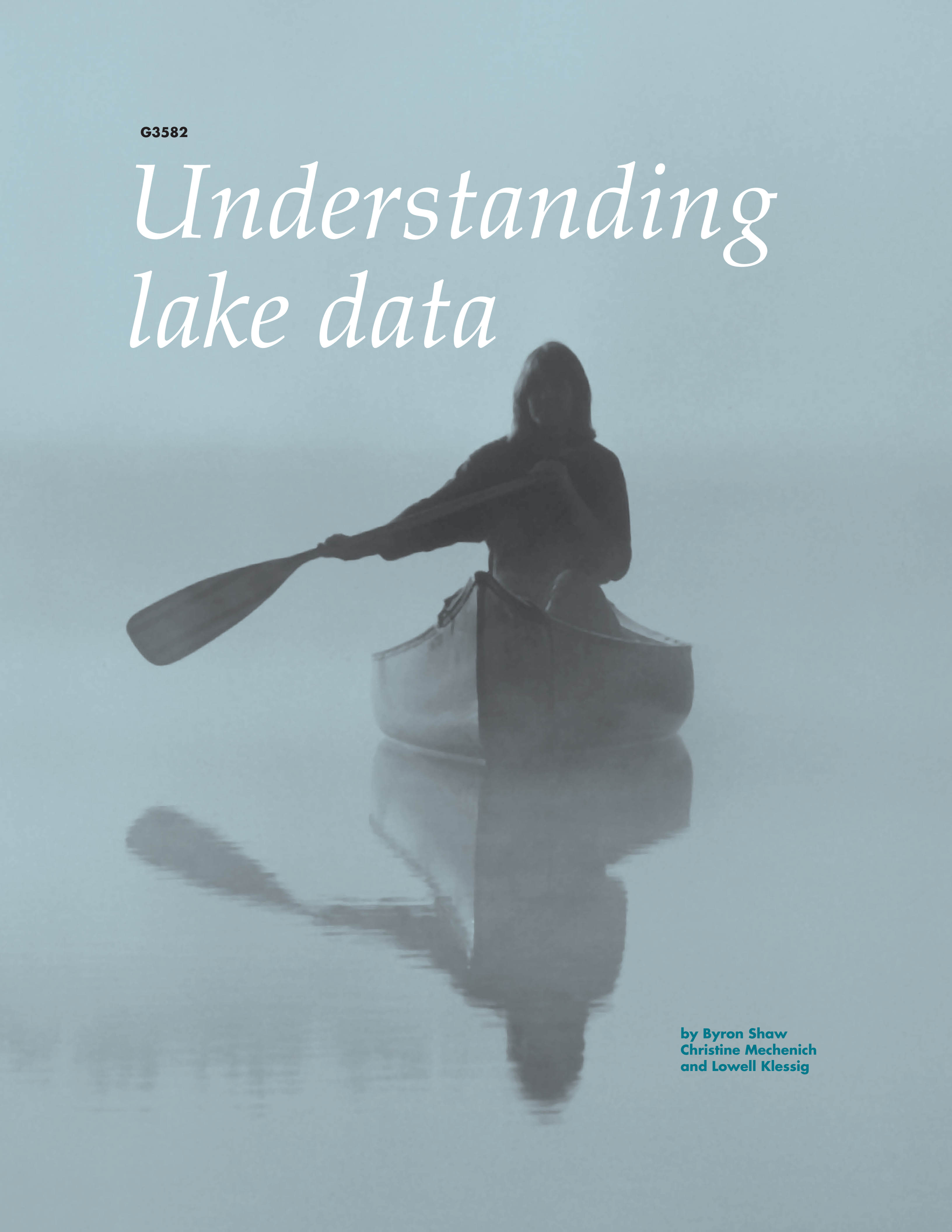
G3582

Understanding lake data



by Byron Shaw
Christine Mechenich
and Lowell Klessig

CONTENTS

PHYSICAL CHARACTERISTICS 3
- Lake types 3
- Water source 3
- Mixing and stratification 4
- Retention time 5
- Drainage basin/lake area ratio (DB:LA) 5
- Lake water levels 6
- Water clarity 6
- Trophic state 7

CHEMICAL PROPERTIES 8
- Phosphorus 8
- Nitrogen 9
- Chloride 11
- Sulfate 11
- Sodium and potassium 12

DISSOLVED GASES 12
- Oxygen 12
- Carbon dioxide 13
- Nitrogen gas 14
- Other gases 14

CARBONATE SYSTEMS 14
- pH—acidity 14
- Alkalinity and hardness 15
- Alkalinity—a lake's buffer against acid rain ..15
- Marl deposits 16

SUMMARY 16

BIBLIOGRAPHY AND ADDITIONAL REFERENCES 16

GLOSSARY 17

THIS GUIDE WAS WRITTEN to help people understand information about lake water quality and to interpret lake data. Each lake possesses a unique "personality," or set of physical and chemical characteristics which may change over time. Lakes exhibit chemical changes on a daily basis while other changes, such as plant and algae growth, occur seasonally.

Year-to-year changes in a lake are common because surface runoff, groundwater inflow, precipitation, temperature and sunlight vary. For example, the loss of dissolved oxygen can destroy a lake's fish population, but may improve water clarity. Eliminating fish allows algae-eating zooplankton (microscopic animals) to increase, which might reduce algae populations. Because of changes like these, data from several years are needed to show whether a lake is experiencing significant changes in water quality.

This publication explains the physical and chemical compositions of different types of lakes. It covers lakes' nutrient status (trophic condition), and their susceptibility to acid rain. It discusses toxic metals that accumulate in fish and tells how to use general water chemistry principles to document potential changes in water quality. A glossary of technical terms is included to help the reader understand the language used in the study of lakes (limnology).

PHYSICAL CHARACTERISTICS

Lake types

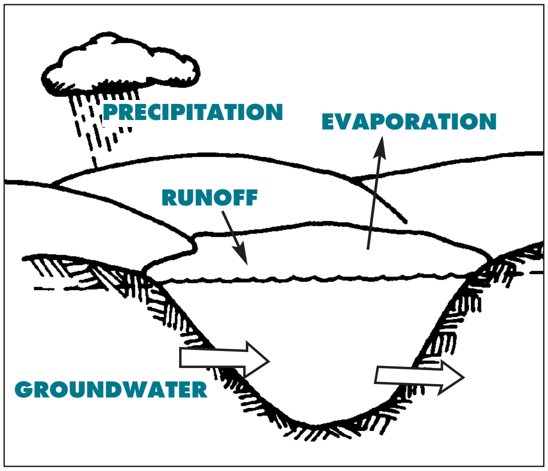
Lakes are often classified into four types based on water source and type of outflow (see Figure 1 below).

Water source

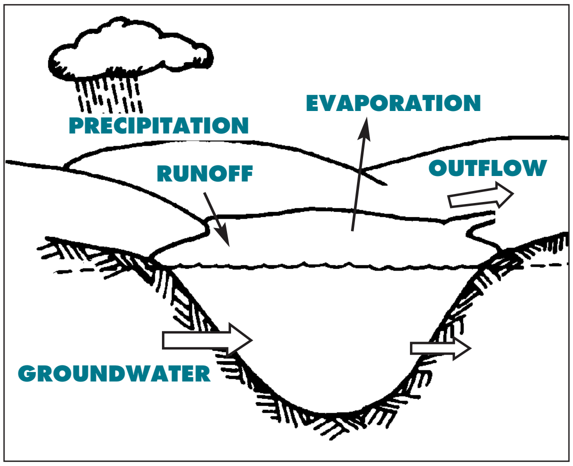
The source of a lake's water supply is very important in determining its water quality and in choosing management practices to protect that quality. If precipitation is the major water source, the lake will be acidic, low in nutrients, and susceptible to acid rain. (This includes many seepage lakes.)

If groundwater is the major water source, the lake is usually well buffered against acid rain and contains low to moderate amounts of nutrients. (This includes all groundwater drainage lakes and some seepage lakes.) Local septic systems or other groundwater contamination could cause problems. Water exchange is fairly slow.

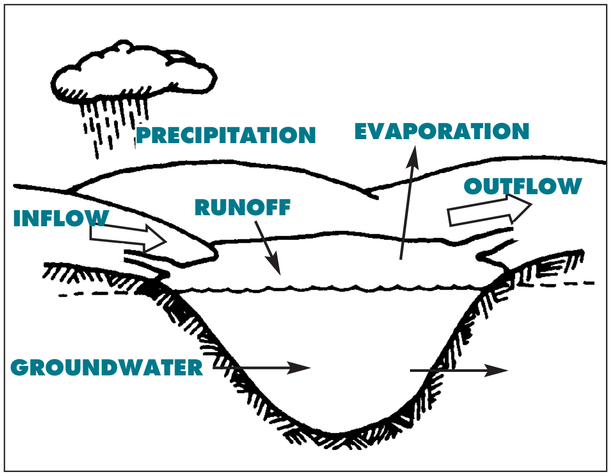
◀ **FIGURE 1.**
LAKE TYPES.
MAJOR WATER INPUTS AND OUTFLOWS OF DIFFERENT LAKE TYPES. (LARGE ARROWS INDICATE HEAVY WATER FLOW.)



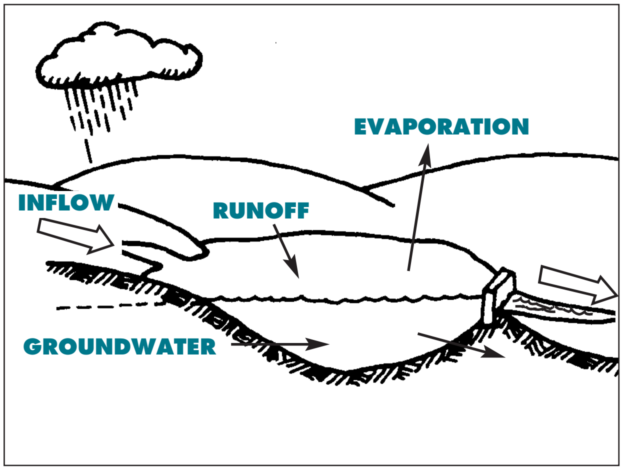
1. SEEPAGE LAKE—a natural lake fed by precipitation, limited runoff and groundwater. It does not have a stream outlet.



2. GROUNDWATER DRAINAGE LAKE—a natural lake fed by groundwater, precipitation and limited runoff. It has a stream outlet.



3. DRAINAGE LAKE—a lake fed by streams, groundwater, precipitation and runoff and drained by a stream.



4. IMPOUNDMENT—a manmade lake created by damming a stream. An impoundment is also drained by a stream.

If streams are the major source of lake water, nutrient levels are often high and water exchange takes place more rapidly. These lakes have the most variable water quality depending on the amount of runoff and human activity in the watershed (land that drains toward the lake).

Managing the watershed to control nutrients and soil that enter the lake is essential to protecting water quality. Controlling water that runs from the land's surface into the lake is important for drainage lakes and impoundments, and some seepage and groundwater lakes. Protecting groundwater quality is particularly important for seepage and groundwater drainage lakes.

Watershed management becomes especially critical in impoundment lakes. If a stream is dammed the natural movement of water will be restricted, causing soil and nutrients to collect in the impoundment.

Lake managers measure inflow and outflow to determine a lake's water budget. As shown in the formula below, a water budget consists of several elements. Precipitation in Wisconsin averages 30 inches per year. Evaporation depends on the type of summer weather, but is usually about 21 inches. Groundwater flow is more difficult to measure, but can be estimated .

The water budget can be expressed in percent or in volume. A typical water budget for a drainage lake follows:

30%	+	10%	+	60%	=	5%	+	11%	+	84%
Groundwater inflow		Precipitation		Surface runoff		Groundwater outflow		Evaporation		Stream outlet

Mixing and stratification

A lake's water quality and ability to support fish are affected by the extent to which the water mixes. The depth, size and shape of a lake are the most important factors influencing mixing, though climate, lakeshore topography, inflow from streams, and vegetation also play a role.

Water density peaks at 39°F. It is lighter at both warmer and colder temperatures. Variations in density caused by different temperatures can prevent warm and cold water from mixing.

When lake ice melts in early spring, the temperature and density of lake water will be similar from top to bottom. The uniform water density allows the lake to mix completely, recharging the bottom water with oxygen and bringing nutrients up to the surface. This is called **spring overturn.** As surface water warms in the spring, it loses density. Wind and waves can circulate the warmed water only 20 to 30 feet deep, so deeper areas are not mixed. If the lake is shallow (less than 20 feet), however, the water may stay completely mixed all summer.

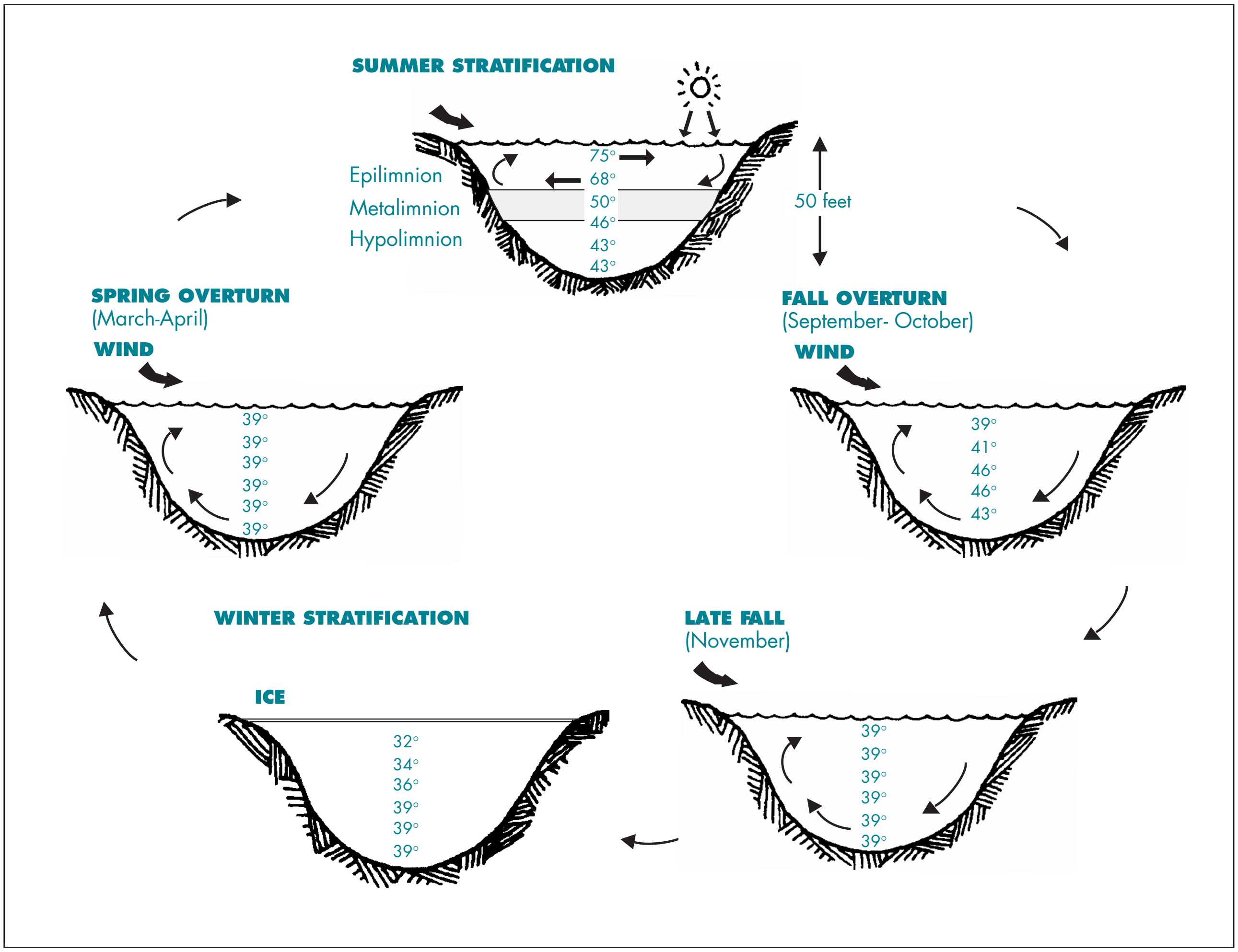
During the summer, lakes more than 20 feet deep usually experience a layering called **stratification.** Depending on their shape, small lakes can stratify even if they are less than 20 feet deep. In larger lakes, the wind may continuously mix the water to a depth of 30 feet or more. Lake shallows do not form layers, though deeper areas may stratify.

Summer stratification, as shown in Figure 2, divides a lake into three zones: **epilimnion** (warm surface layer), **thermocline** or **metalimnion** (transition zone between warm and cold water), and **hypolimnion** (cold bottom water). Stratification traps nutrients released from bottom sediments in the hypolimnion. In the fall, the surface cools until the water temperature evens out from top to bottom, which again allows mixing (**fall overturn**). A fall algae bloom often appears when nutrients mix and rise to the surface.

Winter stratification, with a temperature difference of only 7°F (39° on the lake bottom versus 32° right below the ice), remains stable because the ice cover prevents wind from mixing the water.

The lake's orientation to prevailing winds can affect the amount of mixing that occurs. Some small, deep lakes may not undergo complete mixing in the spring or fall if there is not enough wind action. The mixing that takes place in the bays of a large lake will more closely resemble that of a small lake because the irregular shoreline blocks the wind .

Because mixing distributes oxygen throughout a lake, lakes that don't mix may have low oxygen levels in the hypolimnion, which can harm fish. Some fish species require lake stratification. The cold water in the hypolimnion (bottom) can hold more oxygen than warmer water in the epilimnion (top) and thus provide a summer refuge for cold water fish such as trout. But if the lake produces too much algae, which fall into the hypolimnion to decay, oxygen becomes depleted. The steep temperature gradient of the metalimnion prevents any surface water with dissolved atmospheric oxygen from reaching the bottom waters.



▲**FIGURE 2.** Annual temperature cycles in stratified lakes.

Retention time

The average length of time water remains in a lake is called the **retention time** or **flushing rate.** The lake's size, water source, and watershed size primarily determine the retention time.

Rapid water exchange rates allow nutrients to be flushed out of the lake quickly. Such lakes respond best to management practices that decrease nutrient input. Impoundments, small drainage lakes, and lakes with large volumes of groundwater inflow and stream outlets (groundwater drainage lakes) fit this category.

Longer retention times occur in seepage lakes with no surface outlets. Average retention times range from several days for some small impoundments to many years for large seepage lakes. Lake Superior has the longest retention time of Wisconsin lakes—500 years!

Nutrients that accumulate over a number of years in lakes with long retention times can be recycled annually with spring and fall mixing. Reserve nutrients in lake sediments can continue to recirculate, even after the source of nutrients in the watershed has been controlled. Thus, the effects of watershed protection may not be apparent for a number of years. Nevertheless, lakes with long retention times tend to have the best water quality as shown by the lower levels of the plant nutrient phosphorus in Table 1. Better water quality results from both their greater depth and relatively smaller watersheds.

Drainage basin/lake area ratio (DB:LA)

The size of the watershed (drainage basin) feeding a lake relative to the lake's size (area) is an important factor in determining the amount of nutrients in a lake. Table 1 shows this relationship for a sample of Wisconsin lakes.

Lakes with relatively large drainage basins usually have significant surface water inflow. This inflow carries more nutrients and sediments into these drainage lakes or impoundments. By definition, seepage lakes have small drainage basins, more groundwater flow, and fewer nutrients from runoff. Groundwater drainage lakes typically have an intermediate-sized drainage basin.

Table 1 shows the relationship between retention time and the drainage basin:lake area ratio. Low ratio lakes (small drainage basin and large lake area) have high retention times while high-ratio lakes have short retention times. Drainage basin:lake area ratios can be used to estimate a lake's retention time.

Lake water levels

Lake levels fluctuate naturally due to precipitation which varies widely from season to season and year to year. While some lakes with stream inflows show the effect of rainfall almost immediately, others, such as seepage lakes, do not reflect changes in precipitation for months. For example, heavy autumn rains often cause water levels to rise in the winter when rain enters the lake as groundwater.

Water level fluctuations significantly affect lake water's quality. Low levels may cause stressful conditions for fish and increase the number of nuisance aquatic plants. High water levels can boost the amount of nutrients from runoff and flooded lakeshore soils. Older septic systems, located near lakes, may flood when groundwater levels are high. Yet another consequence of fluctuating water levels is shoreline erosion.

Water clarity

Strictly speaking, clarity is not a chemical property of lake water. More accurately, it is an indicator or *measure* of water quality related to chemical and physical properties.

Water clarity has two main components: true color (materials *dissolved* in the water) and turbidity (materials *suspended* in the water such as algae and silt). The algae population is usually the largest and most variable component.

Water clarity often indicates a lake's overall water quality, especially the amount of algae present. Algae are natural and essential, but too much of the wrong kind can cause problems. Table 2 shows the inverse relationship between **Secchi disc depth** (a measure of clarity) and **chlorophyll *a*** (a measure of algae) for different types of lakes.

Secchi disc readings are taken using an 8-inch diameter weighted disc painted black and white. The disc is lowered over the downwind, shaded side of the boat until it just disappears from sight, then raised until it is just visible. The average of the two depths is recorded. Secchi disc readings should be taken on calm, sunny days between 10 a.m. and 2 p.m. since cloud cover, waves, and the sun's angle can affect the reading.

TABLE 2. Water clarity index.

Water clarity	Secchi depth (ft.)
Very poor	3
Poor	5
Fair	7
Good	10
Very good	20
Excellent	32

TABLE 1. Several characteristics of lakes with different retention times. (*Adapted from Lillie and Mason, 1983.*)

Retention time in days	0-14	15-60	61-180	181-365	366-730	>730
Mean depth (ft.)	6	8	11	11	13	23
Max. depth (ft.)	16	21	25	27	35	57
Mean total phosphorus (µg/l)*	94	85	56	48	33	25
Mean DB:LA ratio**	1166	142	42	15	8	6

*Summer values; µg/l = micrograms per liter or parts per billion
**DB:LA = Drainage basin/lake area

Secchi disc values vary throughout the summer as algal populations increase and decrease. Measuring several sites may be useful in some lakes, depending upon the uniformity of the lake. Year to year changes result from weather and nutrient accumulation. *Weekly or biweekly Secchi records (April-November) over a number of years provide an excellent and inexpensive way to document long-term changes in water clarity.*

The color of lake water reflects the type and amount of dissolved organic chemicals it contains. Measured and reported as standard color units on filtered samples, color's main significance is aesthetic. Color may also reduce light penetration, slowing weed and algae growth. Many lakes possess natural, tan-colored compounds (mainly humic and tannic acids) from decomposing plant material in the watershed. Brown water can result from bogs draining into a lake. Before or during decomposition, algae may impart a green, brown or even reddish color to the water.

Color can affect the Secchi disc reading. Table 3 lists color values associated with varying degrees of water color.

Another measure of water clarity, **turbidity** is caused by particles of matter rather than dissolved organic compounds. Suspended particles dissipate light, which affects the depth at which plants can grow.

TABLE 3. Water color. *(Adapted from Lillie and Mason, 1983.)*

0–40 units	Low
40-100 units	Medium
>100 units	High

Turbidity affects the aesthetic quality of water. Lakes receiving runoff from silt or clay soils often possess high turbidities. These values vary widely with the nature of the seasonal runoff.

Suspended plants and animals also produce turbidity. Many small organisms have a greater effect than a few large ones. Turbidity caused by algae is the most common reason for low Secchi disc readings.

Trophic state

Trophic state is another indicator of water quality. Lakes can be divided into three categories based on trophic state—oligotrophic, mesotrophic, and eutrophic. These categories reflect a lake's nutrient and clarity levels.

Oligotrophic lakes are generally clear, deep and free of weeds or large algae blooms. Though beautiful, they are low in nutrients and do not support large fish populations. However, oligotrophic lakes often develop a food chain capable of sustaining a very desirable fishery of large game fish.

Eutrophic lakes are high in nutrients and support a large biomass (all the plants and animals living in a lake). They are usually either weedy or subject to frequent algae blooms, or both. Eutrophic lakes often support large fish populations, but are also susceptible to oxygen depletion. Small, shallow, eutrophic lakes are especially vulnerable to winterkill which can reduce the number and variety of fish. Rough fish are commonly found in eutrophic lakes.

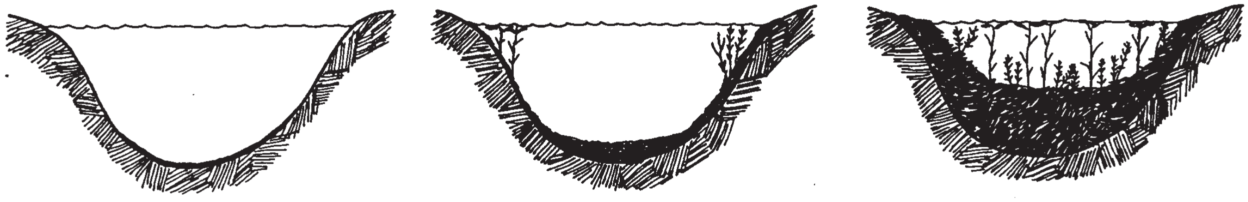
Mesotrophic lakes lie between the oligotrophic and eutrophic stages. Devoid of oxygen in late summer, their hypolimnions limit cold water fish and cause phosphorus cycling from sediments.

A natural aging process occurs in all lakes, causing them to change from oligotrophic to

The Wisconsin Department of Natural Resources (DNR) operates a "Self-Help Monitoring Program" for lakes. Local volunteers take Secchi disc and other readings and the DNR provides computer data storage and annual reports. For more information, contact a district DNR office or write to:

DNR Lake Management Program
WRM/2
P.O. Box 7921
Madison, WI 53707.

FIGURE 3. Lake aging process.



OLIGOTROPHIC
- Clear water, low productivity
- Very desirable fishery of large game fish

MESOTROPHIC
- Increased production
- Accumulated organic matter
- Occasional algal bloom
- Good fishery

EUTROPHIC
- Very productive
- May experience oxygen depletion
- Rough fish common

CONCENTRATION UNITS express the amount of a chemical dissolved in water. The most common ways chemical data is expressed is in milligrams per liter (mg/l) and micrograms per liter (µg/l). One milligram per liter is equal to one part per million (ppm). To convert micrograms per liter (µg/l) to milligrams per liter (mg/l), divide by 1000 (e.g., 30 µg/l = 0.03 mg/l). To convert milligrams per liter (mg/l) to micrograms per liter (µg/l), multiply by 1000 (e.g., 0.5 mg/l = 500 µg/l). Microequivalents per liter (µeq/l) is also sometimes used, especially for alkalinity. It is calculated by dividing the equivalent weight of the compound by 1000 and then dividing that number into the milligrams per liter.

TABLE 4. Trophic classification of Wisconsin lakes based on chlorophyll *a*, water clarity measurements, and total phosphorus values. (*Adapted from Lillie and Mason, 1983.*)

Trophic class	**Total phosphorus** µg/l	**Chlorophyll *a*** µg/l	**Secchi Disc** feet
Oligotrophic	3	2	12
	10	5	8
Mesotrophic	18	8	6
	27	10	6
Eutrophic	30	11	5
	50	15	4

eutrophic over time, and eventually to fill in (Figure 3). People can accelerate the eutrophication process by allowing nutrients from agriculture, lawn fertilizers, streets, septic systems, and urban storm drains to enter lakes.

In nutrient-poor areas, the aging process may lead instead to dystrophic and bog lakes which are highly colored, acid, and not as productive as eutrophic lakes.

Researchers use various methods to calculate the trophic state of lakes. Common characteristics used to make the determination are:

- total phosphorus concentration (important for algae growth)
- chlorophyll *a* concentration (a measure of the amount of algae present)
- Secchi disc readings (an indicator of water clarity).

The trophic states associated with these three measures are shown in Table 4. Clearly, low levels of phosphorus are associated with low levels of algae (chlorophyll *a*), which are associated with high Secchi disc readings.

CHEMICAL PROPERTIES

Phosphorus

Phosphorus promotes excessive aquatic plant growth. In more than 80% of Wisconsin's lakes, phosphorus is the key nutrient affecting the amount of algae and weed growth.

Phosphorus originates from a variety of sources, many of which are related to human activities. Major sources include human and animal wastes, soil erosion, detergents, septic systems and runoff from farmland or lawns.

Phosphorus provokes complex reactions in lakes. An analysis of phosphorus often includes both *soluble reactive phosphorus* and *total phosphorus*.

Soluble reactive phosphorus dissolves in the water and readily aids plant growth. Its concentration varies widely in most lakes over short periods of time as plants take it up and release it.

Total phosphorus is considered a better indicator of a lake's nutrient status because its levels remain more stable than soluble reactive phosphorus. Total phosphorus includes soluble phosphorus and the phosphorus in plant and animal fragments suspended in lake water.

Ideally, soluble reactive phosphorus concentrations should be 10 µg/l (micrograms

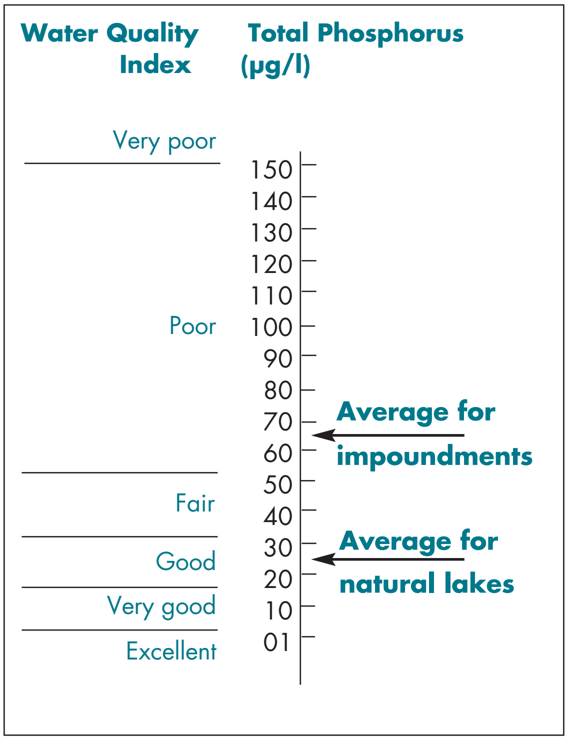


FIGURE 4. Total phosphorus concentrations for Wisconsin's natural lakes and impoundments. (*Adapted from Lillie and Mason, 1983.*)

per liter) or less at spring turnover to prevent summer algae blooms. A concentration of 10 micrograms per liter is equal to 10 parts per billion (ppb) or 0.01 milligrams per liter (mg/l). A concentration of total phosphorus below 20 μg/l for lakes and 30 μg/l for impoundments should be maintained to prevent nuisance algal blooms (Figure 4).

Phosphorus does not dissolve easily in water. It forms insoluble precipitates (particles) with calcium, iron, and aluminum. In hard water areas of Wisconsin, where limestone is dissolved in the water, marl (calcium carbonate) precipitates and falls to the bottom. Marl formations absorb phosphorus, reducing its overall concentration as well as algae growth. Aquatic plants with roots in the marl bottom still get phosphorus from sediments. Hard water lakes often have clear water, but may be weedy.

Iron also forms sediment particles that store phosphorus—but only if oxygen is present. When lakes lose oxygen in winter or when the deep water (hypolimnion) loses oxygen in summer, iron and phosphorus again dissolve in water. Strong summer winds or spring and fall turnover may mix iron and phosphorus with surface water. For this reason, algae blooms may still appear in lakes for many years even if phosphorus inputs are controlled.

Figure 5 shows the increase in total phosphorus for stratified lakes following fall turnover. Since shallow and windswept lakes that stay mixed do not experience oxygen depletion, they have the highest total phosphorus levels in summer following spring turnover and early summer runoff.

The amount of iron that might react with phosphorus varies widely in Wisconsin lakes. Lakes in the southern part of the state are often low in iron due to a higher pH and more sulfur, both of which limit iron solubility. This in turn affects whether phosphorus mixed into lakes during fall turnover precipitates or stays in solution during the winter.

Lakes with low iron and insufficient calcium to form marl are most likely to retain phosphorus in solution once it is released from sediments or brought in from external sources. These lakes are the most vulnerable to naturally occurring phosphorus or to phosphorus loading from human activities because the phosphorus remains dissolved in the water—not pulled down into the sediments. Such lakes often respond with greater algae problems.

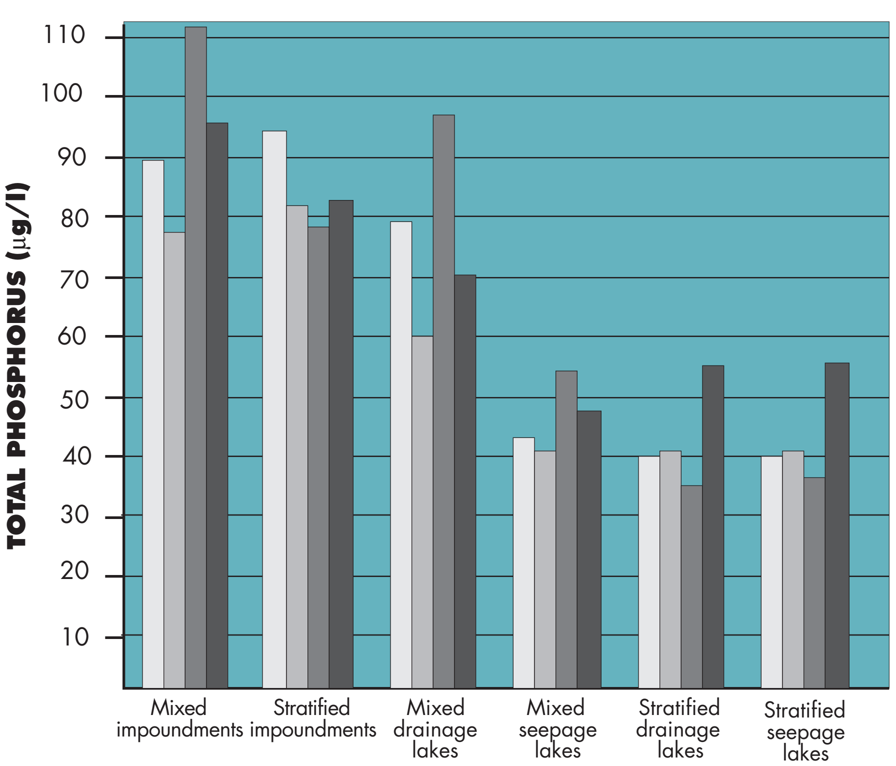
Figure 5 also shows that impoundments have the highest phosphorus levels. Mixed drainage lakes sustain intermediate levels, while seepage and stratified drainage lakes have the lowest. Even with the potential for internal phosphorus cycling caused by oxygen depletion, deep stratified lakes tend to have lower phosphorus levels than their mixed counterparts.

Phosphorus control has been attempted in some lakes by using alum (aluminum sulfate) to precipitate phosphorus. Sewage treatment plants use the same process to remove phosphorus. Aluminum phosphate precipitate, unlike iron phosphate, is not redissolved when oxygen is depleted.

Nitrogen

Nitrogen is second only to phosphorus as an important nutrient for plant and algae growth. A lake's nitrogen sources vary widely. Nitrogen compounds often exceed 0.5 mg/l in rainfall, so

▼**FIGURE 5.** Seasonal total phosphorus averages for six lake types by season. (*Adapted from Lillie and Mason, 1983*).



that precipitation may be the main nitrogen source for seepage and some drainage lakes.

In most cases, however, the amount of nitrogen in lake water corresponds to local land use. Nitrogen may come from fertilizer and animal wastes on agricultural lands, human waste from sewage treatment plants or septic systems, and lawn fertilizers used on lakeshore property. Nitrogen may enter a lake from surface runoff or groundwater sources.

Nitrogen exists in lakes in several forms. Analysis usually includes nitrate (NO_3^-) plus nitrite (NO_2^-), ammonium (NH_4^+), and organic plus ammonium (Kjeldahl nitrogen). Total nitrogen is calculated by adding nitrate and nitrite to Kjeldahl nitrogen. Organic nitrogen is often referred to as biomass nitrogen.

Nitrogen does not occur naturally in soil minerals, but is a major component of all organic (plant and animal) matter. Decomposing organic matter releases ammonia, which is converted to nitrate if oxygen is present. This conversion occurs more rapidly at higher water temperatures. All inorganic forms of nitrogen (NO_3^-, NO_2^- and NH_4^+) can be used by aquatic plants and algae. If these inorganic forms of nitrogen exceed 0.3 mg/l (as N) in spring, there is sufficient nitrogen to support summer algae blooms.

Figure 6 shows the various ways that nitrogen enters and cycles within a lake. Sediments clearly cause nitrogen to undergo a number of changes. Nitrogen recycled back into overlying water at spring and fall turnover will often increase ammonia levels in samples taken during turnover. Nitrogen can be lost from the lake to the atmosphere by denitrification as shown in the figure. This only occurs if oxygen is depleted, allowing nitrate to be converted back to nitrogen gas.

In about 10% of Wisconsin's lakes, nitrogen (rather than phosphorus) limits algae growth. This occurs when the ratio of total nitrogen to total phosphorus is less than 10:1. Values between 10:1 and 15:1 are considered transitional, while lakes with values greater than 15:1 are considered phosphorus limited—algae growth is controlled by the amount of phosphorus.

Low nitrogen levels do not guarantee limited algae growth in the same way low phosphorus levels do. Nuisance blue-green algae blooms are often associated with lakes that have low nitrogen to phosphorus (N:P) ratios. These algae use atmospheric nitrogen gas (N_2) dissolved in lake waters as a nitrogen source; other more desirable types of algae and plants depend on the inorganic nitrate and ammonium forms of nitrogen.

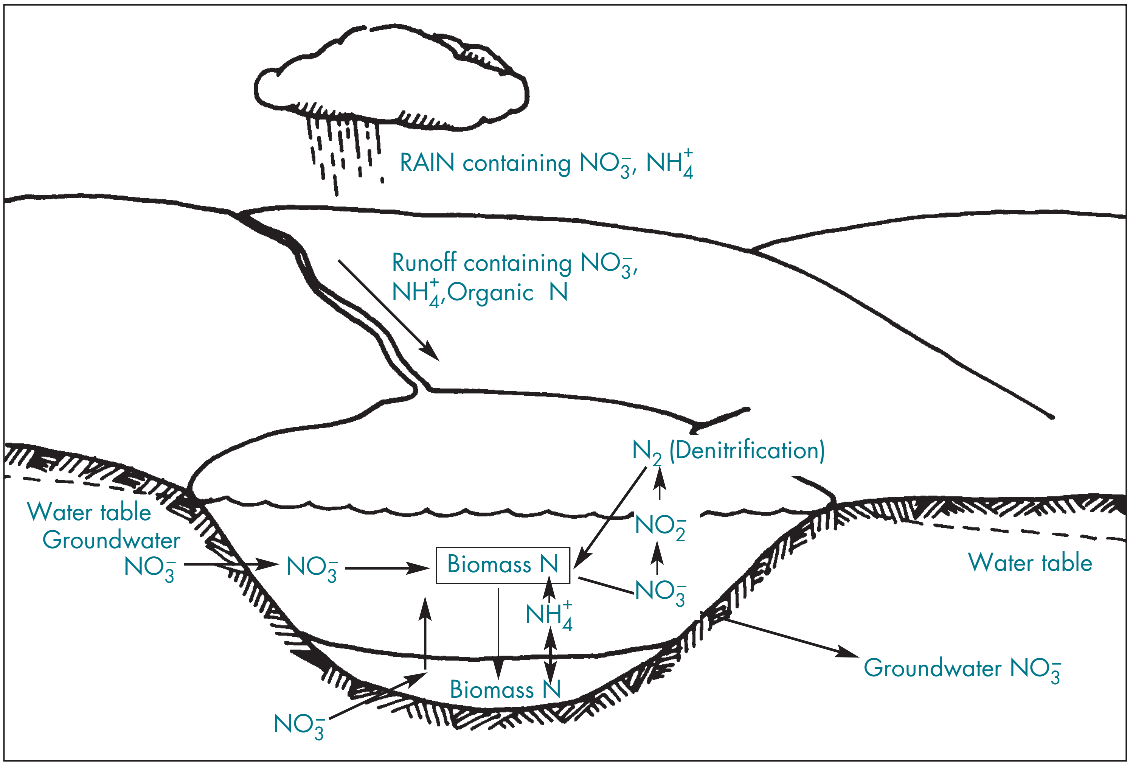


FIGURE 6. Sources and cycling of nitrogen in lake.

Larger plants also need nitrogen and may depend on spring runoff for septic systems to recharge the sediments with nitrogen. Growth of Eurasian milfoil has been correlated with such fertilization of the sediment.

Chloride

The presence of chloride (Cl^-) where it does not occur naturally indicates possible water pollution. Chloride does not affect plant and algae growth and is not toxic to aquatic organisms at most of the levels found in Wisconsin. Chloride is not common in Wisconsin soils, rocks or minerals, except in areas with limestone deposits. Figure 7 shows the geographic distribution of chloride in Wisconsin lakes.

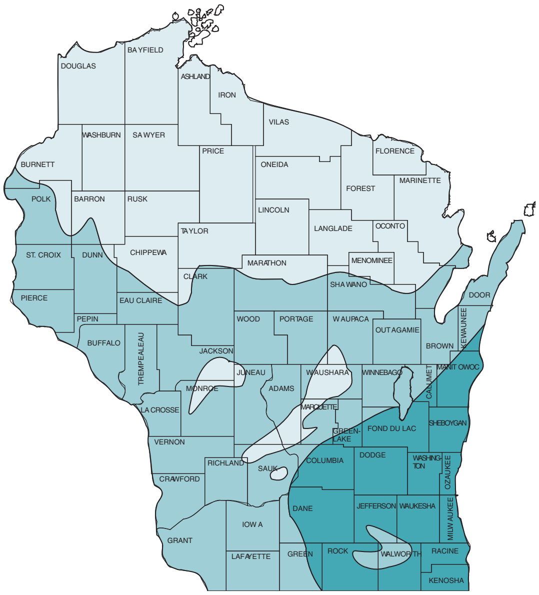
Sources of chloride include septic systems (chloride values of 50 to 100 mg/l are common in septic tank effluent), animal waste, potash fertilizer (potash = potassium chloride), and drainage from road-salting chemicals. Increases in chloride, either seasonally or over time, can mean that one or more of these sources is affecting the lake.

An increase in chloride from human or animal waste suggests that other nutrients are also entering the lake. Higher chloride concentrations from spring to fall may be the effect of lawn fertilizer runoff or septic systems during heavy use by summer residents. Higher values in spring after the snow melts may signify runoff from drainage basins or highways as a major source of chloride. Since lakes vary in their natural chloride content, it is important to have background data or a long term database to document changes.

Sulfate

Sulfate in lake water is primarily related to the types of minerals found in the watershed and to acid rain. Industries and utilities that burn coal release sulfur compounds into the atmosphere that are carried into lakes by rainfall. In Wisconsin, the highest lake sulfate levels are found in the southeast portion of the state (Figure 8), where mineral sources and acid rain are more common.

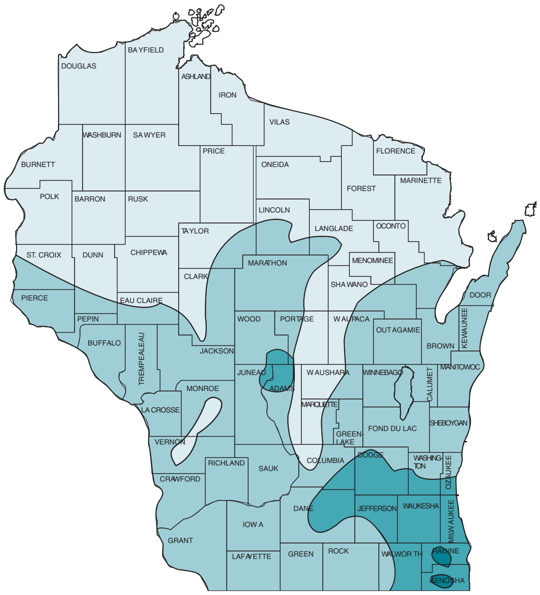
In water depleted of oxygen (anaerobic water), sulfate can be reduced to hydrogen sulfide (H_2S). Hydrogen sulfide gas smells like rotten eggs and



CHLORIDE CONCENTRATIONS (mg/l)

☐ >10 ▨ >3 - 10 ■ <3

FIGURE 7. Generalized distribution gradients of chloride in the surface waters of Wisconsin lakes. (*Adapted from Lillie and Mason, 1983.*)



SULFATE CONCENTRATIONS (mg/l)

■ >40 ▨ 20 - 40 ▨ 10 - 20 ☐ <10

FIGURE 8. Generalized distribution gradients of sulfate in the surface waters of Wisconsin lakes. (*Adapted from Lillie and Mason, 1983.*)

is toxic to aquatic organisms. The sulfide ion ($S^{=}$) produced under these conditions can also affect the amount of metal ions in the lake since most metals, including iron and mercury, form insoluble sulfide precipitates. As a result of the high sulfate content (Figure 8), iron often exists in lower concentrations in southern lakes because it precipitates and settles out in sediments as iron sulfide.

Sodium and potassium

Since natural levels of sodium and potassium ions in soil and water are very low, their presence may indicate lake pollution caused by human activities. Sodium is often associated with chloride. It finds its way into lakes from road salt, fertilizers, and human and animal waste. Potassium is the key component of commonly-used potash fertilizer, and is abundant in animal waste.

Soils retain sodium and potassium to a greater degree than chloride or nitrate; therefore, sodium and potassium are not as useful as pollution indicators. Increasing sodium and potassium values over time can mean there are long-term effects caused by pollution. Although not normally toxic themselves, these compounds strongly indicate possible contamination from more damaging compounds.

DISSOLVED GASES

Three gases found in the air—oxygen, carbon dioxide and nitrogen—are very important to lake ecosystems. Three main factors determine the amount of gases present in a lake:
- wind mixing that brings water into contact with the atmosphere;
- the biological activity that consumes or produces gases within a lake; and
- gas composition of groundwater and surface water entering a lake.

Oxygen

Oxygen (O_2) is undoubtedly the most important of the gases, since most aquatic organisms need it to survive. The solubility of oxygen and other gases depends on water temperature. The colder the water, the more gases it can hold. Boiling water removes all gases. Table 5 shows this effect for oxygen in typical lake water temperatures.

The values in Table 5 are found in lakes where continuous mixing occurs, allowing free oxygen exchange between water and the atmosphere. (The atmosphere contains about 21% oxygen.) However, the levels often differ greatly from the values found in Table 5 because mixing is seldom complete. Ice cover dramatically reduces mixing. In addition, biological reactions in the lake consume or release oxygen.

TABLE 5. Oxygen solubility at different temperatures.

Temperature °C	**°F**	**Oxygen solubility (mg/l)**
0	32	15
5	41	13
10	50	11
15	59	10
20	68	9
25	77	8

Oxygen is produced whenever green plants grow. Plants use carbon dioxide and water to produce simple sugars and oxygen, using sunlight as the energy source. Chlorophyll, the green pigment in plants, absorbs sunlight and serves as the oxygen production site. This process is called photosynthesis (Equation 1).

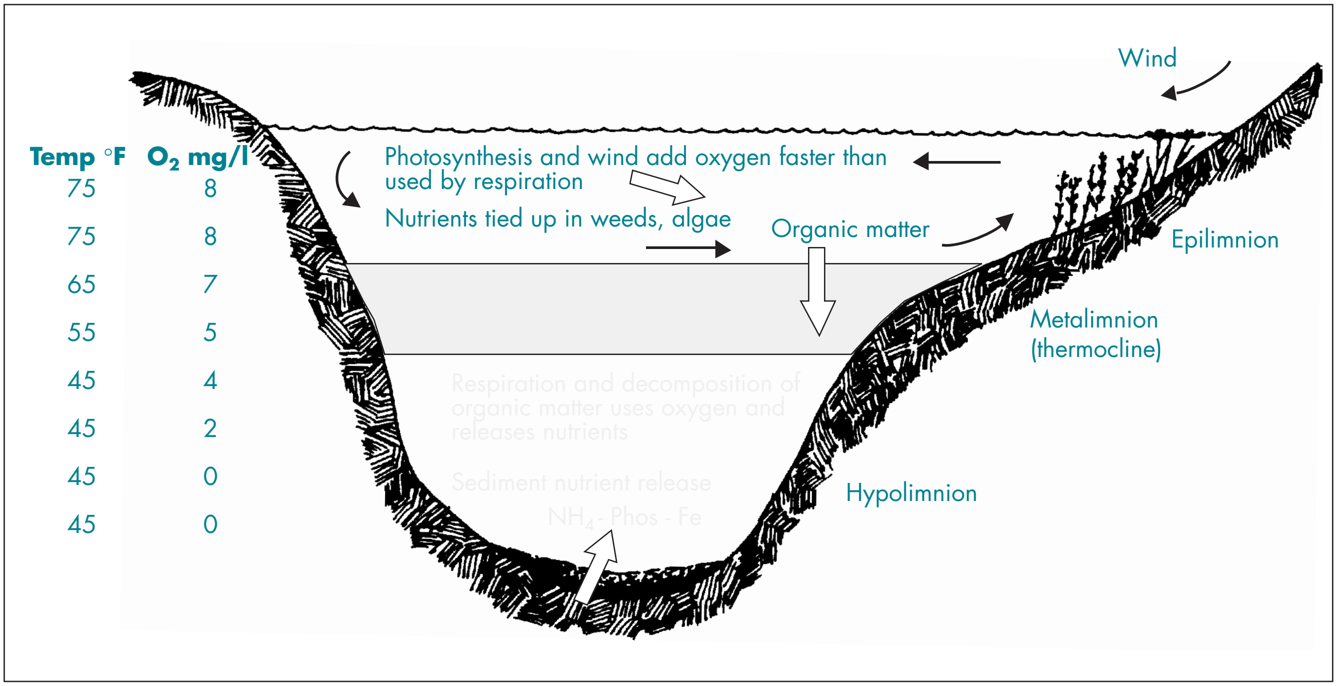
Photosynthesis occurs only during daylight hours and only to the depths where sunlight penetrates. The amount of photosynthesis depends on the quantity of plants, nutrient availability, and water temperature. Higher temperatures speed up the process. Plants and animals also constantly use oxygen to break down sugar and obtain energy by a process called **respiration**, basically the reverse of the photosynthetic reaction as shown in Equation 2. Burning fossil fuels or other organic matter produces the same chemical reactions shown for respiration, releasing more carbon dioxide (CO_2) to the atmosphere.

EQUATION 1. PHOTOSYNTHESIS.

$$\underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} \xrightarrow[\text{sunlight}]{\text{chlorophyll}} \underset{\text{sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

EQUATION 2. RESPIRATION.

$$\underset{\text{sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2} \longrightarrow \underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O}$$



▲ FIGURE 9. Typical oxygen and nutrient status of mesotrophic and eutrophic lakes after summer stratification.

The combination of these two reactions largely determines the amount of oxygen and carbon dioxide present in lakes at different times of day and at different depths. During daylight hours, it is not uncommon to find oxygen values in surface waters that exceed those listed in Table 5 (supersaturation), while at night or early morning before photosynthesis begins they may fall below those values. At lake depths below the reach of sunlight, the only reaction that occurs is oxygen-consuming respiration. The deep hypolimnic waters of productive lakes often experience oxygen depletion. Lakes with high biological activity undergo greater fluctuations than lakes with few plants and animals.

Typical oxygen levels in a productive lake following summer stratification are shown in Figure 9. Low oxygen levels in the hypolimnion mean that fish must live in the epilimnion and metalimnion. Fish (trout) that need high oxygen levels and cool water disappear from such lakes.

Winter oxygen depletion (winterkill) is a common problem in many shallow Wisconsin lakes. It happens in years when at least four inches of snow cover the lake, which prevents sunlight from reaching the water. All photosynthesis stops and plants begin to die and decompose. The extent of oxygen loss depends on the total amount of plant, algae and animal matter that decays. Drought increases the chance of winterkill by reducing the volume of water in the lake.

The water quality standard for oxygen in "warm water" lakes and streams is 5 mg/l. This is the minimum amount of oxygen needed for fish to survive and grow. The standard for trout waters is 7 mg/l. A smart angler would know that the lake in Figure 9 contains no trout and that it would be silly to fish for walleye in the deep holes in late summer. (See Equation 3.)

Carbon dioxide

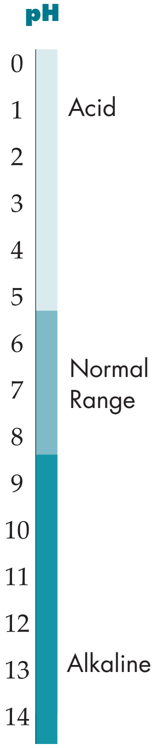
Carbon dioxide (CO_2), like oxygen, is affected by photosynthesis, respiration and contact with the atmosphere. It is also affected by a third reaction involving the amount of carbonate minerals, or alkalinity, present in lake water. Alkalinity is discussed in another section.

Carbon dioxide is essential to plant growth. It is the basic carbon source from which plants produce sugar and more complex organic matter. Values often fluctuate, being highest late at night and lowest early in the evening.

EQUATION 3. CARBON DIOXIDE REACTIONS.

CO_2	+	H_2O	$\longrightarrow$	H_2CO_3	$\Longleftrightarrow$	H^+	+	HCO_3^-
carbon dioxide		water		carbonic acid		hydrogen		bicarbonate

HCO_3^-	$\Longleftrightarrow$	H^+	+	$CO_3^=$
bicarbonate		hydrogen		carbonate



The measure of the hydrogen ion (acid) concentration in water is called pH. A pH of 7 is neutral. Values above 7 are alkaline or basic. Those below 7 are acidic. A change of 1 pH unit is a tenfold change in acid level. Iron may also be found in high levels in acidic water.

As carbon dioxide changes from morning to evening, so does water's pH, especially in low-alkaline, productive lakes.

When carbon dioxide reacts with water, it forms carbonic acid. This in turn affects the pH (acidity) of water. Acidity regulates the solubility of many minerals.

Nitrogen gas

Nitrogen comprises 78% of the gas in the atmosphere. Like other gases, it is more soluble at cooler temperatures. Most aquatic plants do not derive nutritional value from nitrogen gas, though blue-green algae is an exception. Nitrogen gas is important in lakes containing such algae.

Some bacteria convert nitrate back to nitrogen gas under anaerobic conditions when soluble organic matter is present. This reaction, called denitrification, is one of the main ways nitrogen is lost from certain lakes and some soils. This reaction is being investigated as a means of reducing pollution from septic systems.

Other gases

Under anaerobic conditions, hydrogen sulfide (H_2S) and methane gas (CH_4) may form and disperse into lake water from underlying sediments. Commonly referred to as "swamp gases," hydrogen sulfide and methane can be seen bubbling out when an oar pierces shallow, mucky sediments. Hydrogen sulfide (H_2S) smells like rotten eggs and is toxic to fish.

CARBONATE SYSTEMS

A lake's carbonate system contains a number of naturally-occurring chemicals that affect basic biological productivity, determine the lake's acid buffering capacity, and regulate the solubility of many toxic chemicals. The complex carbonate system undergoes constant change in response to biological activity, temperature change, sunlight, and even wave action. The previous discussion on oxygen and carbon dioxide introduced some of these reactions.

pH—acidity

An index of lake water's acid level, pH is an important component of the carbonate system. It is the negative logarithm of the hydrogen ion (H^+) concentration and therefore inversely related to the amount of hydrogen ion in the water. *Lower* pH waters have *more* hydrogen ions and are *more acidic* than higher pH waters.

A pH of 7 is neutral. Water with a pH of 7 has equal amounts of hydrogen ions and hydroxide ions (OH^-) from the natural separation of a tiny fraction of water molecules as shown in Equation 4. Pure, distilled water without any carbon dioxide has a pH value of 7.

EQUATION 4. SEPARATION OF WATER MOLECULES.

H_2O	<====>	H^+	+	OH^-
water		hydrogen ion		hydroxide ion

In Wisconsin, pH ranges from 4.5 in some acid bog lakes to 8.4 in hard water, marl lakes. For every 1.0 pH unit, the hydrogen ion concentration changes tenfold. Therefore, a lake with a pH of 6 is ten times more acid (ten times as much H^+) than a lake with a pH of 7. Water with a pH of 5 has 100 times as many hydrogen ions (H^+) as pH 7. Lakes with a pH of 8 have one-tenth as many hydrogen ions as water with a pH of 7.

While moderately low pH does not usually harm fish, the metals that become soluble under low pH can be important. In low pH water, aluminum, zinc and mercury concentrations increase if they are present in lake sediment or watershed soils. Table 6 shows the effects commonly found in lakes acidified by acid rain or experimentally acidified.

TABLE 6. Effects of acidity on fish species. *(Olszyk, 1980).*

Water pH	**Effects**
6.5	Walleye spawning inhibited
5.8	Lake trout spawning inhibited
5.5	Smallmouth bass disappear
5.2	Walleye, burbot, lake trout disappear
5.0	Spawning inhibited in many fish
4.7	Northern pike, white sucker, brown bullhead, pumpkinseed, sunfish and rock bass disappear
4.5	Perch spawning inhibited
3.5	Perch disappear
3.0	Toxic to all fish

TABLE 7. Solubility of aluminum at various pH levels.

pH	Aluminum (mg/l
4	4.8
5	.0048
6	.0000048
7	.0000000048
8	.0000000000048

Aluminum has been blamed for many of the problems associated with acidification of lakes and streams in certain areas of North America and Europe. Mercury levels in fish are high in acidified lakes. While not usually toxic to fish, high aluminum and mercury levels pose a health problem for loons, eagles, osprey and humans who eat chemically tainted fish. Some aquatic organisms appear unable to maintain calcium levels when pH is low, and consequently develop weak bones and shells.

Rainfall in Wisconsin varies from a pH of 4.4 in southeastern Wisconsin to nearly 5.0 in northwestern Wisconsin. Natural rainfall, exposed to CO_2 in the atmosphere, maintains a pH of 5.6. Thus, most fish could not reproduce in even the best rainfall if rainwater pH were not raised by the chemical buffering of the carbonate system in streams, lakes and the surrounding watershed.

Alkalinity and hardness

The carbonate system provides acid buffering through two alkaline compounds: bicarbonate (HCO_3^-) and carbonate ($CO_3^=$). These compounds are usually found with two hardness ions: calcium (Ca^{++}) and magnesium (Mg^{++}).

A lake's hardness and alkalinity are affected by the type of minerals in the soil and watershed bedrock, and by how much the lake water comes into contact with these minerals. If a lake gets groundwater from aquifers containing limestone minerals such as calcite ($CaCO_3$) and dolomite ($CaMgCO_3$), hardness and alkalinity (Table 8) will be high.

EQUATION 5. HARDNESS AND ALKALINITY.

$$\underset{\text{limestone}}{\mathrm{CaMg(CO_3)_2}} \text{ <====> } \underset{\text{(hardness)}}{\mathrm{Ca^{++} + Mg^{++}}} + \underset{\text{(alkalinity)}}{\mathrm{2CO_3^{=}}}$$

TABLE 8. Categorization of hardness by mg/l of calcium carbonate ($CaCO_3$).

Level of hardness	Total hardness as mg/l $CaCO_3$
soft	0-60 mg/l
moderately hard	61-120 mg/l
hard	121-180 mg/l
very hard	>180 mg/l

High levels of hardness (greater than 150 mg/l) and alkalinity can cause marl ($CaCO_3$) to precipitate out of the water. Hard water lakes tend to produce more fish and aquatic plants than soft water lakes. Such lakes are usually located in watersheds with fertile soils that add phosphorus to the lake. As a balancing mechanism, however, phosphorus precipitates with marl, thereby controlling algae blooms.

If the soils are sandy and composed of quartz or other insoluble minerals, or if direct rainfall is a major source of lake water, hardness and alkalinity will be low. This is the case in much of northern Wisconsin, where glacial deposits contain little limestone or other soluble minerals. Lakes with low amounts of alkalinity are more susceptible to acidification by acid rain and are generally unproductive.

Alkalinity—a lake's buffer against acid rain

Alkalinity acts to buffer lakes from the effects of acid rain because bicarbonate (HCO_3^-) and carbonate ($CO_3^=$) neutralize hydrogen ions from the acid inputs. Buffering occurs when excess hydrogen ions are removed from the water solution as shown in Equation 5. As the hydrogen ions are removed, pH goes up or halts its decline.

Alkalinity results are reported in two different ways: as milligrams per liter (mg/l) or microequivalents per liter (µeq/l). Table 9 lists

TABLE 9. Sensitivity of lakes to acid rain. (*Adapted from Taylor, 1984.*)

Sensitivity to acid rain	Alkalinity Values	
	ppm $CaCO_3$	µeq/l $CaCO_3$
High	0-2	0-39
Moderate	2-10	40-199
Low	10-25	200-499
Nonsensitive	>25	≥500

EQUATION 6. CARBONATE BUFFERING OF pH.

$CO_3^{=}$ + H^+ <====> HCO_3^-
carbonate hydrogen bicarbonate

HCO_3^- + H <====> H_2CO_3 <===> H_2O + CO_2
bicarbonate bicarbonate water carbon dioxide

alkalinity values by these two methods for different degrees of acid rain susceptibility based on 1 mg/l = 20 μeq/l.

As can be seen in Equation 6, alkalinity is also connected to the carbon dioxide reactions discussed earlier.

The amount of alkalinity largely determines a lake water's pH. Water with low alkalinity has low pH value (high acid) and all of its alkalinity in the bicarbonate (HCO_3^-) form. Highly alkaline lakes have pH values above 7 and some alkalinity in the carbonate form ($CO_3^{=}$). Each bicarbonate ion can neutralize one hydrogen (H^+) ion. The carbonate form is a better buffer, since it neutralizes two hydrogen ions.

Marl deposits

If the amount of carbonate ($CO_3^{=}$) is high enough, it will react with calcium in the water to form $CaCO_3$ (marl). Marl precipitates out, leaving a white substance in the sediment—sometimes even producing elaborate underwater formations. Marl can often be observed as a white precipitate on plant leaves in hard water lakes. Plants speed up marl deposition by using carbon dioxide (CO_2), which raises the pH and converts most alkalinity to the carbonate ($CO_3^{=}$) form. By precipitating phosphorus, marl formations help control algae growth in marl lakes.

SUMMARY

The primary purpose of this publication is to help people understand the elements affecting lake water quality. Another goal is to show the benefits of keeping a long-term record of water quality data. Such a record documents changes and helps to distinguish between a lake's natural variability and the impacts of human activity.

Lake water quality changes over time, so interpreting data based on one or two samples is not enough. Data collected during spring and fall overturn represent a lake's most uniform water quality conditions and are most valuable for comparing year-to-year changes. More extensive sampling provides additional information. *A long-term commitment to continue a modest sampling program is better than an extensive program which cannot be sustained because of a lack of funds or volunteers.*

The Environmental Task Force Program at the University of Wisconsin–Stevens Point provides laboratory analysis and long-term data storage of spring and fall turnover sample results.

If you have comments about this publication, would like to receive a free quarterly newsletter (*Lake Tides*), or simply want more information, contact your local University of Wisconsin–Extension or DNR office, or the Extension lake management specialists at the College of Natural Resources, University of Wisconsin, Stevens Point WI 54481.

BIBLIOGRAPHY AND ADDITIONAL REFERENCES

Bartsch, A.F. and J. Gakstatter. 1978. *Management decisions for lake systems based on a survey of trophic status, limiting nutrients, and nutrient loading*. U.S. EPA Amer.-Sov. Symp. on use of Math. Models to Optimize Water Qual. Manage., Washington D.C., U.S. EPA Rep. 600/9-78-024, pp. 372-96.

Klessig, L. L., N. W. Bouwes and D. A. Yanggen. 1986. *The Lake in Your Community.* UW-Extension, Madison. 24 pp.

Lillie, R. A. and J. W. Mason. 1983. *Limnological Characteristics of Wisconsin Lakes*. Wis. Dept. of Natural Resources Tech. Bull. 138, Madison.

Lundquist, J. B. 1975. *A Primer on Limnology*. Limnological Research Center, St. Paul, Univ. of Minnesota. 28 pp.

Moore, L. and K. Thornton, eds. 1988. *Lake and Reservoir Restoration Guidance Manual*. U.S. EPA, Washington DC.

Olszyk, D. 1980. *Biological Effects of Acid Rain*. Testimony, Wis. Public Service Commission Docket No. 05-EP-2. 5 pp.

Sawyer, C.N. 1947. *Fertilization of lakes by agricultural and urban drainage.* J. New Engl. Waterworks Assoc. 61(2):109-127.

Shaw, B.H. and N. Nimphius. 1985. *Acid Rain in Wisconsin: Understanding Measurements in Acid Rain Research* (#2). UW-Extension, Madison. 4 pp.

Stumm, W. and J. J. Morgan. 1981. *Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters.* 2nd Ed. Wiley-Interscience. 780 pp.

Taylor, J. W. ed. 1984. "The Acid Test." *Natural Resources Magazine*. Wis. Dept. of Natural Resources. 40 pp.

Wisconsin Dept. of Natural Resources Acid Deposition Task Force. 1980. *A Review of Acid Deposition in Wisconsin: Recommendations for Studying and Solving the Problem*. 46 pp.

GLOSSARY

Algae: One-celled (phytoplankton) or multicellular plants either suspended in water (plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll *a* (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake. Numerous species occur. Algae are an essential part of the lake ecosystem and provides the food base for most lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Alkalinity: A measure of the amount of carbonates, bicarbonates, and hydroxide present in water. Low alkalinity is the main indicator of susceptibility to acid rain. Increasing alkalinity is often related to increased algae productivity. Expressed as milligrams per liter (mg/l) of calcium carbonate ($CaCO_3$), or as microequivalents per liter (μeq/l).
20 μeq/l = 1 mg/l of $CaCO_3$.

Ammonia: A form of nitrogen found in organic materials and many fertilizers. It is the first form of nitrogen released when organic matter decays. It can be used by most aquatic plants and is therefore an important nutrient. It converts rapidly to nitrate (NO_3^-) if oxygen is present. The conversion rate is related to water temperature. Ammonia is toxic to fish at relatively low concentrations in pH-neutral or alkaline water. Under acid conditions, non-toxic ammonium ions (NH_4^+) form, but at high pH values the toxic ammonium hydroxide (NH_4OH) occurs. The water quality standard for fish and aquatic life is 0.02 mg/l of NH_4OH. At a pH of 7 and a temperature of 68°F (20°C), the ratio of ammonium ions to ammonium hydroxide is 250:1; at pH 8, the ratio is 26:1.

Anion: Refers to the chemical ions present that carry a negative charge in contrast to cations, which carry a positive charge. There must be equal amounts of positive and negative charged ions in any water sample. Following are the common anions in their order of decreasing concentration for most lakes: bicarbonate (HCO_3^-), sulfate ($SO_4^=$), chloride (Cl^-), carbonate ($CO_3^=$), nitrate (NO_3^-), nitrite (NO_2^-), and phosphates (H_2PO4^-, HPO_4=, and $PO_4^=$).

Aquatic invertebrates: Aquatic animals without an internal skeletal structure such as insects, mollusks, and crayfish.

Bioaccumulation: see "Food chain."

Biomass: The total quantity of plants and animals in a lake. Measured as organisms or dry matter per cubic meter, biomass indicates the degree of a lake system's eutrophication or productivity.

Blue-green algae: Algae that are often associated with problem blooms in lakes. Some produce chemicals toxic to other organisms, including humans. They often form floating scum as they die. Many can fix nitrogen (N_2) from the air to provide their own nutrient.

Calcium (Ca^{++}): The most abundant cation found in Wisconsin lakes. Its abundance is related to the presence of calcium-bearing minerals in the lake watershed. Reported as milligrams per liter (mg/l) as calcium carbonate ($CaCO_3$), or milligrams per liter as calcium ion (Ca^{++}).

Cation: Refers to chemical ions present that carry a positive charge. The common cations present in lakes in normal order of decreasing concentrations follow: calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^+), sodium (Na^+), ammonium ($NH4^+$), ferric iron (Fe^{+++}) or ferrous iron (Fe^{++}), manganese (Mn^{++}), and hydrogen (H^+).

Chloride (Cl^-): Chlorine in the chloride ion (Cl^-) form has very different properties from chlorine gas (Cl_2), which is used for disinfecting. The chloride ion (Cl^-) in lake water is commonly considered an indicator of human activity. Agricultural chemicals, human and animal wastes, and road salt are the major sources of chloride in lake water.

Chlorophyll *a*: Green pigment present in all plant life and necessary for photosynthesis. The amount present in lake water depends on the amount of algae and is therefore used as a common indicator of water quality.

Clarity: see "Secchi disc."

Color: Measured in color units that relate to a standard. A yellow-brown natural color is associated with lakes or rivers receiving wetland drainage. The average color value for Wisconsin lakes is 39 units, with the color of state lakes ranging from zero to 320 units. Color also affects light penetration and therefore the depth at which plants can grow.

Concentration units express the amount of a chemical dissolved in water. The most common ways chemical data is expressed is in milligrams per liter (mg/l) and micrograms per liter (μg/l). One milligram per liter is equal to one part per million (ppm). To convert micrograms per liter (μg/l) to milligrams per liter (mg/l), divide by 1000 (e.g. 30 μg/l = 0.03 mg/l). To convert milligrams per liter (mg/l) to micrograms per liter (μg/l), multiply by 1000 (e.g. 0.5 mg/l = 500 μg/l). Microequivalents per liter (μeq/l) is also sometimes used, especially for alkalinity; it is calculated by dividing the weight of the compound by 1000 and then dividing that number into the milligrams per liter.

Conductivity (specific conductance): Measures water's ability to conduct an electric current. Conductivity is reported in micromhos per centimeter (μmhos/cm) and is directly related to the total dissolved inorganic chemicals in the water. Values are commonly two times the water hardness unless the water is receiving high concentrations of contaminants introduced by humans.

Drainage basin: The total land area that drains toward the lake.

Drainage lakes: Lakes fed primarily by streams and with outlets into streams or rivers. They are more subject to surface runoff problems but generally have shorter residence times than seepage lakes. Watershed protection is usually needed to manage lake water quality.

Dystrophic lake: A typically brownish-colored lake high in dissolved organic substances associated with bog vegetation. Does not follow eutrophication's normal pattern because of natural acidity or other chemical imbalances.

Epilimnion: see "Stratification."

Eutrophication: 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: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Filamentous algae: Algae that forms filaments or mats attached to sediment, weeds, piers, etc.

Flushing rate: see "Retention time."

Food chain: The sequence of algae being eaten by small aquatic animals (zooplankton) which in turn are eaten by small fish which are then eaten by larger fish and eventually by people or predators. 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.

Groundwater drainage lake: Often referred to as spring-fed lake; has large amounts of groundwater as its source, and a surface outlet. Areas of high groundwater inflow may be visible as springs or sand boils. Groundwater drainage lakes often have intermediate retention times with water quality dependent on groundwater quality.

Hardness: The quantity of multivalent cations (cations with more than one +), primarily calcium (Ca^{++}) and magnesium (Mg^{++}) in the water expressed as milligrams per liter of $CaCO_3$. Amount of hardness relates to the presence of soluble minerals, especially limestone, in the lake watershed.

Hypolimnion: see "Stratification."

Impoundment: Manmade lake or reservoir usually characterized by stream inflow and always by a stream outlet. Because of nutrient and soil loss from upstream land use practices, impoundments ordinarily have higher nutrient concentrations and faster sedimentation rates than natural lakes. Their retention times are relatively short.

Ion: A charged atom or group of atoms that has separated from an ion of the opposite charge. In water, some chemical molecules separate into cations (positive charge) and anions (negative charge). Thus the number of cations equals the number of anions.

Insoluble: incapable of dissolving in water.

Kjeldahl nitrogen: The most common analysis run to determine the amount of organic nitrogen in water. The test includes ammonium and organic nitrogen.

Limiting factor: The nutrient or condition in shortest supply relative to plant growth requirements. Plants will grow until stopped by this limitation; for example, phosphorus in summer, temperature or light in fall or winter.

Macrophytes: see "Rooted aquatic plants."

Marl: White to gray accumulation on lake bottoms caused by precipitation of calcium carbonate ($CaCO_3$) in hard water lakes. Marl may contain many snail and clam shells, which are also calcium carbonate. While it gradually fills in lakes, marl also precipitates phosphorus, resulting in low algae populations and good water clarity. In the past, marl was recovered and used to lime agricultural fields.

Metalimnion: see "Stratification."

Nitrate (NO_3^{-}): An inorganic form of nitrogen important for plant growth. Nitrogen is in this stable form when oxygen is present. Nitrate often contaminates groundwater when water originates from manure pits, fertilized fields, lawns or septic systems. High levels of nitrate-nitrogen (over 10 mg/l) are dangerous to infants and expectant mothers. A concentration of nitrate-nitrogen ($NO_3^{-}N$) plus ammonium-nitrogen ($NH_4^{-}N$) of 0.3 mg/l in spring will support summer algae blooms if enough phosphorus is present.

Nitrite (NO_2^{-}): A form of nitrogen that rapidly converts to nitrate (NO_3^{-}) and is usually included in the NO_3^{-} analysis.

Overturn: Fall cooling and spring warming of surface water increases density, and gradually makes temperature and density uniform from top to bottom. 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.

Phosphorus: Key nutrient influencing plant growth in more than 80% of Wisconsin lakes. Soluble reactive phosphorus 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: Process by which green plants convert carbon dioxide (CO_2) dissolved in water to sugar 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.

Phytoplankton: see "Algae."

Precipitate: A solid material which forms and settles out of water as a result of certain negative ions (anions) combining with positive ions (cations).

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.

Respiration: The process by which aquatic organisms convert organic material to energy. It is the reverse reaction of photosynthesis. Respiration consumes oxygen (O_2) and releases carbon dioxide (CO_2). It also takes place as organic matter decays.

Rooted aquatic plants (macrophytes): Refers to higher (multi-celled) plants growing in or near water. Macrophytes are beneficial to lakes because they produce oxygen and provide substrate for fish habitat and aquatic insects. Overabundance of such plants, especially problem species, is related to shallow water depth and high nutrient levels.

Secchi disc: An 8-inch diameter plate with alternating quadrants painted black and white that is used to measure 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 disc reading. For best results, the readings should be taken on sunny, calm days .

Sedimentation: Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and weeds, marl, and soil and organic matter eroded from the lake's watershed.

Seepage lakes: Lakes without a significant inlet or outlet, fed by rainfall and groundwater. Seepage lakes lose water through evaporation and groundwater moving on a down gradient. Lakes with little groundwater inflow tend to be naturally acidic and most susceptible to the effects of acid rain. Seepage lakes often have long residence times. and lake levels fluctuate with local groundwater levels. Water quality is affected by groundwater quality and the use of land on the shoreline.

Soluble: capable of being dissolved.

Stratification: The layering of water due to differences in density. Water's greatest density occurs at 39ºF (4ºC). As water warms during the summer, it remains near the surface while colder water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which usually extends to a depth of about 20 feet. The narrow transition zone between the epilimnion and cold bottom water (hypolimnion) is called the metalimnion or thermocline.

Sulfate ($SO_4^{=}$)**:** The most common form of sulfur in natural waters. The amounts relate primarily to soil minerals in the watershed. Sulfate (SO_4) can be reduced to sulfide ($S^{=}$) and hydrogen sulfide (H_2S) under low or zero oxygen conditions. Hydrogen sulfide smells like rotten eggs and harms fish. Sulfate ($SO_4^{=}$) input from acid rain is a major indicator of sulfur dioxide (SO_2) air pollution. Sulfate concentration is used as a chemical fingerprint to distinguish acid lakes acidified by acid rain from those acidified by organic acids from bogs.

Suspended solids: A measure of the particulate matter in a water sample, expressed in milligrams per liter. When measured on inflowing streams, it can be used to estimate the sedimentation rate of lakes or impoundments.

Thermocline: see "Stratification."

Trophic state: see "Eutrophication."

Turnover: see "Overturn."

Watershed: see "Drainage basin."

Zooplankton: Microscopic or barely visible animals that eat algae. These suspended plankton are an important component of the lake food chain and ecosystem. For many fish, they are the primary source of food.

Authors: Byron Shaw is a professor emeritus of soil and water science, University of Wisconsin–Stevens Point, and a water quality specialist with the University of Wisconsin–Extension, Cooperative Extension. Lowell Klessig is a professor emeritus of resource management at the University of Wisconsin–Stevens Point and a lake management specialist with the University of Wisconsin–Extension, Cooperative Extension. Christine Mechenich was formerly an Extension groundwater education specialist with the Central Wisconsin Groundwater Center, University of Wisconsin–Stevens Point.

To see more publications or to order copies of this publication, visit our web site at http://cecommerce.uwex.edu or call toll-free: 877-WIS-PUBS (947-7827).

Understanding Lake Data (G3582) RP-03/2004