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.

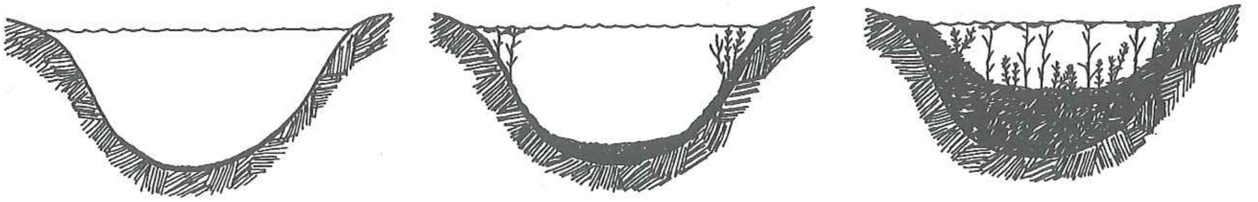
Mesotrophic lakes lie between the oligotrophic and eutrophic stages. Devoid of oxygen in late summer, their hypolimnions limit cold water fish and cause phosphorus cycling from sediments.

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

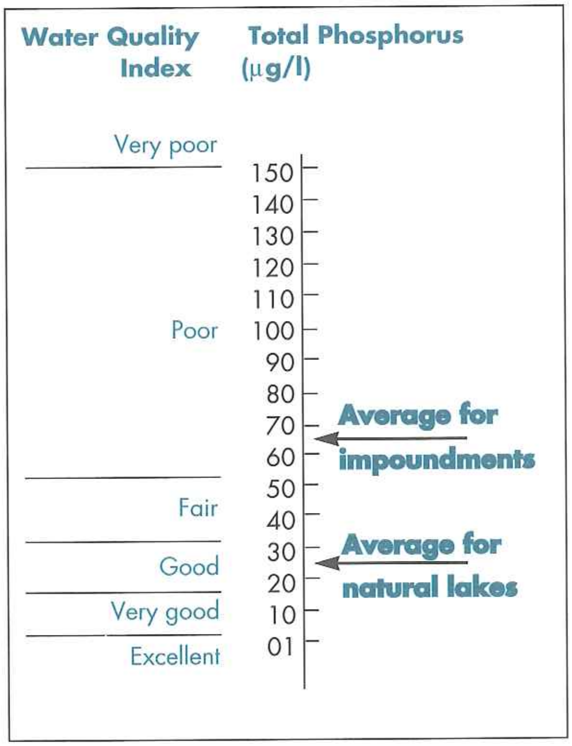


FIGURE 4. Total phosphorus concentrations for Wisconsin's natural lakes and impoundments. (*Adapted from Lillie and Mason, 1983.*)

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.

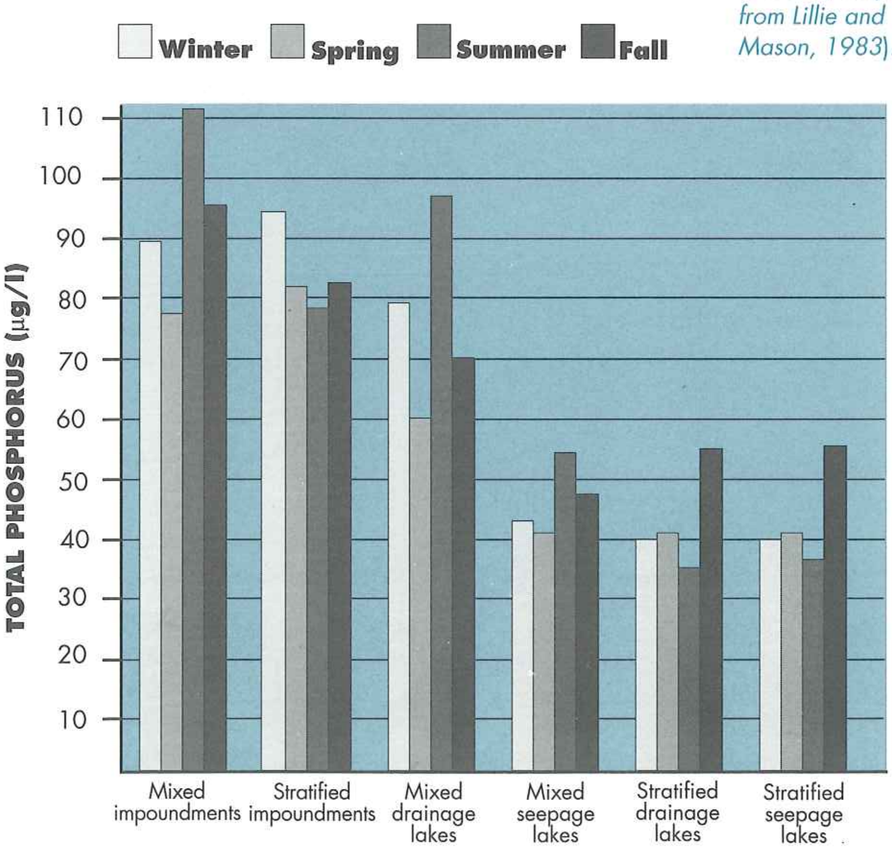
Lakes with low iron and insufficient calcium to form marl are most likely to retain phosphorus in solution once it is released from sediments or brought in from external sources. These lakes are the most vulnerable to naturally occurring phosphorus or to phosphorus loading from human activities because 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)*.