WATER QUALITY

Lakes can be classified into three broad categories based on their productivity or ability to support plant and animal life. The three basic lake classifications are "oligotrophic," "mesotrophic," and "eutrophic" (Figure 9). Oligotrophic lakes are generally deep and clear with little aquatic plant growth. These lakes maintain sufficient dissolved oxygen in the cool, deep bottom waters during late summer to support coldwater fish such as trout and whitefish. By contrast, eutrophic lakes are generally shallow, turbid, and support abundant aquatic plant growth. In deep eutrophic lakes, the cool bottom waters usually contain little or no dissolved oxygen. Therefore, these lakes can only support warmwater fish such as bass and pike. Lakes that fall between these two extremes are called mesotrophic lakes. In a recent assessment of Michigan's lakes, the U.S. Geological Survey estimated that statewide about 25% of lakes are oligotrophic, 52% are mesotrophic and 23% are eutrophic (Fuller and Taricska 2012).

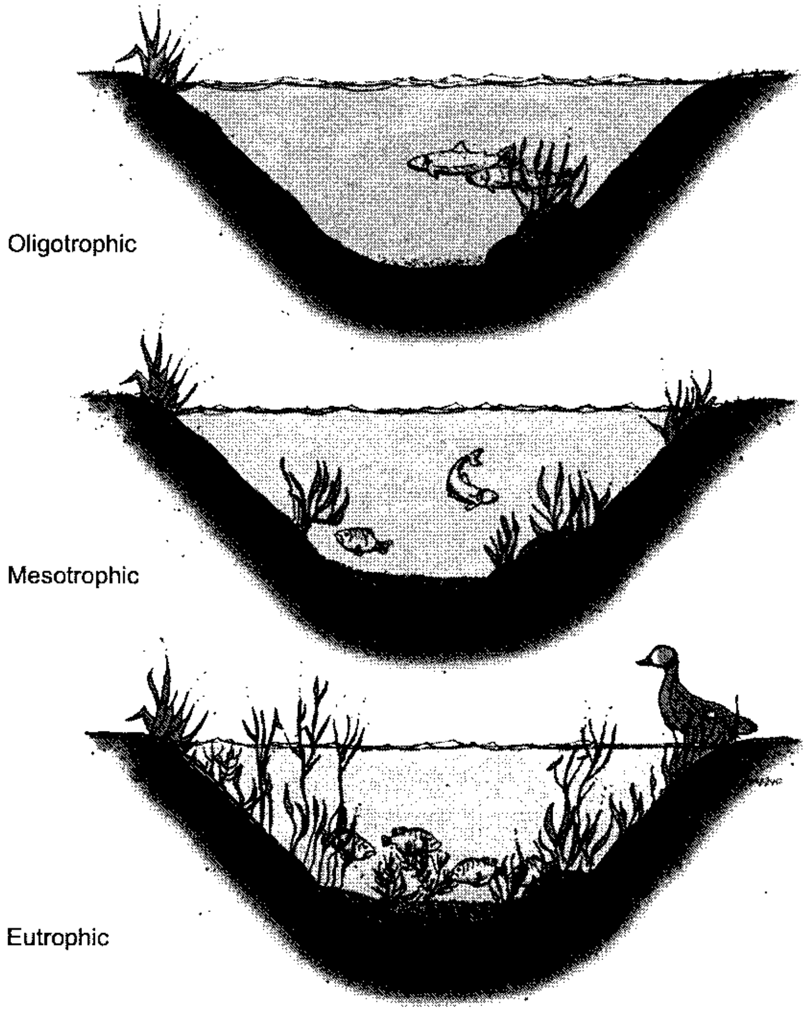

Figure 9. Lake classification.

Under natural conditions, most lakes will ultimately evolve to a eutrophic state as they gradually fill with sediment and organic matter transported to the lake from the surrounding watershed. As the lake becomes shallower, the process accelerates. When aquatic plants become abundant, the lake slowly begins to fill in as sediment and decaying plant matter accumulate on the lake bottom. Eventually, terrestrial plants become established and the lake is transformed to a marshland. The natural lake aging process can be greatly accelerated if excessive amounts of sediment and nutrients (which stimulate aquatic plant growth) enter the lake from the surrounding watershed. Because these added inputs are usually associated with human activity, this accelerated lake aging process is often referred to as *cultural eutrophication*.

There are many ways to measure lake water quality, but there are a few important physical, chemical, and biological parameters that indicate the overall condition of a lake. These measurements include temperature, dissolved oxygen, total phosphorus, chlorophyll-*a*, and Secchi transparency.

Temperature

Temperature is important in determining the type of organisms that may live in a lake. For example, trout prefer temperatures below 68°F. Temperature also determines how water mixes in a lake. As the ice cover breaks up on a lake in the spring, the water temperature becomes uniform from the surface to the bottom. This period is referred to as "spring turnover" because water mixes throughout the entire water column. As the surface waters warm, they are underlain by a colder, more dense strata of water. This process is called thermal stratification. Once thermal stratification occurs, there is little mixing of the warm surface waters with the cooler bottom waters. The transition layer that separates these layers is referred to as the "thermocline." The thermocline is characterized as the zone where temperature drops rapidly with depth. As fall approaches, the warm surface waters begin to cool and become more dense. Eventually, the surface temperature drops to a point that allows the lake to undergo complete mixing. This period is referred to as "fall turnover." As the season progresses and ice begins to form on the lake, the lake may stratify again. However, during winter stratification, the surface waters (at or near 32°F) are underlain by slightly warmer water (about 39°F). This is sometimes referred to as "inverse stratification" and occurs because water is most dense at a temperature of about 39°F. As the lake ice melts in the spring, these stratification cycles are repeated (Figure 10). Shallow lakes do not stratify. Lakes that are 15 to 30 feet deep may stratify and destratify with storm events several times during the year.

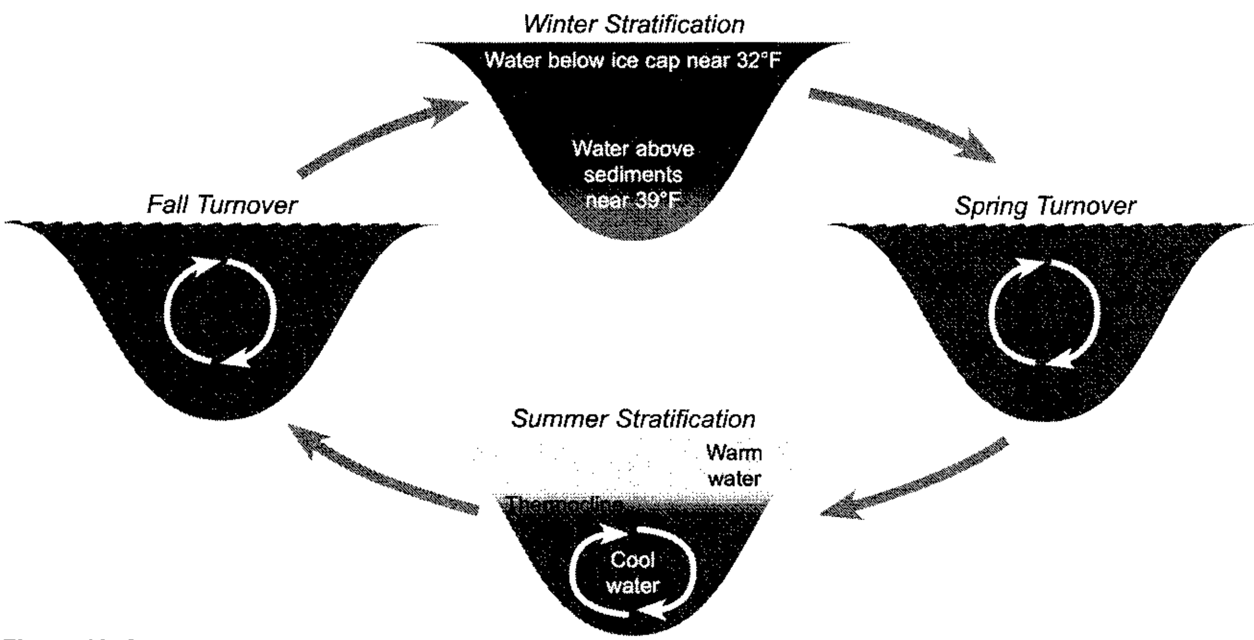

Figure 10. Seasonal thermal stratification cycles.

Dissolved Oxygen

An important factor influencing lake water quality is the quantity of dissolved oxygen in the water column. The major inputs of dissolved oxygen to lakes are the atmosphere and photosynthetic activity by aquatic plants. An oxygen level of about 5 mg/L (milligrams per liter, or parts per million) is required to support warmwater fish. In lakes deep enough to exhibit thermal stratification, oxygen levels are often reduced or depleted below the thermocline once the lake has stratified. This is because deep water is cut off from plant photosynthesis and the atmosphere, and oxygen is consumed by bacteria that use oxygen as they decompose organic matter (plant and animal remains) at the bottom of the lake. Bottom-water oxygen depletion is a common occurrence in eutrophic and some mesotrophic lakes. Thus, eutrophic and most mesotrophic lakes cannot support coldwater fish because the cool, deep water (that the fish require to live) does not contain sufficient oxygen.

Phosphorus

The quantity of phosphorus present in the water column is especially important since phosphorus is the nutrient that most often controls aquatic plant growth and the rate at which a lake ages and becomes more eutrophic. In the presence of oxygen, lake sediments act as a phosphorus trap, retaining phosphorus and, thus, making it unavailable for algae growth. However, if bottom-water oxygen is depleted, phosphorus will be released from the sediments and may be available to promote aquatic plant growth. In some lakes, the internal release of phosphorus from the bottom sediments is the primary source of phosphorus loading (or input).

By reducing the amount of phosphorus in a lake, it may be possible to control the amount of aquatic plant growth. In general, lakes with a phosphorus concentration greater than 20 µg/L (micrograms per liter, or parts per billion) are able to support abundant plant growth and are classified as nutrient-enriched or eutrophic.

Chlorophyll-*a*

Chlorophyll-*a* is a pigment that imparts the green color to plants and algae. A rough estimate of the quantity of algae present in lake water can be made by measuring the amount of chlorophyll-*a* in the water column. A chlorophyll-*a* concentration greater than 6 µg/L is considered characteristic of a eutrophic condition.

Secchi Transparency

A Secchi disk is often used to estimate water clarity. The measurement is made by fastening a round, black and white, 8-inch disk to a calibrated line (Figure 11). The disk is lowered over the deepest point of the lake until it is no longer visible, and the depth is noted. The disk is then raised until it reappears. The average between these two depths is the Secchi transparency. Generally, it has been found that aquatic plants can grow at a depth of approximately twice the Secchi transparency measurement. In eutrophic lakes, water clarity is often reduced by algae growth in the water column, and Secchi disk readings of 7.5 feet or less are common.

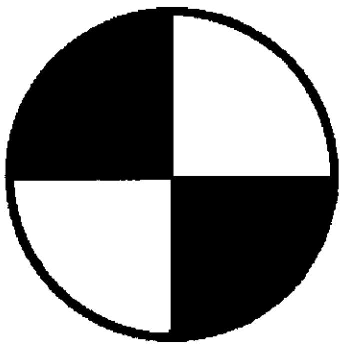

Figure 11. Secchi disk.

Lake Classification Criteria

Ordinarily, as phosphorus inputs (both internal and external) to a lake increase, the amount of algae will also increase. Thus, the lake will exhibit increased chlorophyll-*a* levels and decreased transparency. A summary of lake classification criteria developed by the Michigan Department of Natural Resources (Warbach et al. 1990) is shown in Table 2.

TABLE 2

LAKE CLASSIFICATION CRITERIA

Lake Classification	Total Phosphorus (µg/L)[1]	Chlorophyll-*a* (µg/L)[1]	Secchi Transparency (feet)
Oligotrophic	Less than 10	Less than 2.2	Greater than 15.0
Mesotrophic	10 to 20	2.2 to 6.0	7.5 to 15.0
Eutrophic	Greater than 20	Greater than 6.0	Less than 7.5

1 µg/L = micrograms per liter = parts per billion.

pH and Total Alkalinity

pH is a measure of the amount of acid or base in the water. The pH scale ranges from 0 (acidic) to 14 (alkaline or basic) with neutrality at 7. The pH of most lakes in the Upper Midwest ranges from 6.5 to 9.0 (Michigan Department of Environmental Quality (MDEQ) 2012; Table 3). In addition, according to the Michigan Department of Environment, Great Lakes, and Energy (EGLE 2020):

> While there are natural variations in pH, many pH variations are due to human influences. Fossil fuel combustion products, especially automobile and coal-fired power plant emissions, contain nitrogen oxides and sulfur dioxide, which are converted to nitric acid and sulfuric acid in the atmosphere. When these acids combine with moisture in the atmosphere, they fall to earth as acid rain or acid snow. In some parts of the United States, especially the Northeast, acid rain has resulted in lakes and streams becoming acidic, resulting in conditions which are harmful to aquatic life. The problems associated with acid rain are lessened if limestone is present, since it is alkaline and neutralizes the acidity of the water.
>
> Most aquatic plants and animals are adapted to a specific pH range, and natural populations may be harmed by water that is too acidic or alkaline. Immature stages of aquatic insects and young fish are extremely sensitive to pH values below 5. Even microorganisms which live in the bottom sediment and decompose organic debris cannot live in conditions which are too acidic. In very acidic waters, metals which are normally bound to organic matter and sediment are released into the water. Many of these metals can be toxic to fish and humans. Below a pH of about 4.5, all fish die.

The Michigan Water Quality Standard (Part 4 of Act 451) states that pH shall be maintained within the range of 6.5 to 9.0 in all waters of the state.

Alkalinity, also known as acid-neutralizing capacity or ANC, is the measure of the pH-buffering capacity of water in that it is the quantitative capacity of water to neutralize an acid. pH and alkalinity are closely linked and are greatly impacted by the geology and soil types that underlie a lake and its watershed. According to MDEQ (2012):

> Michigan's dominant limestone geology in the Lower Peninsula and the eastern Upper Peninsula contributes to the vast majority of Michigan lakes being carbonate-bicarbonate dominant [which increases alkalinity and moderates pH] and lakes in the western Upper Peninsula having lower alkalinity and thus lesser buffering capacity.

The alkalinity of most lakes in the Upper Midwest is within the range of 23 to 148 milligrams per liter, or parts per million, as calcium carbonate (MDEQ 2012; Table 3).

TABLE 3
pH AND ALKALINITY OF UPPER MIDWEST LAKES

Measurement	Low	Moderate	High
pH (in standard units)	Less than 6.5	6.5 to 9.0	Greater than 9.0
Total Alkalinity or ANC (in mg/L as $CaCO_3$[1])	Less than 23	23 to 148	Greater than 148

1 mg/L $CaCO_3$ = milligrams per liter as calcium carbonate.

Total Suspended Solids

According to EGLE (2020):

> Total suspended solids (TSS) include all particles suspended in water which will not pass through a filter... Most people consider water with a TSS concentration less than 20 mg/L to be clear. Water with TSS levels between 40 and 80 mg/L tends to appear cloudy, while water with concentrations over 150 mg/L usually appears dirty.

Chloride

Normally, chloride is a very minor component of freshwater systems and background concentrations are generally less than about 10 milligrams per liter (Wetzel 2001; Fuller and Taricska 2012, Figure 12). However, chloride pollution from sources such as road salting, industrial or municipal wastewater, water softeners, and septic systems can increase chloride levels in lakes. Increased chloride levels can reduce biological diversity and, because chloride increases the density of water, elevated chloride levels can prevent a lake from completely mixing during spring and fall. Michigan's water quality standards require that waters designated as a public water supply source not exceed 125 milligrams per liter of chlorides as a monthly average.

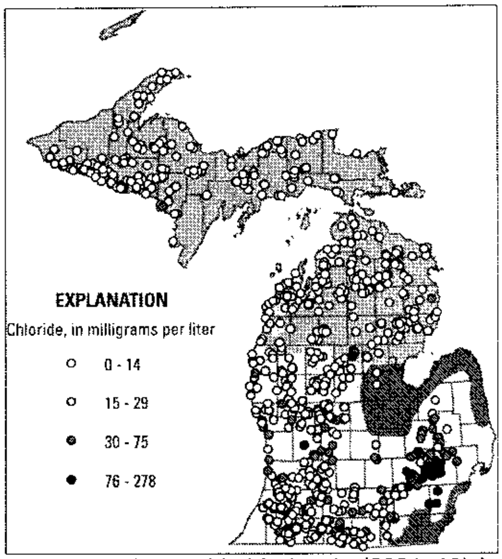

Figure 12. Lake chloride levels (2001–10) in USEPA ecoregions. Fuller and Taricska 2012.

Hess Lake Water Quality

In order to evaluate baseline water quality conditions in Hess Lake, samples were collected at five-foot intervals over the three deep lake basins in April and August of 2018 (Figure 13; Appendix A). In addition to the in-lake sampling locations, samples were collected from each of the five tributaries to the lake. Tributary samples were collected in April and August of 2018 and again in April of 2019.

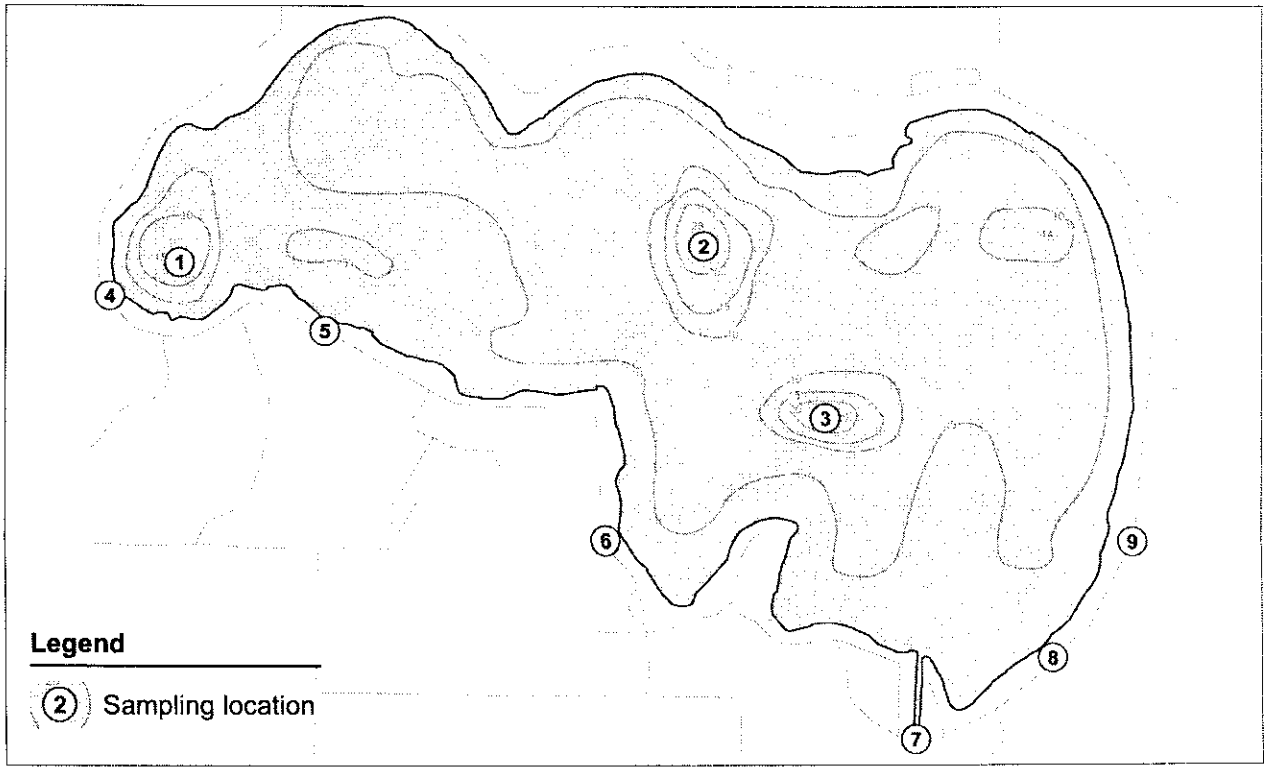

Figure 13. Hess Lake and tributary sampling location map.

Sampling results for Hess Lake indicate the following:

The April sampling occurred during spring turnover when temperature and dissolved oxygen were uniform from the lake surface to bottom (Table 4). During the summer sampling period, thermal stratification was observed over the deep lake basins and the bottom waters were anoxic (i.e., devoid of oxygen). With the exception of the deep basins in Hess Lake, the remainder of the lake is too shallow to stratify and, during ice free periods, most of the lake is mixed and well oxygenated.

While conditions in Hess Lake are suitable for warmwater fish, the cool, deep bottom waters lack oxygen during summer stratification. Thus, the lake is uninhabitable for coldwater fish, and coolwater fish such as northern pike will be stressed (Jude 2020).

Phosphorus levels were moderate in spring and elevated during the summer sampling period, often exceeding the eutrophic threshold concentration. Given the small size of the deep basins, it's unlikely that internal phosphorus release from anoxic deep-water sediments is a primary phosphorus source in Hess Lake.

Secchi transparency readings were low during both sampling periods (Table 5). Chlorophyll-*a* levels were elevated during spring sampling indicating abundant algae growth in the water column at that time. During the summer sampling, algae growth was more moderate. At the times of sampling, total suspended solids levels were low and did not appear to be contributing to the poor transparency in the lake. Reduced transparency in Hess Lake is likely related to a combination of factors including wind-induced sediment resuspension, algae growth, roiling action of common carp, and motorized boat activity.

pH and total alkalinity in Hess Lake were generally within a moderate range for Michigan lakes.

Chloride levels in Hess Lake were low and similar to concentrations found in other rural areas of the state (Table 4).

Tributary data indicate discharge and pollutant loadings (i.e., total phosphorus and total suspended solids) are greatest from Wheeler Drain (Table 6). The relatively high total phosphorus and total suspended solids levels measured in Wheeler Drain in April of 2018 were likely influenced by excavation occurring in the sediment basin upstream of the lake. Discharge rates from all tributaries are greater in spring than summer.

Current and historical water quality data indicate Hess Lake is eutrophic (Table 7 and Appendix B). The lake generally has elevated phosphorus and chlorophyll-*a* levels, and reduced transparency. In a state-wide assessment of lake water quality conducted by the U.S. Geological Survey, Hess Lake was classified as hyper-eutrophic (Fuller and Taricska 2012).

TABLE 4
HESS LAKE 2018 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolv. Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]	Total Suspended Solids (mg/L)[1]	Chloride (mg/L)[1]
12-Apr-18	1	1	45	9.5	19	9.0	137	10	13
12-Apr-18	1	5	45	9.8	25	8.9	137	9	13
12-Apr-18	1	10	45	9.8	21	8.9	142	24	15
12-Apr-18	1	13	45	9.4	20	8.9	135	11	13
12-Apr-18	2	1	44	9.2	22	9.4	139	8	13
12-Apr-18	2	5	44	9.6	21	9.3	142	8	13
12-Apr-18	2	10	44	9.6	5	9.4	138	10	13
12-Apr-18	2	15	44	9.3	<5	9.4	137	11	14
12-Apr-18	2	20	44	9.8	16	9.4	137	9	13
12-Apr-18	3	1	45	9.8	12	9.4	138	5	13
12-Apr-18	3	5	44	9.5	16	9.4	136	10	13
12-Apr-18	3	10	44	10.8	<5	9.4	136	14	13
12-Apr-18	3	15	44	11.5	<5	9.3	140	10	13
20-Aug-18	1	1	78	8.9	16	8.7	114	20	16
20-Aug-18	1	5	74	9.7	22	8.6	114	20	16
20-Aug-18	1	10	69	1.3	58	7.0	155	13	31
20-Aug-18	1	13	69	0.0	90	6.8	189	11	15
20-Aug-18	2	1	79		16	8.7	114	15	15
20-Aug-18	2	5	79	9.5	35	8.8	112	20	15
20-Aug-18	2	10	73	10.0	17	8.7	114	19	15
20-Aug-18	2	15	71	6.9	18	8.2	117	16	16
20-Aug-18	2	20	71	0.0	43	6.9	192	20	16
20-Aug-18	3	1	79	8.2	12	8.7	112	12	15
20-Aug-18	3	5	78	7.5	80	8.7	114	26	15
20-Aug-18	3	10	73	9.2	45	8.5	112	14	16
20-Aug-18	3	16	73	0.7	48	6.9	164	18	15

1 mg/L = milligrams per liter = parts per million.
2 µg/L = micrograms per liter = parts per billion.
3 S.U. = standard units.
4 mg/L as $CaCO_3$ = milligrams per liter as calcium carbonate.

TABLE 5
HESS LAKE 2018 SURFACE WATER QUALITY DATA

Date	Station	Chlorophyll-*a* (µg/L)[1]	Secchi Transparency (feet)
12-Apr-18	1	4	2.5
12-Apr-18	2	11	2.5
12-Apr-18	3	12	2.5
20-Aug-18	1	5	2.0
20-Aug-18	2	4	1.5
20-Aug-18	3	3	2.0

TABLE 6
HESS LAKE 2018-2019 TRIBUTARY WATER QUALITY DATA

Date	Station	Stream	Discharge (cfs)	Total Phosphorus (µg/L)[1]	Total Suspended Solids (mg/L)[2]
12-Apr-18	4	West trib	0.1	5	<4
12-Apr-18	5	Alger Creek	1.2	45	21
12-Apr-18	6	South trib	0.3	<5	<4
12-Apr-18	7	Wheeler Drain	10.5	329	194
12-Apr-18	8	Southeast trib	0.4	22	19
12-Apr-18	9	East trib	---	7	9
20-Aug-18	4	West trib	0	---	---
20-Aug-18	5	Alger Creek	---	55	6
20-Aug-18	6	South trib	0	---	---
20-Aug-18	7	Wheeler Drain	1.5	61	8
20-Aug-18	8	Southeast trib	0.1	35	8
20-Aug-18	9	East trib	0.3	64	<4
23-Apr-19	4	West trib	1.6	16	<4
23-Apr-19	5	Alger Creek	3.1	21	<4
23-Apr-19	6	South trib	0.6	<10	<4
23-Apr-19	7	Wheeler Drain	19.3	47	<4
23-Apr-19	8	Southeast trib	0.5	<10	<4
23-Apr-19	9	East trib	1.3	<10	<4

1 µg/L = micrograms per liter = parts per billion.
2 mg/L = milligrams per liter = parts per million.

TABLE 7
HESS LAKE WATER QUALITY SUMMARY STATISTICS (1974-2019)

	Total Phosphorus (µg/L)[1]	Chlorophyll-a (µg/L)[1]	Secchi Transparency (feet)
Mean	33	12	3.3
Standard deviation	19	8	1.9
Median	32	10	2.5
Minimum	5	3	1.5
Maximum	90	35	10.5
Number of samples	65	48	185

AQUATIC PLANTS

Aquatic plants are an important ecological component of lakes. They produce oxygen from photosynthesis, provide food and habitat for fish, and help stabilize shoreline and bottom sediments (Figure 14).

The distribution and abundance of aquatic plants are dependent on several variables including light penetration, bottom type, temperature, water levels, and the availability of plant nutrients. The term "aquatic plants" includes both the algae and the larger aquatic plants or macrophytes. The macrophytes can be categorized into four groups: emergent, floating-leaved, submersed, and free floating (Figure 15). Each plant group provides unique habitat essential for a healthy fishery.

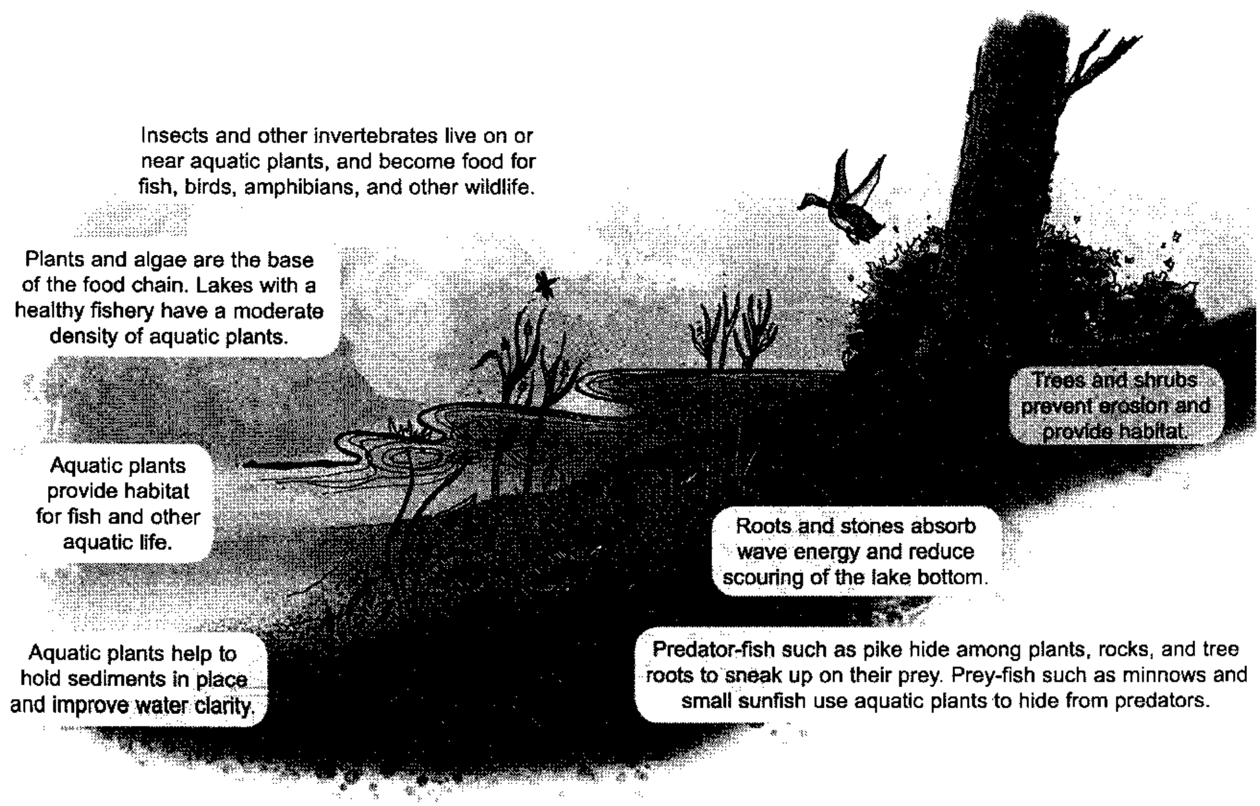

Figure 14. Benefits of aquatic plants.

1 µg/L = micrograms per liter = parts per billion.