# INTRODUCTION

The following is an edited version of a PDF document available on the U.S. Environmental Protection Agency's web site. The original document can be accessed on line by clicking on the following box:

Click Here to Access the Original Document

This document provides an excellent, comprehensive introduction to the field of Limnology using a variety of diagrams, interactive links, and real life examples.

Of course, because this is an American document, the examples used are from U.S. lakes. However, the information is still valid and, since many of the examples are from sites in Minnesota and other northern U.S. states, the data are often similar to what we would expect to find in many Manitoba lakes.

We have taken the liberty of removing several sections that were either not particularly relevant for Manitoba or contained orphaned links that no longer led to the information indicated. We have also inserted Canadian information to replace some of the U.S. material that was removed, or to supplement the U.S. material. For example; a map of major Manitoba watersheds has been inserted, photos of Manitoba fish species have been inserted in place of Minnesota species, and the original map and associated information about U.S. Ecoregions has been removed and replaced with information about the Canadian and Manitoba system for ecological classification of landscapes. Also, some Manitoba and northwestern Ontario lake examples have been added to tables 1 and 2.

While the total document is lengthy, much of its content is in the form of figures. The detailed text constitutes a relatively small portion of the content. Also, as an aid for understanding many of the more technical terms in the document, a comprehensive Glossary is appended and can be accessed directly by clicking on any of the many highlighted terms within the document. A clickable listing of "first letters" at the top of the first page of the Glossary will take you directly to the section containing all words starting with the selected letter and their definitions.

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# UNDERSTANDING LAKE ECOLOGY

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## OVERVIEW

The following overview is taken from LAKE ECOLOGY OVERVIEW (Chapter 1, Horne, A.J. and C.R. Goldman. 1994. Limnology. 2nd edition. McGraw-Hill Co., New York, New York, USA.)

> Limnology is the study of fresh or saline waters contained within continental boundaries. Limnology and the closely related science of oceanography together cover all aquatic ecosystems. Although many limnologists are freshwater ecologists, physical, chemical, and engineering limnologists all participate in this branch of science. Limnology covers lakes, ponds, reservoirs, streams, rivers, wetlands, and estuaries, while oceanography covers the open sea. Limnology evolved into a distinct science only in the past two centuries, when improvements in microscopes, the invention of the silk plankton net, and improvements in the thermometer combined to show that lakes are complex ecological systems with distinct structures.
>
> Today, limnology plays a major role in water use and distribution as well as in wildlife habitat protection. Limnologists work on lake and reservoir management, water pollution control, and stream and river protection, artificial wetland construction, and fish and wildlife enhancement. An important goal of education in limnology is to increase the number of people who, although not full-time limnologists, can understand and apply its general concepts to a broad range of related disciplines.

A primary goal of Water on the Web is to use these beautiful aquatic ecosystems to assist in the teaching of core physical, chemical, biological, and mathematical principles, as well as modern computer technology, while also improving our students' general understanding of water - the most fundamental substance necessary for sustaining life on our planet.

# ACKNOWLEDGMENTS

The Lake Ecology section is intended to provide a general background to Water on the Web by introducing the basic concepts necessary to understand how lake ecosystems function. The reader is later referred to a list of texts and journals for more in-depth coverage of the science of freshwater ecosystems. Much of the text, formatting, and figures are based on the four documents listed below, although extensive modifications have been made to include the original lecture notes of Co-principal Investigator Richard Axler. Additional citations have been included to provide appropriate credit.

Moore, M.L. 1989. NALMS management guide for lakes and reservoirs. North American Lake Management Society, P.O. Box 5443, Madison, WI, 53705-5443, USA.

NALMS. 1990. Lake and reservoir restoration guidance manual. Second edition (note - a revised manual is currently in preparation). North American Lake Management Society, P.O. Box 5443, Madison, WI, 53705-5443, USA.

Michaud, J.P. 1991. A citizen's guide to understanding and monitoring lakes and streams. Publ. #94-149. Washington State Department of Ecology, Publications Office, Olympia, WA, USA 360-407-7472.

Monson, B. 1992. A primer on limnology, second edition. Water Resources Center, University of Minnesota, 1500 Cleveland Avenue, St. Paul, MN 55108, USA.

# PHYSICAL STRUCTURE & GEOLOGICAL CHARACTERISTICS

## FORMATION OF LAKES

Knowledge of the formation and history of a lake is important to understanding its structure. The current chemical and biological condition of a lake depends on many factors, including:

- how it was formed
- size and shape of the lake basin
- size, topography, and chemistry of its watershed
- regional climate
- local biological communities
- activities of humans during the past century

There are three major areas in the US with abundant lakes:

- limestone sinkholes of Florida
- mountain lakes of the Pacific Northwest
- glaciated landscapes of the Great Lakes region

The focus of Water on the Web, and this Lake Ecology section, is on lakes in the glaciated landscapes of the Great Lakes region. In Minnesota, there are 12,034 lakes larger than 4 hectares (10 acres). The glaciers that covered much of the state until about 12,000 years ago created most Minnesota lakes. Glaciers formed lake basins by gouging holes in loose soil or soft bedrock, depositing material across stream beds, or leaving buried chunks of ice that later melted to leave lake basins (Figure 1). When these natural depressions or impoundments filled with water, they became lakes.

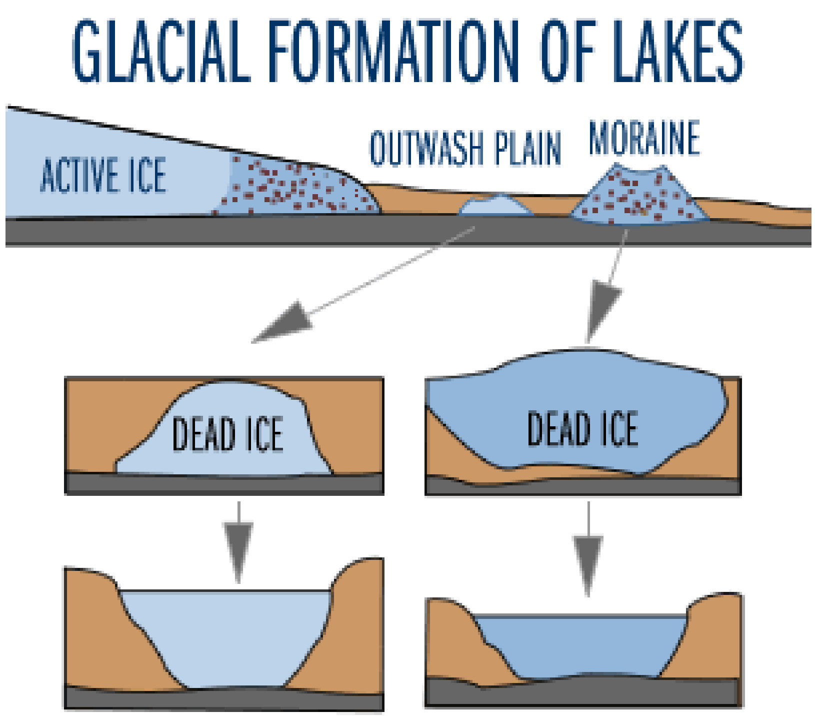



**Figure 1**

After the glaciers retreated, sediments accumulated in the deeper parts of the lake. These sediments entered the lakes from tributaries and from decomposed organic material derived from both the watershed and aquatic from plants and algae. An average Minnesota lake contains 9-12 meters of such sediment in its deeper parts.

Lake sediment deposits provide a record of a lake's history. Paleolimnology is the study of lake sediments. Paleolimnologists collect lake sediments using special coring devices to study a lake's physical, chemical and biological history. Lake sediments are often dated using the radioisotopes lead-210 and carbon-14. The age of a given sediment sample is based on the radioactive decay of the isotope. Other dating methods are based on identifying sharp increases of pollen in the core from ragweed and other plants indicative of agricultural soil disturbances or deforestation. Stratigraphic analyses of sediments have been used increasingly to assess the history of lakes, especially with regard to human impact. Lake acidity, water clarity, and algal productivity have been inferred by analyzing diatom abundance and composition, as well as plant pigments. Soil erosion can be inferred by the proportion of inorganic and organic matter and by chemical analyses for metals. Recently in Minnesota, these sediment dating, coring, and analysis techniques have been used to estimate spatial and temporal patterns in the mercury (Hg) content of lake sediments. These data were used to infer trends and sources of Hg in the state.

# LAKE VARIABILITY

People often visualize a lake as a uniform mass of water, almost like a full bathtub that is evenly mixed from top to bottom, side to side and front to back. In fact, lakes are extremely heterogeneous, or patchy. The physical, chemical, and biological characteristics of lakes are extremely variable. Lakes vary physically in terms of light levels, temperature, and water currents. Lakes vary chemically in terms of nutrients, major ions, and contaminants. Lakes vary biologically in terms of structure and function as well as static versus dynamic variables, such as biomass, population numbers, and growth rates. There is a great deal of spatial heterogeneity in all these variables, as well as temporal variability on the scales of minutes, hours, diel (day/night), seasons, decades, and geological time. Though lakes vary in many dimensions they are actually highly structured, similar to a forest ecosystem where, for example, a variety of physical variables (light, temperature, moisture) vary from the soil up through the canopy.

# LIGHT

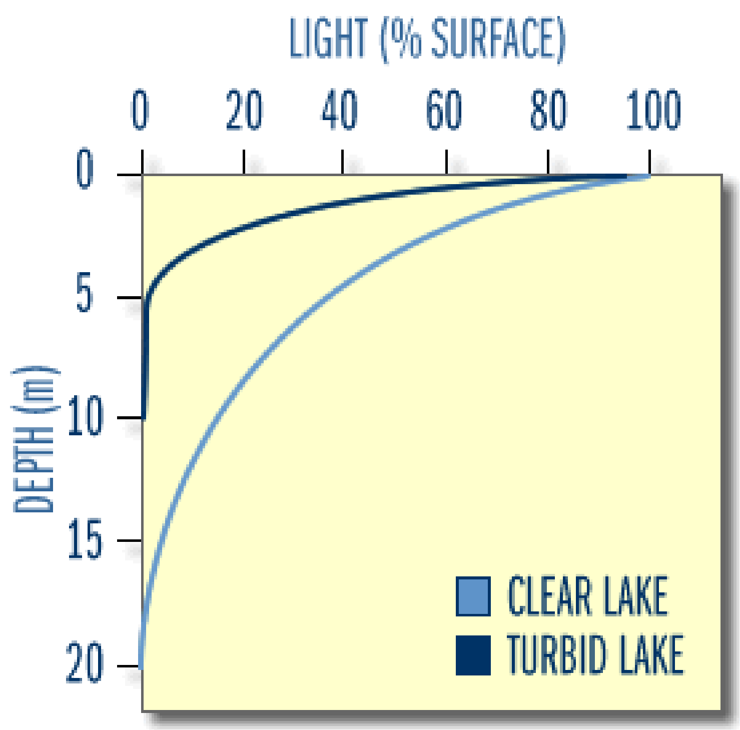
Perhaps the most fundamental set of properties of lakes relates to the interactions of light, temperature and wind mixing. The absorption and attenuation of light by the water column are major factors controlling temperature and potential photosynthesis. Photosynthesis provides the food that supports much of the food web. It also provides much of the dissolved oxygen in the water. Solar radiation is the major source of heat to the water column and is a major factor determining wind patterns in the lake basin and water movements.

Light intensity at the lake surface varies seasonally and with cloud cover and decreases with depth down the water column. The deeper into the water column that light can penetrate, the deeper photosynthesis can occur. Photosynthetic organisms include algae suspended in the water (phytoplankton), algae attached to surfaces (periphyton), and vascular aquatic plants (macrophytes).

The rate at which light decreases with depth depends upon the amount of light-absorbing dissolved substances (mostly organic carbon compounds washed in from decomposing vegetation in the watershed) and the amount of absorption and scattering caused by suspended materials (soil particles from the watershed, algae and detritus).

The percentage of the surface light absorbed or scattered in a 1 meter long vertical column of water, is called the vertical extinction coefficient. This parameter is symbolized by "k".

In lakes with low k-values, light penetrates deeper than in those with high k-values. Figure 2 shows the light attenuation profiles from two lakes with attenuation coefficients of 0.2/m and 0.9/m.




LIGHT VERSUS DEPTH PROFILES FOR A CLEAR LAKE ($k=0.2\ M^{-1}$) AND A TURBID LAKE ($k=0.9\ M^{-1}$).

**Figure 2**

The maximum depth at which algae and macrophytes can grow is determined by light levels. Limnologists estimate this depth to be the point at which the amount of light available is reduced to 0.5%–1% of the amount of light available at the lake surface. This is called the euphotic zone. A general rule of thumb is that this depth is about 2 to 3 times the limit of visibility as estimated using a Secchi disk. Light may be measured in a variety of ways for a number of different characteristics. The reader is referred to the reference texts for more information. Since photosynthesis depends fundamentally on light, significant changes in light penetration in a lake will produce a variety of direct and indirect biological and chemical effects. Significant changes in lake transparency are most often the result of human activities, usually in association with landuse activities in the watershed.

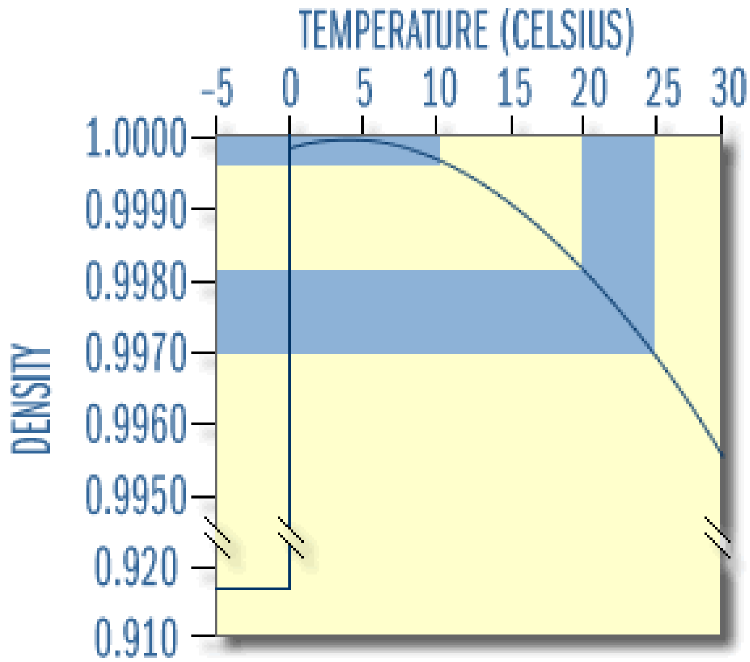
**Table 1. Estimated ranges of water transparency values for various lakes.**
"Clear" water refers to the lack of bog-staining color. WOW lakes in bold face.
Vertical extinction coefficient, k, defined previously. Secchi depths in meters.

| LAKE | k ($m^{-1}$) | Secchi Depth (m) | Euphotic Zone (m) | Description |
|---|---|---|---|---|
| Crater Lake (OR) | 0.06—0.12 | 25—45 | >120 | Clear, sky blue ultra-oligotrophic lake |
| Lake Tahoe (CA/NV) | 0.12 | 40 | 90—136 | As above but decreasing clarity since1960s due to watershed overdevelopment |
| | | | | |
| | | **Lake Superior** | | |
| Lake Superior (Blue water) | 0.13 | 15—20 | 46—60 | Ultra-oligotrophic; most oligotrophic of the Laurentian Great Lakes |
| Lake Superior (Green water near Duluth) | 0.3 | 5—12 | 20—30 | Western arm near Duluth and St. Louis River and harbor inputs |
| **St. Louis River** (Duluth-Superior Harbor) | 4.21 | 0.7 | >5 | Brown (bog) stained from river plus high suspended sediments |
| | | | | |
| Lake Michigan | 0.19—0.24 | ? | 19—31 | Meso-oligotrophic |
| Lake Huron | 0.1 — 0.5 | ? | 25—31 | Meso-oligotrophic |
| Lake Erie | 0.2 — 1.2 | 2—10 (1970—1990) >10 (1993—1995) | 12—26 | Eutrophic (clarity improving recently due to zebra mussels) |
| Lake Ontario | 0.15 — 1.2 | ? | 12—29 | Mesotrophic |
| Lake Baikal, Siberia | 0.2 | 5—40 | 15—75 | Oligotrophic |
| **Grindstone Lake** (Pine County, MN) | 0.82 | 3—6 | 8—20 | Mesotrophic, water is fairly stained or colored |
| **Ice Lake** (Itasca County, MN) | 0.83 | 2—5 | 6—15 | Mesotrophic |
| | | | | |
| **Lake Minnetonka** (Hennepin County, MN) | | | | |
| **West Upper** | 0.78 | 1.4 | 3—5 | Mesotrophic |
| **Halsted Bay** | 2.9 | 0.5 | <2 | Eutrophic |
| | | | | |
| **West Hawk Lake** (MB) | 0.16 - 0.25 | 8 - 12 | 20 - 30 | Meteorite crater, deep, oligotrophic |
| **Dauphin Lake** (MB) | 1.5 - 2.6 | 0.4 - 2.0 | 0.8 - 3.5 | Shallow, windswept, eutrophic |

# DENSITY STRATIFICATION

In the spring, immediately after ice-out in temperate climates, the water column is cold and nearly isothermal with depth. The intense sunlight of spring is absorbed in the water column, which also heats up as the average daily temperature of the air increases. In the absence of wind, a temperature profile with depth might be expected to resemble Figure 2 (see the Light section), decreasing exponentially with depth. However, density, another physical characteristic of water, plays an important role in modifying this pattern.

Water differs from most other compounds because it is less dense as a solid than as a liquid. Consequently ice floats, while water at temperatures just above freezing sinks. As most compounds change from a liquid to a solid, the molecules become more tightly packed and consequently the compound is denser as a solid than as a liquid. Water, in contrast, is most dense at 4°C and becomes less dense at both higher and lower temperatures. The density/temperature relationship of fresh water is shown in Figure 3. Because of this density-temperature relationship, many lakes in temperate climates tend to stratify, that is, they separate into distinct layers.




DENSITY/TEMPERATURE RELATIONSHIP FOR DISTILLED WATER. SHADED AREAS SHOW RELATIVE DIFFERENCE IN DENSITY FOR 5°C TEMPERATURE CHANGES.

**Figure 3**

## Spring

In lakes of the upper Midwest and at higher elevations, the water near a lake's bottom will usually be at 4°C just before the lake's ice cover melts in the spring. Water above that layer will be cooler, approaching 0°C just under the ice. As the weather warms, the ice melts. The surface water heats up and therefore it decreases in density. When the temperature (density) of the surface water equals the bottom water, very little wind energy is needed to mix the lake completely. This is called turnover. After this spring turnover, the surface water continues to absorb heat and warms. As the temperature rises, the water becomes lighter than the water below. For a while winds may still mix the lake from bottom to top, but eventually the upper water becomes too warm and too buoyant to mix completely with the denser deeper water. As Figure 3 suggests, the relatively large differences in density at higher temperatures are very effective at preventing mixing. It simply takes too much energy to mix the water any deeper.

It is useful to visualize a more extreme example of density stratification. Imagine a bottle of salad dressing containing vegetable oil and vinegar. The oil is lighter (more buoyant) than the vinegar which is mostly water. When you shake it up you are supplying the energy to overcome the buoyant force, so the two fluids can be uniformly mixed together. However, if allowed to stand undisturbed, the more buoyant (less dense) oil will float to the top and a two-layer system will develop.

In some cases, such as happened at Ice Lake in April, 1998 and 1999, the surface water may warm up rapidly immediately after ice-out, causing the lake to stratify thermally without completely mixing. This prevents atmospheric oxygen from reaching the bottom waters. As a consequence, the entire water column never reaches 100% oxygen saturation. This can be observed for Ice Lake by comparing temperature and oxygen profiles from March 5, 1998 (still frozen), April 18, 1998 (the lake was completely ice-free on April 11, 1998), and April 30, 1998.

### Summer

As summer progresses, the temperature (and density) differences between upper and lower water layers become more distinct. Deep lakes generally become physically stratified into three identifiable layers, known as the epilimnion, metalimnion, and hypolimnion (Figure 4). The epilimnion is the upper, warm layer, and is typically well mixed. Below the epilimnion is the metalimnion or thermocline region, a layer of water in which the temperature declines rapidly with depth. The hypolimnion is the bottom layer of colder water, isolated from the epilimnion by the metalimnion. The density change at the metalimnion acts as a physical barrier that prevents mixing of the upper and lower layers for several months during the summer.

The depth of mixing depends in part on the exposure of the lake to wind (its fetch), but is most closely related to the lake's size. Smaller to moderately-sized lakes (50 to 1000 acres) reasonably may be expected to stratify and be well mixed to a depth of 3–7 meters in north temperate climates. Larger lakes may be well mixed to a depth of 10–15 meters in summer (e.g., Western Lake Superior near Duluth, MN).

Note that although "thermocline" is a term often used synonymously with metalimnion, it is actually the plane or surface of maximum rate of decrease of temperature with respect to depth. Thus, the thermocline is the point of maximum temperature change within the metalimnion.

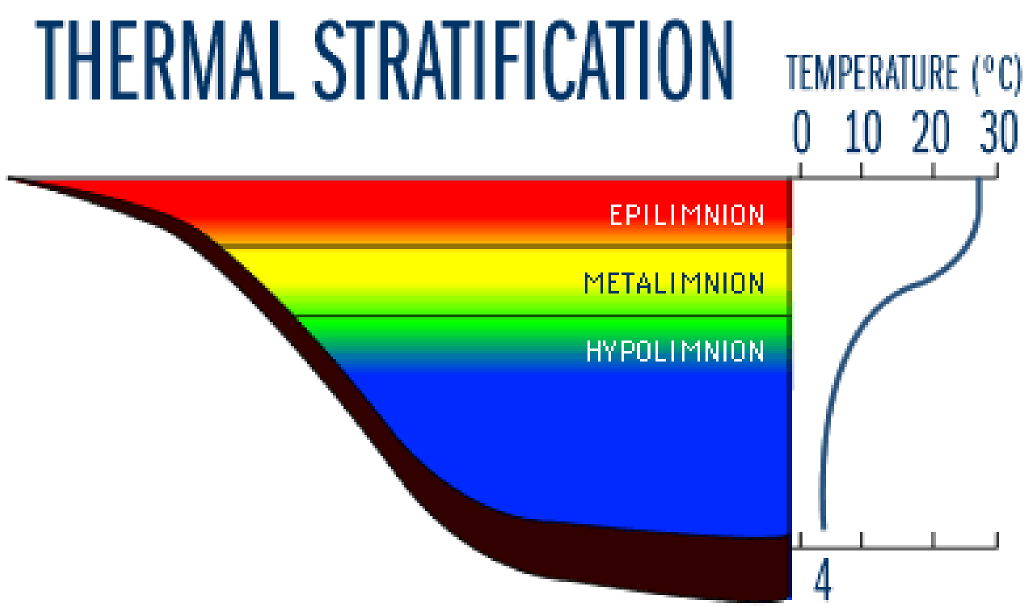



**Figure 4**

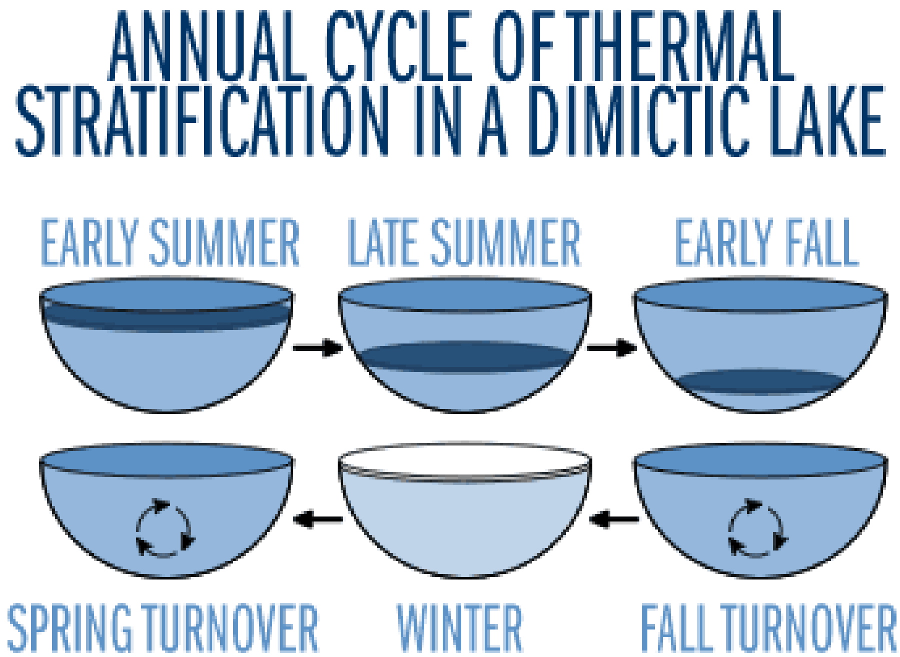



**Figure 5**

### Autumn

As the weather cools during autumn, the epilimnion cools too, reducing the density difference between it and the hypolimnion (Figure 5). As time passes, winds mix the lake to greater depths, and the thermocline gradually deepens. When surface and bottom waters approach the same temperature and density, autumn winds can mix the entire lake; the lake is said to "turn over." As the atmosphere cools, the surface water continues to cool until it freezes. A less distinct density stratification than that seen in summer develops under the ice during winter. Most of the water column is isothermal at a temperature of 4°C, which is denser than the colder, lighter water just below the ice. In this case the stratification is much less stable, because the density difference between 0°C and 4°C water is quite small. However, the water column is isolated from wind-induced turbulence by its cap of ice. Therefore, the layering persists throughout the winter.

This pattern (spring turnover — summer stratification — fall turnover — winter stratification) is typical for temperate lakes. Lakes with this pattern of two mixing periods are referred to as dimictic. Many shallow lakes, however, do not stratify in the summer, or stratify for short periods only, throughout the summer. Lakes that stratify and destratify numerous times within a summer are known as polymictic lakes. Both polymictic and dimictic lakes are common in Minnesota, Manitoba, and other temperate regions.

While monitoring conditions in Ice Lake we have made an interesting observation. Spring turnover is incomplete. There was not enough mixing in spring, 1998 or 1999 to completely re-aerate the entire water column to 100% saturation. On the other hand, Lake Independence, a lake of comparable depth (15-18 meters) but much larger in size (more fetch) and less sheltered from the wind, mixed completely. We suspect that most aquatic scientists would not have expected to see Ice Lake's bottom water, nearly saturated with oxygen in fall, 1998, to be anoxic by mid-winter and then persist in this state until the following fall. Once stratified thermally in summer, even the barrage of severe thunderstorms that occurred near Ice Lake in summer, 1999, lacked the energy to dramatically decrease the thermocline or increase the oxygen content of the hypolimnion.

It was cold and windy enough during fall, 1998, for Ice Lake to mix thoroughly, bringing oxygen to the bottom waters (to about 100% saturation). This is likely typical for Ice Lake during most autumns, although it is possible for a cold, calm period to allow the lake surface to freeze before the water column has been fully exposed to the atmosphere and re-charged with oxygen.

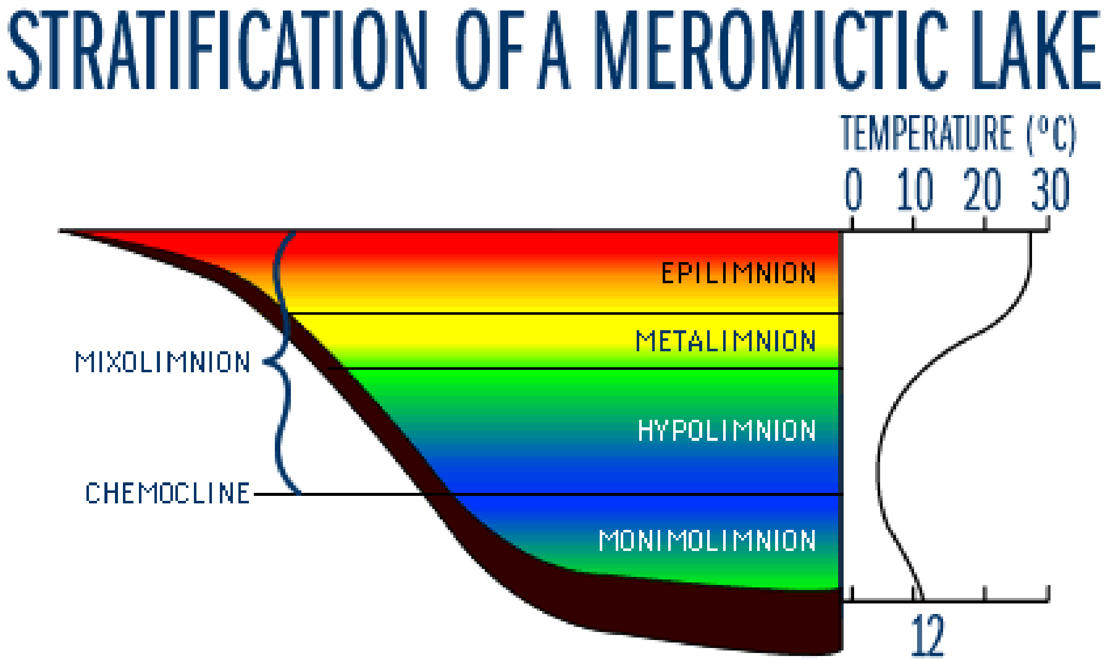



**Figure 6**

The West Upper Lake Station of Lake Minnetonka, Lake Independence and thousands of other Upper Midwestern lakes that are relatively deep (>10 meters) and reasonably large (>100-200 acres or 40-80 ha) are probably dimictic, leading to complete re-oxygenation of the water column for at least some period of time. Ice Lake, though small (41 acres or 16.6 ha), is sheltered and deep (16 m) for its size. Lakes that have formed in former open pit mines in Northeastern Minnesota are unusually deep for their size. Lakes with these characteristics probably only mix completely once a year in the fall for a brief period before freezing. Some of the deeper mine pit lakes (>75 meters deep) probably never mix completely to the bottom, although data are sparse.

Much less common are lakes that circulate incompletely resulting in a layer of bottom water that remains stagnant. To distinguish them from the holomictic (mixing from top to bottom) lakes, these partially mixing lakes are referred to as meromictic. They mix partially, in the sense that they may have extensive mixing periods which go quite deeply into the hypolimnion, but they do not turn over completely, and a layer of bottom water remains stagnant and anoxic for years at a time. The non-mixing bottom layer is known as the monimolimnion and is separated from the mixolimnion (the zone that mixes completely at least once a year) by the chemocline (Figure 6). The stagnant, and typically anaerobic, monimolimnion has a high concentration of dissolved solids compared to the mixolimnion. In general, meromictic lakes have large relative depths. These lakes are typically small and sheltered from the wind by the morphology of their basin. In this case, the density differences caused by temperature are smaller than density differences due to the high dissolved solids (salts) concentration of the monimolimnion. Large lakes that rarely freeze over are also typically monomictic, mixing throughout the fall, winter and spring and stratifying in the summer.

To visualize this effect, try dissolving several tablespoons of table salt (NaCl) in hot water. Add a few drops of food coloring and then fill a mayonnaise jar half-full. Now, very gently add cool tap water with a small measuring cup to fill the glass. Set up a second jar half full with clear, cool water and then add the colored hot water to fill the glass - but don't add the salt. Compare the stability of the density stratification in the two systems by gently shaking or stirring the water columns.

**Table 2**

| MIXING REGIME | LAKES | MAX DEPTH (m) | AREA (acres/hectares) |
|---|---|---|---|
| DIMICTIC<br><br>(2mixes/yr) | **Lake Minnetonka** (Minneapolis, MN) | 34 | 14,004 acres (5,670 ha) |
| | **Grindstone Lake** (Sandstone, MN) | 46 | 500 acres (200 ha) |
| | **Clearwater Lake** (MB) | 39 | 72,250 acres (28,900 ha) |
| | **West Hawk Lake** (MB) | 112 | 4,050 acres (1620 ha) |
| MONOMICTIC<br><br>(1mix/yr – mixed all winter and spring) | **Lake Erie** | 70 | 6.4 x 106 acres (2.6 x 106 ha) |
| | **Lake Huron** | 228 | 14.8 x 106 acres (6.0 x 106 ha) |
| | **Ice Lake*** (Grand Rapids, MN) | 16 | 41 acres (16.6 ha) |
| | **Lake Michigan** | 281 | 14.4 x 106 acres (5.8 x 106 ha) |
| | **Lake Ontario** | 244 | 4.9 x 106 acres (2.0 x 106 ha) |
| | **Lake Superior** | 300 | $20.3 \times 10^6$ acres ($8.2 \times 10^6$ ha) |
| | **Lake Tahoe** (CA/NV) | 499 | 123,253 acres (49,900 ha) |
| | **Lake Mead** (NV largest US reservoir) | 180 | 163,320 acres (66,096 ha) |
| POLYMICTIC<br><br>(many mixes/yr) | Shallow lakes & ponds | < 4 | wide range |
| | **Mille Lacs Lake**, MN | 13 | 132,510 acres (53,648 ha) |
| | **Dauphin Lake** (MB) | 3.5 | 130,500 acres (52,200 ha) |
| | **Lake Winnipeg, south basin** (MB) | 14 | 695,000 acres (278,000 ha) |
| MEROMICTIC<br><br>(never totally mixed because of stagnant bottom layer) | **Pennington Pit Lake**, (Crosby, MN) | 79 | 57 acres (23 ha) |
| | **Brownie Lake** (Minneapolis, MN) | 15 | 18 acres (7.3 ha) |
| | **Big Soda Lake** (Fallon, NV) | 60 | 400 acres (160 ha) |
| | **Lake 111** (Experimental Lakes Area, ON) | 32 | 12.5 acres (6 ha) |

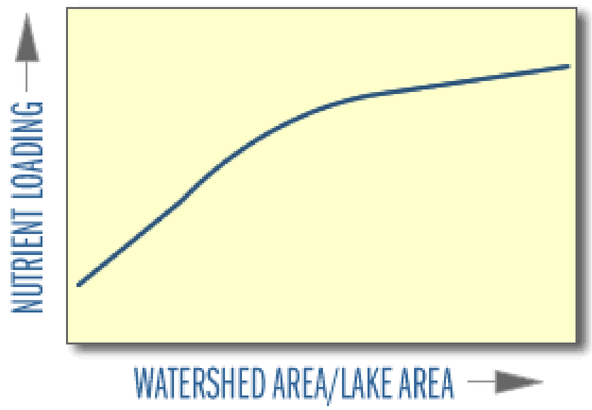
* variable from year to year

For additional information, Learn about ARCHIMEDES's principle at EXPLORATORIUM.

# THE WATERSHED

The watershed, also called the drainage basin, is all of the land and water areas that drain toward a particular river or lake. Thus, a watershed is defined in terms of the selected lake (or river). There can be subwatersheds within watersheds. For example, a tributary to a lake has its own watershed, which is part of the larger total drainage area to the lake.

A lake is a reflection of its watershed. More specifically, a lake reflects the watershed's size, topography, geology, landuse, soil fertility and erodibility, and vegetation. The impact of the watershed is evident in the relation of nutrient loading to the watershed:lake surface area ratio (Figure 7).




GENERAL PATTERN OF NUTRIENT LOADING ASSOCIATED WITH INCREASING WATERSHED SIZE RELATIVE TO LAKE AREA.

**Figure 7**

Typically, water quality decreases with an increasing ratio of watershed area to lake area. This is obvious when one considers that as the watershed to lake area increases there are additional sources (and volumes) of runoff to the lake. In larger watersheds, there is also a greater opportunity for water from precipitation to contact the soil and leach minerals before discharging into the lake. Lakes with very small watersheds that are maintained primarily by groundwater flow are known as seepage lakes. In contrast, lakes fed primarily by inflowing streams or rivers are known as drainage lakes. In keeping with the watershed:lake area relationship, seepage lakes tend to have good water quality compared with drainage lakes. However, seepage lakes are often more susceptible to acidification from acid rain because of their low buffering capacity.

STORMWATER DISCHARGES FROM VARIOUS LAND COVERS

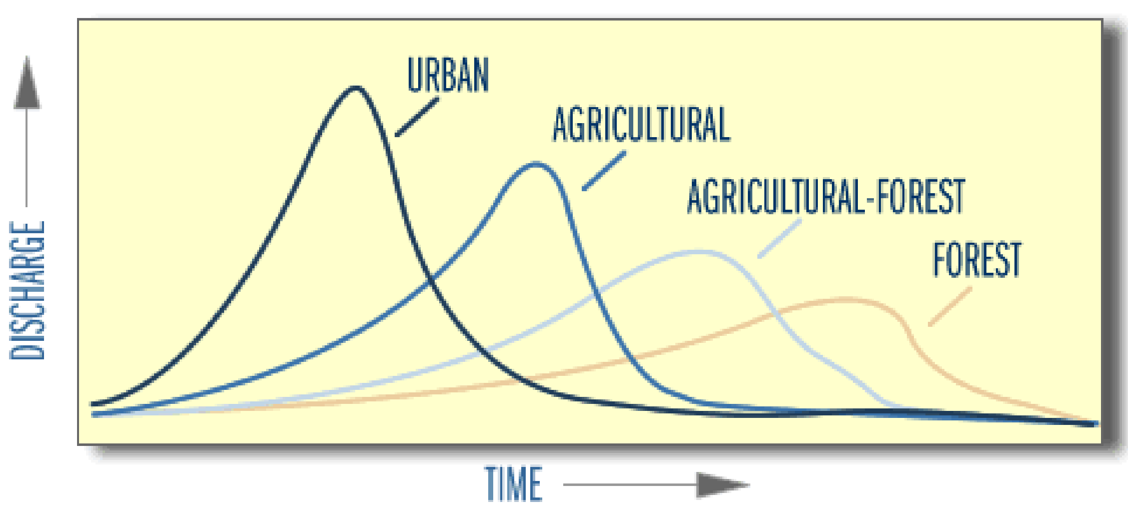



**Figure 8**

Landuse has an important impact on the quality and quantity of water entering a lake. As Figure 8 shows, the stormwater discharge to a lake differs greatly among landuses. In urban areas, the high proportion of impervious surfaces prevents absorbance of rainwater into the soil and increases the rate of surface water flow to the lake. The high flushing rates from urban areas can increase erosion of stream banks and provide sufficient force to carry large particles (i.e., soil) to the lake. Thus, water quantity affects water quality.

Additionally, as water flows over roads, parking lots and rooftops, it accumulates nutrients and contaminants in both dissolved and particulate form.

**Table 3.** Phosphorus export coefficients
(from Reckhow and Simpson, 1980).

| | Phosphorus ($kg/km^2yr$) | | |
|---|---|---|---|
| | **HIGH** | **MID** | **LOW** |
| **Urban** | 500 | 80-300 | 50 |
| **Rural/Agriculture** | 300 | 40-170 | 10 |
| **Forest** | 45 | 14-30 | 2 |
| **Precipitation** | 60 | 20-50 | 15 |

Table 3 gives representative values of export rates of phosphorus from various landuses and other sources. Phosphorus is particularly important because its availability often controls the amount of algae and the overall productivity of a lake. These values are in units of $kg/km^2/yr$ (mass of phosphorus per unit area per year). Not included here, but also important, is the influence of soil type and slope. Finer particles and steeper slopes mean higher export rates.

To clarify the relative landuse impacts, we can compare annual loads from 10 hectare (24 acre) plots of the selected landuses using the high export coefficients in Table 3.

| | |
|---|---|
| **Forest** | 4.5 kg phosphorus |
| **Rural/Agriculture** | 30.0 kg phosphorus |
| **Urban** | 50.0 kg phosphorus |

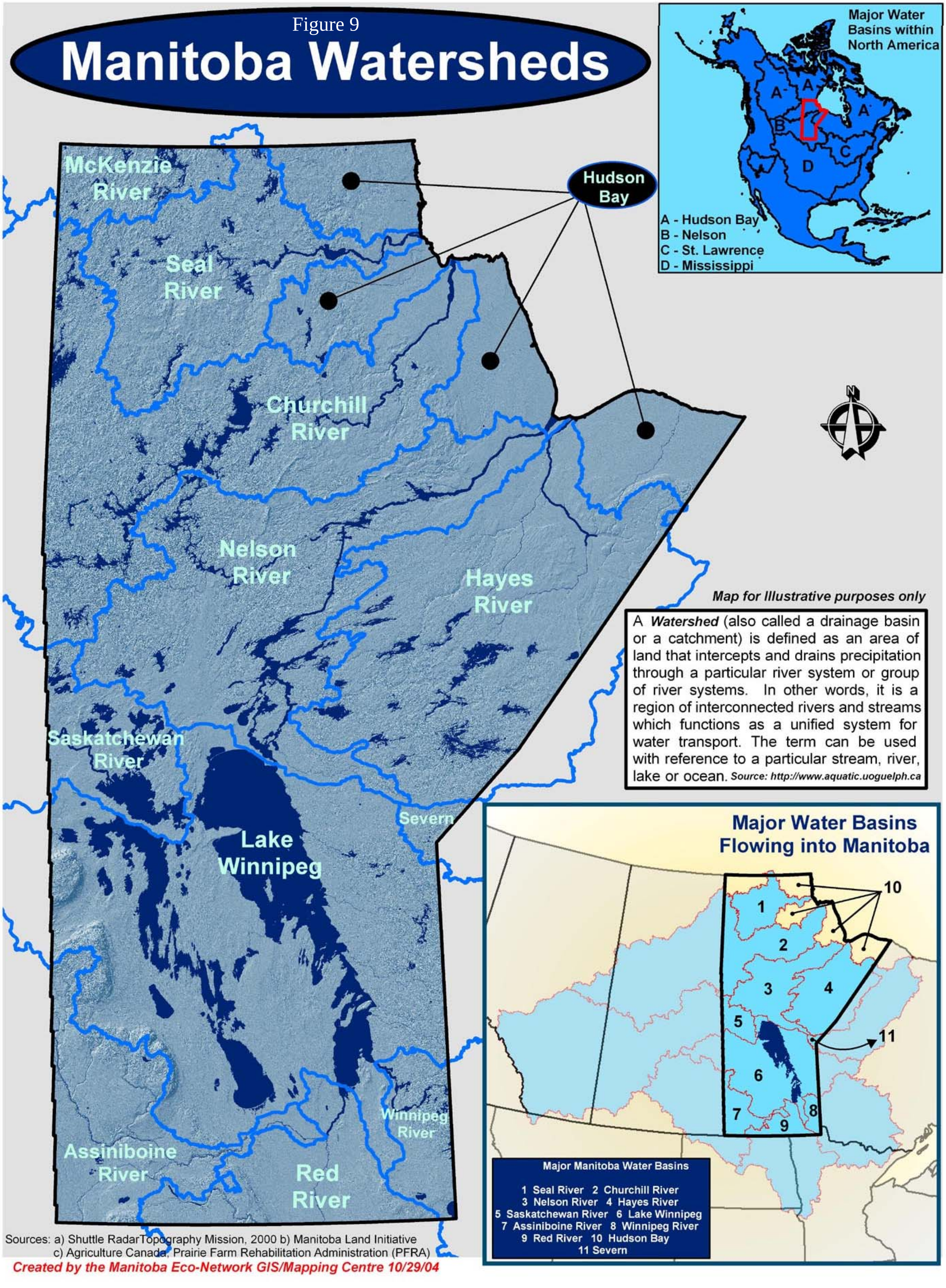
One can see that, all other things being equal, converting a forest into a city can increase the phosphorus export to a lake more than ten times. Another way to look at these numbers is that almost seven years of phosphorus loading from a forested area can be deposited within one year by mixed agriculture areas and almost eleven years of phosphorus loading from a forested area can be deposited within a year from urbanized areas. A greater loading rate puts a greater strain on the system to assimilate the nutrients.

Figure 9, on the following page, illustrates the major watersheds of Manitoba. Of course, all of these major watersheds can be further subdivided into many smaller and smaller watersheds, or sub-basins, depending on the spatial scale in which one is interested.

Note that most of these major Manitoba watersheds extend beyond the provincial borders in one or more directions, including reaching all the way to the continental divide in the Rocky Mountains at the Alberta/British Columbia border.

Most of Manitoba lies at a lower average elevation than its neighbouring provinces and states. This means that much of the runoff from these neighbouring regions flows into, and through, Manitoba. We Manitobans must rely on the goodwill of our neighbours to ensure that the quality and quantity of water flowing into Manitoba are not unduly affected by human activities in these neighbouring jurisdictions. Of course, we must be responsible to ensure that we do not unduly impair the waters flowing out of our province.

Figure 9



Manitoba Watersheds
Major Water Basins within North America
A - Hudson Bay
B - Nelson
C - St. Lawrence
D - Mississippi
Hudson Bay
McKenzie River
Seal River
Churchill River
Nelson River
Hayes River
Saskatchewan River
Lake Winnipeg
Severn
Winnipeg River
Assiniboine River
Red River
Map for Illustrative purposes only
A *Watershed* (also called a drainage basin or a catchment) is defined as an area of land that intercepts and drains precipitation through a particular river system or group of river systems. In other words, it is a region of interconnected rivers and streams which functions as a unified system for water transport. The term can be used with reference to a particular stream, river, lake or ocean. Source: http://www.aquatic.uoguelph.ca
Major Water Basins Flowing into Manitoba
Major Manitoba Water Basins
1 Seal River 2 Churchill River
3 Nelson River 4 Hayes River
5 Saskatchewan River 6 Lake Winnipeg
7 Assiniboine River 8 Winnipeg River
9 Red River 10 Hudson Bay
11 Severn
Sources: a) Shuttle RadarTopography Mission, 2000 b) Manitoba Land Initiative
c) Agriculture Canada, Prairie Farm Rehabilitation Administration (PFRA)
Created by the Manitoba Eco-Network GIS/Mapping Centre 10/29/04

# CHEMICAL

## GENERAL LAKE CHEMISTRY

In the absence of any living organisms, a lake contains a wide array of molecules and ions from the weathering of soils in the watershed, the atmosphere, and the lake bottom. Therefore, the chemical composition of a lake is fundamentally a function of its climate (which affects its hydrology) and its basin geology. Each lake has an ion balance of the three major anions and four major cations (see Table 4).

| Table 4. ION BALANCE FOR TYPICAL FRESH WATER | | | |
|---|---|---|---|
| **Anions** | **Percent** | **Cations** | **Percent** |
| $HCO_3^-$ | 73% | $Ca^{+2}$ | 63% |
| $SO_4^{-2}$ | 16% | $Mg^{+2}$ | 17% |
| $Cl^-$ | 10% | $Na^+$ | 15% |
| | | $K^+$ | 4% |
| other | < 1% | other | < 1% |

Ion balance means the sum of the negative ions equals the sum of the positive cations when expressed as equivalents. These ions are usually present at concentrations expressed as mg/L ppm whereas other ions such as the nutrients phosphate, nitrate, and ammonium are present at µg/L ppb levels.

Humans can have profound influences on lake chemistry. Excessive landscape disturbance causes higher rates of leaching and erosion by removing vegetative cover, exposing soil, and increasing water runoff velocity. Lawn fertilizers, wastewater and urban stormwater inputs all add micronutrients such as nitrogen and phosphorus, major ions such as chloride and potassium, and, in the case of highway and parking lot runoff, oils and heavy metals. Emissions from motorized vehicles, fossil fuel-burning electric utilities and industry, and other sources produce a variety of compounds that affect lake chemistry.

Perhaps the best understood ions are $H^+$ (hydrogen ion, which indicates acidity), $SO_4^{-2}$ (sulfate) and $NO_3^-$ (nitrate) which are associated with acid rains. Mercury (Hg) is another significant air pollutant affecting aquatic ecosystems and can bioaccumulate in aquatic food webs, contaminating fish and causing a threat to human and wildlife health.

Lakes with high concentrations of the ions calcium ($Ca^{+2}$) and magnesium ($Mg^{+2}$) are called hardwater lakes, while those with low concentrations of these ions are called softwater lakes. Concentrations of other ions, especially bicarbonate, are highly correlated with the concentrations of the hardness ions, especially $Ca^{+2}$. The ionic concentrations influence the lake's ability to assimilate pollutants and maintain nutrients in solution. For example, calcium carbonate ($CaCO_3$) in the form known as marl can precipitate phosphate from the water and thereby remove this important nutrient from the water.

The total amount of ions in the water is called the TDS (total dissolved salt, or total dissolved solids concentration). Both the concentration of TDS and the relative amounts or ratios of different ions influence the species of organisms that can best survive in the lake, in addition to affecting many important chemical reactions that occur in the water. One example of particular interest in the Great Lakes region involves the calcium requirement of the exotic zebra mussel that is causing profound changes in Lake Erie. Lake Superior appears to be relatively immune to infestation by this invader because of low calcium concentration. Its bays, however, such as the lower St. Louis River and Duluth-Superior Harbor, may not be immune to zebra mussel infestation.

# DISSOLVED OXYGEN

Biological activity peaks during the spring and summer when photosynthetic activity is driven by high solar radiation. Furthermore, during the summer most lakes in temperate climates are stratified. The combination of thermal stratification and biological activity causes characteristic patterns in water chemistry. Figure 10 shows the typical seasonal changes in dissolved oxygen (DO) and temperature. The top scale in each graph is oxygen levels in mg $O_2$/L. The bottom scale is temperature in °C. In the spring and fall, both oligotrophic and eutrophic lakes tend to have uniform, well-mixed conditions throughout the water column. During summer stratification, the conditions in each layer diverge.

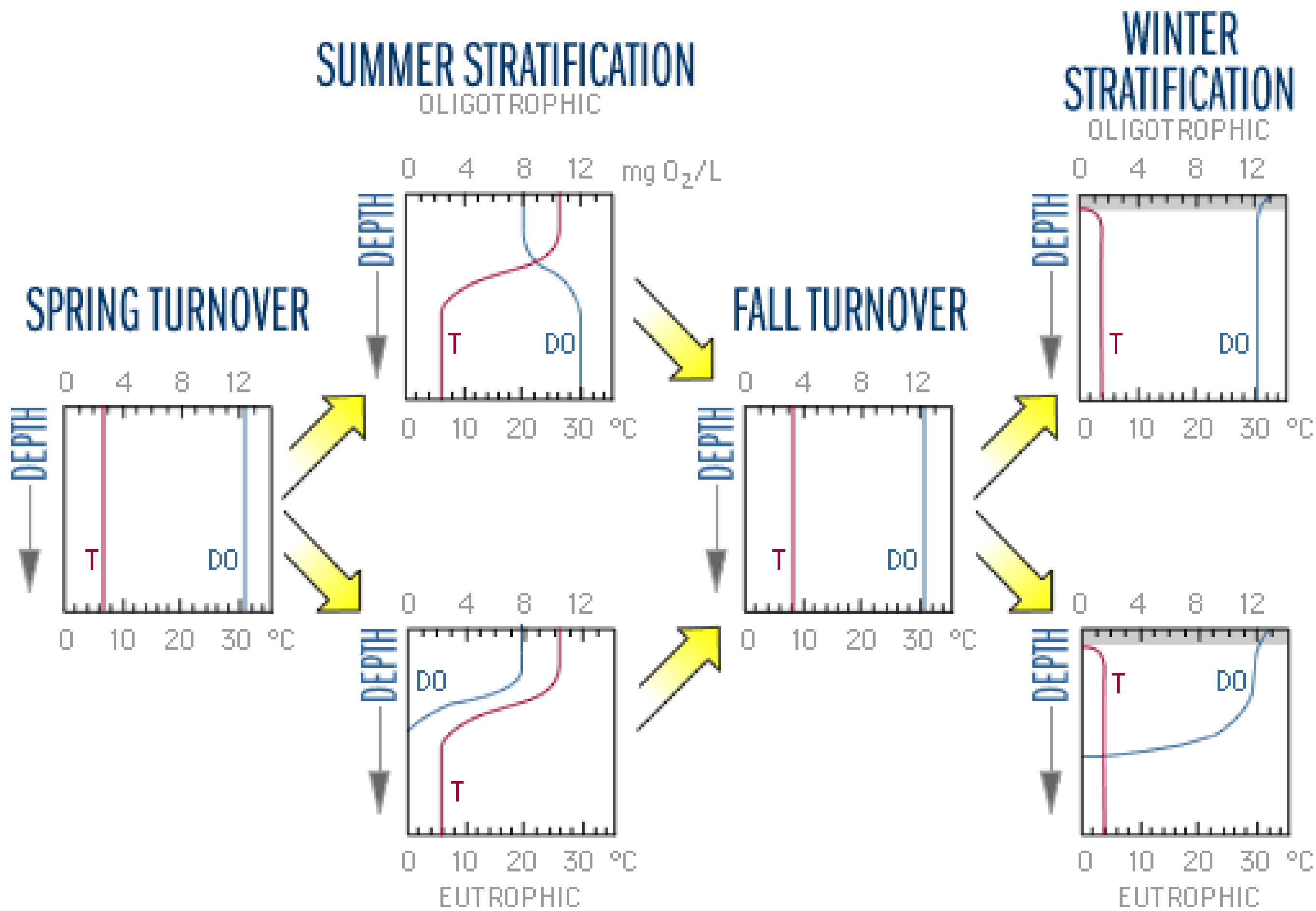



**Figure 10**

The DO concentration in the epilimnion remains high throughout the summer because of photosynthesis and diffusion from the atmosphere. However, conditions in the hypolimnion vary with trophic status. In eutrophic (more productive) lakes, hypolimnetic DO declines during the summer because it is cut-off from all sources of oxygen, while organisms continue to respire and consume oxygen. The bottom layer of the lake and even the entire hypolimnion may eventually become anoxic, that is, totally devoid of oxygen. In oligotrophic lakes, low algal biomass allows deeper light penetration and less decomposition. Algae are able to grow relatively deeper in the water column and less oxygen is consumed by decomposition. The DO concentrations may therefore increase with depth below the thermocline where colder water is "carrying" higher DO leftover from spring mixing (recall that oxygen is more soluble in colder water). In extremely deep, unproductive lakes such as Crater Lake, OR, Lake Tahoe, CA/NV, and Lake Superior, DO may persist at high concentrations, near 100% saturation, throughout the water column all year. These differences between eutrophic and oligotrophic lakes tend to disappear with fall turnover (Figure 10).

In the winter, oligotrophic lakes generally have uniform conditions. Ice-covered eutrophic lakes, however, may develop a winter stratification of dissolved oxygen. If there is little or no snow cover to block sunlight, phytoplankton and some macrophytes may continue to photosynthesize, resulting in a small increase in DO just below the ice. But as microorganisms continue to decompose material in the lower water column and in the sediments, they consume oxygen, and the DO is depleted. No oxygen input from the air occurs because of the ice cover, and, if snow covers the ice, it becomes too dark for photosynthesis. This condition can cause high fish mortality during the winter, known as "winter kill." Low DO in the water overlying the sediments can exacerbate water quality deterioration, because when the DO level drops below 1 mg $O_2$/L chemical processes at the sediment-water interface frequently cause release of phosphorus from the sediments into the water. When a lake mixes in the spring, this new phosphorus and ammonium that has built up in the bottom water fuels increased algal growth.

# NUTRIENTS

Aquatic organisms influence (and are influenced by) the chemistry of the surrounding environment. For example, phytoplankton extract nutrients from the water and zooplankton feed on phytoplankton. Nutrients are redistributed from the upper water to the lake bottom as the dead plankton gradually sink to lower depths and decompose. The redistribution is partially offset by the active vertical migration of the plankton.

In contrast to DO, essential nutrients such as the bioavailable forms of phosphorus and nitrogen (dissolved phosphate, nitrate, and ammonium) typically increase in the spring from snowmelt runoff and from the mixing of accumulated nutrients from the bottom during spring turnover. Concentrations typically decrease in the epilimnion during summer stratification as nutrients are taken up by algae and eventually transported to the hypolimnion when the algae die and settle out. During this period, any "new" input of nutrients into the upper water may trigger a "bloom" of algae. Such inputs may be from upstream tributaries after rainstorms, from die-offs of aquatic plants, from pulses of urban stormwater, direct runoff of lawn fertilizer, or from leaky lakeshore septic systems. In the absence of rain or snowmelt, an injection of nutrients may occur simply from high winds that mix a portion of the nutrient-enriched upper waters of the hypolimnion into the epilimnion. In less productive systems, such as those in Northeastern Minnesota, significant amounts of available nitrogen may be deposited during rainfall or snowfall events (wet deposition) and during the less obvious deposition of aerosols and dust particles (dry deposition). For instance, Lake Superior has been enriched by as much as 300 µg/L during this century, presumably due to air pollution. Nitrogen and phosphorus in dry fallout and wet precipitation may also come from dust, fine soil particles, and fertilizer from agricultural fields.

# BIOLOGICAL

## LAKE ZONES

A typical lake has distinct zones of biological communities linked to the physical structure of the lake (Figure 11). The littoral zone is the near shore area where sunlight penetrates all the way to the sediment and allows aquatic plants (macrophytes) to grow. Light levels of about 1% or less of surface values usually define this depth. The 1% light level also defines the euphotic zone of the lake, which is the layer from the surface down to the depth where light levels become too low for photosynthesizers. In most lakes, the sunlit euphotic zone occurs within the epilimnion.

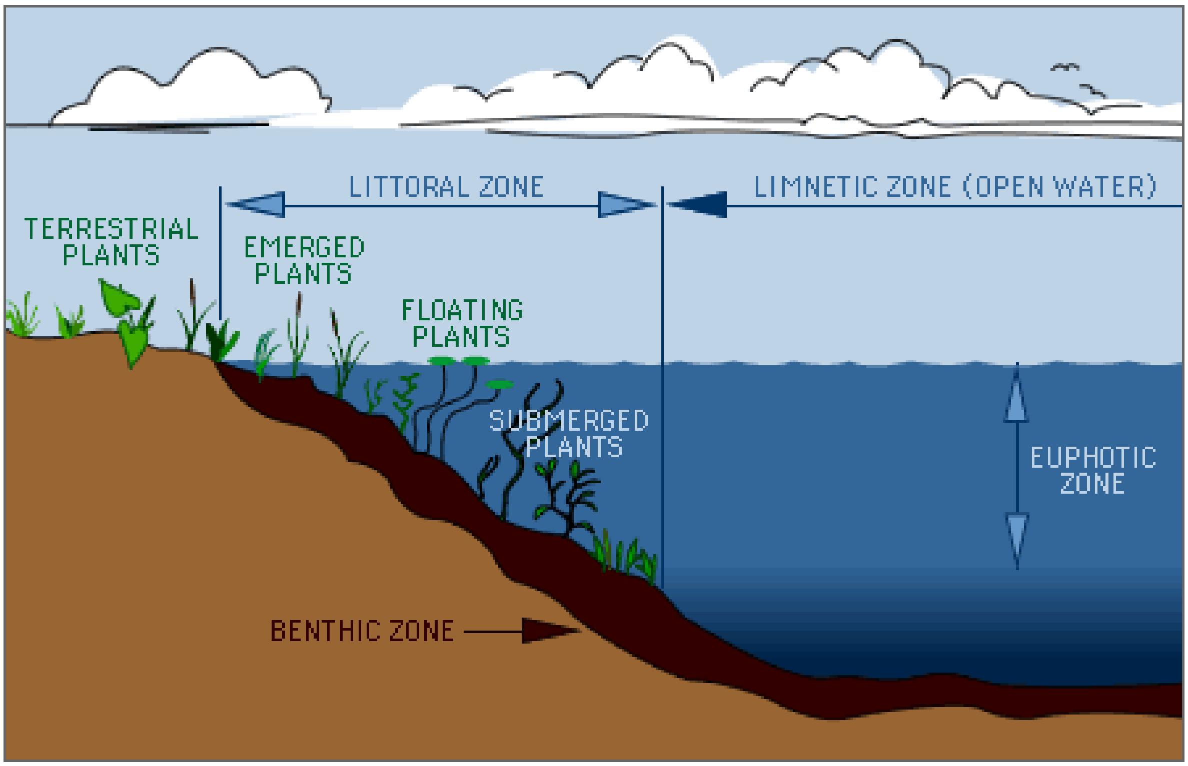



**Figure 11**

However, in unusually transparent lakes, photosynthesis may occur well below the thermocline into the perennially cold hypolimnion. For example, in western Lake Superior near Duluth, MN, summertime algal photosynthesis and growth can persist to depths of at least 25 meters, while the mixed layer, or epilimnion, only extends down to about 10 meters. Ultra-oligotrophic Lake Tahoe, CA/NV, is so transparent that algal growth historically extended to over 100 meters, though its mixed layer only extends to about 10 meters in summer. Unfortunately, inadequate management of the Lake Tahoe basin since about 1960 has led to a significant loss of transparency due to increased algal growth and increased sediment inputs from stream and shoreline erosion.

The higher plants in the littoral zone, in addition to being a food source and a substrate for algae and invertebrates, provide a habitat for fish and other organisms that is very different from the open water environment.

The limnetic zone is the open water area where light does not generally penetrate all the way to the bottom. The bottom sediment, known as the benthic zone, has a surface layer abundant with organisms. This upper layer of sediments may be mixed by the activity of the benthic organisms that live there, often to a depth of 2-5 cm (several inches) in rich organic sediments. Most of the organisms in the benthic zone are invertebrates, such as Dipteran insect larvae (midges, mosquitoes, black flies, etc.) or small crustaceans. The productivity of this zone largely depends upon the organic content of the sediment, the amount of physical structure, and in some cases upon the rate of fish predation. Sandy substrates contain relatively little organic matter (food) for organisms and poor protection from predatory fish. Higher plant growth is typically sparse in sandy sediment, because the sand is unstable and nutrient deficient. A rocky bottom has a high diversity of potential habitats offering protection (refuge) from predators, substrate for attached algae (periphyton on rocks), and pockets of organic "ooze" (food). A flat mucky bottom offers abundant food for benthic organisms but is less protected and may have a lower diversity of structural habitats, unless it is colonized by higher plants.

## LAKE ORGANISMS

CREATURES THAT GO WHERE THEY CHOOSE

| **FISH** | **AMPHIBIANS** | **LARGER ZOOPLANKTON** (e.g., mysids) |
|---|---|---|

CREATURES THAT GO WHERE THE WATER TAKES THEM

| **LIVING CREATURES = PLANKTON** | **DEAD CREATURES = DETRITUS** |
|---|---|
| animals - zooplankton | internal - produced within lake |
| algae - phytoplankton | external - washed in from watershed |
| bacteria - bacterioplankton | |

CREATURES THAT LIVE ON THE BOTTOM

| **BENTHOS = ANIMALS** | **PLANTS** | **BACTERIA & FUNGI** |
|---|---|---|
| aquatic insects | higher plants - macrophytes | sewage sludge |
| molluscs - clams, snails | attached algae - periphyton | aufwuchs - mixture of algae, fungi and bacteria |
| other invertebrates - worms, crayfish | | |

Figure 12

Figure 12 illustrates how organisms over a range of sizes utilize the different regions, or ecological niches, within a typical lake ecosystem. Many of the larger organisms are capable of moving about freely within, or even between, large regions of a lake. Many smaller organisms tend to drift with lake currents or settle with gravity, or, like rooted plants, find ways of attaching to the bottom or to other substrate in locations where conditions are suitable for them.

# THE FOOD WEB

The biological communities within lakes may be organized conceptually into food chains and food webs to help us understand how the ecosystem functions (Figures 13 and 14). The simplest illustration of the organization of the organisms within an ecosystem is the ecological pyramid (Figure 15). The broad base of primary producers supports overlying levels of herbivores (zooplankton), planktivores and much smaller numbers of carnivores (predators). These individual trophic levels may be idealized as a food chain, but in fact many organisms are omnivorous and not necessarily characterized by a particular level. Further, consumers in particular often shift levels throughout their life cycle. For example, a larval fish may initially eat fine particulate material that includes algae, bacteria and detritus. Then it may switch and graze on larger zooplankton and ultimately end up feeding on so called "forage fish" or even young game fish (i.e., top predators) when it reaches maturity (Figure 14).

**TYPICAL FOOD CHAIN**

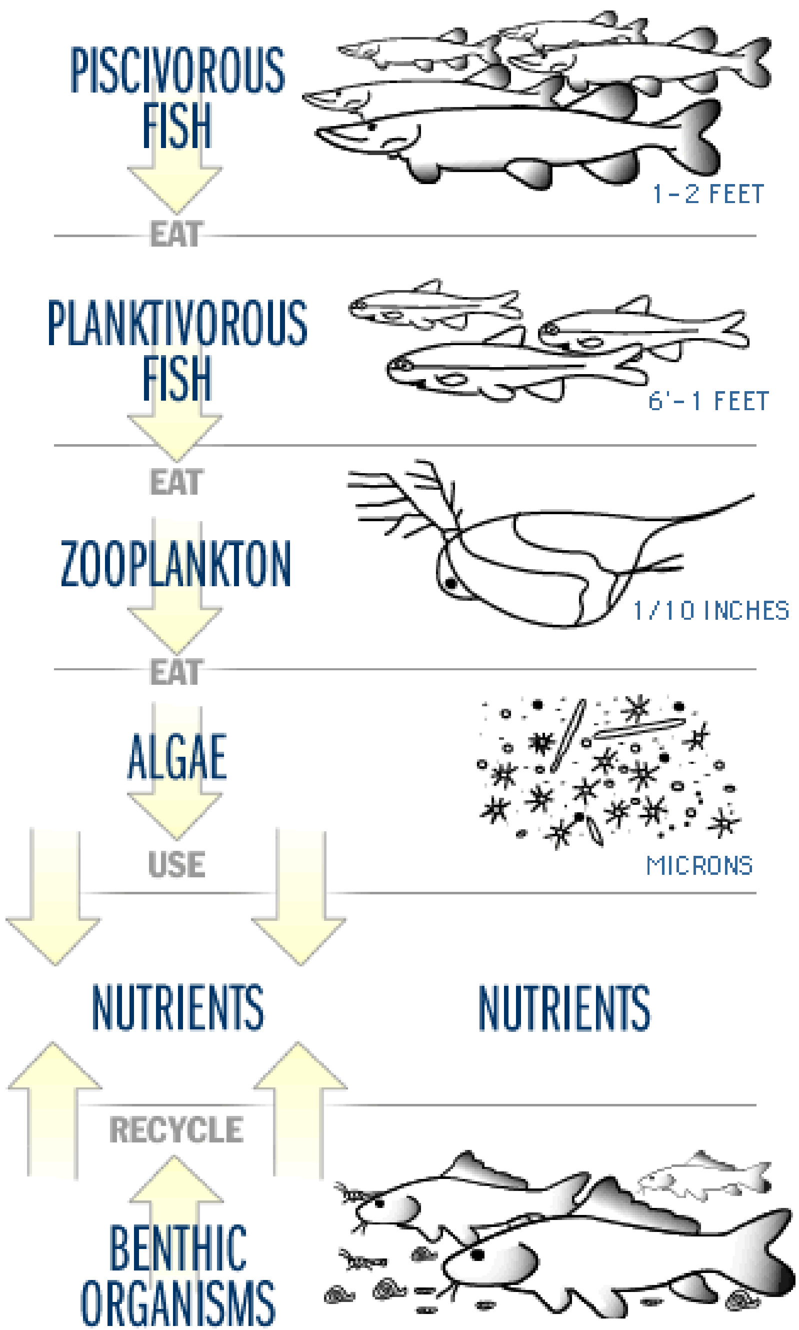



**Figure 13**

**FOOD WEB FOR LAKE MEAD, NV**

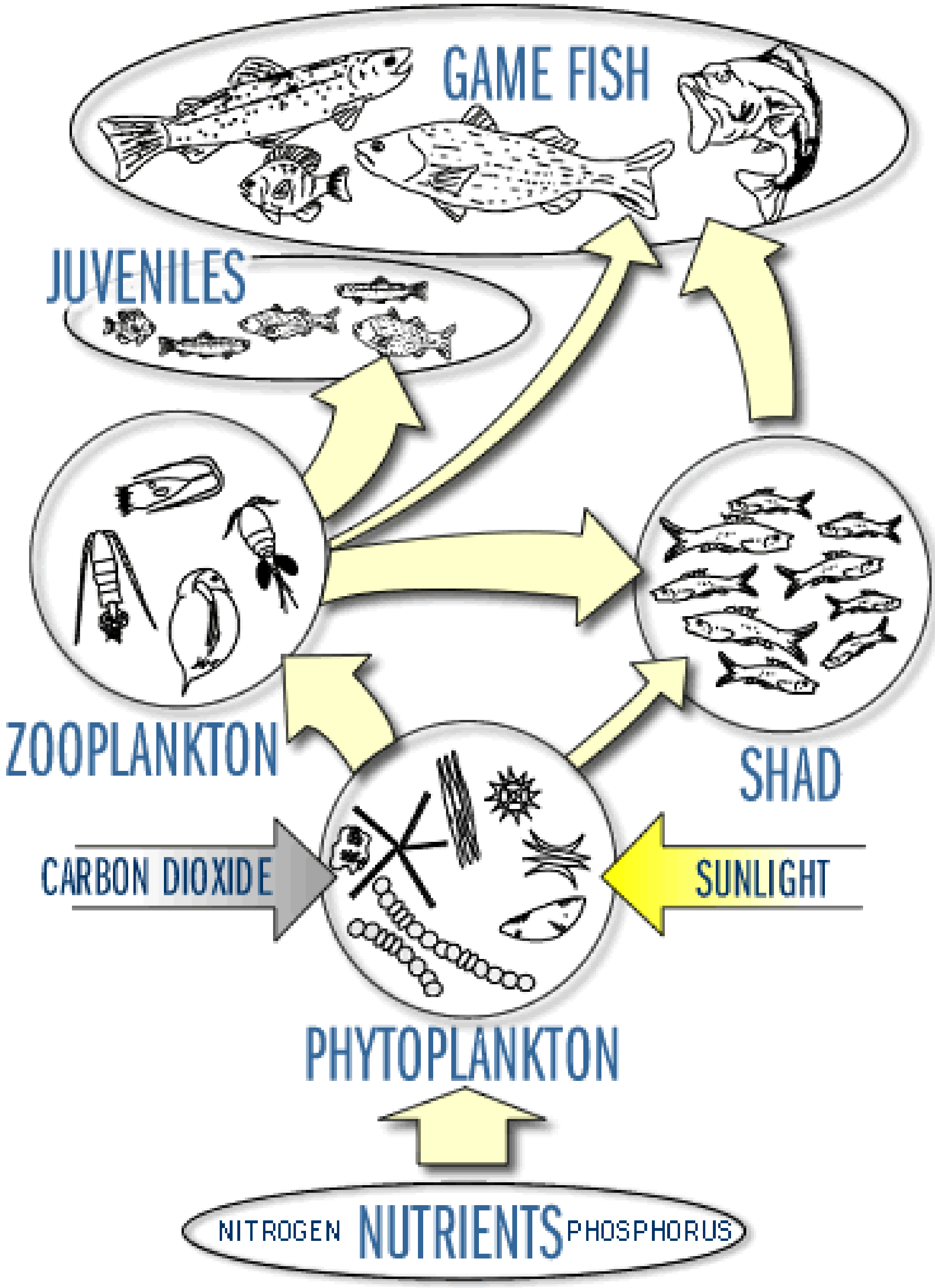



**Figure 14**

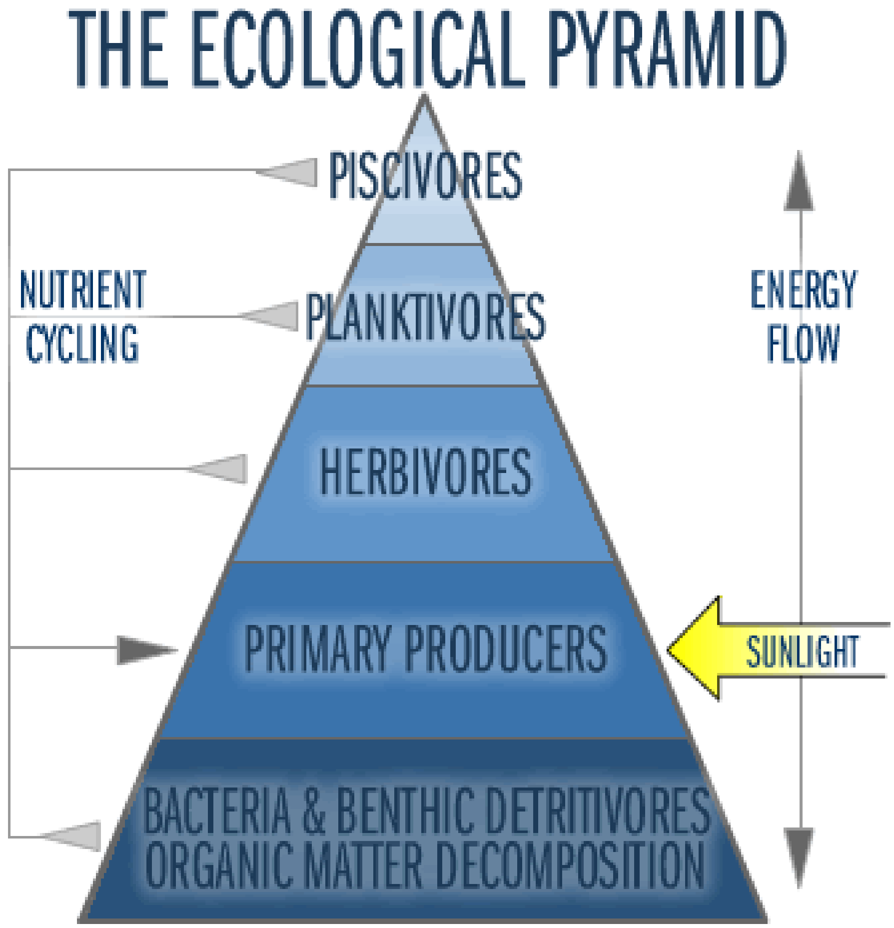



**Figure 15**

Food webs may be described in terms of both energy and nutrient (carbon, nitrogen or phosphorus) flows (Figure 16). Although the process typically begins with sunlight-driven photosynthesis by algae and plants, balanced nutrition is also required to sustain life. For example, we cannot live strictly on sugar, despite its high caloric content, irrespective of what our kids may argue.

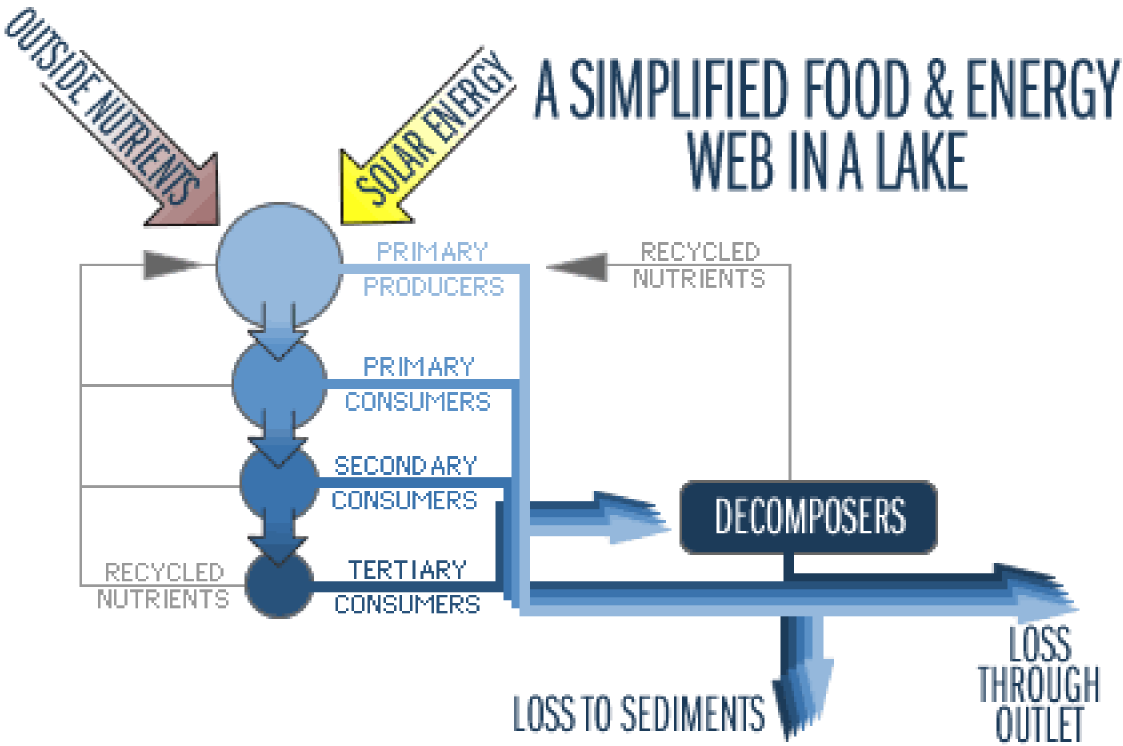



**Figure 16**

There are two basic life-sustaining processes in lakes, just as on land; photosynthesis and respiration. Green plants capture energy from sunlight to convert nonliving, inorganic chemicals (carbon dioxide, water, and mineral compounds) into living, organic plant tissue. Lake photosynthesizers include algae and macrophytes. Together, they are the primary producers, because they create the organic material required by most other organisms for nutrients and energy. Oxygen, the waste product of photosynthesis, adds to the oxygen supplied to the lake by the atmosphere. In water layers where photosynthetic rates are very high, such as during an algal bloom, the water may become supersaturated. That is, the oxygen content may exceed 100% of saturation with respect to the amount the water could hold if it was allowed to equilibrate with the atmosphere. This saturation value, in turn, depends on the temperature of the water. Colder water can hold more $O_2$ than warmer water. During periods of stratification, the only potential source of $O_2$ to the deeper zones of the lake is photosynthesis. This occurs only if light penetrates below the thermocline. In lakes where light does not penetrate below the thermocline, there is no internal source of oxygen to the deeper waters.

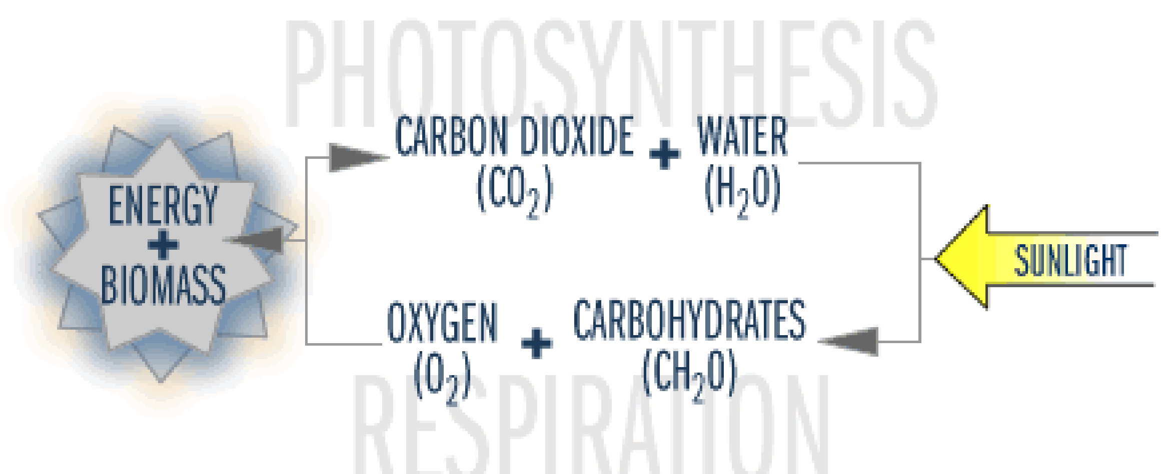



**Figure 17**

Besides light, algae and higher plants need oxygen, carbon dioxide ($CO_2$), and mineral nutrients to survive and grow. Except for a very few species of blue green algae, most are unable to survive in anoxic (no $O_2$) water. $CO_2$ is virtually always available and comes from the weathering of carbonate rocks, such as limestone, in the watershed, diffusion from the atmosphere (very important in softwater, acid rain sensitive lakes), and from the respiration of organic matter by all of the organisms in the lake (see below). Dissolved mineral nutrients are absorbed from the water by algae and from the water and the sediments by higher plants. Typically, the most important nutrients are phosphorus and nitrogen, because they are present in very low concentrations unless there are sources of pollution ( see trophic state section) and are typically low enough to limit the growth of algae. Other minerals essential to life, such as the major ions (calcium, magnesium, sodium, and potassium) and certain trace metals (iron, cobalt, molybdenum, manganese, copper, boron, and zinc), are usually present at sufficient concentrations. Silicon is required by diatoms and a few other groups of algae and is usually, though not always, present at sufficient levels. Another mineral required by all living things, sulfur (in the form of sulfate), is typically not deficient in lakes.

The whole interaction of photosynthesis and respiration by plants, animals, and microorganisms represents the food web. Food webs are usually very complex and, in any one lake ecosystem, hundreds of different species can be involved. Because the available energy decreases at each trophic level, a large food base of primary producers (mostly plants) is necessary to support relatively few large fish.

These plants may die and decompose or be eaten by primary consumers – the second trophic level. This link in the food chain typically involves zooplankton grazing on algae but also includes larval fish eating zooplankton and a variety of invertebrates that eat attached algae (periphyton) and higher plants. Other animals, such as small fish, secondary consumers (third trophic level) eat the primary consumers and thus are considered secondary consumers. Still larger consumers such as large fish, ospreys, and people are tertiary consumers (fourth trophic level). Thus, energy and nutrients originating from the photosynthetic production of biomass and energy cascade through the food web (Figure 15). There is some recycling of nutrients back up to the top of the cascade. Respiration, the oxidation of organic material, releases the energy that was originally captured from sunlight by photosynthesis. Both plants and animals respire to sustain their lives, and in doing so, consume oxygen. Microorganisms (bacteria and fungi) consume a large fraction of available oxygen in the decomposition of excreted and dead organic material.

Decomposers are sinks for plant and animal wastes, but they also recycle nutrients for photosynthesis. The amount of dead material in a lake far exceeds the living material. Detritus is the organic fraction of the dead material, and can be in the form of small fragments of plants and animals or as dissolved organic material. In recent years, scientists have recognized that zooplankton grazing on detritus and its associated bacterial community represent an additional important trophic pathway in lakes.

# PRIMARY PRODUCERS

Much of modern limnological study revolves around the primary productivity of lakes. The ecology of plant growth is of great importance to the character and history of lakes and to all other organisms that live in lakes. The major threat to lakes involves the excessive growth of primary producers due to nutrient inputs caused by poor landuse management. Therefore, it is worth a closer look at these organisms.

The littoral zone is defined by the growth of rooted and floating aquatic plants, or macrophytes. Figure 18 provides examples of common macrophytes found in Minnesota lakes. The macrophyte community can also include large algae, such as *Chara*,*Nitelle*,or*Cladophora*.In shallow, clear lakes, macrophytes may represent most of the green plant material present and may account for most of the photosynthesis.

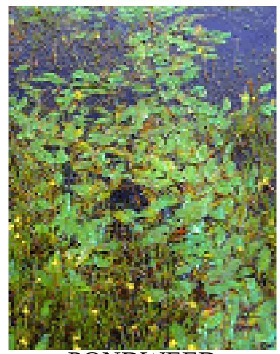
**SOME COMMON MACROPHYTES**

click on the photos to see larger images

FLOATING

WATER LILY
*Nymphaea*

DUCKWEED
*Spirodela*



PONDWEED
*Potamogeton*

SUBMERGENT

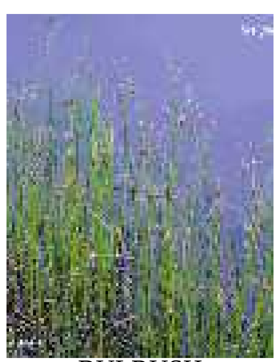
STONEWORT
*Chara*

COONTAIL
*Ceratophyllum*

BLADDERWORT
*Utricularia*

EMERGENT

CATTAIL
*Typha*



BULRUSH
*Scirpus*

WILD RICE
*Zizania*

EXOTICS

PURPLE LOOSESTRIFE
*Lythrum salicaria*

EURASIAN WATER MILFOIL
*Myriophyllum spicatum*

**Figure 18**

Photos from the University of Florida's Aquatic, Wetland, and Invasive Plant Information Retrieval System

There may be few macrophytes in a lake when the bottom is too rocky or too sandy for the plants to anchor themselves, wave action too severe, or the water too deep. Also, sunlight may not reach the bottom even in shallow areas if the concentration of algae or silt is high.

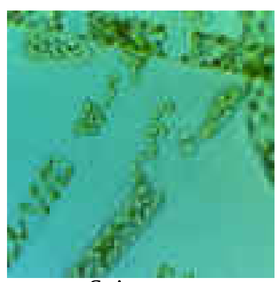
Algae constitute the other main group of primary producers (Figure 19). They come in countless forms and live in nearly all kinds of environments. Most are microscopic, growing as single cells, small colonies, or filaments of cells.

Suspended algae are called phytoplankton, while attached algae are called periphyton. Phytoplankton grow suspended in open water by taking up nutrients from the water and energy from sunlight. If their populations are dense, the water will become noticeably green or brown and will have low transparency

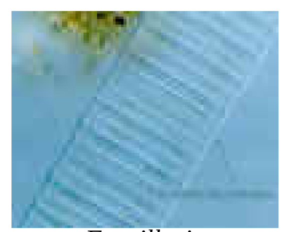
## ALGAL PHOTOS

click on the photos to see larger images

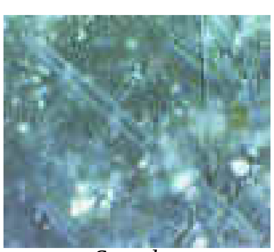
*Ankistrodesmus*



*Spirogyra*



*Fragillaria*

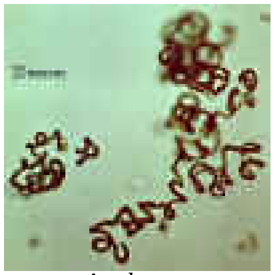


*Synedra*

*Dinobryon*

*Peridinium*

*Cryptomonas*



*Anabaena*

*Aphanizomenon*

*Microcystis*

*Oscillatoria*

**Figure 19**

Images courtesy of the Susquehanna University Algal Image Archive and Cyanosite (Purdue University).

Phytoplankton are classified into groups by the type of pigments they use to perform photosynthesis. While chlorophyll-a is common to all groups there are many other accessory pigments that allow the algae to capture different types of light. Green algae are considered the most closely related to higher plants. Within this group alone there is a great diversity of size, shape, and growth form (single celled, colonial, filamentous, and flagellated). Diatoms belong to a large group, classified as the golden-brown algae, which also includes chrysophytes and dinoflagellates. The most striking characteristic of diatoms and chrysophytes is the ability to form silica (glass) cell walls. Diatoms cell walls are similar to a petri dish, having two halves that fit together. Some chrysophytes have elaborate silica scales, spines, or vase-like shells called loricas. Diatoms are non-motile (unable to swim), so they depend on water turbulence to remain suspended. Chrysophytes have flagella (whip-like appendages) that allow them to control their position in the water column. There are other important algal groups containing motile forms.

Dinoflagellates are another group of golden-brown algae that also have flagella. These cells are capable of moving very rapidly; positioning themselves where light and nutrients are optimal for growth. Another flagellated group called the cryptomonads are very small algae and contain pigments that enable them to photosynthesize under very low light conditions, either very deep in the water column or during those times of the year when sunlight isn't very strong.

Blue-green "algae" are technically referred to as cyanobacteria since, except for their chlorophyll-based photosynthesis, they are bacteria. They generally receive the greatest amount of research and management attention because of their ability to form nuisance blooms in eutrophic lakes. It is important to remember, however, that blue-green algae are very important primary producers in both freshwater and marine systems, despite often being a nuisance.

Blue-greens have several characteristics that often enable them to dominate and create nuisance or noxious conditions. Some blue-green species have the ability to adjust their buoyancy. They can float or sink depending on light conditions and nutrient supply. All plants, including all algae, typically satisfy their nitrogen requirement by absorbing nitrate ($NO_3^-$) and/or ammonium ($NH_4^+$) from the water. However, some blue-greens can fix molecular nitrogen ($N_2$) derived from the atmosphere and dissolved in the water and convert it to ammonium in the cell through a process called nitrogen fixation. This allows them to maintain high rates of growth when other forms of nitrogen are sufficiently depleted to limit growth by other types of algae. Blue-green algae typically are well-adapted to phosphorus deficiency because of their ability to absorb and store excess phosphorus when it is available -- enough to last days to weeks in some cases.

Unlike the green algae and diatoms, the blue-green algae are less suitable food for primary consumers. This is partly because some blue-greens can form large colonies of cells embedded in a gelatinous matrix which may pose handling problems for grazers. They also may produce chemicals that inhibit grazers or makes them "taste bad" to the grazers. Consequently, blue-greens have advantages over other algae at using nutrient and light resources, as well as avoiding being eaten.

*Aphanizomenon flos-aquae* is a common species of filamentous blue-green algae (see Figure 18) with the ability to regulate its buoyancy, fix nitrogen, form large inedible colonies, and form algal blooms. Other common bloom genera are *Anabaena* ($N_2$-fixing filamentous algae) and *Microcystis* (colonial; not a $N_2$-fixer). These bloom-forming algae are known to produce toxins in farm ponds that can poison cattle and, more recently, have been found to produce potent neurotoxins and hepatotoxins that may be a greater public health concern than previously realized.

# CHLOROPHYLL - A MEASURE OF ALGAE

An in-depth microscopic enumeration of the dozens of species of algae present in a water column each time a lake is sampled is prohibitively costly and technically impossible for most monitoring programs. Further, in many lakes a large portion of the algal biomass may be unidentifiable by most experts (these are appropriately called LRGTs or LRBGTs -- little round green things and little round blue-green things). However, measuring the concentration of chlorophyll-a is much easier and provides a reasonable estimate of algal biomass. Chlorophyll-a is the green pigment that is responsible for a plant's ability to convert sunlight into the chemical energy needed to fix $CO_2$ into carbohydrates. To measure chlorophyll-a, a volume of water from a particular depth is filtered through a fine glass-fiber filter to collect all of the particulate material greater than about 1 micron (1/1000th of a millimeter) in size. The chlorophyll-a in this material is then extracted with a solvent (acetone or alcohol) and quantified using a spectrophotometer or a fluorometer.

Both chlorophyll-a and secchi depth are long-accepted methods for estimating the amount of algae in lakes. Secchi depth is much easier and less expensive to determine. However, care must be used in interpreting secchi data because of the potential influence of non-algal particulate material, such as silt from stream discharge or re-suspended bottom sediment. Also, the tea color of some lakes that's due to dissolved organic matter from bogs, can have an effect on secchi depth readings as well. Even if chlorophyll-a is measured, it may be important to also examine the algal community microscopically on occasion, since the mix of species may influence lake management decisions.

# ALGAL SUCCESSION

A lake's biological characteristics are determined in large part by physical characteristics of the water column. Important physical characteristics include temperature, light transparency, and wave action, as well as the total abundance of inorganic nutrients, which is largely a watershed characteristic. In addition, preceding populations influence successive populations by assimilating critical nutrients. Populations also have varying susceptibilities to grazing by zooplankton, which vary seasonally in type and abundance. As physical, chemical, and biological conditions in the lake change over time, some species will be effectively eliminated from a lake because they cannot tolerate the new conditions. Other species will be out-competed by organisms that are better adapted to the new environment.

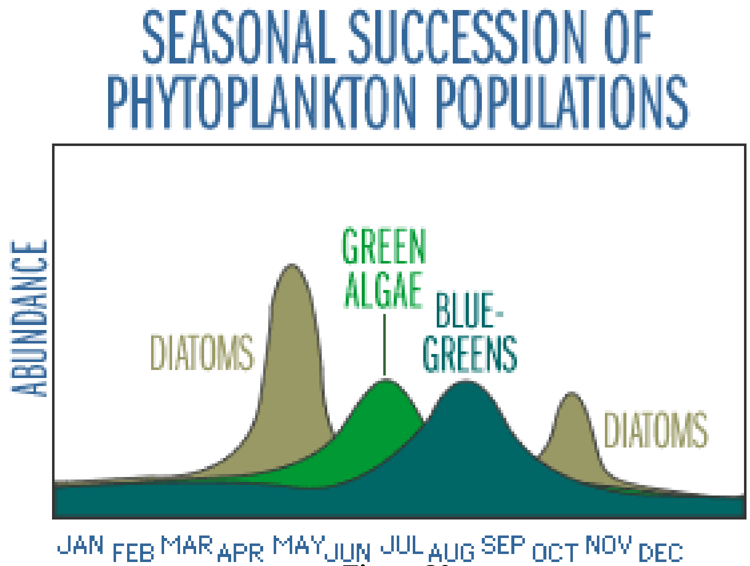



**Figure 20**

These changes represent an important ecological pattern in lakes known as algal succession. In most natural systems the seasonal succession of algae (and macrophytes) is a recurrent, if not exactly repetitive, yearly cycle. A typical algal succession is shown in Figure 20. Some species flourish for a period of time and then give way to other species more compatible with changed conditions, such as warmer water, more daylight, or lower concentrations of phosphorus or nitrogen. Short-lived plankton communities are characterized by these seasonal fluctuations; longer-lived organisms, such as fish, must be tolerant of lake conditions all year.

# CONSUMERS

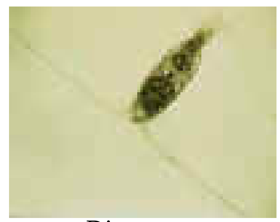
Zooplankton, small animals that swim about in open water (Figure 21), are primary consumers. They graze on algae, bacteria, and detritus (partially decayed organic material). Some species can be seen with the naked eye, although they are more easily observed with a hand lens or low-power microscopes. If you wish to see them, stare into the water of a pond or lake on a calm night with a flashlight beam shining from above.

Secondary consumers, such as planktivorous fish or predaceous invertebrates, eat zooplankton. While photosynthesis limits plant growth to the sunlit portions of lakes, consumers can live and grow in all lake zones, although the lack of oxygen (anoxia) may limit their abundance in bottom waters and sediments.

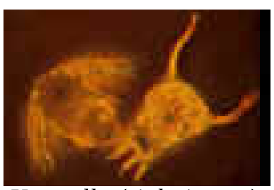
## ZOOPLANKTON

click on the photos to see larger images

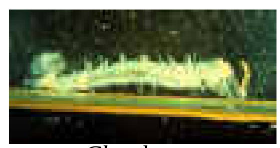
*Daphnia Pulicaria*



*Diaptomus*



*Keratella (right image)*



*Chaoborus*

**Figure 21**
Images courtesy of University of Minnesota Limnology

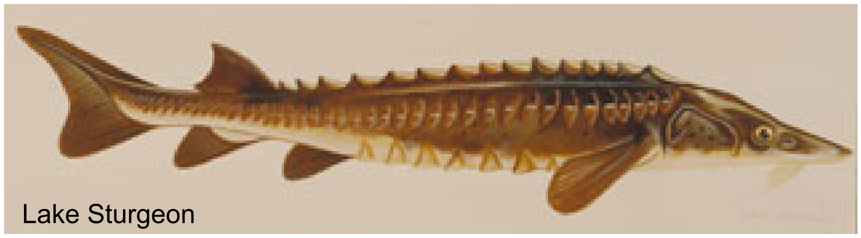
Benthic organisms are major consumers and are also important recyclers of nutrients otherwise trapped in the sediments. Benthic organisms include invertebrates and bottom-feeding fish. Their feeding strategies vary widely. Some, such as clams, filter small bits of organic material from water as it flows by. Others eat detritus that has sunk to the bottom. The spread of the exotic invader, the zebra mussel, has caused dramatic changes in the water quality and ecology of Lake Erie in the past decade due to its high rates of filtration and high reproductive rate.

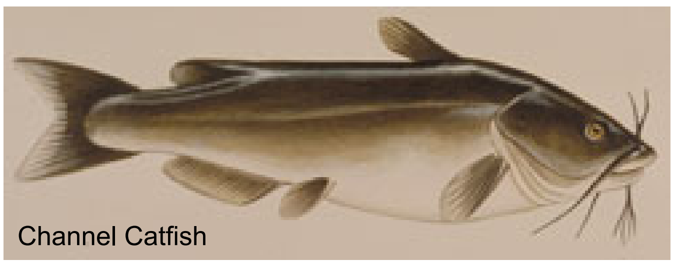
Not all organisms are easily classified as planktonic or benthic. For example, *Chaoborus*,Dipteran insect larvae, remain near the sediments in daytime and migrate to upper waters at night. These transparent predators ("phantom midges") migrate upward to feed on zooplankton, and are, themselves, a favorite food for fish. Mysid shrimp behave in a similar fashion and have been shown to migrate enormous distances (>100 meters) in Lake Tahoe each night.

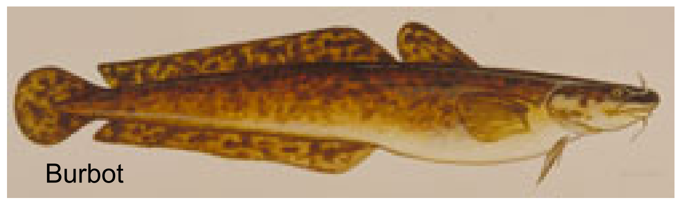
The best known group of aquatic consumers is fish. Many small fish, such as sunfish and perch, primarily eat zooplankton. Tertiary consumers that prey on the smaller fish include larger fish and other carnivorous animals (loons, grebes, herons, and otters). Different species exploit different habitats (niches). Bass and pike are found in lakes that have beds of aquatic macrophytes suitable for spawning. Walleyes, on the other hand, spawn on a gravel bottom. Lake trout live only in very clear lakes with cold, well-oxygenated deep water. In contrast, carp are adapted to warm turbid, low oxygen lakes with mucky, high organic matter bottoms. View images of fish, Figure 22.

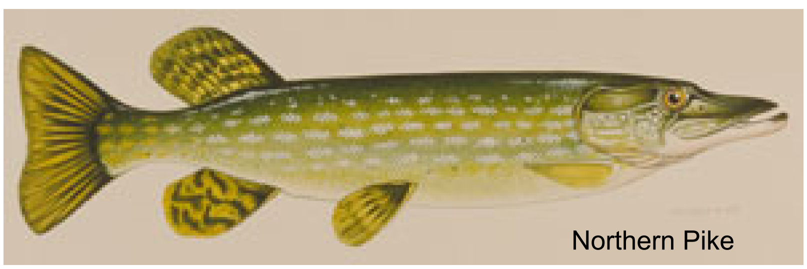
# Important Fish Species of Manitoba

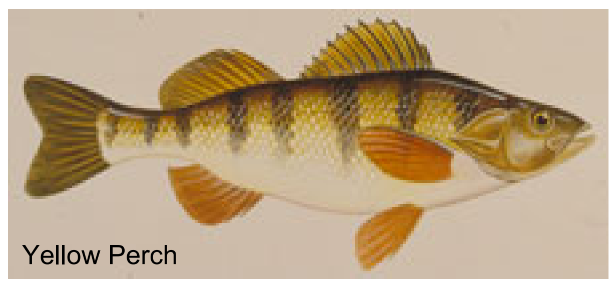
These eight species are among the most common and/or commercially important fish species in Manitoba. All, except the Lake Sturgeon and the Channel Catfish are widely distributed in the province. Many of these are large, tertiary consumer species, but there are also many common species (e.g. Johnny Darter, Slimy Sculpin, Longnose Dace, Emerald Shiner, etc.) of smaller fish, sometimes called minnows or forage fish). These usually feed at a lower trophic level, but play equally important roles within Manitoba's aquatic ecosystems. Without them, most of these top predators could not exist.


Lake Sturgeon

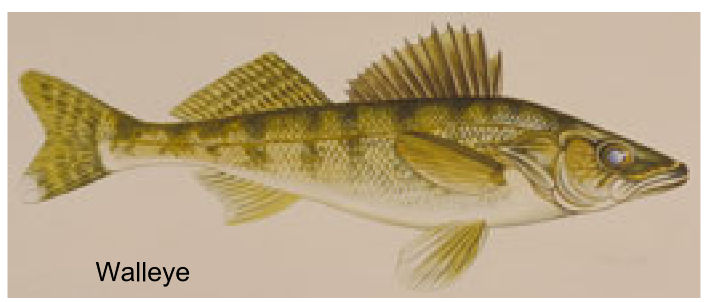

Channel Catfish


Burbot


Northern Pike


Yellow Perch


Lake Trout


Walleye

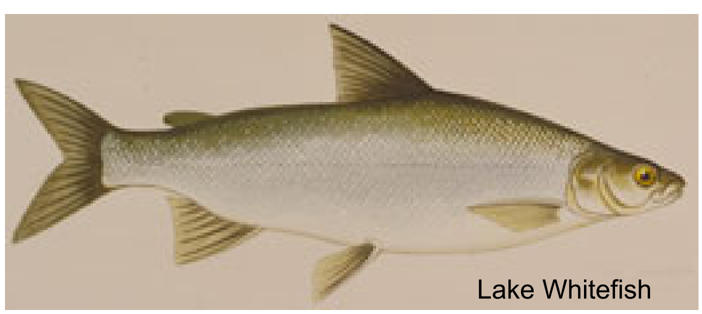

Lake Whitefish

Figure 22

# DECOMPOSERS

Decomposers, which include bacteria, fungi, and other microorganisms, are the other major group in the food web. They feed on the remains of all aquatic organisms and in so doing break down or decay organic matter, returning it to an inorganic state. Some of the decayed material is subsequently recycled as nutrients, such as phosphorus (in the form of phosphate, $PO_4^{-3}$) and nitrogen (in the form of ammonium, $NH_4^+$) which are readily available for new plant growth. Carbon is released largely as carbon dioxide that acts to lower the pH of bottom waters. In anoxic zones some carbon can be released as methane gas ($CH_4$). Methane gas causes the bubbles you may have observed in lake ice.

The decomposers can be found in all biological zones of a lake, although they are the dominant forms in the lower hypolimnion where there is an abundance of dead organic matter. Oxidation of organic matter by the decomposers (respiration) in the hypolimnion is responsible for the depletion of dissolved oxygen over the course of the summer, potentially leading to anoxic conditions (no dissolved oxygen). There is no source of oxygen in the hypolimnion to replace oxygen lost through decomposition. Stratification prevents atmospheric oxygen from being mixed deeper than the thermocline, and it is usually too dark for photosynthesis. Consequently, a large volume of organic matter from a variety of sources (e.g., wastewater, sinking algae, dying macrophytes, and organic sediment washed in from the watershed) leads to faster oxygen depletion and often complete removal of oxygen in the hypolimnion. The resulting anoxia has a profound effect on both the chemistry and the biology of the lake.

# TROPHIC STATUS

Since the early part of the 20th century, lakes have been classified according to their trophic state. "Trophic" means nutrition or growth. A eutrophic ("well-nourished") lake has high nutrients and high plant growth. An oligotrophic lake has low nutrient concentrations and low plant growth. Mesotrophic lakes fall somewhere in between eutrophic and oligotrophic lakes. While lakes may be lumped into a few trophic classes, each lake has a unique constellation of attributes that contribute to its trophic status. Three main factors regulate the trophic state of a lake:

1.Rate of nutrient supply

- Bedrock geology of the watershed
- Soils
- Vegetation
- Human landuses and management

2.Climate

- Amount of sunlight
- Temperature
- Hydrology (precipitation + lake basin turnover time)

3.Shape of lake basin (morphometry)

- Depth (maximum and mean)
- Volume and surface area
- Watershed to lake surface area ratio ($A_w : A_o$)

Trophic status is a useful means of classifying lakes and describing lake processes in terms of the productivity of the system. Basins with infertile soils release relatively little nitrogen and phosphorus leading to less productive lakes, classified as oligotrophic or mesotrophic. Watersheds with rich organic soils, or agricultural regions enriched with fertilizers, yield much higher nutrient loads, resulting in more productive, eutrophic (even hyper-eutrophic) lakes.

Eutrophication, the progress of a lake toward a eutrophic condition, is often discussed in terms of lake history. A typical lake is said to age from a young, oligotrophic lake to an older, eutrophic lake. Geological events, such as glaciation, created lakes in uneven land surfaces and depressions. The landscapes surrounding lakes were often infertile, and thus many lakes were oligotrophic. Eventually some of the shoreline and shallow areas supported colonizing organisms that decomposed unconsolidated materials into reasonably fertile sediments. Active biological communities developed and lake basins became shallower and more eutrophic as decaying plant and animal material accumulated on the bottom. Shallow lakes tend to be more productive than deep lakes, in part because they do not stratify, thereby allowing nutrients to remain in circulation and accessible to plants. They also tend to have a smaller lake volume, so nutrient loading from their watershed has a larger impact. There are undoubtedly exceptions to this typical progression from oligotrophy to eutrophy,where geology, topography, and lake morphology caused eutrophic conditions from the start.

This concept of lake aging has unfortunately been interpreted by some as an inevitable and irreversible process whereby a lake eventually "dies." In fact, many oligotrophic lakes have persisted as such since the last glaciation and some ultra-oligotrophic lakes, such as Lake Tahoe may have been unproductive for millions of years. Furthermore, research in paleolimnology has provided evidence that contradicts the idealized version of a lake becoming more and more eutrophic as it ages. Studies of sediment cores have suggested that the algal productivity of Minnesota lakes actually may have fluctuated a great deal during the past 12 - 14,000 years (the period since the last glaciation). Changes in climate and watershed vegetation seem to have both increased and decreased lake productivity over this period. Some lakes probably experienced high rates of photosynthesis fairly soon after glacial retreat and then became less productive until recent times. It is also possible that water sources for some lakes have changed over the past thousands of years through diversions of stream flow, for example. In such cases water supplies to a lake (and therefore nutrient supplies) could have changed, leading to changes in the lake's productivity.

However, lakes may be culturally eutrophied by accelerating their natural rate of nutrient inflow. This occurs through poor management of the watershed and introduction of human wastes through failing septic systems. Such changes may occur over periods of only decades and are reversible if anthropogenic nutrient loading can be controlled. In the 1960s this was a serious issue, exemplified by the hyper-eutrophic condition of Lake Erie. Although it was pronounced "dead," it eventually returned to less eutrophic conditions, when major point sources of phosphorus were controlled in the early 1970s (by spending millions of dollars to build advanced wastewater treatment plants).

In North America, most of the problems associated with the direct discharge of domestic wastewater have been successfully mitigated. Now the regulatory focus is on the much more difficult problem of controlling non-point sources (NPS) of nutrient pollution such as agricultural drainage, stormwater runoff, and inadequate on-site septic systems. NPS pollution is particularly difficult to address because it is diffuse, not attributable to a small number of polluters, and associated with fundamental changes in the landscape, such as agriculture, urbanization and shoreline development.

An excellent discussion of the factors and issues relating to natural versus cultural eutrophication is contained in a book entitled:

The Algal Bowl: Overfertilization of the World's Freshwaters and Estuaries,
(by D.W. Schindler & J.R. Vallentyne, 2008, University of Alberta Press, ISBN 978-0-88864-484-8)

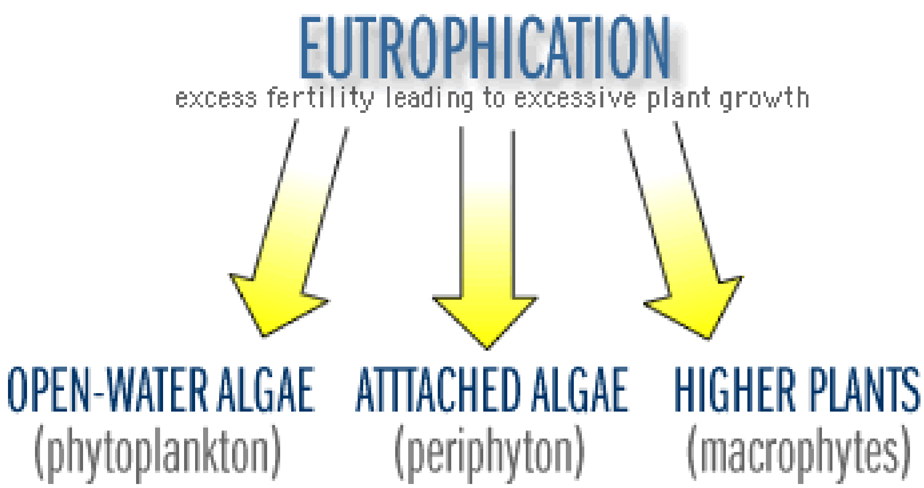



**Figure 23**

WATER QUALITY IMPACTS ASSOCIATED WITH EUTROPHICATION

- Noxious algae (scums, blue-greens, taste and odor, visual)
- Excessive macrophyte growth (loss of open water)
- Loss of clarity (secchi depth goes down)
- Possible loss of macrophytes (via light limitation by algae and periphyton)
- Low dissolved oxygen (loss of habitat for fish and fish food)
- Excessive organic matter production (smothering eggs and bugs)
- Blue-green algae inedible by some zooplankton (reduced food chain efficiency)
- "Toxic" gases (ammonia, $H_2S$) in bottom water (more loss of fish habitat)
- Possible toxins from some species of blue-green algae
- Chemical treatment by lakeshore homeowners or managers may result (copper, diquat, 2,4-D, etc.)
- Drinking water degradation from treatment disinfection byproducts
- Carcinogens, such as chloroform (from increased organic matter reacting with disinfectants like chlorine)

# ECOREGIONS

When studying various components (e.g. geology, soils, vegetation, mammal or fish populations) of natural landscapes, it is advantageous often to classify areas within the landscape according to their similarities to, and differences from, neighbouring areas. In Canada, we have produced a system of ecological classification that has subdivided the landscape into Ecozones, Ecoregions, and Ecodistricts. Figure 25, on the next page, shows the complexity of this classification system within the Prairie Provinces. Ecozones are the largest and most diverse of these divisions.

Each of the six Ecozones (Southern Arctic, Hudson Plains, Taiga Shield, Boreal Shield, Boreal Plains, Prairies) occuring within Manitoba can be subdivided further into Ecoregions. The fifteen Ecoregions of Manitoba are shown in Figure 24, below. These, in turn, are subdivided into smaller Ecodistricts, where appropriate.

Knowing the characteristics of a given Ecoregion can be useful in predicting characteristics (e.g. water quality, productivity, fish communities) of typical lakes lying within that region. For example, most lakes in the Hayes River Upland can be expected to be less turbid, less productive, and have very different plant and animal communities than lakes lying within the Aspen Parkland.

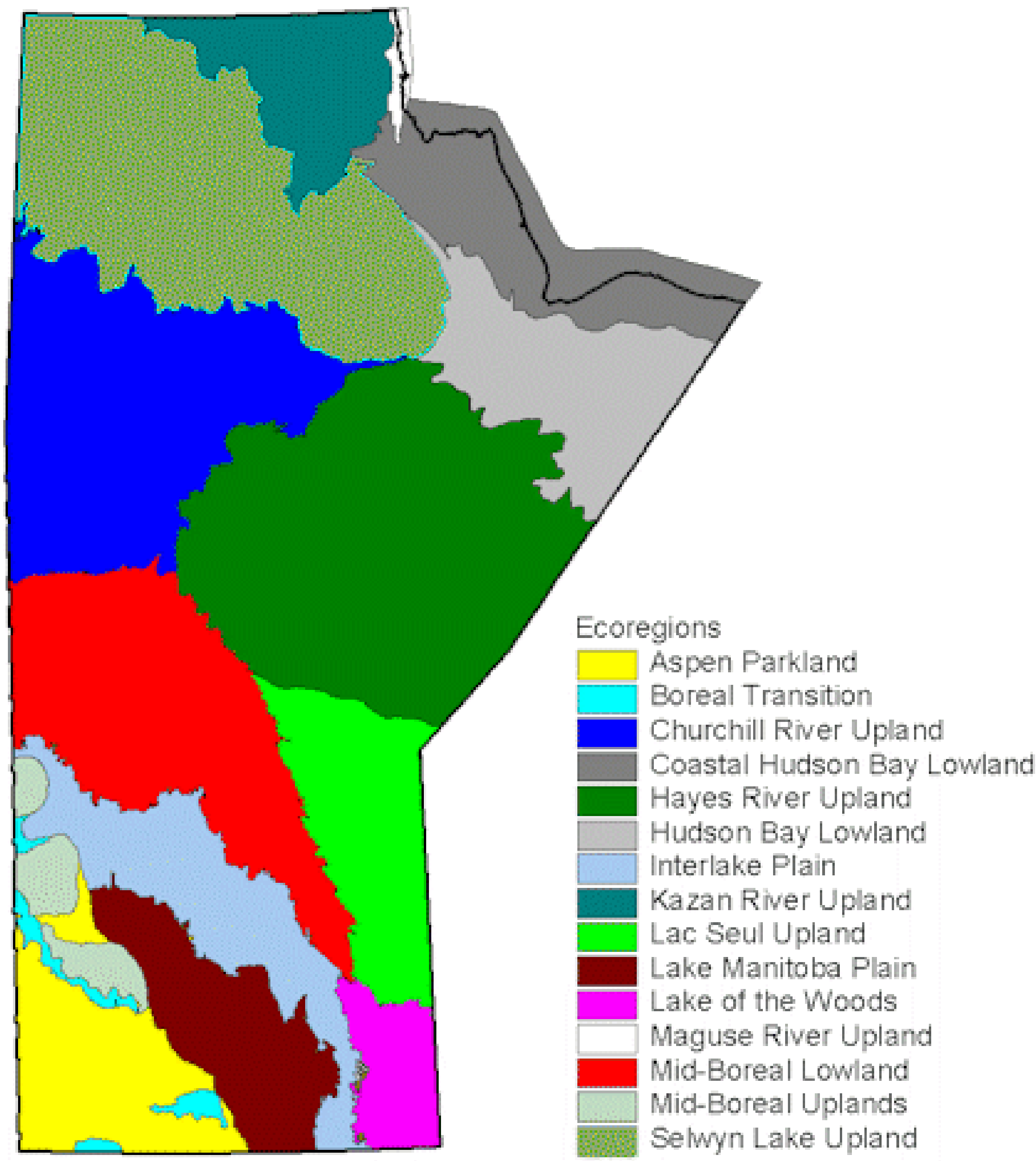



Figure 24

# Ecozones, Ecoregions & Ecodistricts of Canada's Prairie Provinces

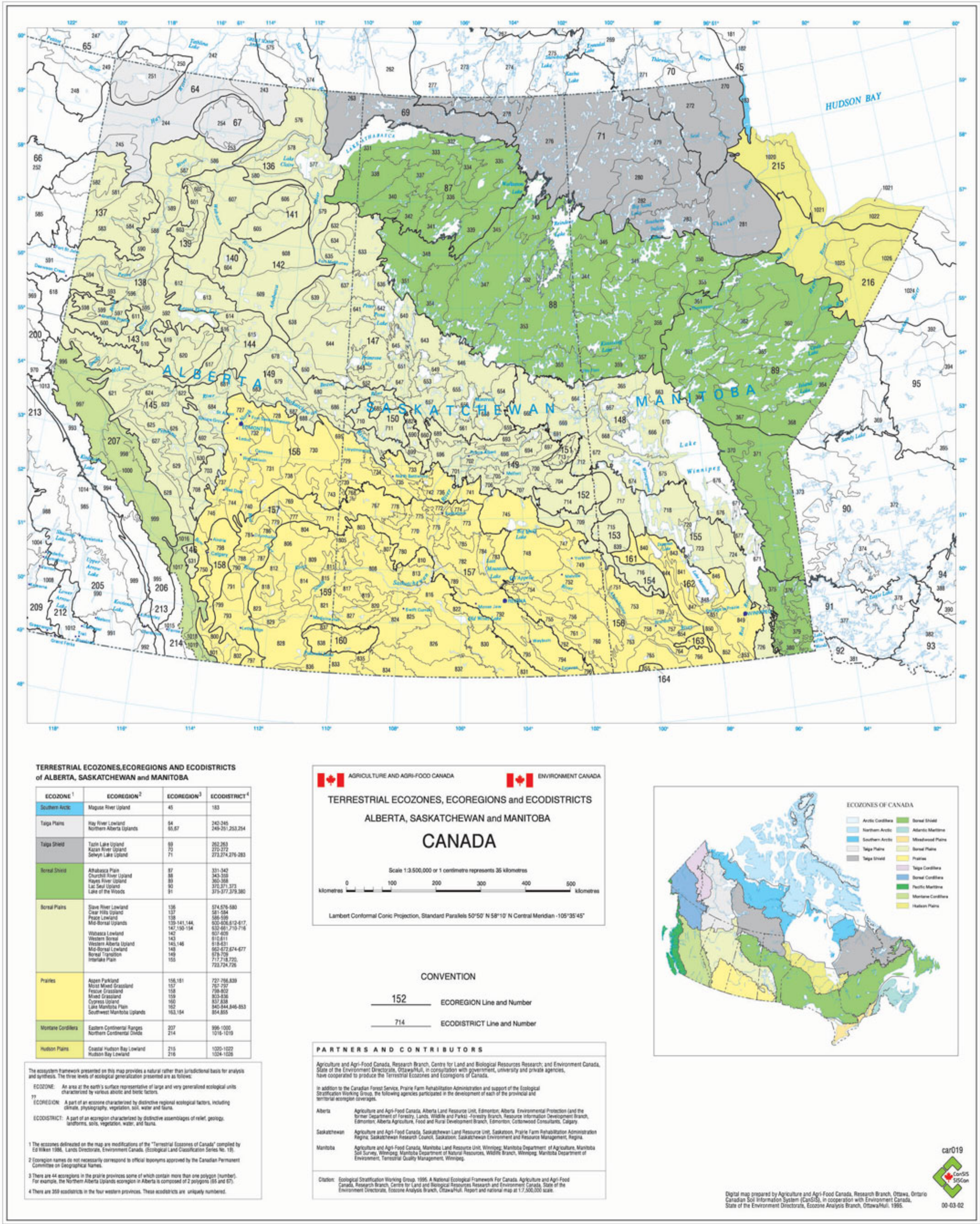



Figure 25

Table 5, below, provides examples of how lake characteristics can differ among different ecoregions. These examples come from Minnesota, but similar patterns could be identified for Manitoba, or for any other large area encompassing a variety of ecoregions.

**Table 5**
**Ecoregion lake data summary**
Values are typical for surface water (0-2 m) in summer (June-September).

| PARAMETER | Northern Lakes and Forests | North Central Hardwood Forests | Western Corn Belt Plains | Northern Glaciated Plains |
|---|---|---|---|---|
| Total Phosphorus (µg/L) | 14 - 17 | 23 - 50 | 65 - 150 | 130 - 250 |
| Chlorophyll-mean (µg/L) | < 10 | 5 -22 | 30 - 80 | 30 - 55 |
| Chlorophyll-max (µg/L) | < 15 | 7 - 37 | 60 - 140 | 40 - 93 |
| Secchi Disk (m) | 2.4 - 4.6 | 1.5 - 3.2 | 0.5 - 1.0 | 0.3 - 1.0 |
| Total Kjeldahl - N (mg/L) | < 0.75 | < 0.60 - 1.2 | 1.3 - 2.7 | 1.8 - 2.3 |
| [Nitrite + Nitrate]-N (mg/L) | < 0.01 | < 0.01 | 0.01 - 0.02 | 0.01 - 0.1 |
| Alkalinity (mg/L) | 40 - 140 | 75 - 150 | 125 - 165 | 160 - 260 |
| Color (Pt-Co units) | 10 - 35 | 10 - 20 | 15 - 25 | 20 - 30 |
| pH | 7.2 - 8.3 | 8.6 - 8.8 | 8.2 - 9.0 | 8.3 - 8.6 |
| Chloride (mg/L) | < 2 | 4 - 10 | 13 - 22 | 11 - 18 |
| TSS (µg/L) | < 1 - 2 | 2 - 6 | 7 - 18 | 10 - 30 |
| Turbidity (NTU) | < 2 | 1 - 2 | 3 - 8 | 6 - 17 |
| EC (uS/cm) | 50 - 250 | 300 - 400 | 300 - 650 | 640 - 900 |
| TN:TP ratio | 25:1 - 35:1 | 25:1 - 35:1 | 17:1 - 27:1 | 7:1 - 18 - 1 |

* Summer averages by ecoregion, based on interquartile range (25th - 75th percentile) for ecoregion reference lakes. Derived in part from Heiskary, S.A. and C.B. Wilson (1990).

# BIOLOGICAL DIFFERENCES

Populations of algae and the animals that feed on them are less dense in oligotrophic lakes because of low nutrient concentrations. Thus the water remains clear. Decay of the relatively small amount of organic matter in oligotrophic lakes does not completely deplete the hypolimnetic supply of dissolved oxygen. Therefore, lack of oxygen does not restrict animals from living in the hypolimnion of oligotrophic lakes. Lake trout, for example, require cold, well-oxygenated water and primarily live in the hypolimnion of oligotrophic lakes. Minnesota's oligotrophic lakes are found in the northeast region of the state, where infertile soils are covered with mixed conifer forests.

Extremely deep oligotrophic lakes such as Lake Superior and Lake Tahoe have hypolimnia that remain completely saturated with oxygen the entire year. However, many moderately deep lakes (with maximum depths greater than about 30 meters) may develop anoxia in the lower hypolimnion during late summer but may still be classified as oligotrophic because of their very low nutrient concentrations, low algal abundance, and relatively high transparency (high secchi depth). These lakes may have a two-story fishery, with warm and cool water fish in the epilimnion and metalimnion and cold water fish (such as trout) in the cold, oxygen rich portion of the hypolimnion. The cold-water fishery is therefore very sensitive to increased inputs of organic matter from sewage or erosion (external inputs), and to increased algal and macrophyte production (internal inputs) due to eutrophication since these factors will accelerate the rate and extent of hypolimnetic oxygen depletion in the summer.

Algae or macrophytes grow so thickly in some eutrophic lakes that light penetrates only a short distance and nutrients below that depth are not assimilated. As discussed earlier, phosphorus is typically the limiting nutrient in freshwater lakes, meaning that the plants deplete all available phosphorus before depleting other nutrients. In a hypereutrophic lake, algae may become so abundant that they suffer from self-shading. In those cases, photosynthesis is limited by light rather than by nutrients. When a great abundance of phosphorus is available in a lake, nitrogen may become limiting. In such lakes, certain species of blue-green algae that can fix atmospheric nitrogen have a clear competitive advantage and frequently become dominant. They dominate the algal community until another nutrient, or usually light, becomes limiting. In many infertile lakes in northeastern Minnesota, both phosphorus and nitrogen may be extremely low during midsummer. Since most sources of either point source or nonpoint-source pollution involve increased inputs of **both** N and P, these lakes are extremely sensitive to such pollution, irrespective of which is technically "most" deficient.

Eutrophic lakes show wide seasonal changes in their biological and chemical conditions. Because of the great amount of organic matter produced in these lakes, the decay rate is high in the hypolimnion, causing oxygen to be depleted. Therefore, eutrophic lakes frequently show a complete loss of dissolved oxygen below the thermocline during summers. Clearly, fish and most other animals cannot live in the hypolimnion of such lakes. Warm-water fish that can live in the epilimnion, however, can be quite productive. Bass, panfish, northern pike, walleye, carp, and bullheads thrive in many of Minnesota's eutrophic lakes. Complete or nearly complete oxygen depletion below the thermocline may also be a common feature of many moderately deep (10 to 30 m) mesotrophic lakes, if deep enough to stratify throughout the summer. Therefore, virtually complete anoxia below the thermocline does not necessarily mean that the lake is eutrophic.

Another oxygen-related problem in eutrophic lakes is winterkill. A dense snow cover over the ice reduces light penetration and keeps oxygen-producing photosynthesis from occurring. The high organic content of the water, however, provides considerable food for the decomposers. If the decomposers succeed in using all the available dissolved oxygen, a fish kill can occur.

In certain cases, a winterkill may lead to a more balanced fishery and possibly even improved water quality. Fish that survive a winterkill will have reduced competition for food for a period of time and so may grow faster and to a larger size. Fewer small fish reduces predation on the larger zooplankton, such as the water flea, *Daphnia sp.*, leading to increased zooplankton grazing on algae and a resultant increase in water clarity. This general scheme, involving fishery manipulations to reduce the abundance of zooplanktivorous fish, has been termed biomanipulation, and is being tried in many urban lakes where it is economically impractical to reduce nutrient inputs enough to significantly reduce algae. In these situations the offending fish may be removed by intense stocking of gamefish, by intensive netting and trapping, or even by poisoning the entire fishery and starting over with greatly reduced planktivores.

# GLOSSARY

In the alphabet listing, below,
click on the first letter of the term that you are searching,
then scroll down to find your term and its definition.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

**A**

Abiotic: Not alive; non-biological; for example, temperature and mixing are abiotic factors that influence the $O_2$ content of lake water whereas photosynthesis and respiration are biotic factors that affect $O_2$ solubility.

Acid: A solution that is a proton ($H^+$) donor and has a pH less than 7 on a scale of 0-14. The lower the pH the greater the acidity of the solution.

Acidity: A measure of how acid a solution may be. A solution with a pH of less than 7.0 is considered acidic. Solutions with a pH of less than 4.5 contain mineral acidity (due to strong inorganic acids), while a solution having a pH greater than 8.3 contains no acidity.

Acid rain: Precipitation having a ph lower than the natural range of ~5.2 - 5.6; caused by sulfur and nitrogen acids derived from anthropogenic emissions.

Acidification: The process by which acids are added to a water body, causing a decrease in its buffering capacity (also referred to as *alkalinity* or *acid neutralizing capacity*), and ultimately a significant decrease in pH that may lead to the water body becoming acidic (pH < 7).

Adhesion: The molecular force of attraction between unlike bodies that that acts to hold them together.

Algae: Simple single-celled, colonial, or multi-celled, aquatic plants. Aquatic algae are (mostly) microscopic plants that contain chlorophyll and grow by photosynthesis, and lack roots and stems ((non-vascular), and leaves. They absorb nutrients (carbon dioxide, nitrate, ammonium, phosphate and micronutrients) from the water or sediments, add oxygen to the water, and are usually the major source of organic matter at the base of the food web in lakes. Freely suspended forms are called *phytoplankton;* forms attached to rocks, stems, twigs, and bottom sediments are called periphyton.

Alkalinity: Acid neutralizing or buffering capacity of water; a measure of the ability of water to resist changes in pH caused by the addition of acids or bases and therefore, the main indicator of susceptibility to acid rain; in natural waters it is due primarily to the presence of bicarbonates, carbonates and to a much lesser extent occasionally borates, silicates and phosphates. It is expressed in units of milligrams per liter (mg/l) of $CaCO_3$ (calcium carbonate) or as microequivalents per liter (ueq/l) where 20 ueq/l = 1 mg/l of $CaCO_3$. A solution having a pH below about 5 contains no alkalinity.

Anaerobic: Technically this means "*without air*" but in limnology it is used synonymously with *"anoxic."*

Angle of incidence: Angle between direction of motion of waves and a line perpendicular to surface the waves are striking.

Angle of reflection: Angle between direction of motion of waves and a line perpendicular to surface the waves are reflected from.

Anions: Negatively charged ions.

Anoxia: Condition of being without dissolved oxygen ($O_2$).

Anoxic: Completely lacking in oxygen.

Anthropogenic: Human caused.

Aquatic respiration: Refers to the use of oxygen in an aquatic system including the decomposition of organic matter and the use of oxygen by fish, algae, zooplankton, aquatic macrophytes, and microorganisms for metabolism.

Atmospheric (Barometric) Pressure: Measure of the pressure of the earth's atmosphere per unit area. It is 760 mm Hg at sea level and decreases with increasing elevation.

Attenuation: Decrease.

Aufwuchs: The community of algae and other microorganisms that attach to surfaces such as rocks, twigs, and aquatic plants; essentially the same as "*periphyton*" that means "*attached algae*."

TOP

**B**

Base: A substance which accepts protons ($H^+$) and has a pH greater than 7 on a scale of 0-14; also referred to as an alkaline substance.

Basin: Geographic land area draining into a lake or river; also referred to as *drainage basin* or watershed.

Benthic: Refers to being on the bottom of a lake.

Benthic zone: Lake bottom sediment.

Bicarbonate: The anion $HCO_3^-$.

Bicarbonate Buffering Equilibrium Equation: See Carbonate Buffering System.

Bioaccumulation: The increase in concentration of a chemical in organisms that reside in environments contaminated with low concentrations of various organic compounds. Also used to describe the progressive increase in the amount of a chemical in an organism resulting from rates of absorption of a substance in excess of its metabolism and excretion. Certain chemicals, such as pcbs, mercury, and some pesticides, can be concentrated from very low levels in the water to toxic levels in animals through this process.

Bioavailable: Able to be assimilated (absorbed) by organisms.

Biochemical Oxygen Demand (BOD): Sometimes referred to as *Biological Oxygen Demand (BOD)*. A measure of the amount of oxygen removed (respired) from aquatic environments by aerobic microorganisms either in the water column or in the sediments.

The parameter BOD uses the maximum rate of $O_2$ consumption over a 5 day period in the dark at $20^0$ to estimate the total amount of "biodegradable" organic matter in the system. Typically too insensitive to be useful for pristine lakes and so is used primarily for wastewater "streams" or systems impacted by organic pollution.

Biomanipulation:

Reducing algal blooms by altering the fish community to reduce predation on certain zooplankton (cladocerans such as *daphnia*) that can most efficiently graze on algae.

Biomass: The weight of a living organism or assemblage of organisms.

Biotic: Referring to a live organism; see also abiotic.

Birgean Heat Budget: See Heat Budget.

Buffer: A substance which tends to keep pH levels fairly constant when acids or bases are added.

Buffering Capacity: Ability of a solution to resist changes in ph when acids or bases are added; the buffering capacity of natural waters is mostly due to dissolved carbonate rocks in the basin; equivalent to acid neutralizing capacity (anc).

TOP

**C**

Calorie: A basic measure of energy where 1 calorie is equal to the total amount of heat required to raise the temperature of 1 gram of water 1 degree Celsius.

Capillary Action: The action by which water is drawn around soil particles (or any other solid substance like a small bore tube) because there is a stronger attraction between the soil or solid particles and the water molecules themselves.

Carbon Cycle: The circulation of carbon atoms through the earth's whole ecosystem.

Carbon Dioxide: A gas which is colorless and odorless; when dissolved in water it becomes carbonic acid; $CO_2$ is assimilated by plants for photosynthesis in the "dark" cycles of photosynthesis.

Carbonate ion: The CO3-2 ion in the Carbonate Buffer System the collective term for the natural inorganic chemical compounds related to carbon dioxide that exists in natural waterways. Combined with one proton, it becomes Bicarbonate, HCO3- and with two protons, Carbonic Acid. The carbonate ion forms a solid precipitant when combined with dissolved ions of calcium or magnesium.

Carbonate Buffering System: The most important buffer system in natural surface waters and wastewater treatment, consisting of a carbon dioxide, water, carbonic acid, *Bicarbonate*, and *Carbonate* ion equilibrium that resists changes in the water's pH. If acid (hydrogen ions) is added to this buffer solution, the equilibrium is shifted and carbonate ions combine with the hydrogen ions to form bicarbonate. Subsequently, the bicarbonate then combines with hydrogen ions to form carbonic acid, which can dissociate into carbon dioxide and water. Thus the system pH is unaltered (buffered) even though acid was introduced.

Carnivores: "Meat" eaters; organisms that eat other organisms.

Cations: Negative ions.

Chemical Equilibrium: Concentrations of reactants and products at which a reaction is in balance; there is no net exchange because the rate of the forward reaction is taking place at the same rate of the reverse reaction.

CHEMetrics Water Quality Test Kits:

CHEMetrics, Inc. (website: http://www.chemetrics.com/) is one of a number of companies that market a variety of test kits and field and lab instruments for water quality testing. Additional companies commonly cited are Hach and LaMotte, and there are probably numerous others accessible to the reader through various educational resources or scientific lab products catalogues. *Water on the Web* does not endorse any particular company s products. Some test kits have been "approved" by state or federal agencies for certain types of tests in specific types of water or wastewater.

Chemocline: Sharp gradient in chemical concentration; the boundary in a meromictic lake separating an upper layer of less-saline water that can mix completely at least once a year (mixolimnion) from a deeper, more saline (dense) layer (monimolimnion) that never is mixed into the overlying layer.

Chlorophyll: Green pigment in plants that transforms light energy into chemical energy in photosynthesis.

Clarity: Transparency; routinely estimated by the depth at which you can no longer see a sechi disk. The Secchi disk is a 20 cm (8 inch) diameter weighted metal plate with alternating quadrants painted black and white that is used to estimate water clarity (light penetration). The disc is lowered into water until it disappears from view. It is then raised until just visible. An average of the two depths, taken from the shaded side of the boat, is recorded as the Secchi depth.

Coefficient of Heat Transfer: The ratio of the temperature of an object to the temperature of its surroundings. The change in temperature of an object is directly proportional to the difference between its temperature and the temperature of its surroundings.

Cohesion: The molecular force between particles within a substance that acts to unite them.

Cohesive Forces: All the forces of attraction among particles of a liquid.

Conductivity (electrical conductivity and specific conductance):

Measures water's ability to conduct an electric current and is directly related to the total dissolved salts (ions) in the water. Called EC for electrical conductivity and is reported in micromhos per centimeter (umhos/cm) which has been recently renamed as uS/cm (microSiemans per centimeter). EC is temperature sensitive and increases with increasing temperature. Most modern probes automatically correct for temperature and standardize all readings to $25^{0}$C and then refer to the data as *specific* EC.

Conduction: Thermal conduction is the transfer of heat between two solid materials that are physically touching each other.

Consumers: Organisms that must eat other organisms for their energy metabolism; organisms that cannot produce new organic matter by photosynthesis or chemosynthesis (producers).

Convection Currents: Air or water movement caused by changes in density or thermal (temperature) gradients.

Covalent: Refers to the chemical bond formed by the sharing of one or more electron pairs between two atoms.

Cyanobacteria: Bluegreen algae; phylum or organisms that are biochemically bacterial in nature but perform plant photosynthesis.

TOP

**D** Decomposition: The breakdown of organic matter by bacteria and fungi.

Denitrification:

Anaerobic bacterial process metabolism in which nitrate is used instead of oxygen during the oxidation of organic carbon compounds to yield energy (respiration). The process oxidizes organic carbon and (chemically) reduces nitrate to the gaseous end products $N_2$ (nitrogen gas) or $N_2O$ (nitrous oxide). This is the major process used in wastewater treatment plants to ultimately convert *combined* nitrogen to a non-polluting state.

Density: The mass of a substance or organism per unit volume (kg/cubic meter; grams/liter).

Density Stratification: Creation of layers in a water body due to density differences; controlled by temperature, dissolved solids concentration and particle concentration.

Detritus: Dead or decaying organic matter; technically called organic detritus to distinguish it from the mineral detritus classified by geologists.

Diatom: Group of algae characterized by glass (silica) cell wall, beautifully ornamented; often the brown stuff attached to rock surfaces.

Diel: A 24 hour period of time.

Diffusion: The movement of a substance from an area of high concentration to an area of low concentration. Turbulent diffusion, or mixing, results from atmospheric motions (wind) diffusing water, vapor, heat, and other chemical components by exchanging parcels called eddies between regions in space in apparent random fashion. Molecular diffusion, which operates in stagnant zones, such as at the bottom sediment-water boundary in a deep lake, occurs much, much more slowly and so is important only on a very small scale such as right at the bottom.

Dimictic: Having two mixing periods, typically in spring and fall.

Dipole: A molecule that has two opposite electrical poles, or regions, separated by a distance.

Dipole - Dipole Forces: Intermolecular attraction between the oppositely charged poles of nearby molecules.

Dipole - Induced Dipole Forces: Very weak forces between a dipole and non-polar molecule that acts like a dipole in the presence of a dipole molecule.

Dipteran: True flies.

Dissolved Oxygen (DO or $O_2$):

The concentration of free (not chemically combined) molecular oxygen (a gas) dissolved in water, usually expressed in milligrams per liter, parts per million, or percent of saturation. Adequate concentrations of dissolved oxygen are necessary for the life of fish and other aquatic organisms and the prevention of offensive odors. DO levels are considered the most important and commonly employed measurement of water quality and indicator of a water body's ability to support desirable aquatic life. Levels above 5 milligrams per liter (mg $O_2$/L) are considered optimal and most fish cannot survive for prolonged periods at levels below 3 mg $O_2$/L. Levels below 1 mg $O_2$/L are often referred to as *hypoxic* and when $O_2$ is totally absent *anoxic* (often called anaerobic which technically means *without air*). Secondary and advanced wastewater treatment systems are generally designed to degrade organic matter to ensure adequate dissolved oxygen in waste-receiving waters (from North American Lake Management Society.

Dissolved Oxygen Profile:

A graph of the amount of dissolved oxygen per unit depth; where the depth is on the z (vertical) axis and dissolved oxygen is on the x (horizontial) axis. Limnologists plot graphs this way but be sure to note that the depth (z) axis is really for the independent variable and the horizontal (x) axis is really for the dependent variable.

The total mass of dissolved mineral constituents or chemical compounds in water; they form the residue that remains after evaporation and drying. Often referred to as the *total dissolved salts* (TDS) concentration or dissolved ion concentration. In seawater or brackish water this is approximated by the *salinity* of the water. All of these parameters are estimated by the electrical conductivity (EC).

Drainage lakes: Lakes having a defined surface inlet and outlet.

Dry deposition: Fine particulate matter and aerosols settling from the atmosphere onto lake and land surfaces during periods w precipitation.

TOP

**E**

Ecological niche: The particular area within a habitat occupied by an organism, or the role within an ecological community occupied by an organism or population.

Ecological pyramid: Conceptual scheme whereby the amount of biomass or energy at each level of the food "chain" decreases a move from primary producers through the different levels of consumers.

Ecoregion: An environmental area characterized by specific land uses, soil types, surface form, and potential natural vegetation

Ecosystem: All of the interacting organisms in a defined space in association with their interrelated physical and chemical environment.

Electrical Conductivity (EC): See Conductivity.

Electromagnetic Radiation: Radiation that travels through space at the speed of light that includes light, radio waves, x-rays, an

Endothermic Reaction: A reaction which absorbs heat; see also exothermic reaction.

Epilimnion: The upper, wind-mixed layer of a thermally stratified lake. This water is turbulently mixed throughout at least som portion of the day and because of its exposure, can freely exchange dissolved gases (such as $O_2$ and $CO_2$) with the atmosphere.

Equilibrium: See Chemical Equilibrium.

Euphotic zone: Layer of water where sunlight is sufficient for photosynthesis to occur.

Eutrophic Lake: A very *biologically productive* type of lake due to relatively high rates of nutrient input. See *Eutrophication*.

Eutrophication:

The process by which lakes and streams are enriched by nutrients (usually phosphorus and nitrogen) which leads to excessive plant growth - algae in the open water, periphyton (*attached* algae) along the shoreline, and macrophytes (the higher plants we often call *weeds*) in the nearshore zone. See the Lake Ecology Primer Biology section for more information about this problem; it remains the biggest pollution problem for Minnesota s (and in fact for the rest of our country as well) lakes . The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile). The less productive a lake is naturally, the more sensitive it is to increased nutrient loads from human-caused disturbances in the watershed.

Evaporation: The process of converting liquid to vapor.

Excel:

Refers to MicrosoftÍs Excel spreadsheet software.

Exothermic Reaction: A reaction which gives off heat; see also endothermic reaction.

Export rates: Amount of a particular nutrient or contaminant annually transported from its source to a lake or stream; usually related to land uses and expressed per unit area per year.

TOP

**F**

Fetch: Distance the wind blows over water without appreciable change in direction; relates to intensity of turbulent mixing.

Fix: Convert $CO_2$ to carbohydrate or $N_2$ to $NH4^+$ (carbon fixation and nitrogen fixation);

Flagella: Whiplike structure that enables motility in certain groups of algae.

Flow Rate: The rate at which water moves by a given point; in rivers it is usually measured in cubic meters per second ($m^3$/sec) or cubic feet per second (cfs).

Flushing Rate:

The retention time (turnover rate or flushing rate), the average length of time water resides in a lake, ranging from several days in small impoundments to many years in large seepage lakes. Retention time is important in determining the impact of nutrient inputs. Long retention times result in recycling and greater nutrient retention in most lakes. Calculate retention time by dividing the volume of water passing through the lake per year by the lake volume.

Food Chain:

The transfer of food energy from plants through herbivores to carnivores. An example: insect-fish-bear or the sequence of algae being eaten by zooplankton (grazers; herbivores) which in turn are eaten by small fish (planktivores; predators) which are then eaten by larger fish (piscivores; fish eating predators) and eventually by people or other predators (fish-eating birds, mammals, and reptiles).

Food Web: Food chains hooked together into a complex interconnected web.

TOP

**G**

Gas Solubility: The ability of a gas to dissolve into another substance.

Geographic Information System (GIS):

A computer system which allows for input and manipulation of geographic data to allow researchers to manipulate, analyze and display the information in a map format.

Grazers: Herbivores; zooplankton in the open water zone.

TOP

**H**

Hach Water Quality Test Kits:

Hach, Inc. (Website: http://www.hach.com/) is one of a number of companies that market a variety of test kits and field and lab instruments for water quality testing. Additional companies commonly cited are LaMotte and CHEMetrics, and there are probably numerous others accessible to the reader through various educational resources or scientific lab products catalogues. *Water on the Web* does not endorse any particular company s products. Some test kits have been "approved" by state or federal agencies for certain types of tests in specific types of water or wastewater.

Hardwater: Lakes that have a high buffering capacity and are not generally sensitive to acid deposition. These lakes have dissolved salt concentrations greater than 120 mg/L.

Heat: Energy that is transferred from one body to another because of a difference in temperature.

Heat Budget: The amount of heat energy required annually to raise the temperature of a water body from its winter minimum to its summer maximum.

Heat Energy: An energy form proportional to and associated with molecular motion. Conduction, convection or radiation can transfer heat from one mass of matter to another.

Heat Reflection: The return of radiant heat energy by a reflecting surface.

Heat of Transformation: See Latent Heat.

Heat of Vaporization: The heat required to convert a substance from the liquid to the gaseous state with no temperature change. This is also called the latent heat of vaporization.

Henry's Law: States that at a given temperature the solubility of a gas is directly proportional to the pressure of the gas directly above the liquid.

Herbivores: Plant eaters.

Heterogeneous: Not uniform; patchy.

Holomictic: Typically mixes completely throughout the water column at least once a year.

Hydrogen: Colorless, odorless and tasteless gas; combines with oxygen to form water.

Hydrogen Bond:

A type of chemical bond caused by electromagnetic forces, occurring when the positive pole of one molecule (e.g., water) is attracted to and forms a bond with the negative pole of another molecule (e.g., another water molecule).

Hydrogen Ion: An individual atom of hydrogen which is not attached to a molecule and therefore has a positive (+) charge.

Hydrology: The study of water's properties, distribution and circulation on Earth.

Hydrostatic Pressure: Pressure exerted in a column of water.

Hypolimnetic Oxygen Depletion:

A condition where the dissolved oxygen in the bottom layer (hypolimnion) of a water body is gradually consumed through respiration and decomposition faster than it can be replaced over the course of the summer. A similar phenomenon may occur in the winter under ice cover. The rate at which $O_2$ is depeleted is a measure of the productivity of the system.

Hypolimnion:

The bottom, and most dense layer of a stratified lake. It is typically the coldest layer in the summer and warmest in the winter. It is isolated from wind mixing and typically too dark for much plant photosynthesis to occur.

TOP

## I

Ice-out: Date when lake thaws.

Impervious surfaces:

Land surfaces such as roads, parking lots, buildings, etc that prevent rainwater from soaking into the soil. The water increases in velocity causing more erosion; it warms causing potential heat stress for downstream trout; it picks up roadway contaminants; and the loss of vegetation removes a "sink" for dissolved nutrients - plant uptake.

Inflow: Water flowing into a lake.

Inorganic: Substances of mineral, not carbon origin.

Ion: An electrically charged particle.

Isothermal: Constant in temperature.

**J**

TOP

**K**

TOP

TOP

**L**

Lake Profile: A graph of a lake variable per depth; where the depth is on the z-axis and the variable is on the x-axis. Depth is the independent variable and the x-axis is the dependent variable.

LaMotte Water Quality Testing Kits:

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Landuse:

The primary or primary and secondary uses of land, such as cropland, woodland, pastureland, forest, water (lakes, wetlands, streams), etc. The description of a particular landuse should convey the dominant character of a geographic area and establish the dominant types of human activities which are prevalent in each region.

Landscape:

All the natural geographical features, such as fields, hills, forests, and water that distinguish one part of the earth's surface from another part. These characteristics are a result not only of natural forces but of human use of the land as well.

Latent Heat (Energy):

The amount of heat (energy) released from or absorbed by a substance when it undergoes a change of state; also known as Heat of Transformation.

Le Chatelier's Principle:

A principle of equilibrium; states that in a balanced equilibrium, if one or more factors changes, the system will readjust to reach equilibrium.

Leach: To remove soluble or other constituents from a medium by the action of a percolating liquid, as in leaching salts from the soil by the application of water.

Limnetic zone: Open water zone.

Littoral: Nearshore out from shore to the depth of the euphotic zone where it is too dark on the bottom for macrophytes to grow.

Loading Rates:
The rate at which materials (typically suspended sediment, nutrients [N and P], or contaminants) are transported into a water body.

Loricas: Glass cell covering.

TOP

**M**

Macrophytes:
Higher aquatic plants; in the sense of "higher" evolutionarily than algae and having roots and differentiated tissues; may be emergent (cattails, bulrushes, reeds, wild rice), submergent (water milfoil, bladderwort) or floating (duckweed, lily pads).

Marl: Encrustation of calcium carbonate that forms on plants in high ph/alkalinity lakes and on your faucet from the precipitation of calcium carbonate.

Meromictic: Describing a lake that doesn't mix completely (see chemocline)

Mesotrophic: Moderately productive; relating to the moderate fertility of a lake in terms of its algal biomass.

Mean Depth: The average depth of a water body; determined by dividing lake volume by the surface area (also called z mean).

Metabolism: The chemical and physical processes continually going on in living organisms and cells, by which the energy is provided for cellular processes and activities, and new material is assimilated to repair waste.

Metalimnion:
The middle or transitional zone between the well mixed epilimnion and the colder hypolimnion layers in a stratified lake. This layer contains the thermocline, but is loosely defined depending on the shape of the temperature profile.

Micronutrient:
Trace nutrients required by microrganisms or zooplankton such as molybdenum and cobalt; nitrogen and phosphorus are considered to be macronutrients.

Mixolimnion: The upper layer of less-saline water that can mix completely at least once a year in a meromictic lake (see chemocline).

Mixture: An aggregate of two or more substances that are not chemically united.

Monimolimnion: Bottom layer of stagnant water in a meromictic lake that never is completely mixed (see chemocline).

Morphoedaphic Index:
A measure of the potential yield of fishery from a lake; computed by taking the concentration of total dissolved solids (TDS) divided by the mean depth of the lake; it assumes that increasing dissolved salt content reflects increased nutrient content due to increased contact of precipitation with the soil prior to entering a lake.

Morphometry:
Relating to the shape of a lake basin; includes parameters needed to describe the shape of the lake such as volume, surface area, mean depth, maximum depth, maximum length and width, shoreline length, shoreline development (length of the perimeter, or shoreline divided by the calculated diameter of a circle of equivalent area [how convoluted the shoreline is]), depth versus volume and surface area curves.

Motile: Able to move at will.

TOP

**N**

Neuston: (1) The collection of minute or microscopic organisms that inhabit the surface layer of a body of water. (2) Organisms resting or swimming on the surface of still bodies of water.

Nitrification:

Bacterial metabolism in which ammonium ion ($NH_4^+$) is oxidized to nitrite ($NO_2^-$) and then to nitrate ($NO_3^-$) in order to yield chemical energy that is used to *fix* carbon dioxide into organic carbon. The process is a type of chemosynthesis which is comparable to photosynthesis except that chemical energy rather than light energy is used. These bacteria are aerobic and so require dissolved oxygen in order to survive.

Nitrogen Fixation:

The conversion of elemental nitrogen in the atmosphere (N2) to a form (e.g., ammonia) that can be used as a nitrogen source by organisms. Biological nitrogen fixation is carried out by a variety of organisms; however, those responsible for most of the fixation in lakes are certain species of bluegreen algae.

Non-motile: Not able to move at will.

Non-polar Molecule: A molecule that does not have electrically charged areas (poles).

Non-polar Gas: A gas that is electrically neutral.

Nonpoint source: Diffuse source of pollutant(s); not discharged from a pipe; associated with land use such as agriculture or contaminated groundwater flow or on-site septic systems.

Nuisance blooms:

Referring to obnoxious and excessive growths of algae caused by excessive nutrient loading; often due to scum forming cyanobacteria (bluegreen algae) that can regulate their buoyancy to float high in the water column to obtain sunlight.

Nutrient loading:

Discharging of nutrients from the watershed (basin) into a receiving water body (lake, stream, wetland); expressed usually as mass per unit area per unit time (kg/ha/yr or lbs/acre/year.

TOP

**O**

Oligotrophic:

Very unproductive; lakes low in nutrients and algae, usually very transparent with abundant hypolimnetic oxygen if stratified.

Omnivorous: Capable of eating plants, fungi and animals.

Organic: Substances which contain carbon atoms and carbon-carbon bonds.

Outflow: Water flowing out of a lake.

Outliers: Data points that lie outside of the normal range of data. Ideally, outliers must be determined by a statistical test before they can be removed from a data set.

Oxygen: An odorless, colorless gas; combines to form water; essential for aerobic respiration.

Oxygen Solubility: The ability of oxygen gas to dissolve into water.

TOP

**P**

Paleolimnology: The study of the history of lakes via the analysis of organisms and chemistry of lake bottom sediments.

Parameter: Whatever it is you measure; a particular physical, chemical, or biological property that is being measured.

Partial Pressure: The pressure exhibited by a single gas in a gas mixture.

Periphyton: Attached algae; the green slime that attaches shoreline and bottom vegetation and the brown stuff attached to rock surfaces.

Petri dish: A shallow, round glass dish + lid used for culturing microorganisms.

pH: A measure of the concentration of hydrogen ions.

pH Profile: A graph of the pH level per depth; where the depth is on the z-axis and pH level is on the x-axis. Depth is the independent variable and the x-axis is the dependent variable.

pH Scale: A scale used to determine the alkaline or acidic nature of a substance. The scale ranges from 1-14 with 1 being the most acidic and 14 the most basic. Pure water is neutral with a pH of 7.

Phosphorus:

Key nutrient influencing plant growth in lakes. Soluble reactive phosphorus ($PO_4^{-3}$) is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Photosynthesis:

The process by which green plants convert carbon dioxide ($CO_2$) dissolved in water to sugars and oxygen using sunlight for energy. Photosynthesis is essential in producing a lake's food base, and is an important source of oxygen for many lakes.

Photosynthesizers: Organisms that produce their energy via phtosynthesis.

Phytoplankton:

Microscopic floating plants, mainly algae, that live suspended in bodies of water and that drift about because they cannot move by themselves or because they are too small or too weak to swim effectively against a current.

Planktivores:

Animals that eat plankton; usually refers to fish that feed on zooplankton but can also refer to fish that graze on algae; includes invertebrate predators, such as the phantom midge.

Polarity: An unsymmetrical distribution of electron density found in a covalent bond.

Polar gas: A gas which is made up of molecules that have electrically charged areas (poles).

Polar molecule:

A molecule in which one structural end (an atom or atoms) possesses a slight negative charge and another structural end possesses a slight positive charge but the charges do not cancel one another out but rather create two separate poles.

Polymictic: Mixes completely intermittently.

Ppb: Part-per-billion; equivalent to a microgram per liter (ug/l).

Ppm: Part-per-million; equivalent to a milligram per liter (mg/l).

Pressure (p): The force exerted per unit area.

Primary consumers:
First level of consumers according to the ecological pyramid concept; organisms that eat herbivorous grazers.

Primary producers:
Organisms that convert $co_2$ to biomass. Usually refers to photosynthesizers, but also includes the chemosynthetic bacteria that use chemical instead of light energy to ***fix*** $co_2$ to biomass.

Primary Productivity:
The productivity of the photosynthesizers at the base of the food chain in ecosystems. This refers to the yield of new biomass (plant) growth during a specified time period. The entire year's accumulation is termed annual production. In the open water of lakes it is typically estimated by measured growth rates of phytoplankton (algae), either via $O_2$ accumulation in light relative to dark bottles of lake water or by the uptake of added radioactive carbon dioxide in sealed bottles of lake water.

Productivity:
The time rate of production of biomass for a given group of organisms; essentially the net growth rate of organisms.

Profile: A vertical, depth by depth characterization of a water column, usually at the deepest part of a lake.

TOP

**Q**

TOP

**R** Radiation: The movement of energy through any medium via heat, light or radio waves.

Radioisotopes:
Radioactive isotopes; radioactive forms of carbon, phosphorus, and other nutrients are used to measure rates of their absorption into biological communities; radioisotopes derived from fallout from atmospheric nuclear weapons testing are used to date layers of lake sediments

Relative depth:
A measure of how deep a lake is relative to its surface area, "*high*" being associated with "*small but deep*" $z_r$ =[ 88.6 *$z_{max}$]/ %a for maximum depth and area.

Respiration:
The metabolic process by which organic carbon molecules are oxidized to carbon dioxide and water with a net release of energy. Aerobic respiration requires, and therefore consumes, molecular oxygen (algae, *weeds*, zooplankton, benthic invertebrates, fish, many bacteria, people). Certain bacteria can use nitrate in place of oxygen (denitrifiers) or sulfate (sulfate reducers), but only under anaerobic (anoxic) conditions - typically present only in the sediments or in the hypolimnion after prolonged oxygen depletion has occurred.

TOP

**S** Saturation:

The point at which a substance has the maximum amount of another substance at a given temperature and pressure; also see supersaturation.

Secchi Disk:

A disk with a 4-6 inch radius that is divided into 4 equal quadrates of alternating black and white colors. It is lowered into a section of shaded water until it can no longer be seen and then lifted back up until it can be seen once again. Averaging the two depths gives the clarity of the water; see also clarity.

Secondary consumers: Consumers such as plankton eating fish or predaceous zooplankton that eat other zooplankton.

Sedimentation:

The removal, transport, and deposition of detached soil particles by flowing water or wind. Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and weeds, precipitated calcium carbonate (marl), and soil and organic matter eroded from the lake's watershed.

Seepage lakes: Lake having an inlet or an outlet but not both; primary water inputs are precipitation and groundwater.

Sewage sludge: The solid portion of sewage that contains organic matter, and a whole community of algae, fungi, bacteria and protozoans that consume it. The terms Biosolids, Sludge, and sewage sludge can be used interchangeably.

Shoreline: The zone where lake and land meet. Shorelands are defined as the lands 1000 ft from the ordinary high water level.

Softwater lakes: Lakes with low buffering capacity (alkalinity) that are most sensitive to acid deposition inputs.

Solubility: The ability of a substance to dissolve into another; also see gas solubility.

Solute: A substance which can be dissolved into another substance.

Solution: A homogenous mixture of two substances.

Solvent: A substance which has the ability to dissolve another; also see Universal Solvent.

Specific conductance:

A measure of the ability of water to conduct an electrical current as measured using a 1-cm cell and expressed in units of electrical conductance (EC), i.e. siemans (uS or mS) at 25 C.

Specific Heat: The amount of heat required to raise the temperature of one gram of substance one degree Celsius.

Spring turnover:

Period of complete or nearly complete vertical mixing in the spring after ice-out and prior to thermal stratification.

States of Matter:

The three basic forms (or states) which a substance can take: solid, liquid, or gas; a fourth form, called a plasma (an ionized gas), is also possible but only at extremely high temperatures.

Stormwater discharge:

Precipitation and snowmelt runoff from roadways, parking lots, roof drains that is collected in gutters and drains; a major source of nonpoint source pollution to water bodies and a major headache to sewage treatment plants in municipalities where the stormwater is combined with the flow of domestic wastewater (sewage) before entering the wastewater treatment plant.

Stratification:

An effect where a substance or material is broken into distinct horizontal layers due to different characteristics such as density or temperature.

Stratified: Separated into distinct layers.

Stratigraphic:

Relating to stratigraphy, the branch of geology which treats the formation, composition, sequence and correlation of the layered rocks as parts of the earth's crust.

Substrate: Attachment surface or bottom material in which organisms can attach or live-within; such as rock substrate or sand or muck substrate or woody debris or living macrophytes.

Supersaturation:

When a substance is more highly concentrated (more saturated) in another substance than is normally possible under normal temperature and pressure.

Surface Tension:

A phenomenon caused by a strong attraction towards the interior of the liquid action on liquid molecules in or near the surface in such a way to reduce the surface area.

Suspended Sediment (SS or Total SS[TSS]):

Very small particles which remain distributed throughout the water column due to turbulent mixing exceeding gravitational sinking; also see turbidity.

Suspension: A heterogeneous mixture in which solute-like particles settle out of solvent-like phase some time after their introduction.

TOP

**T**

TDS: Total dissolved salts or solids in a volume of water; usually in mg/l; estimated by EC (electrical conductivity).

Temperate: Refers to lakes located in a climate where the summers are warm and the winters moderately cold. The Temperate Zone is between the Tropic of Cancer and the Arctic Circle.

Temperature: A measure of whether a substance is hot or cold.

Temperature Profile: A graph of the temperature per depth; where the depth is on the z-axis and temperature is on the x-axis.

Tertiary consumers: Larger consumers in the fourth trophic level like adult northern pike, ospreys and humans that eat fish.

Thermal stratification:

Existence of a turbulently mixed layer of warm water (epilimnion) overlying a colder mass of relatively stagnant water (hypolimnion) in a water body due to cold water being denser than warm water coupled with the damping effect of water depth on the intensity of wind mixing.

Thermocline:

The depth at which the temperature gradient is steepest during the summer; usually this gradient must be at least $1^0$C per meter of depth.

Topography: Configuration of physical surface of land; includes relief imprints and locations of all man-made and natural features.

Total Dissolved Solids (TDS):

The amount of dissolved substances, such as salts or minerals, in water remaining after evaporating the water and weighing the residue.

Tributary: Feeder stream.

Trophic State:
Eutrophication is the process by which lakes are enriched with nutrients, increasing the production of rooted aquatic plants and algae. The extent to which this process has occurred is reflected in a lake's trophic classification or state: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Trophic webs: Conceptual model of the interconnections of species of organisms according to their different feeding groups.

Turbidity: Degree to which light is blocked because water is muddy or cloudy.

Turnover: Fall cooling and spring warming of surface water act to make density uniform throughout the water column. This allows wind and wave action to mix the entire lake. Mixing allows bottom waters to contact the atmosphere, raising the water's oxygen content. However, warming may occur too rapidly in the spring for mixing to be effective, especially in small sheltered kettle lakes.

Two story fishery:
An upper warm water fishery overlying a deeper coldwater salmonid (trout or salmon) fishery; typically these are relatively deep and unproductive lakes that maintain oxygen >5 ppm in much of the hypolimnion throughout the summer.

**U**

Universal Solvent: A substance that has the ability to dissolve both bases and acids, such as water.

TOP

**V**

Vertical extinction coefficient:
A measure of the ability of a particular water sample to exponentially attenuate(decrease) light shining on it. It is the constant **k** in the equation i (z) = i(0)* exp(-k*z) where z is any depth in meters, and "**exp**" refers to the base "**e" the** for the exponential.

TOP

**W**

Water column: A conceptual column of water from lake surface to bottom sediments.

TOP

Water Density: The ratio of water's mass to its volume; water is the most dense at four degrees Celsius.

Watershed: All land and water areas that drain toward a river or lake; also called Drainage Basin or Water Basin.

Watershed area: lake surface area ratio:
$A_w$:$a_0$ ; a measure relating to how much land area is there relative to lake area in a given watershed.

Weathering: The mechanical and chemical breakdown and dissolution of rocks.

Wet deposition: Precipation of all kinds.

Winkler Titration Kit:
A "wet" chemistry analytical procedure used to determine the oxygen content of water via the Winkler reaction.

Winterkill: A sudden and dramatic mass fish death caused by insufficient oxygen in a frozen lake.

**X**

TOP

**Y**

TOP

TOP

**Z**

Zooplankton: The animal portion of the living particles in water that freely float in open water, eat bacteria, algae, detritus and sometimes other zooplankton and are in turn eaten by planktivorous fish.

TOP