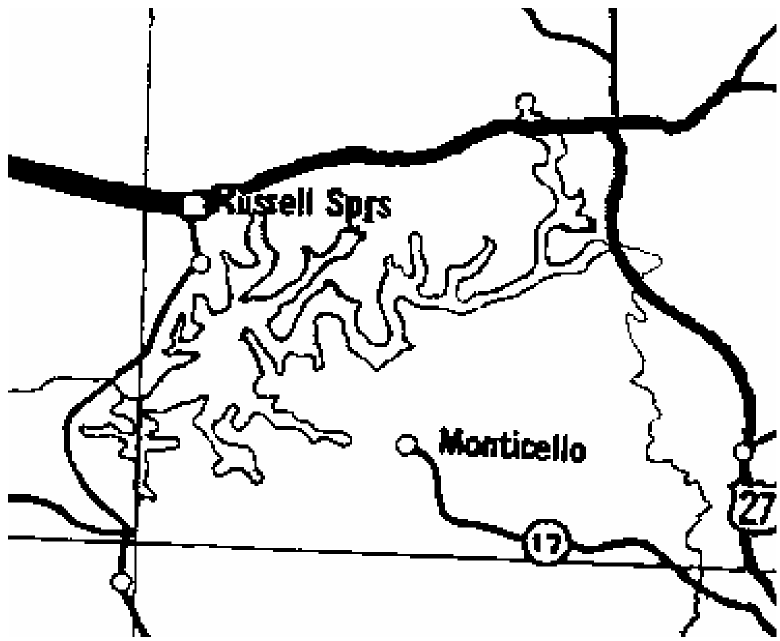
There isn't any real clear point at which something ceases to be called a pond and starts to be called a lake. In Florida, for example, just about anything larger than 5 acres would be called a lake, whether or not it is natural. In northern states such as New York, often bodies of water consisting of thousands of acres are referred to as ponds. Remember the movie On Golden Pond? That pond was actually a lake in New Hampshire that is about 6 miles long and 2-3 miles across!



Finger Lakes in New York State

Lakes tend to be different from one place to another, based partly on local geology and atmospheric conditions, and partly on how the lake was created in the first place.

In the northern states around the Great Lakes and St. Lawrence River, there are numerous long, relatively narrow lakes called *finger lakes*. These lakes were scoured out of the rock by glaciers, hence they are usually elongated in a north-south direction, the direction that the glaciers moved. They tend to be very deep, and as you will see, this has a bearing on the physical and biological conditions within the lake.



A reservoir in Kentucky, Lake Cumberland

In mountainous states like Tennessee, there aren't very many natural lakes, but there are numerous rivers and streams. In such places, dams have often been placed on the rivers, creating a special kind of lake called *reservoirs*. These lakes tend to be long and have many narrow side branches, the result of flooding the side tributaries to the river. Reservoirs also have special physical conditions that result from the way they were created.

Lakes of sinkhole origin in Pinellas County, Florida

In Florida, if you look at an aerial photograph, particularly of a relatively undeveloped area, you will see that the landscape is pock-marked with lots of small, almost perfectly round lakes. Occasionally you will see where two adjacent round lakes are joined, resulting in a peanut-shaped lake.

Florida's geology consists largely of limestone layers, overlain by many feet of sand, remnants of old beach dunes. The limestone is highly fractured, resulting in numerous caves and underground cavities formed by groundwater dissolving the limestone. Occasionally, one of these solution cavities will collapse, resulting in the formation of a sinkhole. If the sinkhole happens to be below the groundwater table, the result will be a sinkhole lake. Most of the natural lakes in Florida were formed in this way.

Most regions of residential development contain numerous small ponds that were dug by the developers. They were dug originally to obtain fill material, used to fill low, wet areas for home sites. Then the resulting ponds were utilized to drain surface runoff into. The resulting development was then sold as waterfront or lakefront property. These small, manmade ponds behave much like any other lake, and as you will see, experience many of the same problems.

Other regions have similarly different types of lakes, resulting from local conditions and geologic history. One researcher actually reported on the numerous lakes in Vietnam which resulted from bomb craters!

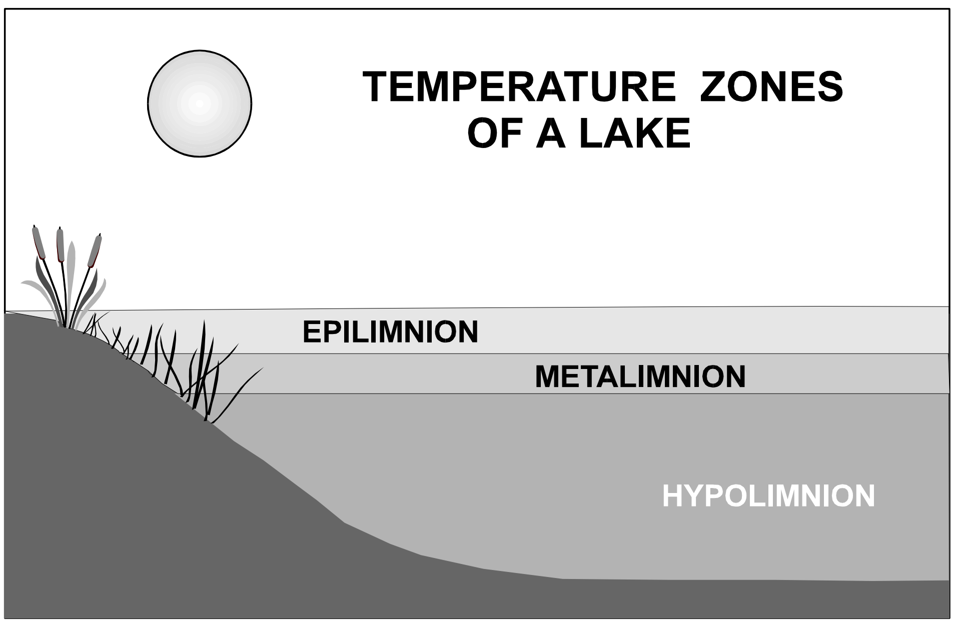
What do you think is the difference between a lake and a stream? In some places, where a stream channel becomes very wide and deep, this wide and deep area may be referred to as a lake. Why? What is there about this part of a stream that makes it *lake-like*? The real answer is the biological conditions; some plants and animals are specially adapted for life in a stream, with its water flowing always in one direction; other plants and animals are better adapted to life in lakes, where there certainly are currents and water movement, but generally not as strong nor one-directional.

Many lakes have streams flowing into and out of them (see the discussion of reservoirs, above), and many are just in reality a wide spot in the stream, but once the physical structure and conditions tend to favor an assemblage of living things typical of lakes, the water body is truly a lake. We will be learning more about those conditions and the living things in lakes in the following pages.

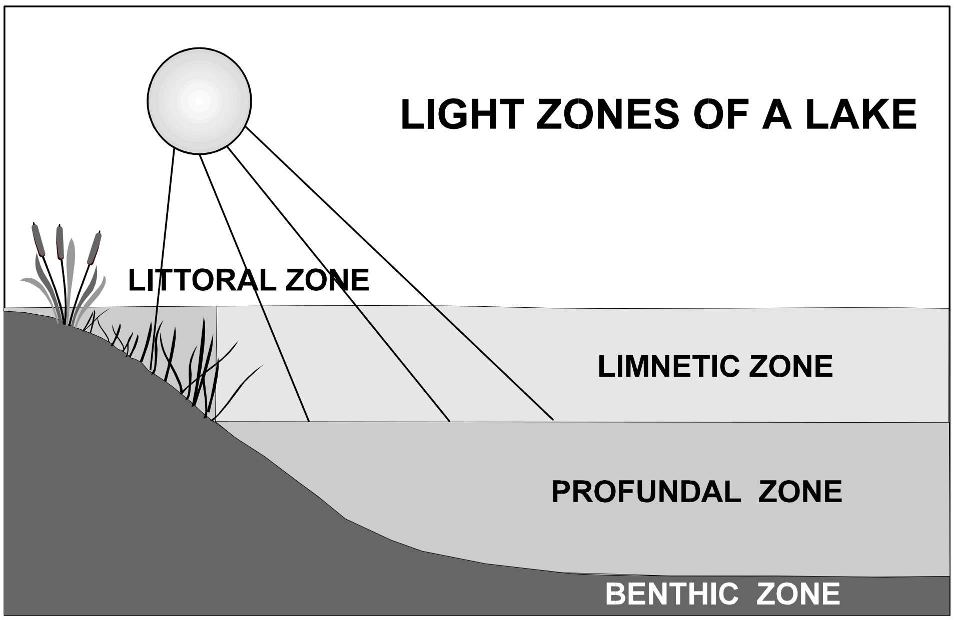
THE ZONES OF A LAKE

You will often hear scientists referring to various zones of the lake, and these terms are often intermingled and confusing.

One such set of terms is based on location within the lake. The *epilimnion*, from the Greek word *epi* meaning upper or top, is the upper layer of water in a lake. The *hypolimnion*, from *hypo* meaning lower, is as you might suspect the lower layer of water, below the epilimnion. Why those layers are considered distinct will be discussed a bit later on.



Often the layer near the bottom of a deep lake is called the *profundal* zone. This is the deep, cold area where dead material settling down from above tends to accumulate and decompose.



Near the shore, where the water is relatively shallow and many plants and animals grow or live on or near the bottom, is the *littoral zone* or *littoral shelf*. Offshore from the littoral zone, where most living things live and move around in the open water, is the *pelagic* or *limnetic zone*.

Some of these same terms are often also used to describe various parts of the ocean.

KINDS OF LIVING THINGS IN LAKES

One expects to see living things such as plants and fish in lakes. The way that scientists categorize living things in lakes is complex and often confusing, and a given living thing may fit into two different categories at the same time. We will attempt to clarify at least some of the commonly used terms.

Plankton, phytoplankton and zooplankton

Plankton are basically plants and animals that are too weak or unable to swim against currents, and tend to be moved around in the lake by the water itself. *Plankton* is based on a Greek word that means wanderer. Plankton are usually split into two major groups: *phytoplankton*, or planktonic plants, and *zooplankton*, or planktonic animals. Plankton are often thought of as being tiny, microscopic organisms, and many are. Plankton need not be small, however; large jellyfish are considered plankton, and large floating plants such as sargassum weed in the ocean are also planktonic.

The zooplankton is largely a group of tiny animals that tend to feed on the phytoplankton, and consists of a variety of different forms including some, such as copepods, that live their entire lives as plankton, and others, such as juvenile shrimp and fish, that eventually grow out of the plankton category.

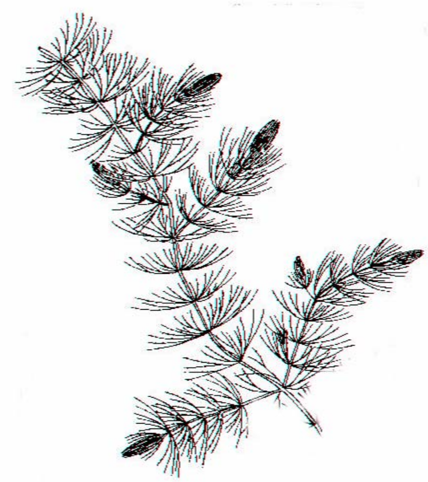
Zooplankton: A copepod (a planktonic, microscopic arthropod).

Algae vs. Higher plants, and macrophytes

Aquatic plants themselves tend to be broken into two major groups: *algae* and higher plants. Algae are simply a more primitive form of plants that don't have real roots or produce flowers. Algae themselves are a very diverse group. They range from tiny, microscopic plants consisting of one or a few cells (the phytoplankton we mentioned before) to large plants such as the giant kelp that grow off California's shores, with a huge variety in between.

You may also hear or read the term *macrophyte*. Again, based on a Greek word *macro* meaning large, macrophyes are large plants. This term is often used to distinguish plants like cattails, pond lilies, and bulrushes from the microscopic algae we mentioned before. Some algae, such as *Nitella*, are macrophytes. It simply means big plant.

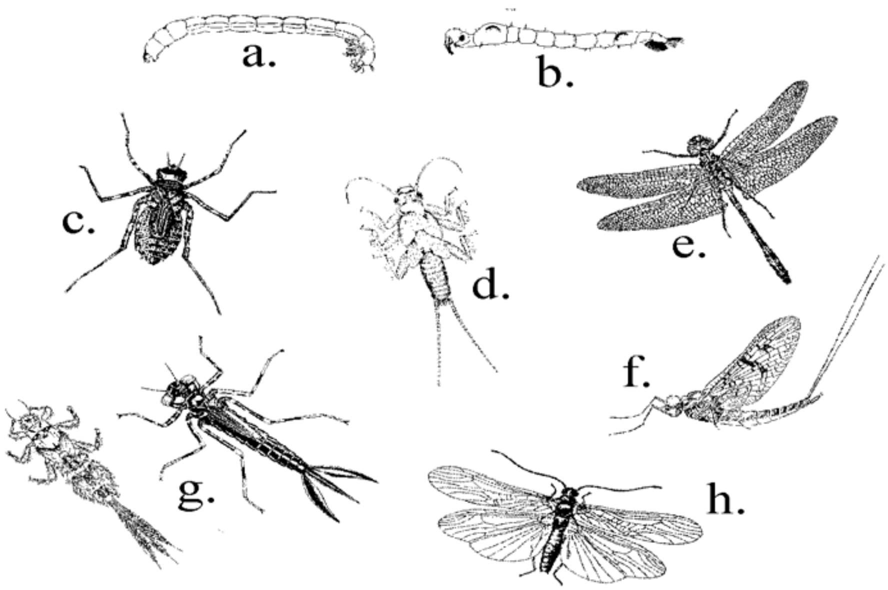
Coontail, an algal macrophyte



Other lake critters

There are a variety of other types of living things in lakes. You don't need to be told what fish are. Likewise, you would probably recognize things like clams, some snails, and crayfish as common inhabitants of lakes. And to a certain extent, birds like loons and herons, and mammals like otters and beavers that depend upon lakes would be considered a part of the community.

Another group of animals that are extremely important in lakes, but almost totally nonexistent in marine habitats, is the insects. Many insects such as dragonflies, mosquitoes, midges, mayflies, and so forth, spend their larval, or developmental stages of their lives in the water. Others, such as water striders, water scorpions, and diving beetles, spend their entire lives in the water. Insects are an important food source for many fishes, and often feed themselves on smaller insects or on plankton. Some of the larger insects may actually prey on small fish!



Aquatic insects. (a) midge larva; (b) mosquito larva; (c) dragonfly naiad; (d) stonefly larva; (e) adult dragonfly; (f) adult mayfly; (g) mayfly larvae; (h) adult stonefly.

One last note about plants and animals: they are often categorized based on where they live. Those that live in or on the bottom are called *benthic* organisms, or *benthos*. These include clams and crayfish, and some rooted plants. Those plants and animals, mostly fish, that live in the open water are generally referred to as *pelagic* organisms.

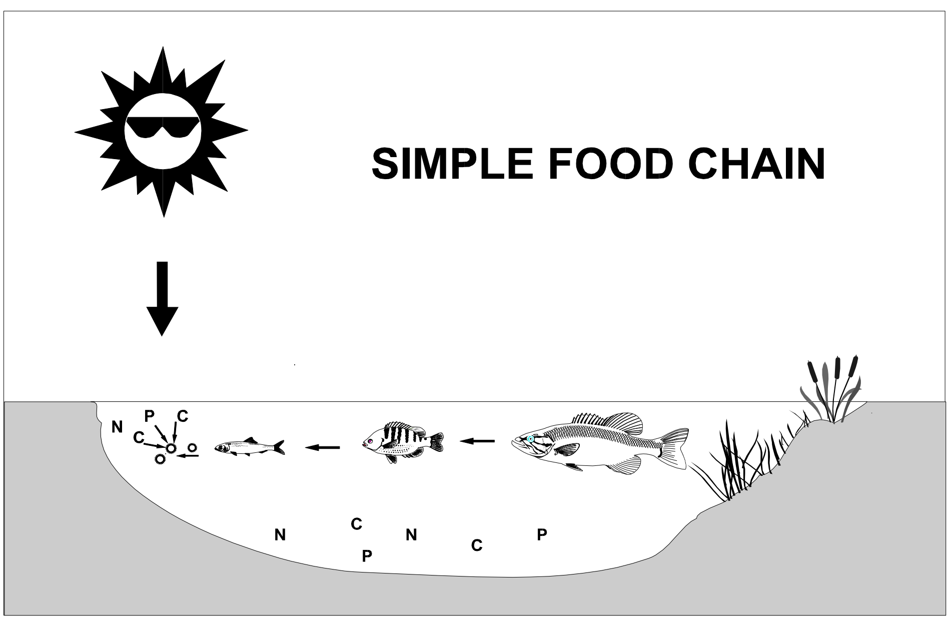
FOOD CHAINS, FOOD WEBS

The relationship between plants and animals in terms of who eats whom is often referred to as a *food chain*, or a *food web*.

Simple food chain

The simple concept of the food chain is that organic matter is first created by plants (we'll learn more about that a bit later on), which are in turn eaten by a first level of consumers called herbivores, then the herbivores are eaten by carnivores, and there may even be another level of top carnivores. Sometimes an additional layer of decomposers is included, but they tend to feed on all of the levels, and don't really fit into the chain concept.

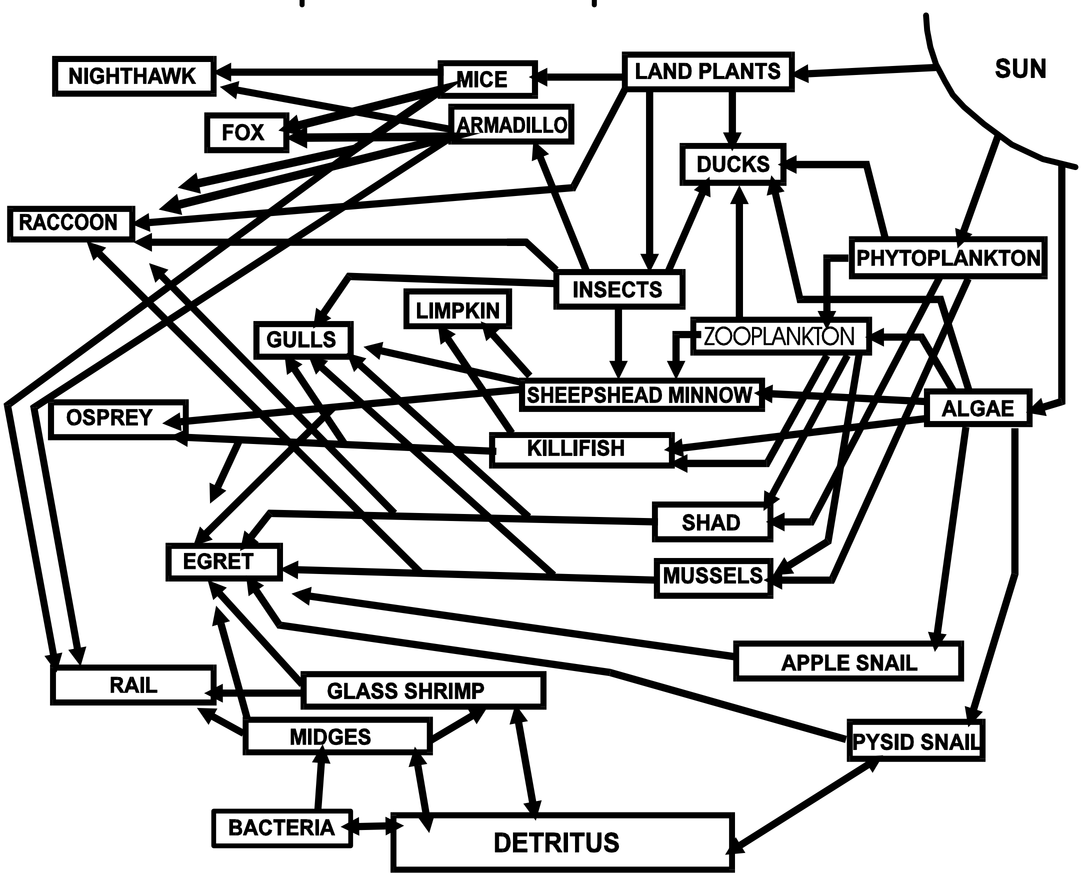
A depiction of a simple food chain.



The food web

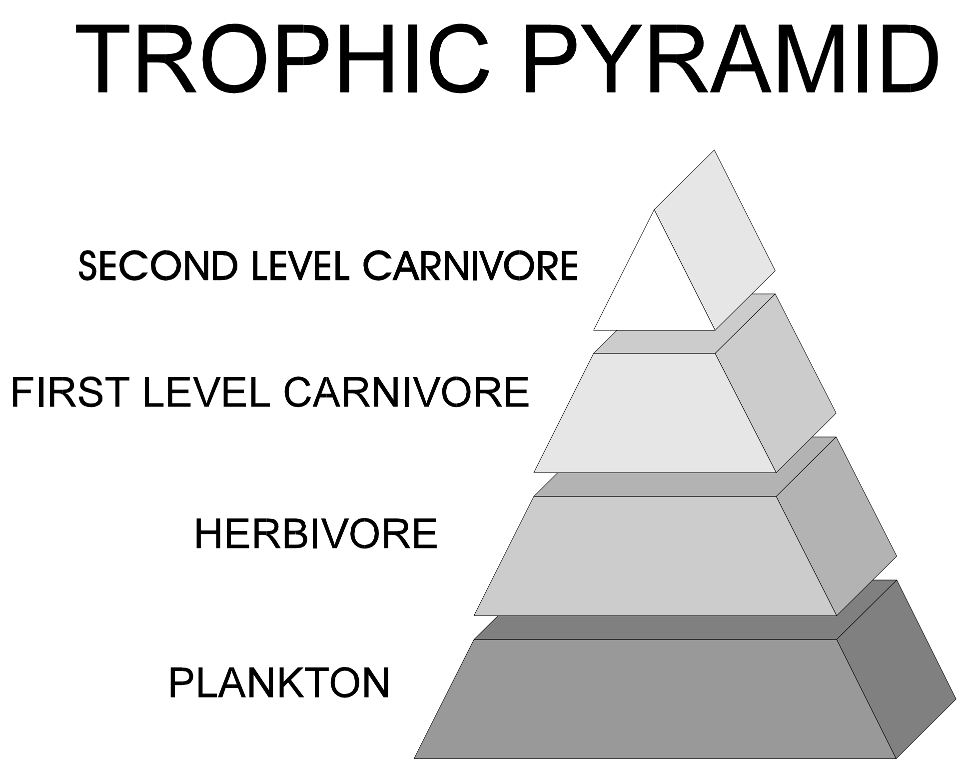
In order to examine relationships in more detail, the concept of a *food web* more closely fits reality. Sometimes, researchers are actually able to quantify the amount of organic material, or energy, that is utilized by each consumer in a food web. They do this by exaggerating the size of the arrows, or by placing numbers on the arrows portraying the amount of energy passed from one level to the next.

Depiction of a complex food web.



The trophic pyramid

In many ecology books, you will run across a graphic called a *trophic pyramid*. Trophic refers to feeding. This trophic pyramid is intended to be a simple way of visualizing *how much* matter, often referred to as biomass, exists on each level of the food chain. In general, and remember, this is only a generalization, each level contains only about one-tenth of the biomass of the level it feeds upon. Thus, in a typical ecosystem, the total biomass of the first level consumers, or



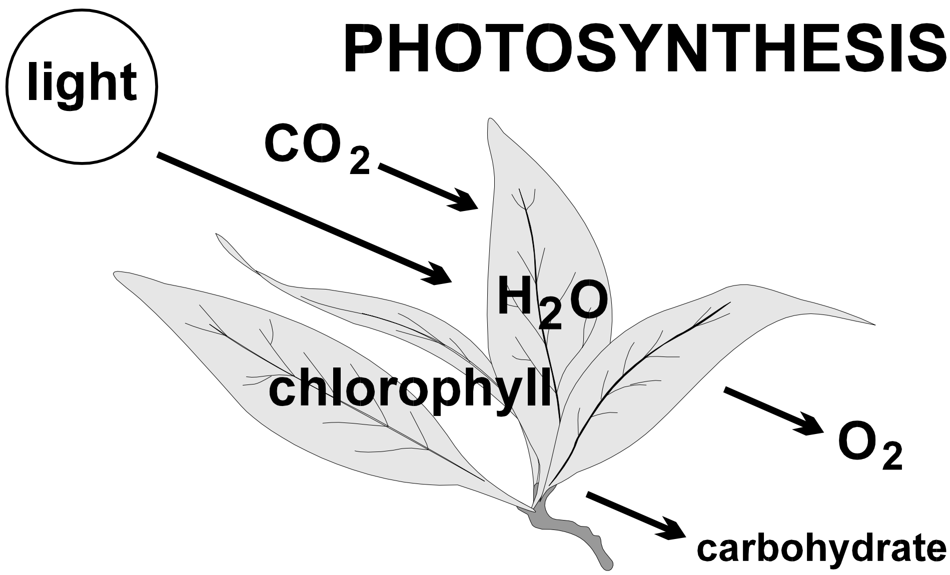
Trophic pyramid, demonstrating the concept of diminishing biomass with each higher trophic level.

herbivores, would be one-tenth of the biomass of the plants they feed upon; that of the next level consumers, or carnivores, would be one-tenth that of the herbivores, and so on. For example, a field containing 1000 pounds of grass would be expected to support 100 pounds of grasshoppers, and 10 pounds of birds that eat grasshoppers, and so on. But remember, this is only a greatly simplified concept - in reality the actual proportions of biomass at each level may vary considerably owing to differences in longevity and other factors.

PHOTOSYNTHESIS AND RESPIRATION

We mentioned a while ago that plants create, or produce organic matter. Just what does that mean, and how is it accomplished?

Living things require certain highly complex molecules (a molecule is a group of atoms of different kinds linked together in a specific fashion) including proteins, carbohydrates, lipids, and others, in order to live. Plants and animals are able to manufacture some of these things themselves, given the right raw materials. They must, however, start with a raw material that is *organic* - that is made of molecules containing carbon atoms.



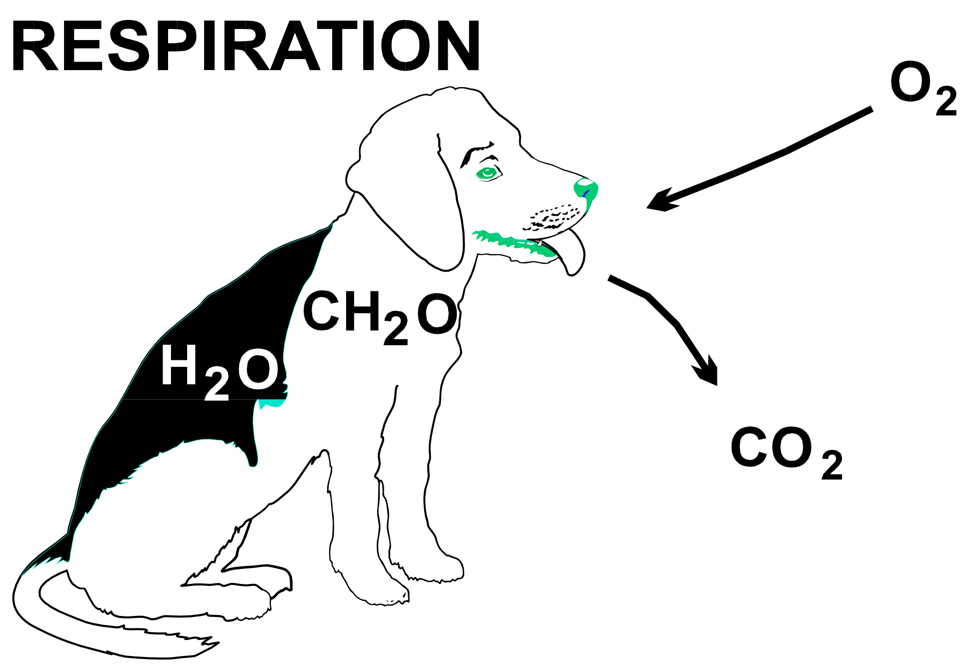
The process of photosynthesis. Carbon dioxide and water molecules are combined in the presence of chlorophyll and using the energy from sunlight, to create carbohydrates (sugar) and oxygen.

Organic molecules tend to be large and complex, and usually contain carbon, hydrogen, and oxygen, with various other atoms to a lesser degree, *and they are all produced in and by living things*. Only one kind of living thing has the ability to create organic molecules from inorganic raw materials, and that is plants. Plants are able to use the energy contained in sunlight to combine carbon dioxide, a gas common in our atmosphere, and water to create carbohydrates, specifically a carbohydrate called glucose. This process is called *photosynthesis* (photo=light, and synthesis=making), and it is done by virtue of a green material found in the cells of plants called *chlorophyll*. An important byproduct of photosynthesis is oxygen. Well discuss that more in a few minutes.

Respiration, how plants and animals use oxygen

Plants and animals use glucose as a fuel, a source of energy. Plants can make their own glucose by photosynthesis, but animals can't. Animals have to get their glucose from eating plants, or eating other animals that have eaten plants. The solar energy that was used to create the glucose can be thought of as being stored in the glucose molecules. By a process called *respiration*, that energy can be released.

Carbohydrates and oxygen are combined to yield carbon dioxide and water, and release stored energy.



Respiration is a process that is essentially the reverse of photosynthesis, in that glucose and oxygen are combined to release water, carbon dioxide, and energy. The energy thus released is used by plants and animals alike to carry out the other functions of living such as locomotion, synthesis of other molecules, and so on.

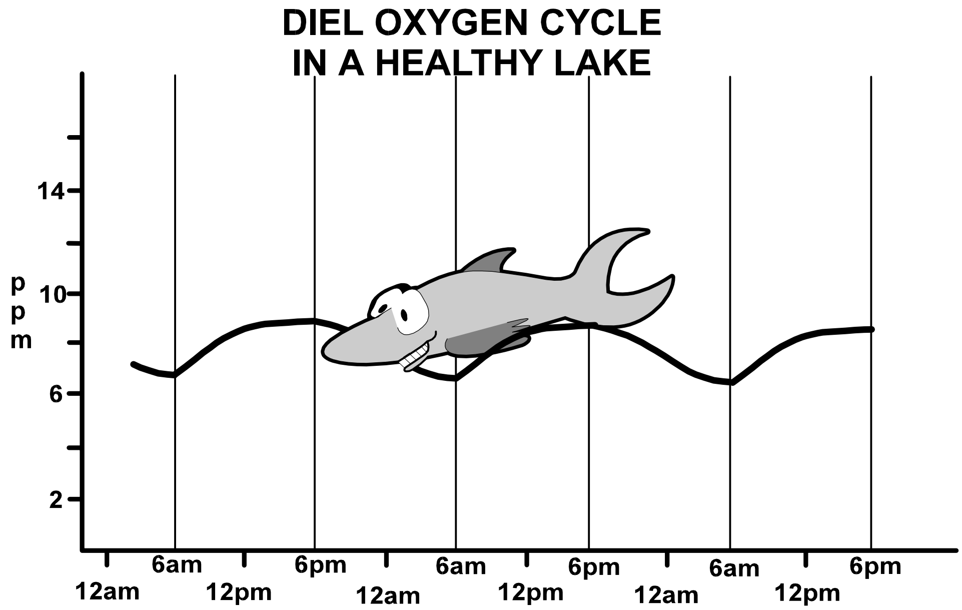
The diel oxygen cycle

Remember we said plants and animals all release energy from glucose, using oxygen in the process. This is not technically correct since a small number of primitive organisms including yeast and some bacteria release energy from glucose in other ways not requiring oxygen. But if you'll think of fish, and clams, and trees, and people - higher plants and animals - then the generalization is correct enough.

We get our oxygen by breathing air; fish and clams use gills to take it from the water. Some of the oxygen in water is dissolved right out of the air as the surface of the water comes in contact with the air. More oxygen is put into the water as aquatic plants photosynthesize. But remember, plants need *light* to photosynthesize, and this means they can only do it during daylight hours (unless you keep them in your house with the lights on). This means that at night, aquatic plants are not able to make oxygen, but plants and animals alike continue respiring, and using oxygen, all the time, day or night.

Now in a lake containing some algae, there will tend to be more oxygen dissolved in the water during the daytime, while the algae are photosynthesizing, than during the night. This is referred to as the *diel* oxygen cycle. Diel means daily.

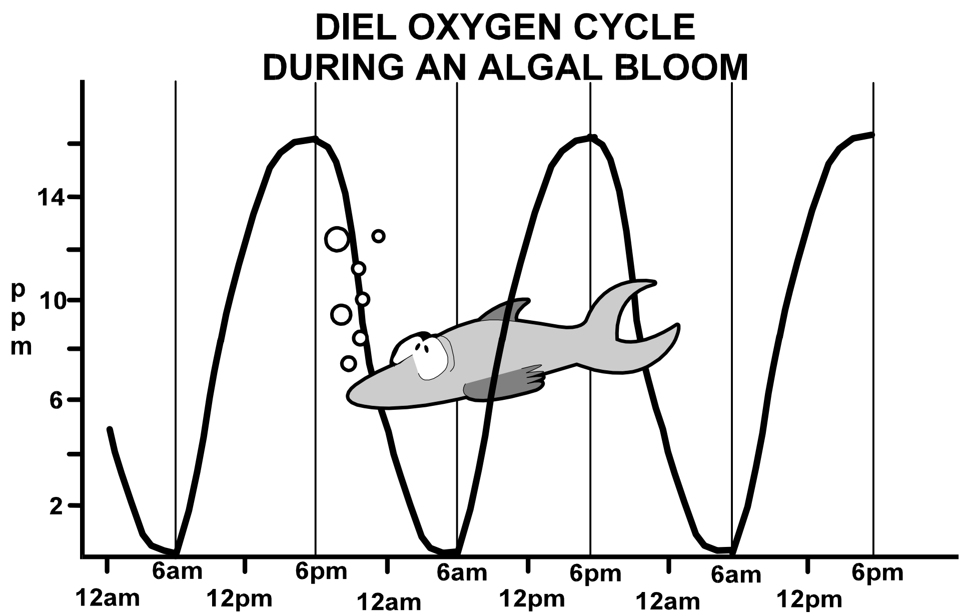
Diel oxygen cycle in a healthy lake. Diel fluctuations in dissolved oxygen are typically low.



The effect of algae blooms

If, however, our lake contains very many algae, that means that much more oxygen can be dissolved into the water during the day. It also means that, since more plants are respiring during nighttime hours, the amount of oxygen drops much lower than normal. In fact, if we have enough plants, the oxygen can become very high, or *supersaturated*, during the day, and drop completely to zero during the night! This obviously results in plants and animals alike, such as fish, dying for lack of oxygen.

Actually, oxygen doesn't have to drop completely to zero to start killing things, and long before conditions are bad enough to cause a fish kill, low oxygen levels may have killed off most of the benthic animals, insects and crayfish and so on, that they feed upon.



Diel oxygen cycle during an algal bloom. Diel fluctuations of dissolved oxygen can be extremely large, and nighttime levels can drop completely to zero in severe cases.

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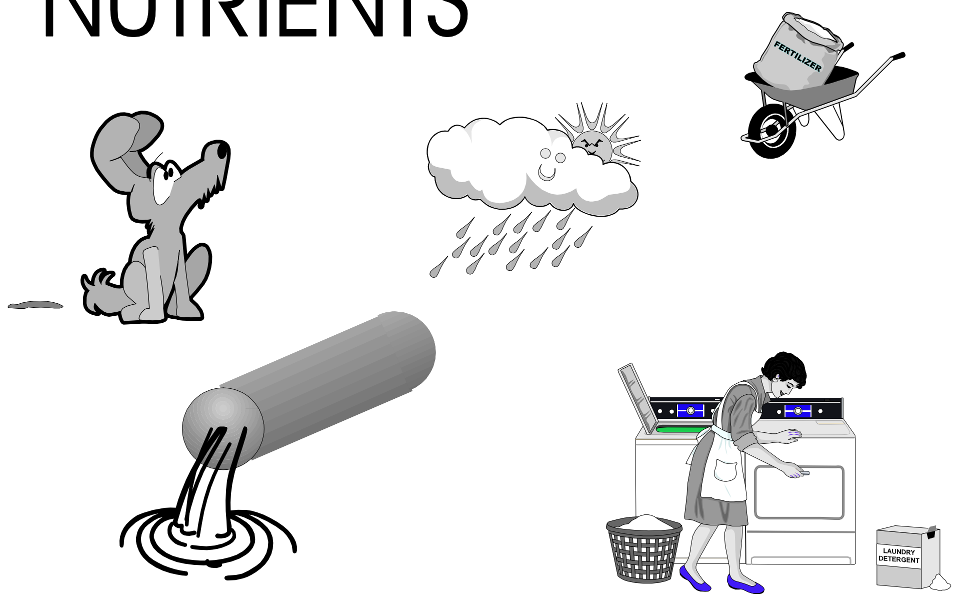
THE BASIC CHEMICAL PROPERTIES OF LAKES AND THEIR SIGNIFICANCE

Nutrients

What causes the amount of algae in a lake to increase? Well, algae are plants. When you want to grow more grass, what do you put on your lawn? The answer is fertilizer. Lawn fertilizer contains chemicals required by plants, grass in the case of your lawn, in order to grow. Such chemicals are referred to as *essential nutrients* (like chocolate, for example). We'll discuss this concept in more detail later on.

NUTRIENTS

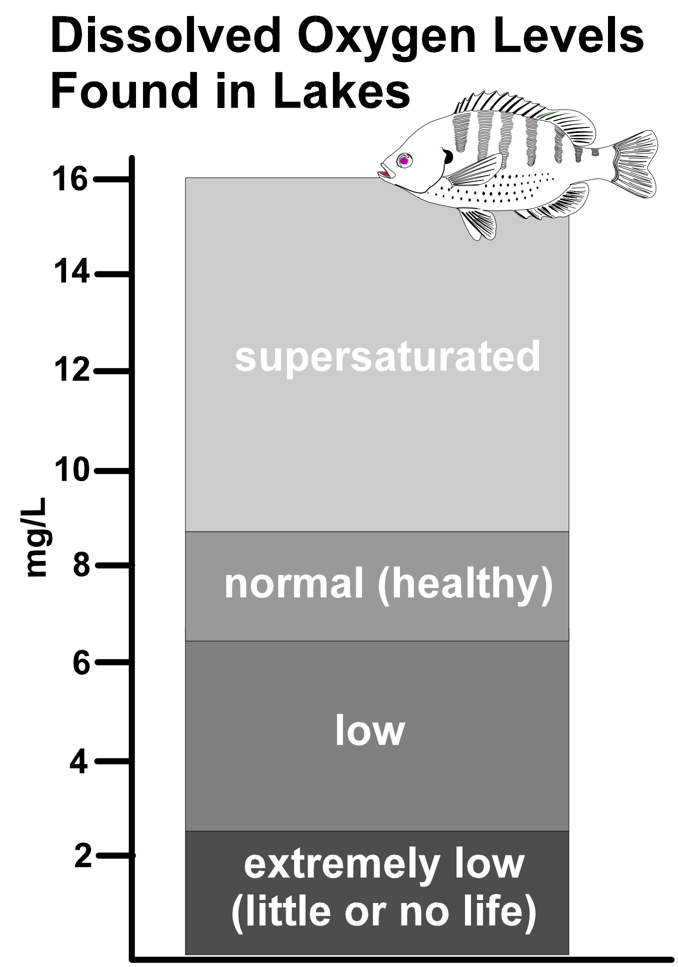


Sources of Nutrients. Clockwise from upper left, animal wastes, even rainfall can carry nutrients and other pollutants, fertilizers, laundry detergents, and stormwater runoff.

The most commonly required nutrients of interest to lakes are nitrogen and phosphorus. Other things like carbon dioxide and water are in abundant supply, but in nature, nitrogen and phosphorus are usually relatively scarce, thus they are the *essential nutrients* that tend to limit how much plant growth can occur. When nitrogen and phosphorus become more enriched in a lake, from discharge of sewage for example, the algae and other plants will respond by multiplying and growing.

Dissolved oxygen

At best, oxygen is relatively scarce in water, as compared to air. At normal temperatures, dissolved oxygen levels are normally in the range of 7-8 milligrams of oxygen per liter, or 1,000 grams of water. This is 7-8 units of oxygen for every million units of water! Any more than this is considered *supersaturated* - unstable and easily lost from solution. At levels of about 3 milligrams per liter (or mg/L), many animals can't live. Thus, there is a fairly small range between the amount of oxygen that can exist in solution at best, and the amount that is too low to support life.

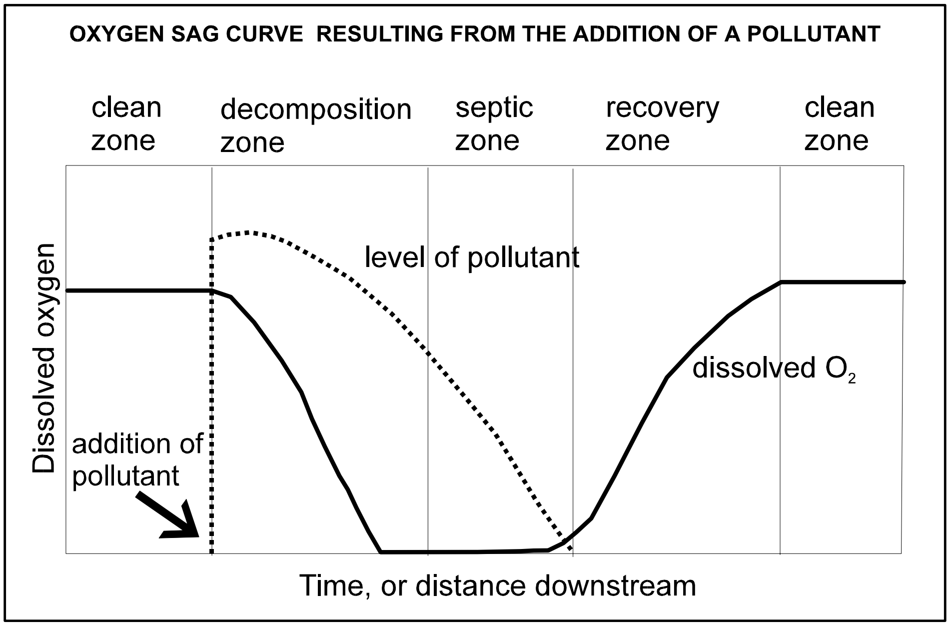


Dissolved oxygen levels in lakes.

In general, oxygen and other dissolved gases are more soluble, or more readily dissolved, at lower temperatures, and conversely, less soluble at high temperatures. As a result, oxygen levels often tend to be lower in lakes during the summer than in the winter.

Oxygen demands - effect on amount of DO

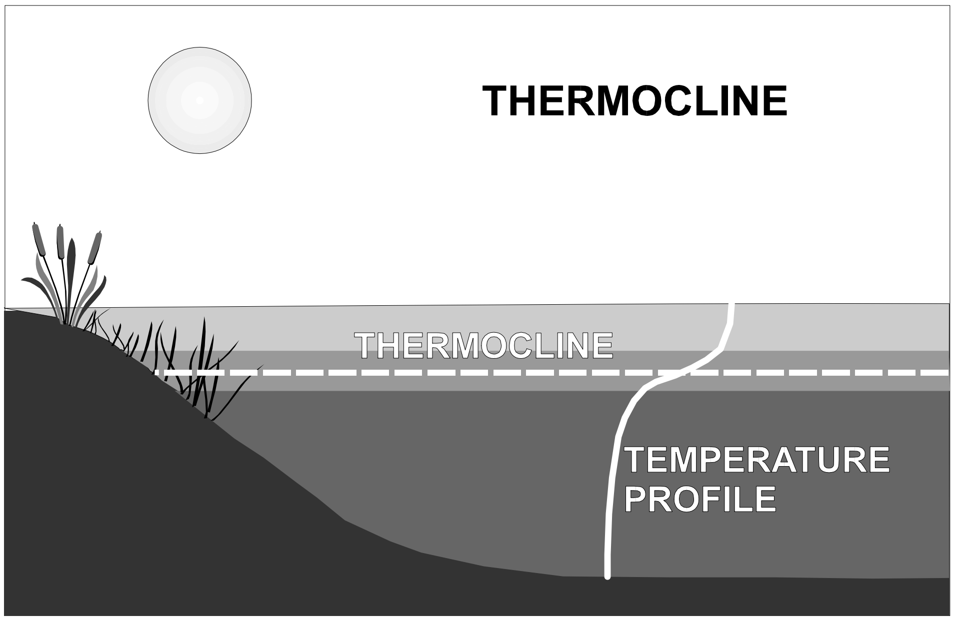
Discharge of organic waste, such as sewage, causes other problems besides increasing nutrients and algal growth. When organic waste is put into a lake or stream, millions of bacteria begin to decompose it - that is, break it down into basic elements. To do this, they use oxygen taken from the water. Scientists measure the amount of oxygen consumed by the organic matter in the water, and refer to it as *Biochemical Oxygen Demand*. Usually, immediately downstream of a waste discharge, the dissolved oxygen level drops very low, and only recovers farther downstream after most of the waste is decomposed. In this zone of low oxygen, fish and other animals are usually severely limited, or completely absent. In some cases, discharges of other chemicals, such as ammonia, can also exert an oxygen demand.



The effects of discharging organic wastes into a stream. As the waste flows downstream, it is oxidized, resulting in eventual destruction of the waste, but also resulting in decrease in dissolved oxygen, until oxygen levels are once again stabilized by reaeration.

Stratification

Partly because the surface of a lake is in contact with sunlight, and partly because warm water tends to be less dense than cool water, the temperature in a lake tends to normally be cooler toward the bottom, and gradually increase as one nears the surface. In some lakes, particularly those in the temperate zone, there is a tendency to become *stratified*. In a stratified lake, the temperature at some given depth drops dramatically. This zone at which the rapid drop in temperature is found is called a *thermocline*. Shallow lakes such as those found in Florida very rarely are found to be stratified. This is primarily because wind keeps the water well-mixed in such lakes, and prevents stratification from happening.



Lake stratification. The water temperature drops very quickly in the region of the thermocline.

The general way stratification occurs is as follows: during the summer, the top waters (epilimnion) are warmed, and as a result do not mix with the lower, cooler and denser water (hypolimnion). Only the epilimnion is able to circulate and come into contact with the air-water interface. The lower (profundal, remember) zone is no longer able to come into contact with the air-water interface, and if the bottom of the thermocline is too deep for sufficient light to penetrate for photosynthesis, the hypolimnion often becomes depleted of oxygen during the summer. This is often referred to as the *summer stagnation*.

With the onset of cooler weather, the epilimnion begins to cool, and at the point at which it reaches the same temperature as the hypolimnion, circulation is once again able to occur, and the entire lake mixes. This is referred to as the *fall overturn*. During the fall overturn, nutrients accumulated in the hypolimnion once again mix with the surface layers, and oxygen is restored to the deeper waters.

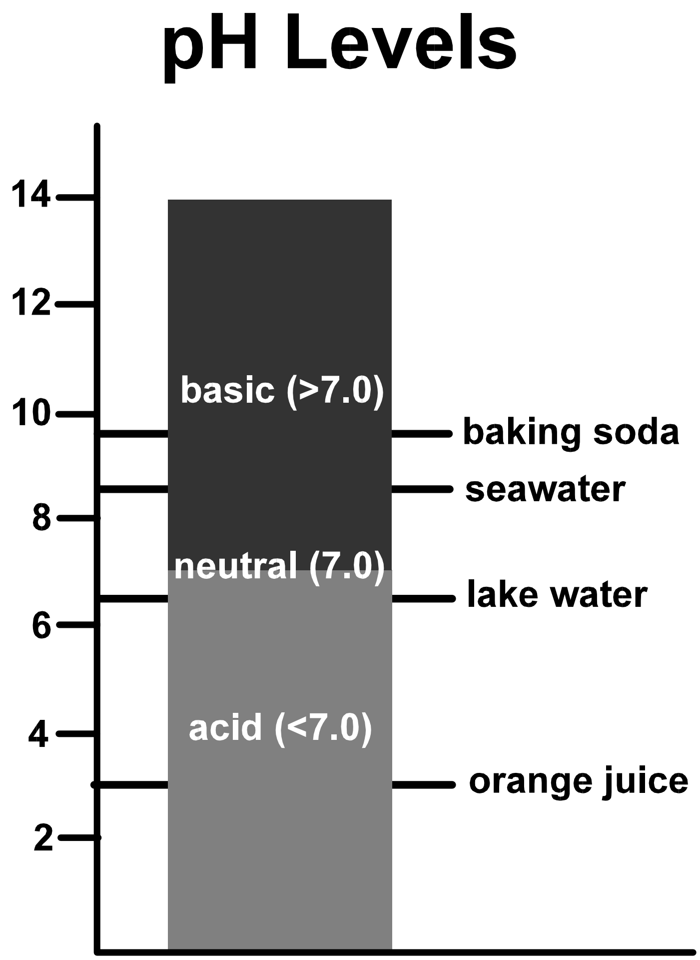
Most Florida lakes are shallow and well-mixed by wind. Consequently, although surface water temperature is generally higher than bottom temperatures, true stratification is rare in Florida lakes.

OTHER IMPORTANT PHYSICAL PROPERTIES

pH

The pH of water is a measure of the relative acidity or alkalinity of the water. The pH scale runs from zero to fourteen; at a pH of seven, the water is said to be neutral, that is neither acid nor alkaline (basic). At a pH lower than seven the water is said to be acidic. Many lakes, especially those with adjoining swamps, tend to be slightly acidic (pH 6.0-6.5). Things like orange juice and vinegar are common household acids.

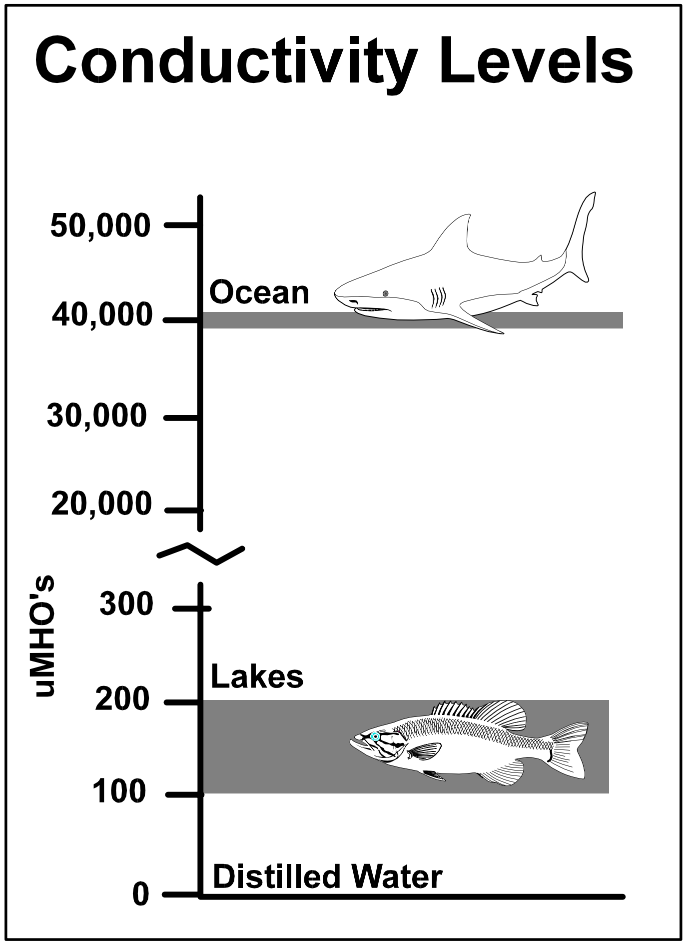
When the pH is higher than seven, the water is alkaline, or basic. Seawater, for example, tends to be slightly basic, with pH in the range of 8.0-8.5. Lye is a very highly basic chemical, and is very caustic.



The pH scale, showing levels typical of various environments.

Specific conductance

Specific conductance, sometimes called *conductivity*, is a measure of the ability of an electric current to travel through water, and that is exactly the way it is measured. Pure, distilled water will not conduct electricity. Many compounds which dissolve into water will enhance its ability to carry an electric current. Saltwater in the ocean has a very high specific conductance, in the range of 35,000 to 40,000 umho/cm (micromhos per centimeter). By contrast, the conductance of most lake water tends to be less than 200 umho/cm. Specific conductance tells the scientist a lot about how much matter is dissolved in the water.



Specific conductance, illustrating the conductance levels typical of various environments.

CONCEPT OF LIMITING FACTORS

A while ago, we talked about how certain chemicals are considered essential nutrients, and implied that some nutrients tend to be less plentiful than others. Ecologists have long utilized the concept of the *limiting factor* to explain what factor controls the absolute number of plants or animals that can exist in a given place.

To understand the concept of the limiting factor, imagine you are planning to bake a chocolate cake, from your grandmother's old favorite recipe. That recipe calls for

2 eggs	1 teaspoon baking soda
2 cups sugar	1/2 cup cocoa
2 cups flour	1 cup buttermilk
1/2 teaspoon salt	

You look in the pantry and find you have 5 pounds of sugar, 5 pounds of flour, plenty of salt and baking powder, and a brand new box of cocoa. You look in the fridge, and find a whole new quart of buttermilk, *but you only have two eggs*. No matter how much of anything else you have, you can still only make one cake. In this example, eggs are the limiting factor. If you bought more eggs, you might be able to make more cakes, but then something else (probably buttermilk) would become the limiting factor.

In some ecosystems, the factor limiting a certain type of animal, say a predator, may be the number of prey organisms. It might instead be a limited number of preferred nesting sites.

In the case of algae, as we explained, the factors that are most often limiting to algal growth are either nitrogen, or phosphorus. In order to find out which is limiting, and to what extent a given amount of the limiting nutrient will affect additional growth, scientists often conduct tests called *algal assays*. In an algal assay, a scientist would add varying amounts of nitrogen, or phosphorus, or combinations thereof, to samples of a lake's water, and determine how much algal growth occurs in each. If, for example, nitrogen is limiting, the assay where phosphorus alone is added would result in no growth.

The Trophic State

Remember a while back we said that *trophic* refers to feeding? Scientists refer to a lake that has lots of nutrients, or is well-nourished, as *eutrophic*. A lake that has few nutrients, or is poorly-nourished, is called *oligotrophic*. A lake somewhere in between is called *mesotrophic*.

This concept of trophic status is important in lake management, because one of the most common problems experienced by lake users is the fact that the lake is too *eutrophic*. Of course, if the lake is too *oligotrophic*, it wouldn't support much in the way of sport fishing. Like most things in life, somewhere in the middle is probably best.

Imagine, for example, that you were to *dig* a lake, like that developer we talked about earlier, or like a glacier. At first, the lake would be just a big hole full of water, and little else. Your lake is very *oligotrophic*. Since the lake is at the bottom of the hill, so to speak, everything on the ground will tend to get washed into it by repeated rainfalls over time. This includes nutrients. As time goes on, the nutrients allow plants such as cattails and phytoplankton to begin growing. Other things such as aquatic insects and fish begin to appear, and increase over time. This is the process of *eutrophication*.

This process will continue, under natural conditions taking many years, until the lake actually begins to fill up with its own accumulation of sediments and organic matter. Now your lake looks more like a swamp than a lake. It is much shallower than when it began, and may have more vegetation than open water. This is a natural process that all lakes will encounter, although it may take place over many years, or even centuries for large lakes.

Dr. Robert Carlson of Kent State University devised a method of comparing different lakes in terms of how eutrophic they are; it is called the *Trophic State Index* or TSI. The TSI is calculated by means of a formula that uses the amount chlorophyll (as a measure of algae), nitrogen or phosphorus (depending upon which is limiting), and water clarity (because the more algae present, the less clarity). A lake with a TSI of 10 would be considered oligotrophic most anywhere; in Florida, even a 20 would be considered pretty good. A TSI in the range of 45-55 would be considered mesotrophic, and at 65 or above, the lake would be very green from the amount of algae present and would be considered eutrophic. In fact, for very highly enriched lakes, some people reserve the special terms *hypereutrophic*, or even *dystrophic*.

TROPHIC STATE INDEX

	TSI	chl a ug/l	SD m
Oligotrophic	0	0.3	7.4
	10	0.6	5.3
	20	1.3	3.8
Mesotrophic	30	2.5	2.7
	40	5.0	2.0
Eutrophic	50	10.0	1.4
	60	20.0	1.0
	70	40.0	0.72
Hypereutrophic	80	80.0	0.51
	90	160.0	0.37
	100	320.0	0.26

Florida lakes are particularly susceptible to eutrophication, for a variety of reasons. The water is warmer than lakes in more northern states, resulting in a longer growing season for algae. The angle of the sun's rays is more vertical, so that there is more light to support plant growth for most of the year. Unfortunately, many Florida lakes become dominated by macrophytes such as hydrilla, and the traditional concept of a TSI based partly on water clarity and chlorophyll doesn't really apply. Some scientists have proposed an alternate TSI that incorporates macrophyte abundance.

TYPICAL MANAGEMENT PROBLEMS

Oftentimes, lakes are perceived as having problems. That is to say, they are for some reason unacceptable to the people that want to use them. A eutrophic lake is, as far as the lake community is concerned, not a problem, it just is. However, if people want to live near the lake, they may not want it to look green, and they'd certainly object to occasional fish kills. If people want to operate boats, they may object to the presence of aquatic macrophytes (which they call aquatic weeds).
In the following, we will discuss a few of the most common problems that people perceive in lakes.

Eutrophication

We have already discussed what eutrophication is, the fact that it is a natural phenomenon, and the fact that it usually takes place fairly slowly. When man begins to live around lakes, certain conditions begin to change which accelerate the rate of eutrophication. Often, sewage or industrial wastes are discharged into lakes. Hardened surfaces such as driveways and roads tends to increase the amount of surface runoff into the lake, and the fertilizers and other things people put onto the ground also tend to flow into the lake at much higher than natural rates.

The result is an accelerated rate of eutrophication, or *cultural eutrophication*. Cultural eutrophication differs from the normal process in two basic ways: first, it is much faster. Lakes that otherwise may have taken many years to become eutrophic may do so in little over a decade. Second, and perhaps more important, naturally eutrophic lakes tend to become actually more stable ecosystems. They tend to have more species of living things than oligotrophic systems. *Culturally eutrophic* systems, on the other hand, tend to be hostile environments, and may support large populations of a relatively small number of species. This is why many of the eutrophic lakes we study tend to be dominated by vast numbers of a single insect species, for example.

Measures used to reverse the process of eutrophication are diverse, but generally involve ways to reduce the amount of limiting nutrients entering the lake, or to increase the amount leaving the lake, or a combination of both. We will discuss some of these specific measures later on.

Aquatic weeds (macrophytes)

Proliferation of aquatic macrophytes may or may not be caused by eutrophication; some plants actually don't take their nutrients from the water. At any rate, large biomass of plants is viewed by boaters to be a real concern. Fishermen, on the other hand, like much higher levels of macrophytes, as long as there is enough adjacent open water to fish in, because macrophytes tend to produce lots of critters for fish to feed on.

Most of our really big aquatic plant problems result from plants that are not native to the area becoming introduced. Hydrilla, a serious nuisance plant in Florida waters, was introduced in the 1950s from Sri Lanka by aquarium hobbyists. The notorious water hyacinth, a native of South America, was brought into the country during the 1880s as an ornamental plant for water gardens and fish ponds. In most of the other parts of the country, Eurasian water milfoil and a number of other exotic species of the same genus are a serious problem. These plants can become prolific, and out-compete other, native forms, by virtue of the fact that there are no naturally occurring predators or diseases which will control them.

Up until now, we have attempted to control such nuisance plants by spraying them with herbicides, a fact that alarmed many environmentalists. In recent years, better herbicides have been produced which target one, or a few, species of plant and do not directly harm fish or other wildlife. Light spraying programs designed to keep the plants from spreading have been found to be much preferable to waiting until they have taken over, and then applying massive doses to eliminate them.

In recent years, the practice of introducing insects or diseases from the place of origin of the nuisance plant, which will control the plant but will not harm any other, native vegetation, has grown in acceptance. Long periods of testing are required to make sure the introduced control doesn't turn out to be a worse pest than the plant it was introduced to control. The Pakistan hydrilla fly, which feeds on hydrilla during its larval stage, has after long testing been cleared for introduction into nature in Florida.

One introduced control used most often to control nuisance plants is the *triploid grass carp*. These fish have been genetically altered so that, presumably, they will be unable to reproduce in the wild, and hence, won't become nuisances. Grass carps are very difficult to manage, however, and once introduced, they don't always limit their feeding to the targeted plant. Once the target species is gone, they will often go on feeding on other, more desirable plants until they finally die of old age.

Algae blooms

An algae bloom is a relatively sudden and dramatic increase in the number of algae in a lake. Usually, though not always, they are comprised of a single species of alga which multiplies rapidly. Sometimes the algae will multiply until they deplete the water of whatever is the limiting nutrient, at which time growth levels off. Sometimes however, numbers of algae grow so dense that they shade each other out, and light becomes a limiting factor, even though there may be excess unused nutrients available. Often during severe algae blooms, dissolved oxygen levels can soar during the daytime hours, but drop to zero during the night, resulting in massive fish kills. In fact, this is the most common cause of fish kills in urban lakes and ponds.

If a lake has abundant nutrients, often a more-or-less permanent algae bloom will persist. In such situations, it only takes the right combination of conditions - several cloudy days of reduced solar intensity, warm water conditions, and lack of wind to circulate and reaerate the water, and fish kills can be triggered. Some highly eutrophic lakes experience occasional fish kills during the summer in this fashion.

Often we dont really know what triggered an algae bloom. They have been known to occur in oligotrophic lakes, with no apparent cause that we can put our finger on. Such a bloom might, however, be a warning sign that conditions in the lake are changing, and warrants further study.

MEANS OF STUDYING LAKES

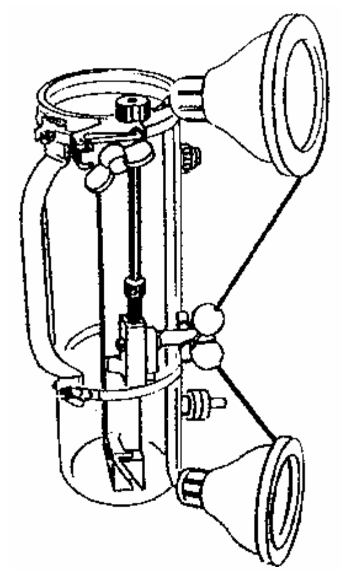
Scientists use a variety of means to study lakes. Many of the methods and tools used to study lakes are identical to those used by oceanographers to study the oceans. Let us discuss a few of the commonly used tools and methods.

Water sampling

Perhaps the most common way of studying lakes is to sample the water occasionally and subject it to chemical analysis for important constituents, including such things as nitrogen, phosphorus, chlorophyll (commonly tested as a way of estimating the number of algae present), biochemical oxygen demand, and occasionally toxics chemicals.

If we want to test the quality of the water at the surface of the lake, we can simply lean over the side of the boat and take a *grab sample*, using any suitable container. It is very important that sampling devices, as well as the bottles we put the samples into for transfer to the lab, are clean so that we end up testing for what was really in the lake, and not something that was added to the sample by a dirty bottle.

If we want to sample the water below the surface, farther than the length of our arm, we need to resort to special sampling tools designed to capture a sample of water at whatever depth we desire. Oceanographers sometimes use these tools to collect water from great depths. There are a number of sample devices that are in common use for this purpose. A few of the most commonly used include the Nansen bottle, the Kemmerer sampler, the Van Dorn bottle, and the Alpha bottle. As you can see, most of them are named after the person who invented them. All of them are constructed so that you can open them, lower them to the desired depth, and then trigger them to close, capturing whatever water was at that depth. For sampling at reasonably shallow depths, some people simply lower a flexible tube to the appropriate depth and use a vacuum pump to pull water up and into a sample container.



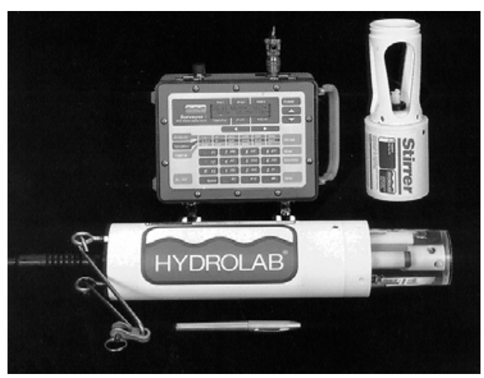
An Alpha Bottle, an example of a device used to sample water from depths.

There are a number of precautions samplers go through, called *quality control* measures, in order to guarantee that the sample is representative of the part of the lake being tested, and does not undergo changes between collection and analysis.

Physical variables

Most samplers also collect certain information *in situ*, that is they directly measure them in the lake using test meters specifically designed for the purpose. These include such things as pH, specific conductance, salinity (in saltwater bodies), temperature, dissolved oxygen, and less often oxidation/reduction (or redox) potential. These variables are extremely important to people studying lakes. The probes designed to sense these variables can be attached to long cables and lowered to any desired depth. The reading is then transmitted up the cable to a separate unit on deck for reading and recording the results.

Most of these variables can be sampled using dedicated meters designed specifically for that one variable. There are several *multi-probe* devices available, and widely used, with the ability to sample for a number of constituents simultaneously from the same device. Use of such devices cuts down on the amount of gear that has to be carried into the field.

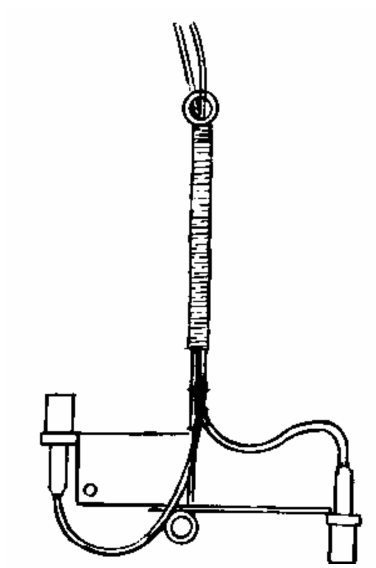


A HYDROLAB®, a device created for measuring several physical variables (pH, temperature, specific conductance, salinity, depth, redox potential, and dissolved oxygen) at various depths. Upper left, deck data recording unit; bottom, sonde (device which is lowered into water); upper right, stirring unit (for dissolved oxygen probe).

Light penetration

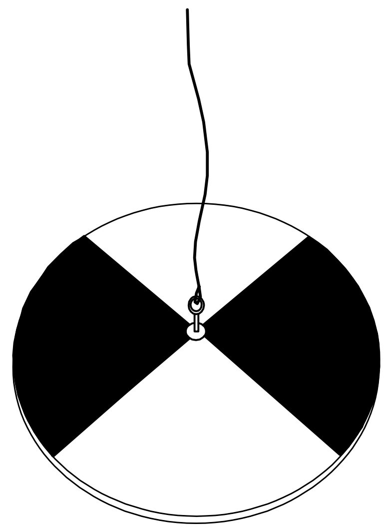
Since plants need sufficient light in order to photosynthesize, the amount of available light and the depth to which sufficient light can penetrate are very important. The most sophisticated way to measure light penetration is by use of light meters. A light sensor is located on deck to measure the amount of light actually reaching the surface of the lake, and another lowered to the desired depth to determine what percent of the available light has been absorbed by the water column.

A light sensor submersible sonde. The cables lead to a meter which is used to read the amount of light reaching the sensors. The sensor pointed downward measures light reflected off the bottom.



Another method, far more commonly used, is the Secchi disk. History tells us that Secchi was the name of a friar, and he introduced the use of a white disk long ago to measure the clarity of wine. Now scientists use a standard white disk with two opposing quarters painted black to measure light penetration. The disk is attached to a rope and lowered into the water until it is no longer visible. This is the *Secchi depth*, and it is surprisingly accurate (i.e., a number of people performing the test will generally come up with the same reading).

A Secchi disk.



Fish Collection

The most common way of collecting fish for purposes of counting, measuring, identification, and so on, is by seining them. A seine is a long net made of twine, or sometimes monofilament, which is dragged through the water with its lower edge on the bottom, so that once the net is dragged ashore, all the fish surrounded by the seine will be trapped. Seines vary in size. They may be anywhere from 3 to 6 feet high, and from 25 to 100 or more feet long. The size of the mesh, or more correctly the holes between the twine, depends upon the kind and size of fish one is interested in trapping.

Some researchers use poisons, the most common of which is called Rotenone, to kill all the fish in an area to be sampled. They might also use electric shockers which stun the fish and cause them to float to the surface where they can be scooped up. The obvious disadvantage of these methods is that the fish are killed and removed from the population. Such methods, while sometimes the only effective method, are not very popular with citizens.

Often researchers use an additional net called a block net to completely encircle an area, trapping all the fish in that area inside. They are then sampled by either seining or poisoning.

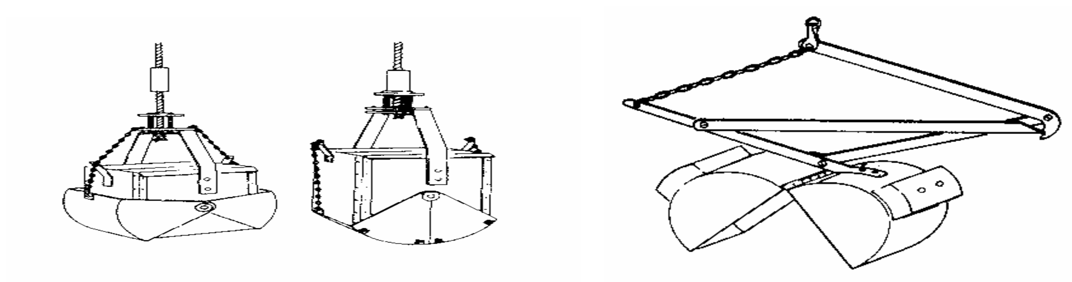
A trawl is a bag-shaped net designed so that it can be towed behind a boat in open water. Panels, referred to as *doors*, hold the mouth of the trawl open and fish are collected in the *bag-end* of the trawl.

Benthic organisms

Benthic organisms, you will recall, are those that live in or on the bottom. All water bodies, whether lakes, streams, or oceans, have a significant community of plants and animals that live on the bottom. These would include, as expected, grasses and other rooted plants. They also include a variety of clams, snails, shrimps, crayfish, worms, and many forms of insects, both adult and larval. Some live on the blades of grass and other vegetation, some crawl upon the bottom itself, and others burrow into the bottom, only coming out far enough to trap food, or to gather oxygen with their gills.

The kinds of organisms living on the bottom are particularly good indicators of the conditions that exist in the lake over the long term. This is because most of these organisms are unable to move for large distances, if at all. Thus, they are most sensitive to water quality and other conditions. If the water quality becomes poor enough, they simply die, and are no longer found in the benthic community, whereas fish would simply swim away from a hostile environment and return when conditions had improved.

Scientists can tell a lot about a lake by studying its benthos. To do this, scientists use a variety of tools for collecting samples. Most of these come under the generic term of *dredge*. Generally, they are designed so as to collect lake sediment - sand and mud - from a known area of bottom. In this way, once the organisms have been identified and enumerated, they can be expressed in terms of how many there were per unit area of bottom, a convenient way of comparing the relative productivity of different lakes, or habitats within the same lake.



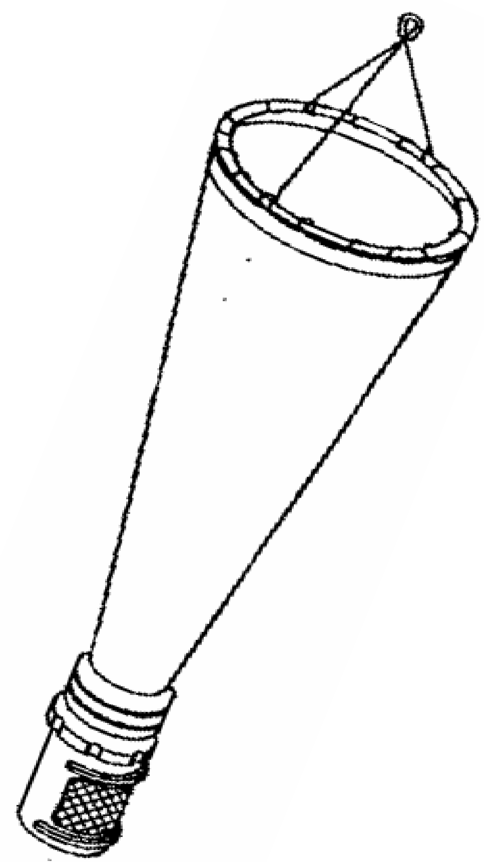
Examples of bottom grabs, or dredges. Left, Eckman grab, open; center, Eckman grab, closed; right, Peterson grab.

Plankton

The plankton, you will recall, are those organisms that are unable to swim faster than the currents and tend to be carried about at the whim of the water mass they are living in. Like benthos, the plankton can tell a lot about the condition of a lake.

The most common means of collecting plankton involves dragging a long, very fine, conical net through the water. The mouth of the net is usually 1-3 feet in width. At the small end of the cone is a sampling jar. The mesh of the net is fine enough that water can pass through, but the microscopic plants and animals that make up most of the plankton will be trapped and funneled into the sample jar.

A Plankton net. It is towed behind a boat. The cone is made of a nylon mesh through which water will pass, but not planktonic organisms, which are collected in the jar.



MANAGEMENT OPTIONS

In the section where we discussed common problems in lakes, we also discussed some of the common ways in which those problems are solved, or managed. We deferred, however, discussion of the methods used for reducing eutrophication until now.

Methods used to solve eutrophication generally involve either keeping nutrients from getting into the lake in the first place, if possible, or taking nutrients out of the lake once they are there, or a combination of both.

Management methods for *point sources*, that is those that discharge from some kind of outfall into the lake (such as sewage treatment plants, and industries), are as diverse as the kinds of sources; each industry has its own ways of treating its waste. Since the onset of pollution control laws in the 1960s and 70s, point sources have for the most part been cleaned up, although even today, lake problems are occasionally tracked back to point sources.

Much more commonly today, nonpoint sources such as runoff from residential or agricultural lands are the biggest contributors of nutrients to lakes. Modern development codes require developers to create stormwater treatment ponds or other accepted systems for treating runoff. Unfortunately, however, many areas were fully developed before such codes were adopted, and runoff flows into the lake untreated. In such areas, finding available land in the right place to construct a treatment pond is difficult, and expensive.

Ponds are by far the most commonly used way to treat runoff, partly because once they are dug, they require much less maintenance than other systems. Ponds work by allowing flowing water to slow down so that particles can settle out. Many of the pollutants in stormwater runoff tend to be adhered to particles like clay, silt, and organic detritus such as grass clippings, so allowing those particles to settle out will effectively prevent them from being discharged into the lake.

Commonly constructed ponds can remove about 80 per cent of the solids and biochemical oxygen demand from runoff, but only remove about 30-35 per cent of the nitrogen. Because material tends to accumulate in ponds over time, reducing the ponds volume, ponds need to be cleaned out occasionally or their treatment efficiency will begin to decline.

A second commonly used treatment is alum precipitation. Alum is aluminum sulfate. When introduced into water, it tends to cause a lot of the suspended and dissolved material to fall out of solution and settle to the bottom. Alum, and other similar flocculants, have occasionally been used directly in lakes to cause rapid settling of nutrients out of the water. Many scientists, however, are skeptical about using alum directly in lakes, since aluminum under the right conditions is very toxic to plants and animals. More commonly nowadays, alum is used to precipitate pollutants from the stormwater *before it reaches the lake*.

Alum treatment requires a system of pumps, alum tanks, and other mechanism, and hence has much higher ongoing operational and maintenance cost than ponds. Although alum treatment of stormwater does require some land for the system and a settling pond, it requires much less land than conventional pond treatment, and thus is often looked at as an alternative when sufficient land for a pond is not available.

In some notable instances, experimental systems have been used involving pumping of water out of a eutrophic lake and allowing it to filter through a marsh system prior to reentering the lake. These systems have had some success, and a sufficient number have been studied so that scientists are able to predict their pollutant removal efficiency reasonably well. Such systems, on the other hand, require a good deal of land, and there are physical limitations to the places that they can be used.

Other compact, manufactured stormwater treatment systems exist which use a variety of physical and biological means to filter runoff and remove pollutants before it is discharged to the lake. Like alum, these systems tend to use less land than ponds, but have higher ongoing operational and maintenance costs. Some of these are being tested around the country, but none have enjoyed the universal popularity of ponds.

Finally, where highly enriched sediments have accumulated in a lake and are contributing significant levels of nutrients back into the water, some managers have resorted to dredging to remove the sediments. This has been demonstrated to be very successful. Unfortunately it is extremely expensive, and requires a satisfactory (and very large) parcel of open land in which to dump the dredged sediment. If the disposal site is not close to the lake, hauling or piping for long distances only tends to make this option inordinately expensive.

Fluctuation

Left alone, the water level of natural lakes tends to fluctuate from year to year, sometimes quite dramatically. Over time, many lakes occasionally go almost dry in very dry years.

As man began to move into lake watersheds and develop the land, however, dams have often been constructed on lakes. Some of these dams were created to produce hydroelectric power, and as a result, water levels tend to be controlled by the need for electric power. In many other cases, the dams were built to allow people to control the lakes levels so as to prevent flooding, on the one hand, and to make sure that there was deep enough water for boating on the other.

As man continued to build homes and farms in increasingly lower lying areas, these lakes began to be controlled over progressively smaller ranges. Furthermore, in lakes that are controlled for flood prevention, the levels are usually dropped at a time of year just opposite to the way the lake fluctuated naturally. Some lakes, in fact, have fixed weirs, or dams that don't allow any control, and the water flows over them only when the level is above that of the dam. The rest of the time, evaporation is essentially the only way that water leaves such lakes.

In recent years, we have learned that not only is fluctuation of water levels natural for lakes, it is essential. Holding lake levels at a fixed point tends to allow certain kinds of vegetation, such as cattails, a competitive advantage over other species, and often results in a lake being taken over by cattails or other nuisance species.

Holding water levels fixed tends to greatly extend the *residence time*, or the average length of time that water is held in the lake. This allows pollutants entering the lake to accumulate instead of simply flowing through, and typically results in a trend toward more rapid eutrophication.

Restoring natural fluctuations to lakes that have been subjected to residential development is often hampered by the need to prevent flooding of existing houses and other structures, and many lake residents object to fluctuating the level of their lake in either direction. Nevertheless, recognizing that fixed levels are contributing to the decline of lakes, lake managers are more and more looking for ways to restore, at least partially, some of the fluctuation that is natural to lakes.

Drawdown

A tool that is almost always controversial, but that has demonstrated success is drawdown. In a drawdown, water is removed from the lake so that as much as 40-50 per cent of the lake bottom is exposed to air. This condition is maintained for several months, during which the enriched sediments partially oxidize, and become more compact. In some cases, earth moving equipment has been brought in to physically remove the enriched sediments to an upland location. In agricultural communities, this rich, organic soil is highly prized and sought after by local farmers.

After a drawdown, once the normal water levels have been established, fish populations in lakes treated in this fashion improved remarkably. Even in highly controversial projects that were opposed by residents, usually they have been very happy that it was done once they see the results. Unfortunately, not every lake is a good candidate for this kind of treatment. Additionally, if nothing has been done to combat the reason that the lake was enriched in the first place, after a few years fisheries will tend to begin declining, and eventually the whole process will have to be done again.

The band aid approach

Some of the management tools discussed above were things done outside the lake, to reduce levels of pollutants being discharged into it. Others were ways of removing accumulated pollutants from the lake itself. Often, simply cleaning up the source is not enough; if significant levels of nutrients are trapped in the lake or its sediments, the process of the lake cleaning itself may take much longer than we are willing to wait. In such cases, we find that we must do both: remove pollutants from the runoff, and remove them from the lake by some in-lake method.

If, however, all we do is an in-lake treatment, but do nothing to eliminate the original cause of the problem, we are usually only applying a stopgap measure that will have to be repeated over and over. This has come to be termed as a band aid approach. Agencies that fund lake restoration are usually unwilling to fund such measures unless they are combined with a real solution to the source of the problem.