Perch and Crystal Lakes Limnological Study and Management Plan

Hillsdale County, Michigan

Prepared by: Restorative Lake Sciences
Jennifer L. Jermalowicz-Jones, PhD, CLP
www.restorativelakesciences.com

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Perch and Crystal Lakes Limnological Study and Management Plan
Hillsdale County, Michigan

September, 2023

1.0 EXECUTIVE SUMMARY

Perch and Crystal Lake are both located in Somerset Township in Hillsdale County, Michigan (T.5S, R.1W, Section 3; Figure 1). The Perch Lake basin is comprised of 45 acres and the Crystal Lake basin consists of 129 acres (RLS, 2023) at the current lake levels. The Perch Lake basin has nearly 1.3 miles of shoreline and the Crystal Lake basin has nearly 3.7 miles of shoreline. The mean depth of the Perch Lake basin is approximately 5.9 feet, and the mean depth of the Crystal Lake basin is approximately 13.6 feet. The maximum depth of the Perch Lake basin is approximately 9.7 feet, and the maximum depth of the Crystal Lake basin is approximately 62.4 feet (RLS, 2023 bathymetric scan data).

The Perch Lake basin also has a fetch (longest distance across the lake) of approximately 0.5 miles and the Crystal Lake basin has a fetch of approximately 0.7 miles (RLS, 2023). The Perch Lake basin has an approximate water volume of 242.2 acre-feet and the Crystal Lake basin has an approximate water volume of 1,980.9 acre-feet (RLS, 2023 bathymetric data). The immediate watershed, which is the area directly draining into the lakes, differs for each lake with Perch Lake being approximately 113.7 acres and Crystal Lake being is approximately 365.3 acres which is about 2.4 times the size of the lake for Perch Lake and about 2.5 times the size of the lake for Crystal Lake. Both immediate watersheds are considered small and favorable. Both lakes are considered closed-basin (seepage) systems, but Crystal Lake does drain into a wetland at the west end of the lake and may enter Lake LeAnn during periods of intense rainfall.

Based on the current study, Perch Lake contains one invasive aquatic plant species which includes the submersed Starry Stonewort and Crystal Lake contains hybrid Eurasian Watermilfoil (EWM), and Curly-leaf Pondweed (CLP). Continued surveys and vigilance are needed to assure that additional invasives do not enter both lakes. Recommendations for prevention of invasives are offered later in this management plan report. Extensive whole-lake aquatic vegetation surveys and biovolume scans were conducted on both lakes on June 13, 2023. Perch Lake contained 5 native submersed, 3 floating-leaved, and 4 emergent aquatic plant species, for a total of 12 native aquatic plant species. Crystal Lake contained 10 native submersed, 3 floating-leaved, and 5 emergent aquatic plant species, for a total of 18 native aquatic plant species .

This represents a fair to good biodiversity that could be enhanced with continued control of the submersed invasives. Aquatic herbicide treatments are recommended on a spot-treatment basis to effectively reduce the invasives over time. Only systemic herbicides should be used on the invasive milfoil for sustained root control. In addition, Curly-leaf Pondweed naturally declines in mid-summer but contact herbicides can also be used to reduce it in the spring. Algaecides should be used sparingly on only dense, green, filamentous algal blooms since many favorable algae are present in both lakes and are critical food for zooplankton and ultimately the fisheries.

Two deep basin water quality sampling locations were sampled in each of the lakes on July 25, 2023. These basins were monitored for physical water quality parameters such as water temperature, dissolved oxygen, pH, specific conductivity, total dissolved solids (TDS), and Secchi transparency. Chemical water quality parameters were also measured at each site and included total Kjeldahl nitrogen (TKN), total inorganic nitrogen (TIN; which consists of ammonia, nitrate, and nitrite), chlorophyll-a, total phosphorus (TP), and ortho (ORP; soluble reactive) phosphorus, total alkalinity, and total suspended solids (TSS). The overall water quality of Perch Lake was measured as fair with high nutrients such as phosphorus (TP) and fair water clarity and elevated chlorophyll-*a*. Perch Lake had elevated concentrations of chlorophyll-a and thus is more productive than Crystal Lake. The water quality of Crystal Lake was measured as good with elevated phosphorus at the lake bottom and good water clarity and low chlorophyll-*a*. Both lakes also have a healthy population of favorable algae and zooplankton. Annual water quality monitoring in addition to the current CLMP scope is advised to monitor the bottom nutrient concentrations which are high for both lakes. In Crystal Lake, this high phosphorus at the lake bottom is present with dissolved oxygen depletion during summer months. This can create internal loading of phosphorus and lead to increased aquatic plant and algae growth over time. The historical CLMP values correspond with RLS measurements, but the CLMP method does not account for nutrients at the lake bottom, which is critical for understanding the true function of the lake relative to eutrophication over time. The majority of the data collected by RLS falls into the same ranges previously collected by lake volunteers through the CLMP program for surface nutrients, chlorophyll-*a*, and Secchi transparency.

Both lakes have multiple land uses such as wetlands, beaches, and riparian properties. The largest threats to both lakes are shoreline erosion and septic system inputs. RLS recommends that the local community implement Best Management Practices (BMP’s) discussed in the immediate watershed management section to reduce the nutrient and sediment loads being transported into the lake from areas with high erosion and septic systems.

It would be beneficial to include the riparian community in the improvement program which could be initiated by holding a community-wide lake education and improvement workshop to introduce residents to the key lake impairments and garner support for continued lake protection. A septic tank and drain field maintenance program is needed to help riparians reduce nutrients such as nitrogen and phosphorus to the lakes. This could include an annual septic tank pump out and maintenance day for all residents.

RLS also recommends aquatic invasive species (AIS) educational signage and/or a boat washing station at the access sites. This is to prevent the transfer of invasive species into or out of the lakes. Regular whole-lake aquatic vegetation surveys are critical in the early detection of all invasives and for determining the efficacy of herbicide treatments.

2.0 LAKE ECOLOGY BACKGROUND INFORMATION

2.1 Introductory Concepts

Limnology is a multi-disciplinary field which involves the study of the biological, chemical, and physical properties of freshwater ecosystems. A basic knowledge of these processes is necessary to understand the complexities involved and how management techniques are applicable to current lake issues. The following terms will provide riparians with a more thorough understanding of the forthcoming lake management recommendations for Perch and Crystal lakes.

2.1.1 Lake Hydrology

Aquatic ecosystems include rivers, streams, ponds, lakes, and the Laurentian Great Lakes. There are thousands of lakes in the state of Michigan, and each possesses unique ecological functions and socio-economic contributions. In general, lakes are divided into four categories:

- Seepage Lakes,
- Drainage Lakes,
- Spring-Fed Lakes, and
- Drained Lakes.

Some lakes (seepage lakes) contain closed basins and lack inlets and outlets, relying solely on precipitation or groundwater for a water source. Seepage lakes generally have small watersheds with long hydraulic retention times that render them sensitive to pollutants. Drainage lakes receive significant water quantities from tributaries and rivers. Drainage lakes contain at least one inlet and an outlet and generally are confined within larger watersheds with shorter hydraulic retention times. As a result, they are less susceptible to pollution. Spring-fed lakes rarely contain an inlet but always have an outlet with considerable flow. The majority of water in this lake type originates from groundwater and is associated with a short hydraulic retention time. Drained lakes are similar to seepage lakes, yet rarely contain an inlet and have a low-flow outlet. The groundwater and seepage from surrounding wetlands supply the majority of water to this lake type and the hydraulic retention times are rather high, making these lakes relatively more vulnerable to pollutants. The water quality of a lake may thus be influenced by the quality of both groundwater and precipitation, along with other internal and external physical, chemical, and biological processes.

Perch Lake and Crystal Lakes may be categorized as closed-basin (seepage) lakes. Crytal Lake drains into a wetland on the west end that may enter Lake LeAnn during periods of intense rainfall.

2.1.2 Biodiversity and Habitat Health

A healthy aquatic ecosystem possesses a variety and abundance of niches (environmental habitats) available for all of its inhabitants. The distribution and abundance of preferable habitat depends on limiting man's influence from man and development, while preserving sensitive or rare habitats. As a result of this, undisturbed or protected areas generally contain a greater number of biological species and are considered more diverse. A highly diverse aquatic ecosystem is preferred over one with less diversity because it allows a particular ecosystem to possess a greater number of functions and contribute to both the intrinsic and socio-economic values of the lake. Healthy lakes have a greater biodiversity of aquatic macroinvertebrates, aquatic macrophytes (plants), fishes, phytoplankton, and may possess a plentiful yet beneficial benthic microbial community (Wetzel, 2001).

2.1.3 Perch and Crystal Lakes Shoreline Soils

Many of the areas around both lakes are of high slope and are prone to erosion. Best Management Practices (BMP's) for water quality protection are offered in the immediate watershed improvement section of this report.

In Perch Lake, there are three major soil types immediately surrounding the lakeshore (Table 1). There are four soil types surrounding the shoreline of Crystal Lake (Table 2) which may impact the water quality of the lake and dictate the particular land use activities within the area. Figure 1 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service, 1999) demonstrates the precise soil types and locations around each lake. Major characteristics of the dominant soil types directly surrounding the lake shorelines are discussed below. The locations of each soil type are listed in the tables below.

Table 1. Perch Lake shoreline soil types (USDA-NRCS data).

USDA-NRCS Soil Series	*Perch Lake Soil Type Location*
15C Boyer loamy sand; 6-12% slopes	N, W, S shores
16C2 Fox sandy loam, Huron Lobe;6-12% slopes, eroded	W, N, SW shores
17 Sebewa loam, disintegration moraine; 0-2% slopes	SW shore

Table 2. Crystal Lake shoreline soil types (USDA-NRCS data).

USDA-NRCS Soil Series	***Crystal Lake Soil Type Location***
15C Boyer loamy sand; 6-12% slopes	N, E, S shores
16C2 Fox sandy loam, Huron Lobe;6-12% slopes, eroded	S, W shores
16E Fox gravelly sandy loam; 18-35%	SW shore
HgtahA Houghton Muck; 0-1% slopes	SW shore

The majority of the soils around Perch Lake and Crystal Lake are sandy loams and many are located on high slopes (>6%). This often results in erosion of properties without proper erosion control management and also during periods of high water. Figure 2 shows a lakefront property on Perch Lake with erosion issues. A survey of all possible erosion locations should be conducted in the future and mitigation strategies to stabilize the shorelines may be needed in some areas.

The only saturated soils present were near the southwest shore of Crystal Lake (Houghton mucks). These soils are very deep, poorly drained soils with the potential for ponding. Ponding occurs when water cannot permeate the soil and accumulates on the ground surface which then may runoff into nearby waterways such as the lake and carry nutrients and sediments into the water. Excessive ponding of such soils may lead to flooding of some low-lying shoreline areas, resulting in nutrients entering the lake via surface runoff since these soils do not promote adequate drainage or filtration of nutrients. The mucks located in the wetlands may become ponded during extended rainfall and the wetlands can serve as a source of nutrients to the lake. When the soils of the wetland are not saturated, the wetland can serve as a sink for nutrients and the nutrients are filtered by wetland plants. Thus, protection of wetlands around lakes is very important.

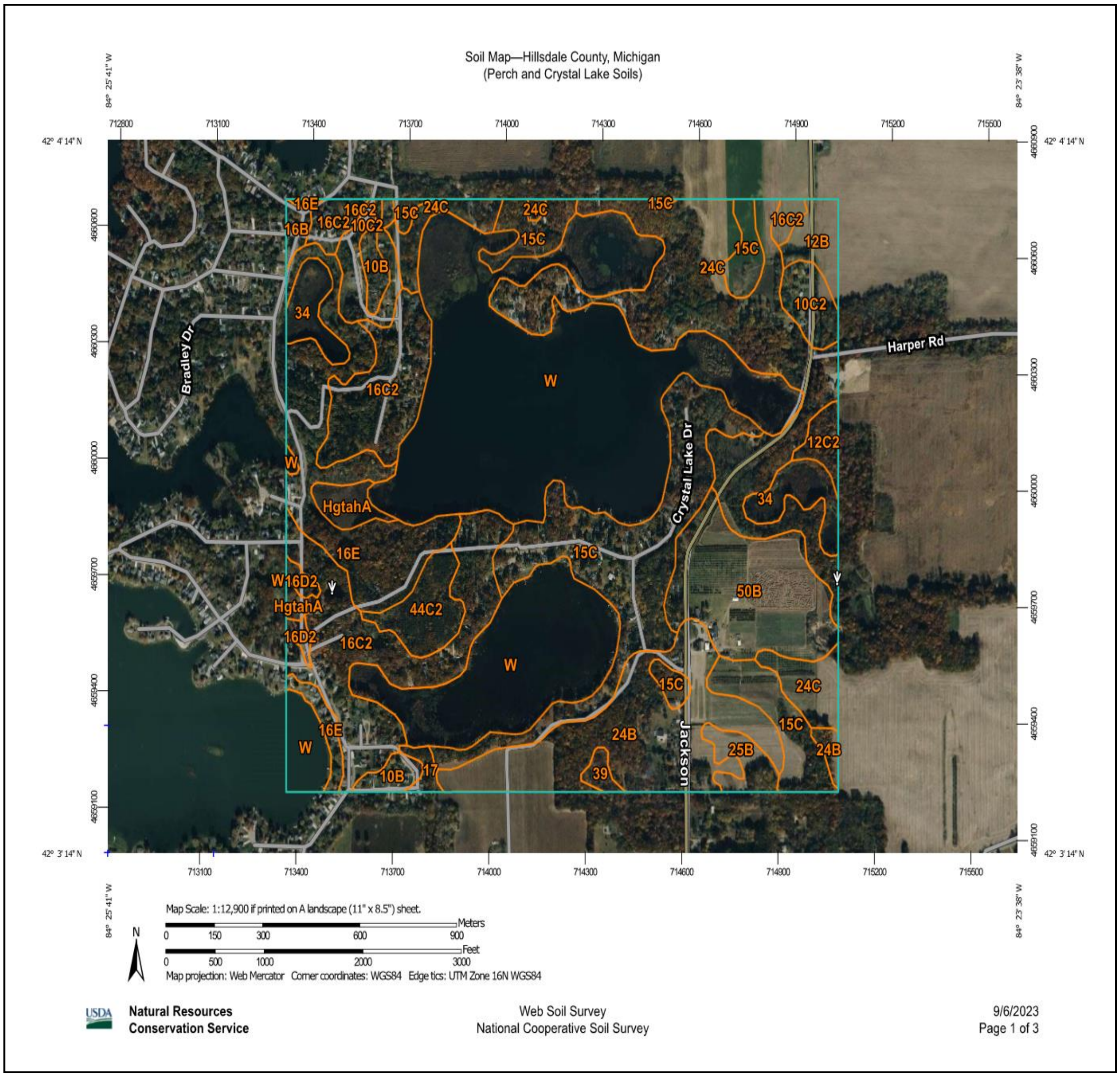


Figure 1. Perch and Crystal Lakes shoreline soils map (USDA-NRCS data).

Figure 2. Erosion on a Perch Lakefront property (NOTE: This photo is for demonstrative purposes and is not meant to implicate any fault).

3.0 PERCH AND CRYSTAL LAKES PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Perch and Crystal Lake Basins

Perch and Crystal Lake are both located in Somerset Township in Hillsdale County, Michigan (T.5S, R.1W, Section 3). The Perch Lake basin is comprised of 45 acres and the Crystal Lake basin consists of 129 acres at the current water levels (RLS, 2023). The Perch Lake basin has nearly 1.3 miles of shoreline and the Crystal Lake basin has nearly 3.7 miles of shoreline. The mean depth of the Perch Lake basin is approximately 5.9 feet, and the mean depth of the Crystal Lake basin is approximately 13.6 feet. The maximum depth of the Perch Lake basin is approximately 9.7 feet, and the maximum depth of the Crystal Lake basin is approximately 62.4 feet (RLS, 2023 bathymetric scan data; Figures 3-4).

The Perch Lake basin also has a fetch (longest distance across the lake) of around 0.5 miles and the Crystal Lake basin has a fetch of around 0.7 miles (RLS, 2023). The Perch Lake basin has an approximate water volume of 242.2 acre-feet and the Crystal Lake basin has an approximate water volume of 1,980.9 acre-feet (RLS, 2023 bathymetric data). Both lakes are classified as closed-basin systems, although Crystal Lake does drain into a wetland at the west end of the lake which may drain into Lake LeAnn during periods of intense rainfall. The immediate watershed, which is the area directly draining into the lakes, differs for each lake with Perch Lake being approximately 113.7 acres and Crystal Lake being is approximately 365.3 acres which is about 2.4 times the size of the lake for Perch Lake and about 2.5 times the size of the lake for Crystal Lake. Both immediate watersheds are considered small and favorable.

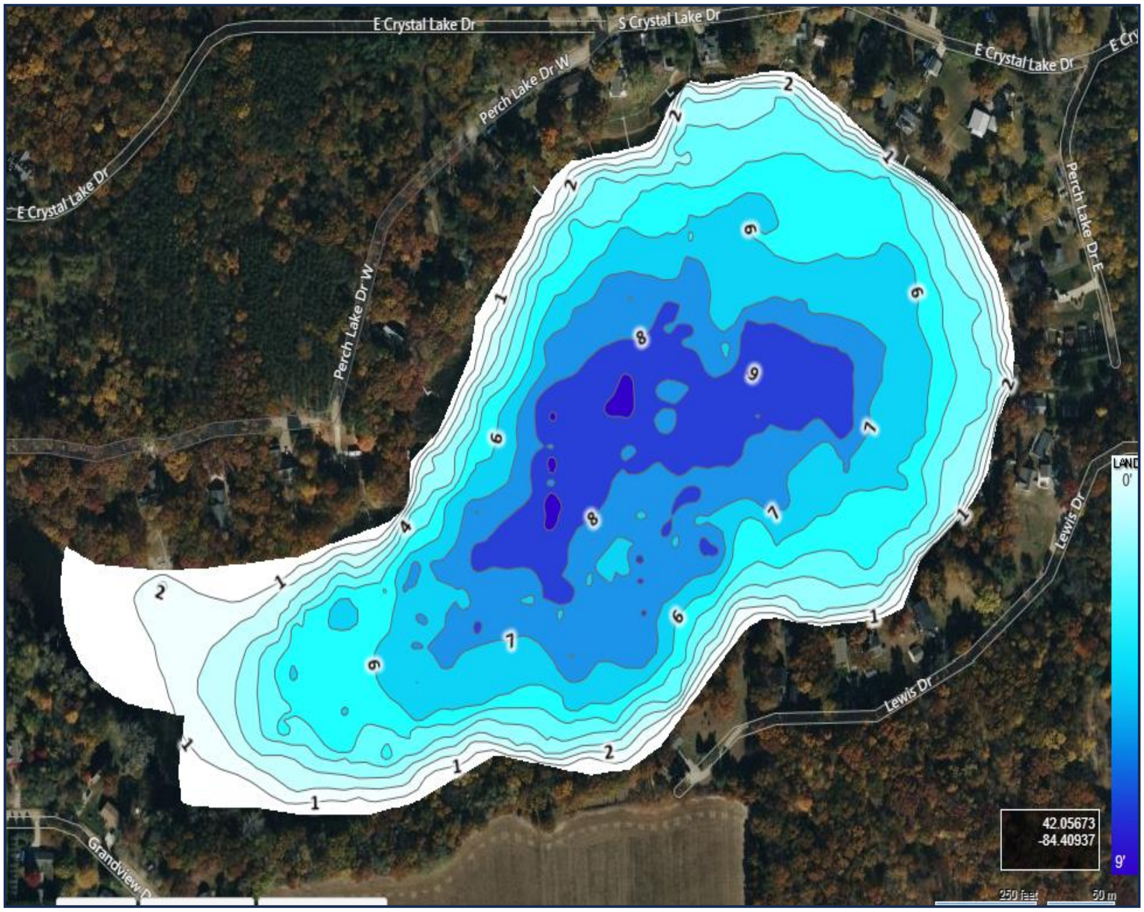


Figure 3. Perch Lake depth contour (bathymetric) map (RLS, 2023).

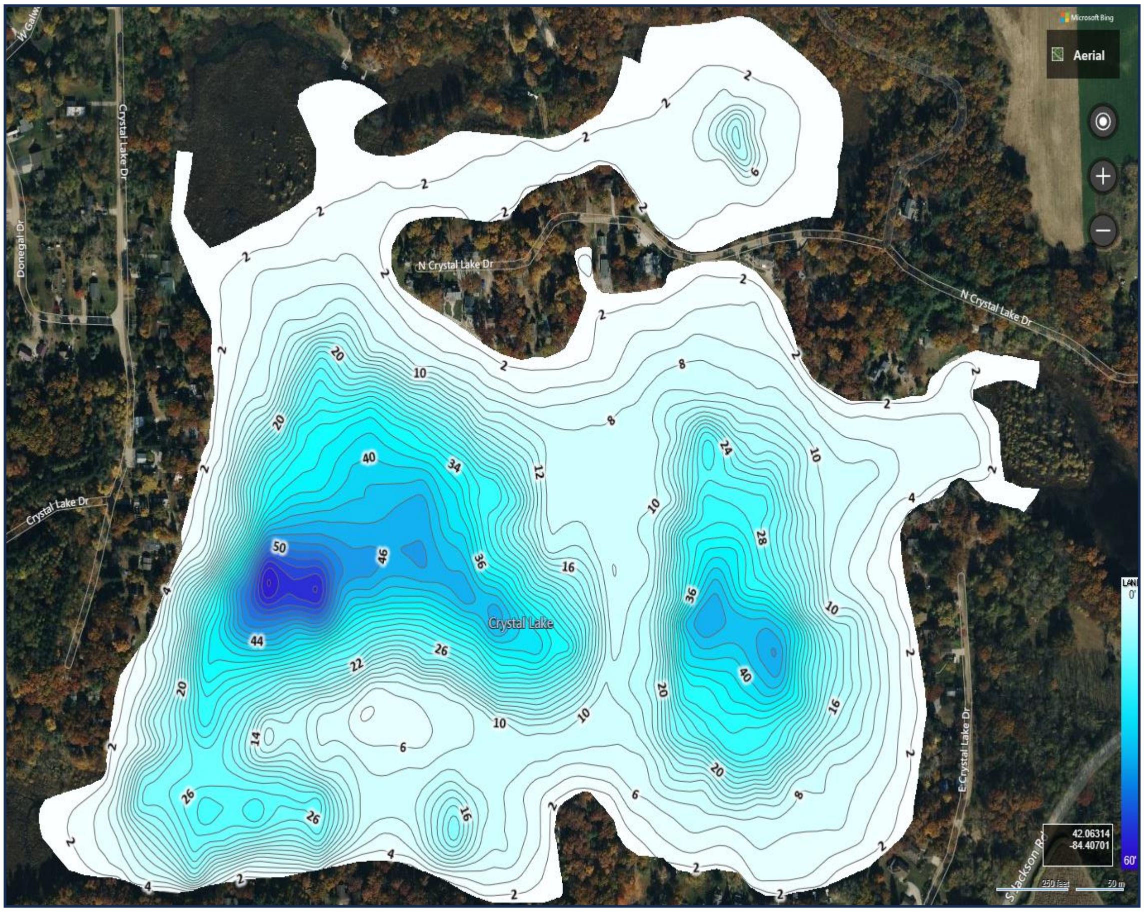


Figure 4. Crystal Lake depth contour (bathymetric) map (RLS, 2023).

Perch and Crystal Lakes Immediate Watersheds

A watershed is defined as an area of land that drains to a common point and is influenced by both surface water and groundwater resources that are often impacted by land use activities. In general, larger watersheds possess more opportunities for pollutants to enter the eco-system, altering the water quality and ecological communities. In addition, watersheds that contain abundant development and industrial sites are more vulnerable to water quality degradation from pollution which may negatively affect both surface and ground water. Since many inland lakes in Michigan are relatively small in size (i.e., less than 300 acres), they are inherently vulnerable to nutrient and pollutant inputs, due to the reduced water volumes and small surface areas. As a result, the living (biotic) components of the smaller lakes (i.e., fishery, aquatic plants, macro-invertebrates, benthic organisms, etc.) are highly sensitive to changes in water quality from watershed influences. Land use activities have a dramatic impact on the quality of surface waters and groundwater.

In addition, the topography of the land surrounding a lake may make it vulnerable to nutrient inputs and consequential loading over time. Topography and the morphometry of a lake dictate the ultimate fate and transport of pollutants and nutrients entering the lake. Surface runoff from the steep slopes surrounding a lake will enter a lake more readily than runoff from land surfaces at or near the same grade as the lake. In addition, lakes with steep drop-offs may act as collection basins for the substances that are transported to the lake from the land.

Land use activities, such as residential land use, industrial land use, agricultural land use, water supply land use, wastewater treatment land use, and storm water management, can influence the watershed of a particular lake. All land uses contribute to the water quality of the lake through the influx of pollutants from non-point sources (NPS) or from point sources. Non-point sources are often diffuse and arise when climatic events carry pollutants from the land into the lake. Point-source pollutants are discharged from a pipe or input device and empty directly into a lake or watercourse.

Residential land use activities involve the use of lawn fertilizers on lakefront lawns, the utilization of septic tank systems for treatment of residential sewage, the construction of impervious (impermeable, hard-surfaced) surfaces on lands within the watershed, the burning of leaves near the lakeshore, the dumping of leaves or other pollutants into storm drains, and removal of vegetation from the land and near the water. In addition to residential land use activities, agricultural practices by vegetable crop and cattle farmers may contribute nutrient loads to lakes and streams. Industrial land use activities may include possible contamination of groundwater through discharges of chemical pollutants.

Perch and Crystal Lakes are located within the Upper Grand River extended watershed (HUC 04050004) which is the headwaters of the Grand River. The watershed flows from Hillsdale County north through the City of Jackson, past Eaton Rapids, and through Lansing and Grand Rapids before exiting to Lake Michigan at Grand Haven. Major land uses in the extended watershed include agriculture, residential lands, forested lands, and wetlands. This information is valuable on a regional scale; however, it is at the immediate watershed scale that significant improvements can be made by the local Perch and Crystal lakes community.

The immediate watershed, which is the area directly draining into the lakes, differs for each lake with Perch Lake being approximately 113.7 acres and Crystal Lake being is approximately 365.3 acres which is about 2.4 times the size of the lake for Perch Lake and about 2.5 times the size of the lake for Crystal Lake. Both immediate watersheds are considered small and favorable. The lakes support a diverse application of land uses such as wetlands, beachfront for swimming, and agricultural and forested lands. Figures 5 and 6 below display the immediate watershed boundaries for both lakes.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5. Perch Lake immediate watershed boundary map (RLS, 2023).

Figure 6. Crystal Lake immediate watershed boundary map (RLS, 2023).

4.0 PERCH AND CRYSTAL LAKES WATER QUALITY

Water quality is highly variable among Michigan's inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by both land use practices and climatic events. Climatic factors (i.e. spring runoff, heavy rainfall) may alter water quality in the short term; whereas, anthropogenic (man-induced) factors (i.e. shoreline development, lawn fertilizer use) alter water quality over longer time periods. Since many lakes have a fairly long hydraulic residence time, the water may remain in the lake for years and is therefore sensitive to nutrient loading and pollutants. Furthermore, lake water quality helps to determine the classification of particular lakes (Table 3). Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a*, and low in transparency are classified as eutrophic (Figure 7); whereas those that are low in nutrients and chlorophyll-*a*, and high in transparency are classified as oligotrophic. Lakes that fall in between these two categories are classified as mesotrophic. Crystal Lake would be classified as a mesotrophic system given its elevated Secchi transparency, low nutrients at the surface and mid-depth, and low chlorophyll-*a*. Perch Lake would be considered meso-eutrophic given its lower Secchi transparency, high chlorophyll-*a*, and moderate to high nutrients and mid-depth and bottom depths.

Table 3. General Lake Trophic Status Classification.

Lake Trophic Status	*Total Phosphorus (mg L^{-1})*	*Chlorophyll-a (μg L^{-1})*	*Secchi Transparency (feet)*
Oligotrophic	< 0.010	< 2.2	> 15.0
Mesotrophic	0.010-0.025	2.2 – 6.0	7.5 – 15.0
Eutrophic	> 0.025	> 6.0	< 7.5

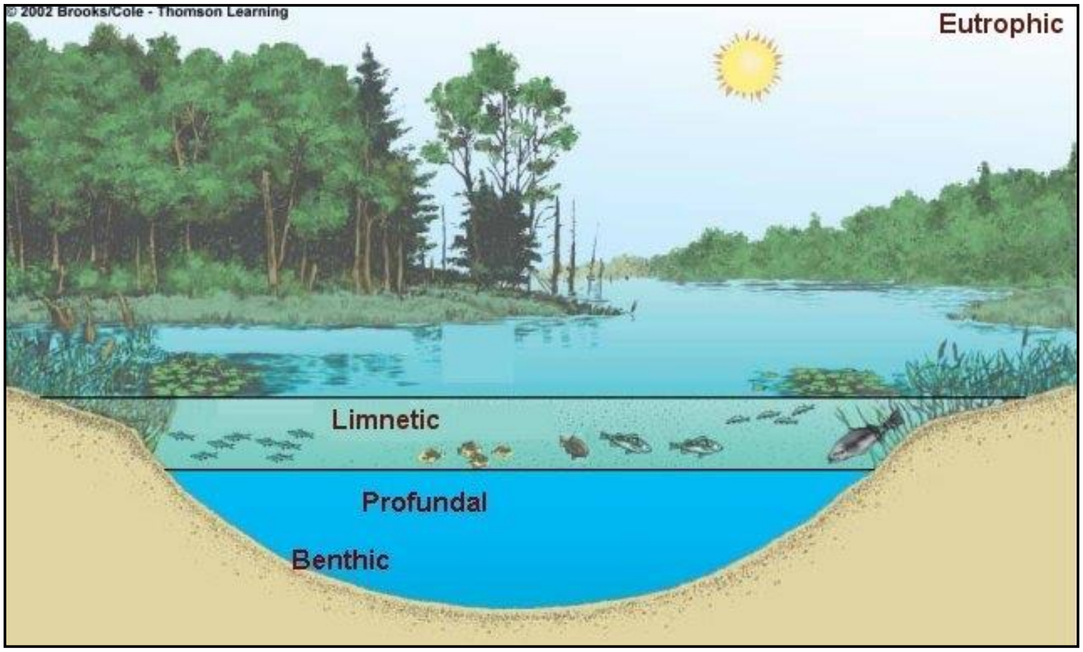


Figure 7. Diagram showing a eutrophic or nutrient-enriched lake ecosystem (photo adapted from Brooks/Cole Thomson learning online).

4.1 Water Quality Parameters Measured

Parameters such as dissolved oxygen (in mg/L), water temperature (in °C or °F), specific conductivity (mS/cm), total dissolved solids (mg/L), total suspended solids (mg/L), total alkalinity (mg/L $CaCO_3$), pH (S.U.), total phosphorus and ortho-phosphorus (also known as soluble reactive phosphorus or SRP measured in mg/L), total Kjeldahl nitrogen and total inorganic nitrogen (in mg/L), chlorophyll-a (in µg/L), and Secchi transparency (in feet) are parameters that respond to changes in water quality and consequently serve as indicators of change in lakes over time. The sampling locations for all water quality samples are shown below in Figures 8-9. All water samples and readings were collected at the deepest basins on July 25, 2023 with the use of a 3.2-liter Van Dorn horizontal water sampler and calibrated Eureka Manta II® multi-meter probe with parameter electrodes, respectively. All samples were taken to a NELAP-certified laboratory for analysis. In addition, 10 sediment samples were collected throughout both lakes (4 samples in Perch Lake and 6 samples in Crystal Lake) using an Ekman hand dredge on July 25, 2023. Sediment samples were analyzed for sediment organic matter (carbon) percentage in mg/kg. Specific sampling methods for each parameter are discussed in each parameter section below.

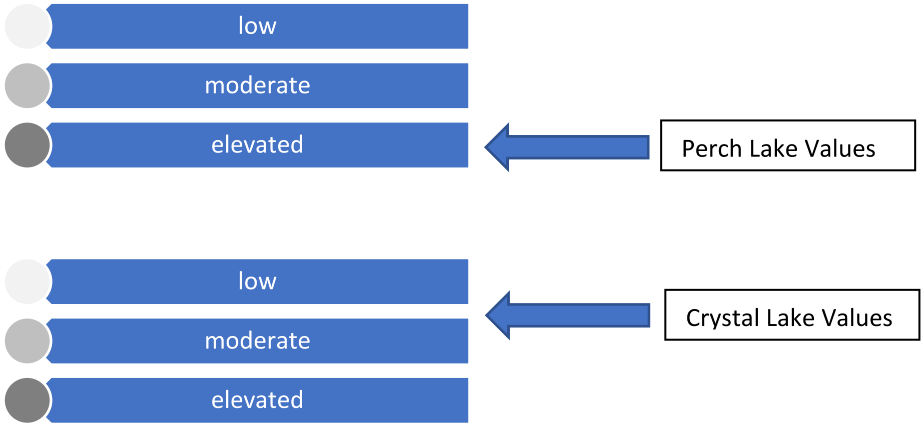
Figure 8. Perch Lake water quality sampling location map (July 25, 2023).

Figure 9. Crystal Lake water quality sampling location map (July 25, 2023).

4.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water column. In general, dissolved oxygen levels should be greater than 5 mg/L to sustain a healthy warm-water fishery. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. Dissolved oxygen was measured in milligrams per liter (mg/L) with the use of a calibrated Eureka Manta II® dissolved oxygen meter. The mean dissolved oxygen concentration in Perch Lake on July 25, 2023 was 9.2±0.6 mg/L which is excellent. Perch Lake did not exhibit any depletion in dissolved oxygen due to its shallow depths. The mean dissolved oxygen concentration in Crystal Lake on July 25, 2023 was only 3.8±3.8 mg/L and this is due to the fact that Crystal Lake loses oxygen rapidly beyond depths of 6.0-7.5 meters (19.7-24.6 feet). The surface and mid-depth dissolved oxygen concentrations were excellent. Given the maximum depth of the lake basins, most of this lake volume is then low in dissolved oxygen.

Although this is common for deep lakes, over time this could lead to water quality impairments where aeration may be necessary to increase overall dissolved oxygen concentrations. The bottom of the lake produces a biochemical oxygen demand (BOD) due to microbial activity attempting to break down high quantities of organic plant matter, which reduces dissolved oxygen in the water column at depth. Furthermore, the lake bottom is distant from the atmosphere where the exchange of oxygen occurs. A decline in the dissolved oxygen concentrations to near zero may result in an increase in the release rates of phosphorus (P) from lake bottom sediments.



4.1.2 Water Temperature

A lake’s water temperature varies within and among seasons, and is nearly uniform with depth under the winter ice cover because lake mixing is reduced when waters are not exposed to the wind. When the upper layers of water begin to warm in the spring after ice-off, the colder, dense layers remain at the bottom. This process results in a “thermocline” that acts as a transition layer between warmer and colder water layers. During the fall season, the upper layers begin to cool and become denser than the warmer layers, causing an inversion known as “fall turnover” (Figure 10). In general, shallow lakes will not stratify and deeper lakes may experience few turnover cycles. Water temperature was measured in degrees Celsius (ºC) with the use of a calibrated Eureka Manta II® submersible thermometer. Crystal Lake is deep enough to exhibit strong thermal stratification during the warm months, but Perch Lake remains isothermic with similar water temperatures from top to bottom.

The mean water temperature in Perch Lake on July 25, 2023 was 26.4±0.9°C which is normal during late July. The mean water temperature in Crystal Lake on July 25, 2023 was 14.4±7.7°C. Crystal Lake is much deeper than Perch Lake and thus it will inherently have lower mean water temperatures.

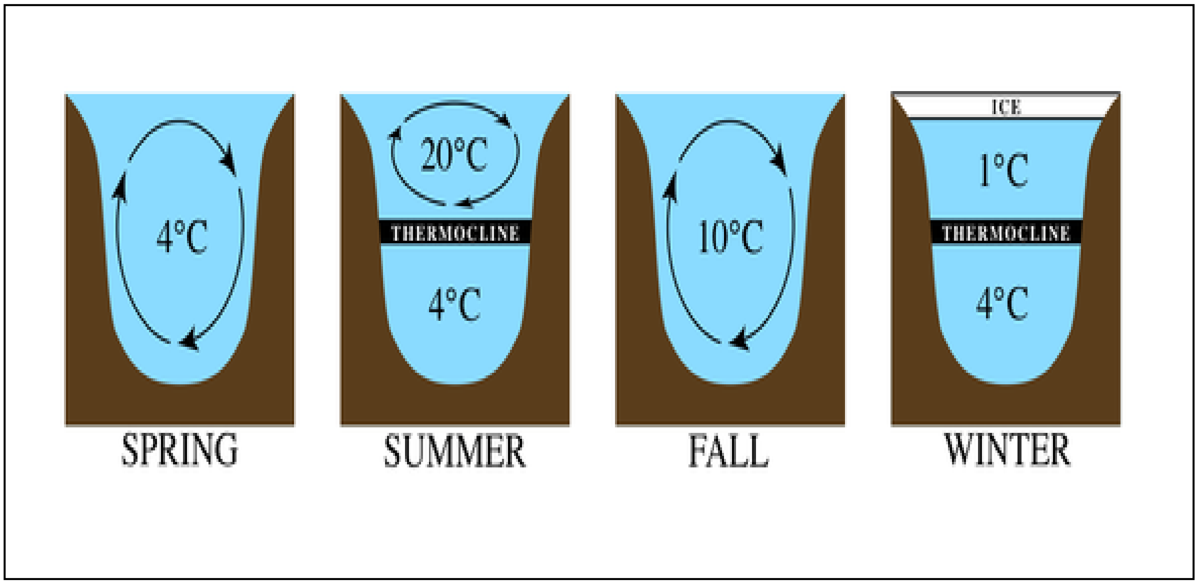
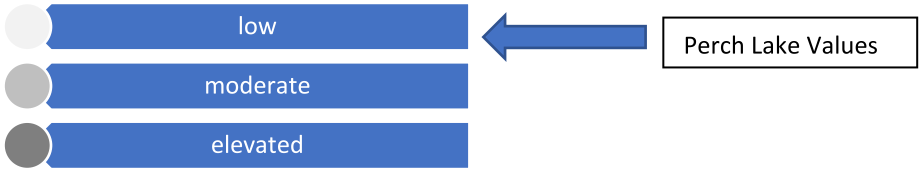


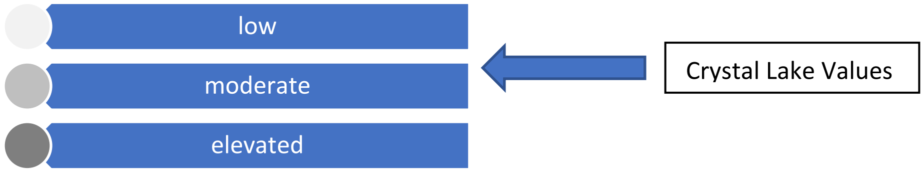
Figure 10. The lake thermal turnover process.

4.1.3 Specific Conductivity

Specific conductivity is a measure of the number of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Specific conductivity was measured in micro Siemens per centimeter (µS/cm) with the use of a calibrated Eureka Manta II® conductivity probe and meter. The mean conductivity value in Perch Lake on July 25, 2023 was 253±12 mS/cm which was favorable and the mean conductivity value in Crystal Lake on July 25, 2023 was 315±24 mS/cm which is moderate and favorable. Since these values are moderate for an inland lake, the lake water contains moderate quantities of dissolved metals and ions such as calcium, potassium, sodium, chlorides, sulfates, and carbonates.

Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on both lakes over a long period of time, or to trace the origin of a substance to the lake in an effort to reduce pollutant loading. Elevated conductivity values over 800 mS/cm can negatively impact aquatic life.



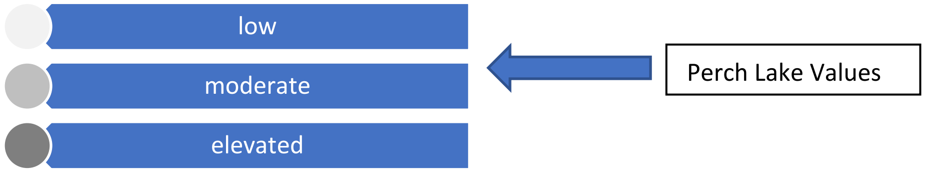


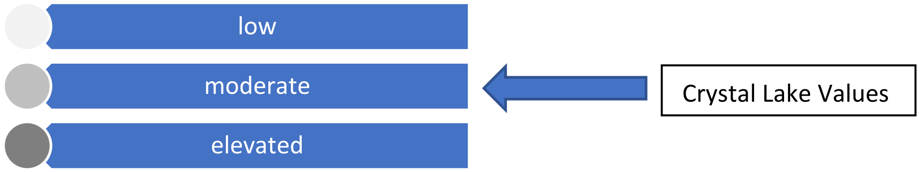
4.1.4 Total Dissolved Solids and Total Suspended Solids

Total Dissolved Solids

Total dissolved solids (TDS) are a measure of the amount of dissolved organic and inorganic particles in the water column. Particles dissolved in the water column absorb heat from the sun and raise the water temperature and increase conductivity.

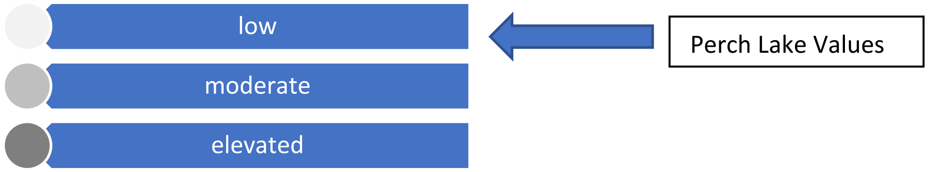
Total dissolved solids were measured with the use of a calibrated Eureka Manta II® meter in mg/L. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The mean TDS concentration in Perch Lake on July 25, 2023 was 166±8.0 mg/L and the mean TDS concentration in Crystal Lake on July 25, 2023 was 197±21.0 mg/L These values are moderate and favorable for an inland lake and correlates with the measured moderate conductivity.

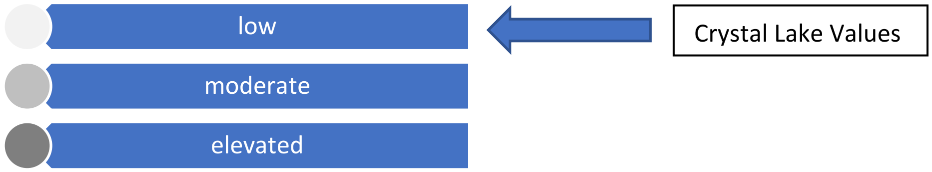




Total Suspended Solids (TSS)

Total suspended solids are a measure of the number of suspended particles in the water column. Particles suspended in the water column absorb heat from the sun and raise the water temperature. Total suspended solids were measured in mg/L and analyzed in the laboratory with Method SM 2540 D-11. The lake bottom contains many fine sediment particles that are easily perturbed from winds and wave turbulence. Spring values would likely be higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The mean TSS concentration in Perch Lake on July 25, 2023 was 10.0±0.0 mg/L and the mean TSS concentration in Crystal Lake on July 25, 2023 was 10.3±0.8 mg/L Ideally values should be < 10 mg/L. These means are considered favorable.





4.1.5 pH

pH is the measure of acidity or basicity of water. pH was measured with a calibrated Eureka Manta II© pH electrode and pH-meter in Standard Units (S.U). The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 7.0 to 9.5 S.U. Acidic lakes (pH< 7) are rare in Michigan and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC).

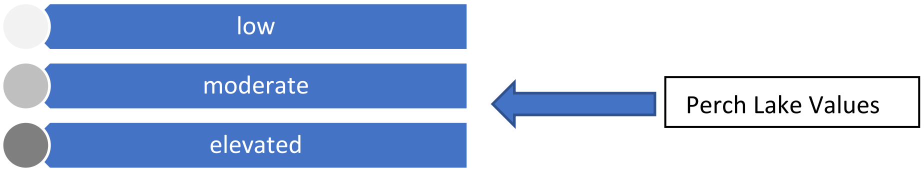
The mean pH value in Perch Lake on July 25, 2023 was 8.5±0.2 S.U. and the mean pH value in Crystal Lake on July 25, 2023 was 8.2±0.3 S.U. This range of pH is neutral to slightly alkaline on the pH scale and is ideal for an inland lake. pH tends to rise when abundant aquatic plants are actively growing through photosynthesis or when abundant marl deposits are present.

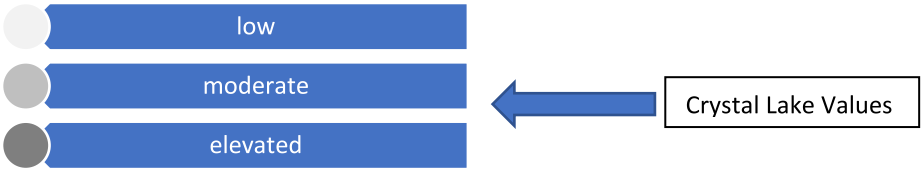
4.1.6 Total Phosphorus and Ortho-Phosphorus (SRP)

Total Phosphorus

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Lakes that contain greater than 0.020 mg/L of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to the higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Phosphorus may also be released from sediments as pH increases. Total phosphorus was measured in milligrams per liter (mg/L) with the use of Method EPA 200.7 (Rev. 4.4). The mean TP concentration in Perch Lake on July 25, 2023 was 0.071±0.1 mg/L which is elevated. The mean TP concentration in Crystal Lake on July 25, 2023 was 0.064±0.1 mg/L which is also elevated. The surface and mid depth concentrations of both lakes were well below the eutrophic threshold which is favorable. Measurement of only surface TP may underestimate the true trophic state of a particular lake.

These concentrations tend to be higher at the bottom depths and are indicative of internal loading of TP which means that the TP is accumulating in the lake bottom and is released when the dissolved oxygen level is low. This in turn re-circulates the TP throughout the lake and makes it constantly available for algae and aquatic plants to use for growth thereby contributing to lake eutrophication over time.

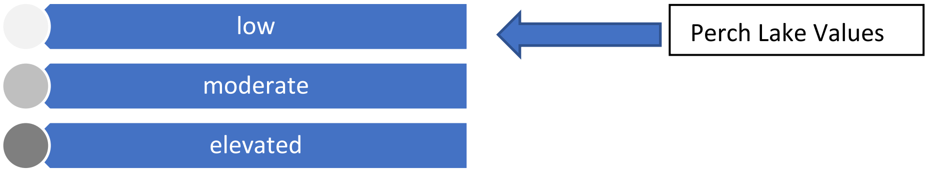


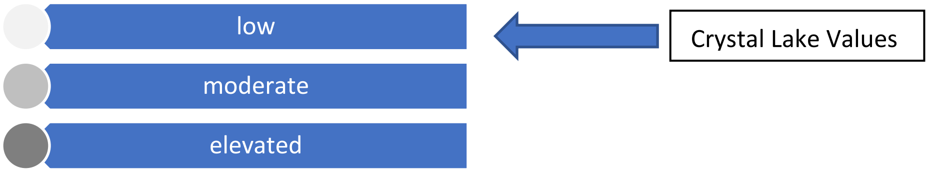


Ortho-Phosphorus

Ortho-Phosphorus (also known as soluble reactive phosphorus or SRP) was measured with Method SM 4500-P (E-11). SRP refers to the most bioavailable from of phosphorus used by all aquatic life.

The mean SRP concentration in Perch Lake on July 25, 2023 was 0.010±0.0 mg/L which is low and favorable. The mean SRP concentration in Crystal Lake on July 25, 2023 was 0.013±0.0 mg/L which is also low and favorable.





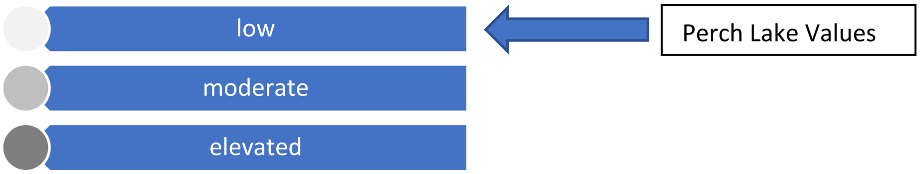
4.1.7 *Total Kjeldahl Nitrogen and Total Inorganic Nitrogen*

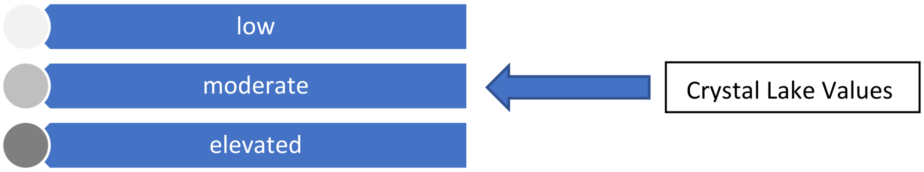
Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3^+), and organic nitrogen forms in freshwater systems. TKN was measured with Method EPA 351.2 (Rev. 2.0) and Total Inorganic Nitrogen (TIN) was calculated based on the aforementioned three different forms of nitrogen at Trace Analytical Laboratories, Inc. (a NELAC-certified laboratory). Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e., burning of fossil fuels), wastewater sources from developed areas (i.e., runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen (N: P > 15), phosphorus may be the limiting nutrient for phytoplankton and aquatic macrophyte growth. Alternatively, in lakes with low nitrogen concentrations (and relatively high phosphorus), the blue-green algae populations may increase due to the ability to fix nitrogen gas from atmospheric inputs. Lakes with a mean TKN value of 0.66 mg/L may be classified as oligotrophic, those with a mean TKN value of 0.75 mg /L may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg/L may be classified as eutrophic.

The mean TKN concentration in Perch Lake on July 25, 2023 was 0.9±0.3 mg/L which is favorable and the mean TKN concentration in Crystal Lake on July 25, 2023 was 0.8±0.4 mg/L, which is also favorable.

In the absence of dissolved oxygen, nitrogen is usually in the ammonia form and will contribute to rigorous submersed aquatic plant growth if adequate water transparency is present, which is the case in both lakes for part of the growing season.

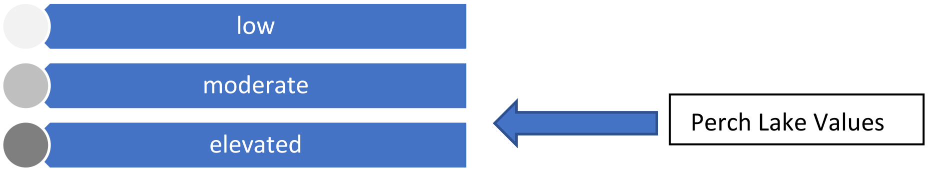
The total inorganic nitrogen (TIN) consists of nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3) forms of nitrogen without the organic forms of nitrogen. The mean TIN concentration in Perch Lake was 0.100±0.0 mg/L which is low and favorable. The mean TIN concentration in Crystal Lake was 0.385±0.4 mg/L which is moderate. The TIN concentration was higher at the bottom of Crystal Lake which is normal for deeper lakes since the bottom is a substantial site for biogeochemical cycling.

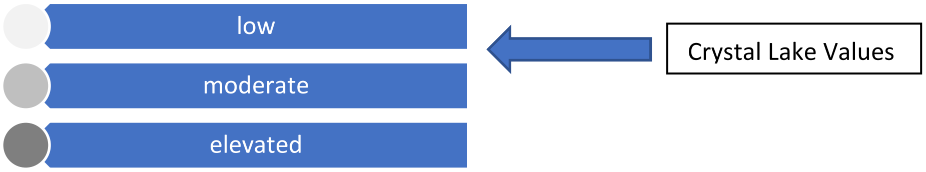




4.1.8 Chlorophyll-a and Algae

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. Chlorophyll-*a* water samples were collected with an integrated tube sampler and transferred to amber bottles preserved with Lugol's solution. Chlorophyll-*a* samples were collected at the two deepest basins of both lakes on July 25, 2023. High chlorophyll-a concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg/L are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg/L are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* was measured in micrograms per liter (µg/L) with an in situ fluorimeter. The chlorophyll-*a* concentrations in both lakes were determined by collecting composite (depth-integrated) samples of the algae throughout the water column (photic zone) at the deep basin sites from just above the lake bottom to the lake surface. The mean chlorophyll-*a* concentration in the deep basins of Perch Lake was 7.0±0.0 µg/L. The mean chlorophyll-*a* concentration in the deep basins of Crystal Lake was 2.0±0.0 µg/L. Based on this data; Perch Lake exhibits more primary production than Crystal Lake as it contains more algae.





To determine the presence of algal genera from the composite water samples collected from the deep basins of both lakes, 500 ml of preserved sample were collected, and a 1-mL subsample was placed to settle onto a Sedgewick-Rafter counting chamber. The ocular micrometer scale was calibrated. The samples were observed under a Zeiss® compound microscope at 400X magnification and scanned at 100X magnification to allow for the detection of a broad range of taxa present. All taxa were identified to Genus level. Phytoplankton samples were enumerated for the July 25, 2023 sampling event and are shown below in Tables 4-5. In both lakes, the green algae and the diatoms were the most abundant taxa with only a few blue-green algal cells present. Cyanobacteria (blue-green algae) have the distinct advantage of using nitrate and ammonia in the water (along with N_2 gas from the atmosphere) as food and can out-compete the green algae due to their faster growth rates and ability to be buoyant at the lake surface which reduces light to underlying algae.
Diatoms and green algae are the more favorable algal genera.

Table 4. Counts (# cells per 1 mL sub-sample) for each genera of algae found at each sampling location (n=2) in Perch Lake (July 25, 2023).

Taxa Present	**Type**	**DB1**	**DB2**
Cosmarium sp.	Green	2	9
Ulothrix sp.	Green	11	5
Mougeotia sp.	Green	13	7
Micrasterias sp.	Green	5	10
Chlorella sp.	Green	25	16
Navicula sp.	Diatom	6	1
Synedra sp.	Diatom	8	5
Stephanodiscus sp.	Diatom	1	0
Fragillaria sp.	Diatom	7	12
Oscillatoria sp.	Blue-Green	1	0

Note: G = green algae (Chlorophyta); BG = blue-green algae
(Cyanophyta); D = diatoms (Bacillariophyta).

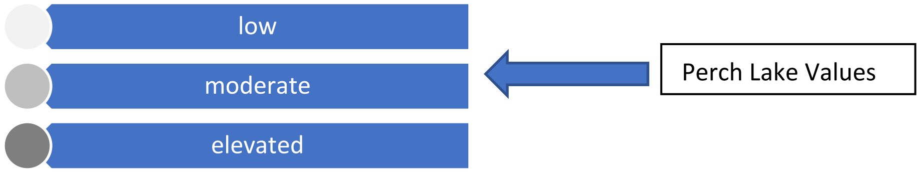
Table 5. Counts (# cells per 1 mL sub-sample) for each genera of algae found at each sampling location (n=2) in Crystal Lake (July 25, 2023).

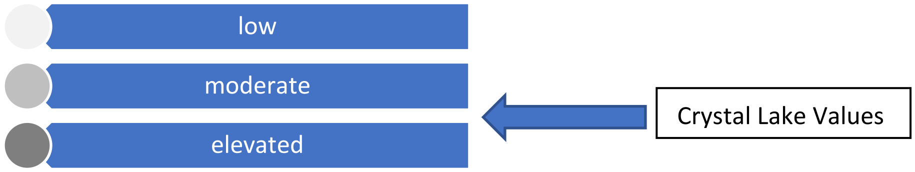
Taxa Present	Type	DB1	DB2
Chlorella sp.	Green	2	6
Ulothrix sp.	Green	5	1
Scenedesmus sp.	Green	13	9
Synedra sp.	Diatom	11	6
Navicula sp.	Diatom	8	4
Stephanodiscus sp.	Diatom	1	3
Rhoicosphenia sp.	Diatom	3	0
Diatoma asp.	Diatom	2	5
Oscillatoria sp.	Blue-Green	0	1

Note: G = green algae (Chlorophyta); BG = blue-green algae (Cyanophyta); D = diatoms (Bacillariophyta).

4.1.9 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and is measured with the use of an 8-inch diameter standardized Secchi disk during calm to light wind conditions. Secchi disk transparency is measured in feet (ft.) or meters (m) by lowering the disk over the shaded side of a boat around noon and taking the mean of the measurements of disappearance and reappearance of the disk (Figure 11). Elevated Secchi transparency readings allow for more aquatic plant and algae growth. Eutrophic systems generally have Secchi disk transparency measurements less than 7.5 feet due to turbidity caused by excessive planktonic algae growth. The mean Secchi transparency of Perch Lake on July 25, 2023 was 6.9±0.1feet which is moderately favorable. The mean Secchi transparency of Crystal Lake on July 25, 2023 was 11.9±0.7 feet which is good. Solids such as suspended particles and algae are present throughout the water column and can increase turbidity and reduce water clarity. Secchi transparency is variable and depends on the amount of suspended particles in the water (often due to windy conditions of lake water mixing) and the amount of sunlight present at the time of measurement.





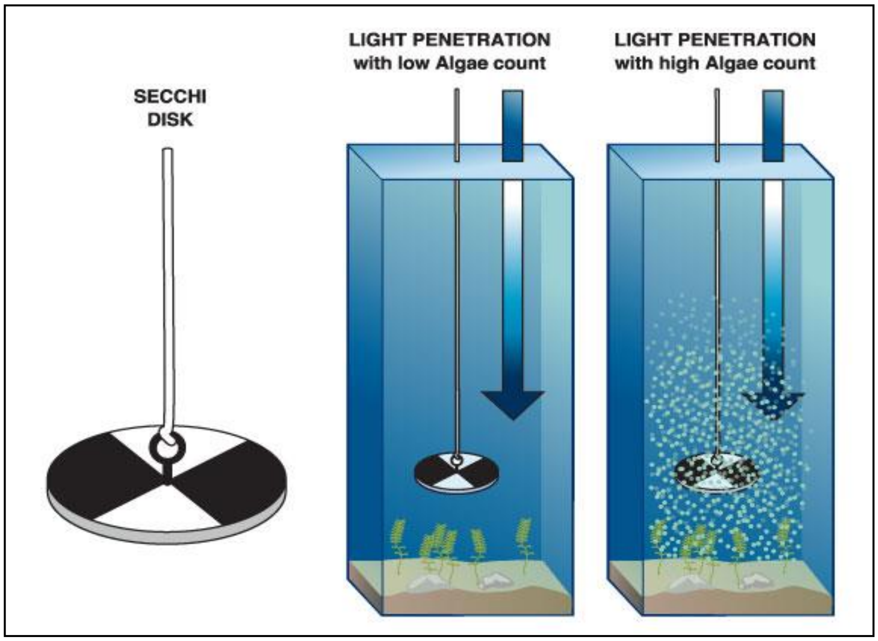


Figure 11. Measurement of water transparency with a Secchi disk.

4.1.10 Total Alkalinity

Total alkalinity is a measure of the pH-buffering capacity of lake water. Lakes with high alkalinity (> 150 mg/L of $CaCO_3$) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of $CaCO_3$ and are categorized as having "hard" water. Total alkalinity was measured in milligrams per liter of $CaCO_3$ through the acid titration Method SM 2320 B-11.

Total alkalinity in the deep basin of Perch Lake averaged 87.5±1.6 mg/L $CaCO_3$ and the total alkalinity in Crystal Lake averaged 122±15 mg/L $CaCO_3$. These values represent a moderate alkalinity and may be a characteristic of the lake sediments and geology. Total alkalinity may change on a daily basis due to the re-suspension of sedimentary deposits in the water and respond to seasonal changes due to the cyclic turnover of the lake water.

4.1.11 Sediment Organic Carbon & Bottom Hardness

Organic matter (OM) contains a high amount of carbon which is derived from biota such as decayed plant and animal matter. Detritus is the term for all dead organic matter which is different than living organic and inorganic matter. OM may be autochthonous or allochthonous in nature where it originates from within the system or external to the system, respectively. Sediment OM is measured with the ASTM D2974 Method and is usually expressed in a percentage (%) of total bulk volume. Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present.

There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then fermented to alcohol, CO_2, or CH_4. Second, proteins may be proteolyzed to amino acids, deaminated to NH_3+, nitrified to NO_2- or NO_3-, and denitrified to N_2 gas. Bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979).

The organic content of Perch Lake sediment averaged 37.8±18.9% and ranged from 14-54% organic matter which is highly variable and not uncommon in post-glacial lakes. The organic content of Crystal Lake sediment averaged 30.7±11.1% and ranged from 11-40%.

A bottom sediment hardness scan was conducted of the entire lake bottoms of both lakes on July 25, 2023. The bottom hardness map for Perch Lake shows (Figure 12) that most of the lake bottom consists of moderately soft sediment throughout the lake with a few areas of more consolidated sediments. The same pattern is present for the Crystal Lake sediments (Figure 13). Tables 6 and 7 below show the categories of relative bottom hardness with 0.0-0.1 referring to the softest and least consolidated bottom and >0.4 referring to the hardest, most consolidated bottom for the two lake basins. This scale does not mean that any of the lake contains a truly “hard” bottom but rather a bottom that is more cohesive and not flocculent. Locations for sediment sampling in Perch and Crystal lakes are shown below in Figures 14 and 15. Sediment percentage of organic carbon (muck) data are displayed in Tables 8 and 9 below.

All physical and chemical water quality data for the deep basins of both lakes are displayed below in Tables 10-17 with statistical means and standard deviations for all water quality parameter data in Tables 18 and 19.

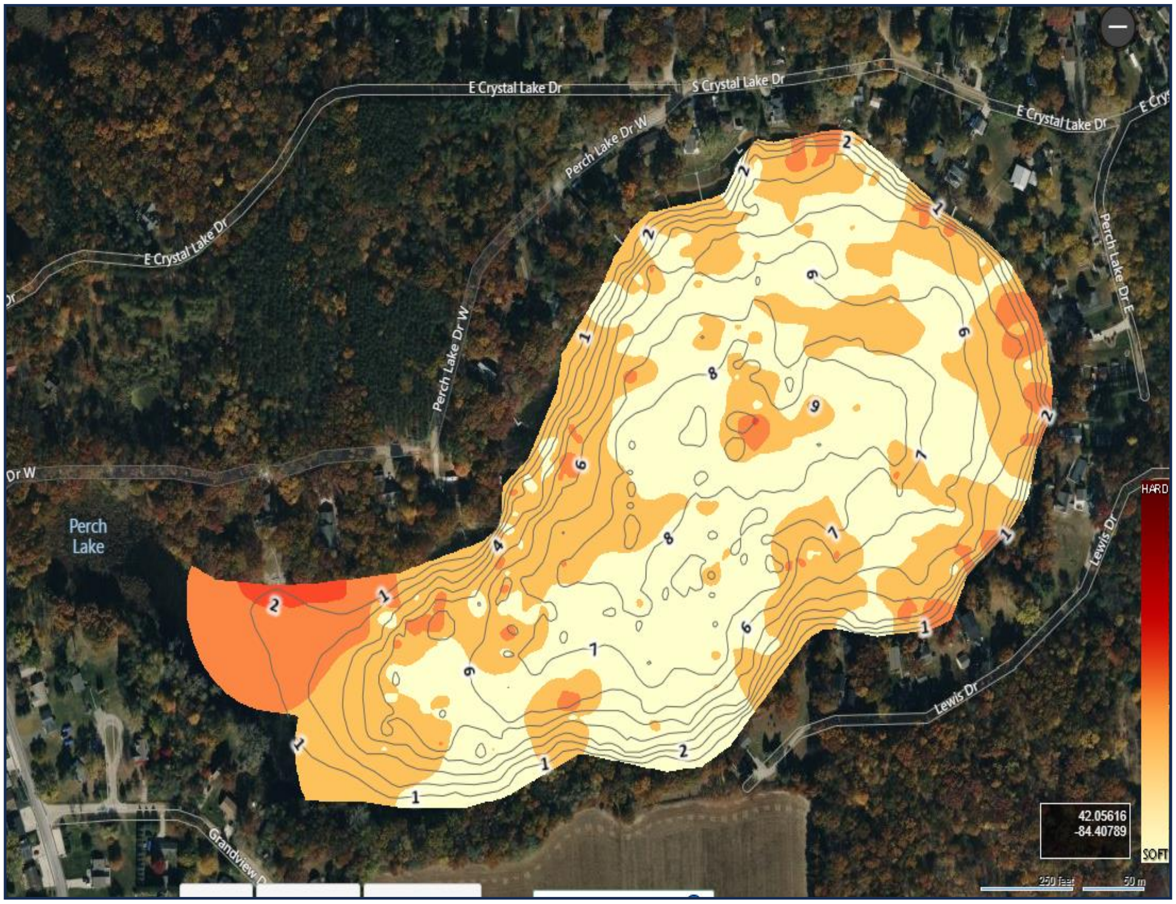


Figure 12. Perch Lake sediment relative hardness map (RLS, 2023).

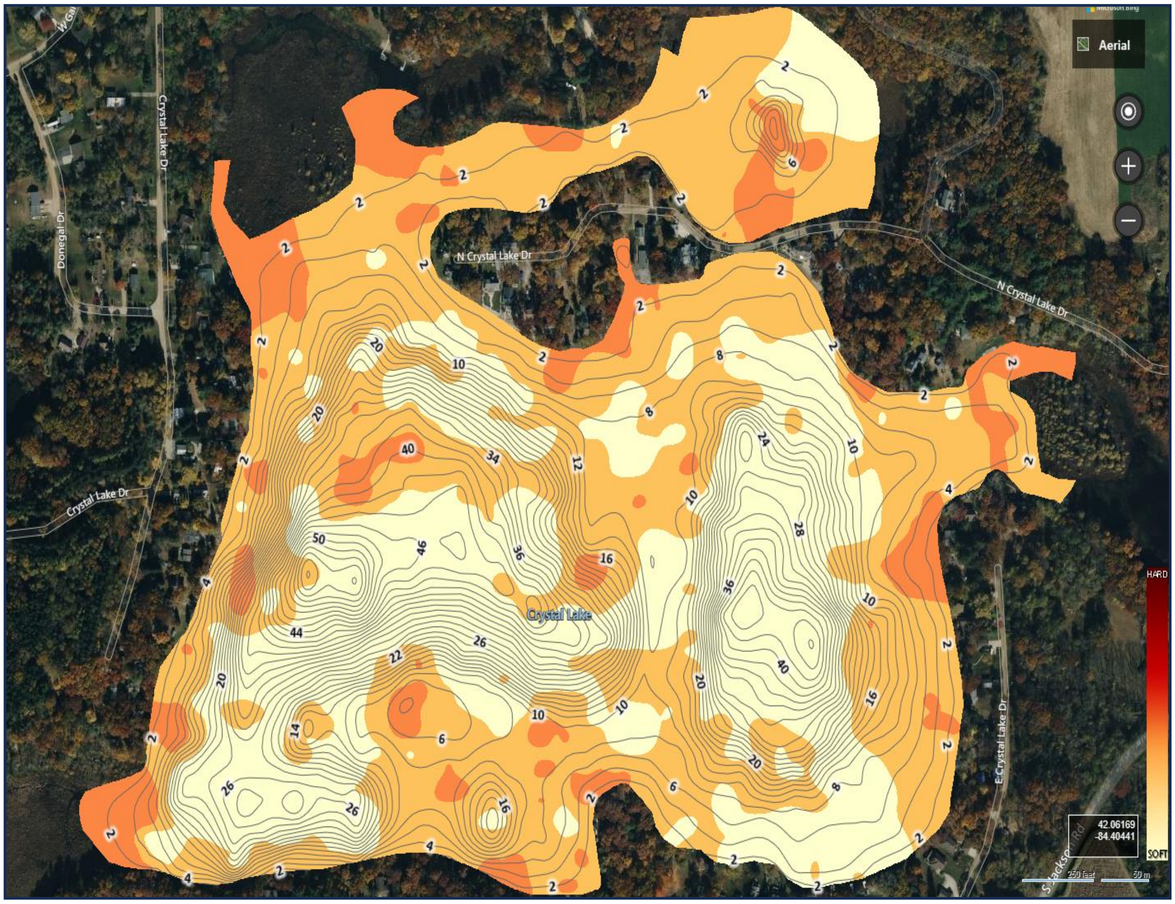


Figure 13. Crystal Lake sediment relative hardness map (RLS, 2023).

Table 6. Perch Lake basin relative hardness of the lake bottom by category or hardness and percent cover of each category (relative cover) on July 25, 2023.

Lake Bottom Relative Hardness Category	# GPS Points in Each Category (Total =12,817)	% Relative Cover of Bottom by Category
0.0-0.1	90	0.70
0.1-0.2	6,092	47.5
0.2-0.3	5,901	46.1
0.3-0.4	713	5.6
>0.4	21	0.2

Table 7. Crystal Lake basin relative hardness of the lake bottom by category or hardness and percent cover of each category (relative cover) on July 25, 2023.

Lake Bottom Relative Hardness Category	# GPS Points in Each Category (Total =4,068)	% Relative Cover of Bottom by Category
0.0-0.1	39	1.0
0.1-0.2	1536	37.8
0.2-0.3	2342	57.6
0.3-0.4	151	3.7
>0.4	0	0.0

Figure 14. Perch Lake sediment organic carbon sampling location map (July 25, 2023).

Figure 15. Perch Lake sediment organic carbon sampling location map (July 25, 2023).

Table 8. Perch Lake sediment organic carbon data (July 25, 2023).

Sediment Sample #	% Organic Carbon
S7	52
S8	54
S9	14
S10	31

Table 9. Crystal Lake sediment organic carbon data (July 25, 2023).

Sediment Sample #	% Organic Carbon
S1	**34**
S2	**34**
S3	**25**
S4	**40**
S5	**40**
S6	**11**

Table 10. Perch Lake deep basin #1 physical water quality parameter data collected on July 25, 2023

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	27.9	9.0	8.4	244	161	7.0
0.5	26.9	9.1	8.5	242	161	
1.0	26.3	9.3	8.6	245	161	
1.5	26.1	9.3	8.6	245	163	
2.0	26.0	9.0	8.7	245	164	
2.5	25.6	8.0	8.4	256	176	

Table 11. Perch Lake deep basin #1 chemical water quality parameter data collected on July 25, 2023.

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH_3 (mg/L)	NO_3- (mg/L)	Talk (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	0.9	0.100	0.010	0.100	89	<10	0.019	<0.010	7.0
1.5	0.8	0.100	0.010	0.100	89	<10	0.028	<0.010	
2.5	0.8	0.100	0.016	0.100	89	<10	0.220	<0.010	

Table 12. Perch Lake deep basin #2 physical water quality parameter data collected on July 25, 2023

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	28.0	8.9	8.3	253	174	6.8
0.5	26.4	10.0	8.6	254	158	
1.0	26.4	10.0	8.7	263	162	
1.5	25.8	10.0	8.8	258	168	
2.0	24.8	8.6	8.4	282	182	

Table 13. Perch Lake deep basin #2 chemical water quality parameter data collected on July 25, 2023.

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH_3 (mg/L)	NO_3^- (mg/L)	Talk (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (μg/L)
0	0.8	0.100	0.010	0.100	86	<10	0.022	<0.010	7.0
1.0	0.8	0.100	0.010	0.100	86	<10	0.024	<0.010	
2.0	1.5	0.100	0.010	0.100	86	<10	0.110	<0.010	

Table 14. Crystal Lake deep basin #1 physical water quality parameter data collected on July 25, 2023

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	26.1	8.3	8.2	309	192	12.4
0.5	25.8	8.3	8.3	309	192	
1.0	25.5	8.4	8.4	308	192	
1.5	25.4	8.4	8.4	308	192	
2.0	25.3	8.5	8.5	308	192	
2.5	25.2	8.5	8.5	308	193	
3.0	25.1	8.4	8.5	308	192	
3.5	24.9	8.3	8.5	309	193	
4.0	23.1	8.2	8.5	311	194	
4.5	20.7	8.3	8.5	306	190	
5.0	17.9	8.1	8.4	304	189	
5.5	15.7	6.2	8.4	303	189	
6.0	14.4	4.7	8.4	303	189	
6.5	13.2	3.7	8.4	302	188	
7.0	12.2	2.1	8.4	305	189	
7.5	11.5	0.6	8.4	306	190	
8.0	10.8	0.3	8.3	305	189	
8.5	10.3	0.2	8.3	303	189	
9.0	9.2	0.1	8.3	302	189	
9.5	9.1	0.1	8.3	305	189	
10.0	8.7	0.0	8.3	305	189	
10.5	8.3	0.0	8.3	303	189	
11.0	7.8	0.0	8.3	303	189	
11.5	7.4	0.0	8.3	306	191	
12.0	7.1	0.0	8.2	310	193	
12.5	6.9	0.0	8.2	314	196	
13.0	6.8	0.0	8.1	318	198	
13.5	6.7	0.0	8.0	320	201	
14.0	6.7	0.0	8.0	323	203	
14.5	6.7	0.0	8.0	324	203	
15.0	6.7	0.0	8.0	324	203	
15.5	6.6	0.0	7.9	325	204	
16.0	6.6	0.0	7.8	327	206	
16.5	6.6	0.0	7.8	327	206	
17.0	6.6	0.0	7.7	331	208	
17.5	6.6	0.0	7.7	331	208	
18.0	6.6	0.0	7.7	336	211	
18.5	6.6	0.0	7.7	443	308	
19.0	6.6	0.0	7.7	443	308	

Table 15. Crystal Lake deep basin #1 chemical water quality parameter data collected on July 25, 2023.

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH_3 (mg/L)	NO_3- (mg/L)	Talk (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	0.5	0.100	0.010	0.100	110	<10	<0.010	<0.010	2.0
9.5	0.7	0.200	0.200	0.100	110	<10	<0.010	<0.010	
19.0	1.6	1.2	1.2	0.100	110	12	0.120	0.025	

Table 16. Crystal Lake deep basin #2 physical water quality parameter data collected on July 25, 2023

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	26.9	8.1	7.7	311	194	11.4
0.5	26.3	8.1	8.0	310	193	
1.0	26.3	8.2	8.2	310	193	
1.5	25.9	8.3	8.3	310	193	
2.0	25.6	8.3	8.3	311	194	
2.5	25.6	8.3	8.3	309	192	
3.0	25.4	8.2	8.4	310	193	
3.5	25.1	8.2	8.4	309	193	
4.0	24.5	8.2	8.4	312	194	
4.5	22.8	8.5	8.4	307	192	
5.0	19.6	8.5	8.3	305	191	
5.5	17.9	8.1	8.2	301	188	
6.0	15.7	7.9	8.2	301	188	
6.5	14.1	7.5	8.1	301	188	
7.0	12.9	6.2	8.1	302	188	
7.5	12.2	5.2	8.1	303	189	
8.0	11.5	3.7	8.1	305	189	
8.5	11.1	3.0	8.0	310	192	
9.0	10.8	2.1	8.0	311	192	
9.5	10.0	1.5	8.0	312	193	
10.0	9.4	1.1	7.9	311	192	
10.5	8.8	0.9	7.9	312	193	
11.0	8.6	0.7	7.9	312	193	
11.5	8.2	0.6	7.9	314	193	
12.0	7.9	0.5	7.8	317	195	
12.5	7.7	0.4	7.8	322	200	
13.0	7.6	0.3	7.7	324	202	

Table 17. Crystal Lake deep basin #2 chemical water quality parameter data collected on July 25, 2023.

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH_3 (mg/L)	NO_3- (mg/L)	Talk (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	0.6	0.100	0.010	0.100	120	<10	<0.010	<0.010	2.0
6.5	<0.5	0.100	0.024	0.100	140	<10	0.015	<0.010	
13.0	1.1	0.610	0.610	0.100	140	<10	0.220	<0.010	

Table 18. Descriptive statistics of all water quality parameters in the Perch Lake basin collected on July 25, 2023.

Water Quality Parameter	Means ± SD
Water temp (°C)	26.4±0.9
pH (S.U.)	8.5±0.2
Dissolved oxygen (mg/L)	9.2±0.6
Conductivity (mS/cm)	253±12
Total dissolved solids (mg/L)	166±8.0
Secchi transparency (ft)	6.9±0.1
Chlorophyll-*a* (µg/L)	7.0±0.0
Total Kjeldahl nitrogen (mg/L)	0.9±0.3
Total inorganic nitrogen (mg/L)	0.100±0.0
Ammonia nitrogen (mg/L)	0.011±0.0
Nitrate nitrogen (mg/L)	0.100±0.0
Nitrite nitrogen (mg/L)	0.100±0.0
Total alkalinity (mg/L $CaCO_3$)	87.5±1.6
Total phosphorus (mg/L)	0.071±0.1
Ortho-Phosphorus (mg/L)	0.010±0.0
Total suspended solids (mg/L)	10±0.0

Table 19. Descriptive statistics of all water quality parameters in the Crystal Lake basin collected on July 25, 2023.

Water Quality Parameter	Means ± SD
Water temp (°C)	14.4±7.7
pH (S.U.)	8.2±0.3
Dissolved oxygen (mg/L)	3.8±3.8
Conductivity (mS/cm)	315±24
Total dissolved solids (mg/L)	197±21
Secchi transparency (ft)	11.9±0.7
Chlorophyll-*a* (μg/L)	2.0±0.0
Total Kjeldahl nitrogen (mg/L)	0.8±0.4
Total inorganic nitrogen (mg/L)	0.100±0.0
Ammonia nitrogen (mg/L)	0.342±0.5
Nitrate nitrogen (mg/L)	0.100±0.0
Nitrite nitrogen (mg/L)	0.100±0.0
Total alkalinity (mg/L $CaCO_3$)	122±15.0
Total phosphorus (mg/L)	0.064±0.0
Ortho-Phosphorus (mg/L)	0.013±0.0
Total suspended solids (mg/L)	10.3±0.8

4.2 Perch and Crystal Lake Aquatic Vegetation Communities

Aquatic plants (macrophytes) are an essential component in the littoral zones of most lakes in that they serve as suitable habitat and food for macroinvertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (if in the rooted growth form), and contribute to the cycling of nutrients such as phosphorus and nitrogen upon decay. In addition, decaying aquatic plants contribute organic matter to lake sediments which further supports healthy growth of successive aquatic plant communities that are necessary for a balanced aquatic ecosystem. An overabundance of aquatic vegetation may cause organic matter to accumulate on the lake bottom faster than it can break down. Aquatic plants generally consist of rooted submersed, free-floating submersed, floating-leaved, and emergent growth forms. The emergent growth form (i.e., Cattails, Native Loosestrife) is critical for the diversity of insects onshore and for the health of nearby wetlands. Submersed aquatic plants can be rooted in the lake sediment (i.e., Milfoils, Pondweeds), or free-floating in the water column (i.e., Coontail). Nonetheless, there is evidence that the diversity of submersed aquatic macrophytes can greatly influence the diversity of macroinvertebrates associated with aquatic plants of different structural morphologies (Parsons and Matthews, 1995). Therefore, it is possible that declines in the biodiversity and abundance of submersed aquatic plant species and associated macroinvertebrates, could negatively impact the fisheries of inland lakes.

Alternatively, the overabundance of aquatic vegetation can compromise recreational activities, aesthetics, and property values. Perch Lake currently has a moderately high quantity of submersed aquatic vegetation which can lead to recreational and navigational issues. Over-management of the native aquatic vegetation is not advised, however, as it will only encourage excess growth by algae since the latter competes with the vegetation for vital water column nutrients. Crystal Lake has an ideal quantity of aquatic vegetation which is limited by its greater depth.

A whole-lake scan of the aquatic vegetation biovolume in both lakes was conducted on June 13, 2023 with a WAAS-enabled Lowrance HDS 9 GPS with variable frequency transducer. This data included 12,817 data points on Perch Lake and 4,068 data points on Crystal Lake. There were more points on the smaller Perch Lake due to its shallow depths and hence more vegetation cover. Points were then uploaded into a cloud software program to reveal maps that displayed depth contours, sediment hardness, and aquatic vegetation biovolume (Figures 16-17). On these maps, the color blue refers to areas that lack vegetation. The color green refers to low-lying vegetation. The colors red/orange refer to tall-growing vegetation. There are many areas around the littoral (shallow) zone of the lakes that contain low-growing plants like Chara. In addition, any emergent canopies or lily pads will show as red color on the map. For this reason, the scans are conducted in conjunction with a whole lake GPS survey to account for individual species identification of all aquatic plants in the lake. Tables 20 and 21 show the biovolume categories by plant cover during the June 13, 2023 scan and survey.

The Point-Intercept Survey method is used to assess the presence and percent cumulative cover of submersed, floating-leaved, and emergent aquatic vegetation within and around the littoral zones of inland lakes. With this survey method, sampling locations are geo-referenced (via GPS waypoints) and assessed throughout the entire lake to determine the species of aquatic macrophytes present and density of each macrophyte which are recorded onto a data sheet. Each separate plant species found in each sampling location is recorded along with an estimate of each plant density. Each macrophyte species corresponds to an assigned number. There are designated density codes for the aquatic vegetation surveys, where a = found (occupying < 2% of the surface area of the lake), b = sparse (occupying 2-20% of the surface area of the lake), c = common, (occupying 21-60% of the surface area of the lake), and d = dense (occupying > 60% of the surface area of the lake).

The survey of Perch Lake consisted of 280 sampling locations around the littoral zone and the survey of Crystal Lake consisted of 204 sampling locations. More sampling stations were required in Perch Lake due to the larger littoral zone (shallow area). Data were placed in a table showing the relative abundance of each aquatic plant species found and a resultant calculation showing the frequency of each plant, and cumulative cover.

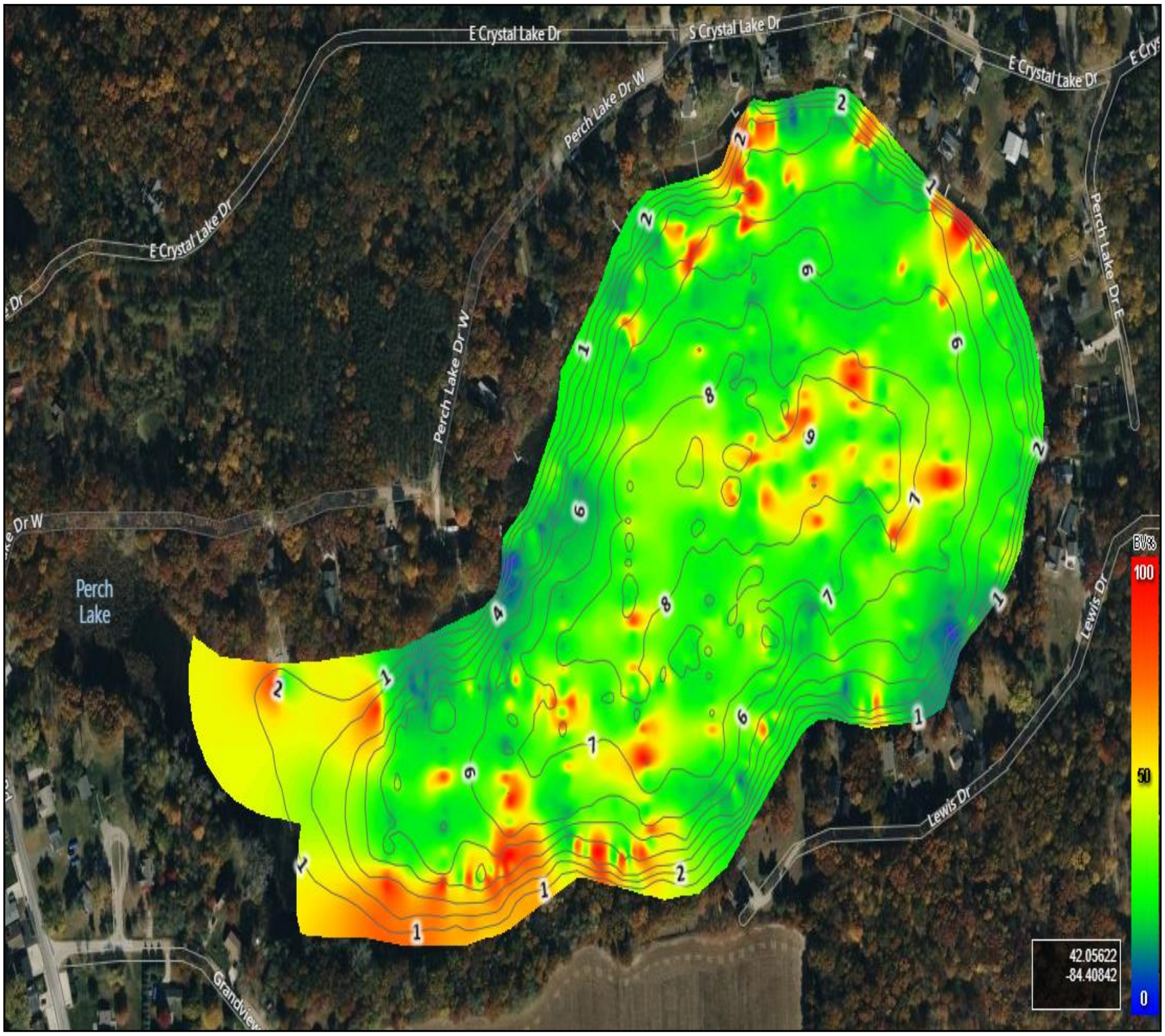


Figure 16. Aquatic plant biovolume of all aquatic plants in Perch Lake, Hillsdale County, Michigan (June 13, 2023). Note: Red color denotes high-growing aquatic plants, green color denotes low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

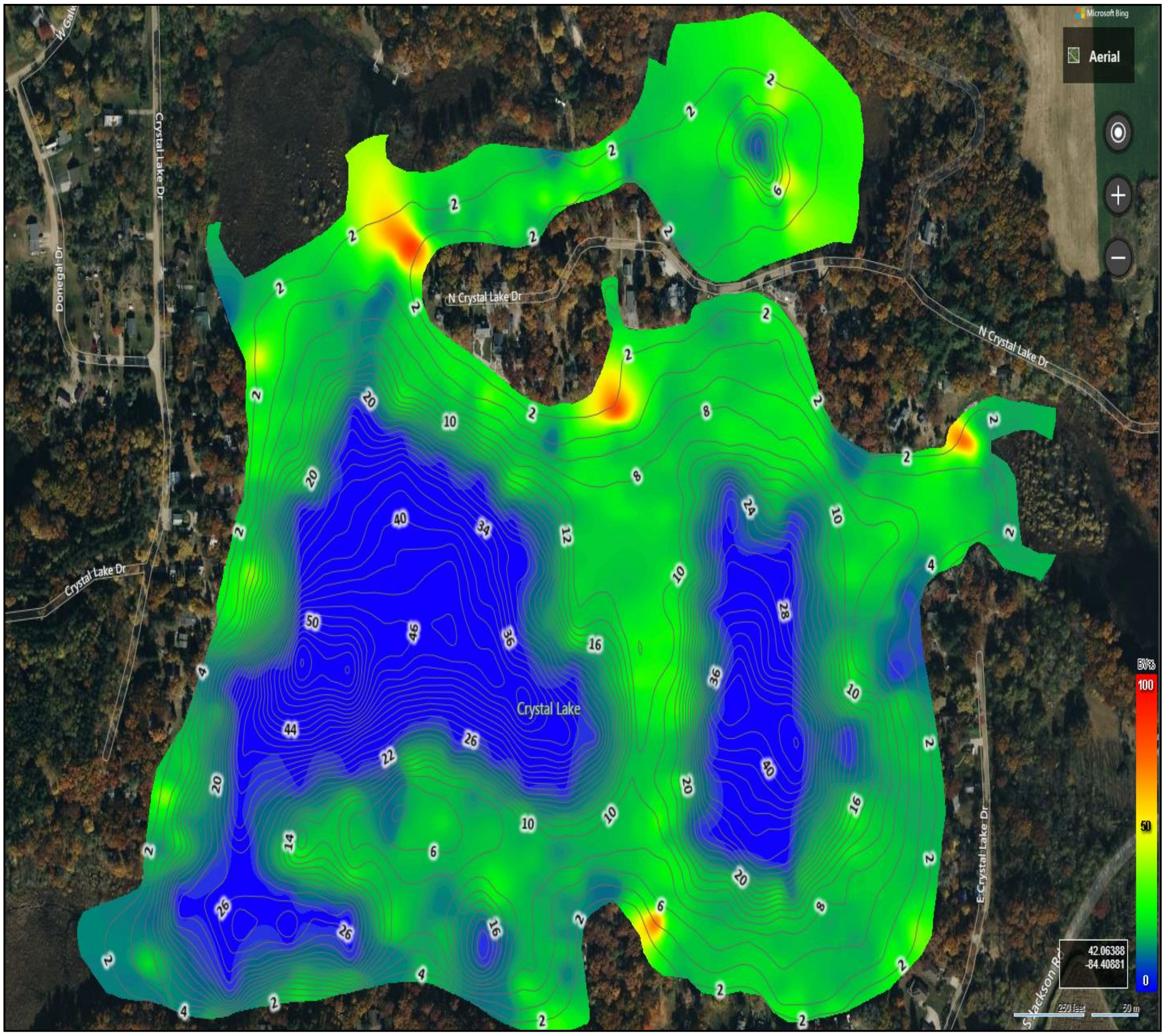


Figure 17. Aquatic plant biovolume of all aquatic plants in Crystal Lake, Hillsdale County, Michigan (June 13, 2023). Note: Red color denotes high-growing aquatic plants, green color denotes low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

Table 20. Perch Lake aquatic vegetation biovolume by category percent cover of each category (relative cover on June 13, 2023).

Biovolume Cover Category	% Relative Cover of Bottom by Category
0-20%	31.2
20-40%	42.4
40-60%	14.5
60-80%	1.9
80-100%	10.0

Table 21. Crystal Lake aquatic vegetation biovolume by category percent cover of each category (relative cover on June 13, 2023).

Biovolume Cover Category	% Relative Cover of Bottom by Category
0-20%	73.0
20-40%	22.1
40-60%	3.2
60-80%	0.3
80-100%	1.4

4.2.1 Perch and Crystal Lakes Native Aquatic Macrophytes

There are hundreds of native aquatic plant species in the waters of the United States. The most diverse native genera include the Potamogetonaceae (Pondweeds) and the Haloragaceae (Milfoils). Native aquatic plants may grow to nuisance levels in lakes with abundant nutrients (both water column and sediment) such as phosphorus, and in sites with high water transparency. The diversity of native aquatic plants is essential for the balance of aquatic ecosystems, because each plant harbors different macroinvertebrate communities and varies in fish habitat structure. Figures 18-19 show unique native aquatic vegetation present in Perch and Crystal lakes with respect to dense waterlilies in Perch Lake and areas of dense variable native watermilfoil in Crystal Lake.

Perch Lake contained 5 native submersed, 3 floating-leaved, and 4 emergent aquatic plant species, for a total of 12 native aquatic macrophyte species (Table 22). Crystal Lake contained 10 native submersed, 3 floating-leaved, and 5 emergent aquatic plant species, for a total of 18 native aquatic macrophyte species (Table 23). Photos of all native aquatic plants are shown below in Figures 20-37. The majority of the emergent macrophytes may be found along the shoreline of the lake and are critical for reducing shoreline erosion and for wildlife habitat along the lakeshore.

Additionally, the majority of the floating-leaved macrophyte species can be found near the shoreline and wetland areas. Both lakes contained an ample population of floating-leaved aquatic plants including white and yellow waterlilies and Watershield. These plants are critical snail habitat and also keep shallow areas cooler during the summer months which can allow for successful fish spawning in those areas. These plants should be preserved. Floating-leaved aquatic vegetation also serves to reduce wave energy in the water along with emergent aquatic plants such as the cattails, swamp loosestrife, bulrushes, and pickerelweed.

The dominant native aquatic plants in Perch Lake included Large-leaf Pondweed (25.7% of the sampling sites), and White Waterlily (13.6% of the sampling sites). The dominant native aquatic plants in Crystal Lake included Chara (39.7% of the sampling sites), and Lage-leaf Pondweed (37.3% of the sampling sites). The Pondweeds grow tall in the water column and serve as excellent fish cover. In dense quantities, they can be a nuisance for swimming and boating and can be controlled with selective herbicide management or with mechanical harvesting.

The relative abundance of rooted aquatic plants (relative to non-rooted plants) in the lake suggests that the sediments are the primary source of nutrients (relative to the water column), since these plants obtain most of their nutrition from the sediments.

Table 22. Perch Lake native aquatic plants (June 13, 2023).

Aquatic Plant Common Name	**Aquatic Plant Latin Name**	**A level**	**B level**	**C level**	**D level**	**# Sites Found (%)**
Muskgrass	*Chara vulgaris*	0	13	0	0	4.6
Illinois Pondweed	*Potamogeton illinoensis*	4	0	0	0	1.4
Large-leaf Pondweed	*Potamogeton amplifolius*	0	38	25	9	25.7
Bladderwort	*Utricularia vulgaris*	2	1	0	0	1.1
Variable Watermilfoil	*Myriophyllum heterophyllum*	3	0	0	0	1.1
Watershield	*Brasenia schreberi*	3	8	2	1	5.0
White Waterlily	*Nymphaea odorata*	7	29	2	0	13.6
Yellow Waterlily	*Nuphar variegata*	4	5	0	0	3.2
Cattails	*Typha latifolia*	1	2	0	0	1.1
Swamp Loosestrife	*Decodon verticillata*	2	7	0	0	3.2
Bulrushes	*Schoenoplectus* sp.	1	1	0	0	0.7
Pickerelweed	*Pontedaria cordata*	8	1	0	0	3.2

Table 23. Crytal Lake native aquatic plants (June 13, 2023).

Aquatic Plant Common Name	**Aquatic Plant Latin Name**	**A level**	**B level**	**C level**	**D level**	**# Sites Found (%)**
Muskgrass	*Chara vulgaris*	19	62	0	0	39.7
Illinois Pondweed	*Potamogeton illinoensis*	13	20	0	0	16.2
Large-leaf Pondweed	*Potamogeton amplifolius*	24	52	0	0	37.3
Fern-leaf Pondweed	*Potamogeton robbinsii*	1	1	0	0	1.0
White-stem Pondweed	*Potamogeton praelongus*	0	2	0	0	1.0
Bladderwort	*Utricularia vulgaris*	5	2	0	0	3.4
Coontail	*Ceratophyllum demersum*	1	0	0	0	0.5
Variable Watermilfoil	*Myriophyllum heterophyllum*	6	8	2	0	7.8
Whorled Watermilfoil	*Myriophyllum verticillatum*	2	0	0	0	1.0
Wild Celery	*Vallisneria americana*	4	1	0	0	2.5
Watershield	*Brasenia schreberi*	10	22	4	0	17.6
White Waterlily	*Nymphaea odorata*	18	34	3	0	27.0
Yellow Waterlily	*Nuphar variegata*	4	27	0	0	15.2
Cattails	*Typha latifolia*	1	3	0	0	2.0
Swamp Loosestrife	*Decodon verticillata*	1	24	2	0	13.2
Bulrushes	*Schoenoplectus* sp.	3	5	0	0	3.9
Pickerelweed	*Pontedaria cordata*	2	9	0	0	5.4
Iris	*Iris* sp.	6	5	0	0	5.4

Figure 18. Dense variable watermilfoil in Crystal Lake (June 13, 2023).

Figure 19. Dense lily pads in Perch Lake (June 13, 2023).

Figure 20. Chara (Muskgrass) ©RLS

Figure 21. Illinois Pondweed ©RLS

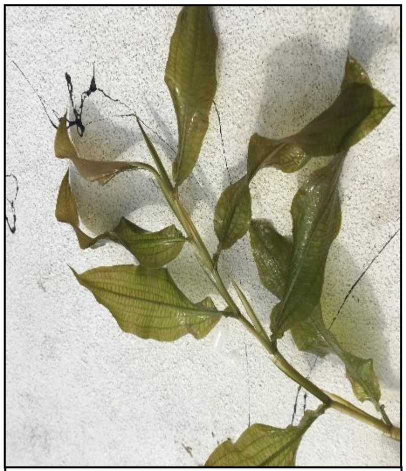


Figure 22. Large-leaf Pondweed ©RLS

Figure 23. Fern-leaf Pondweed ©RLS

Figure 24. White-stem Pondweed ©RLS

Figure 25. Bladderwort ©RLS

Figure 26. Coontail Pondweed ©RLS

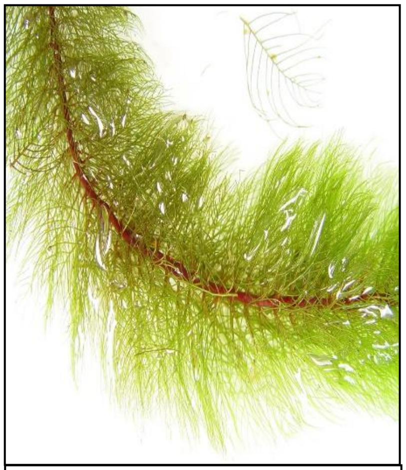


Figure 27. Variable Watermilfoil ©RLS

Figure 28. Whorled watermilfoil ©RLS

Figure 29. Wild Celery ©RLS

Figure 30. Watershield ©RLS

Figure 31. White Waterlily ©RLS

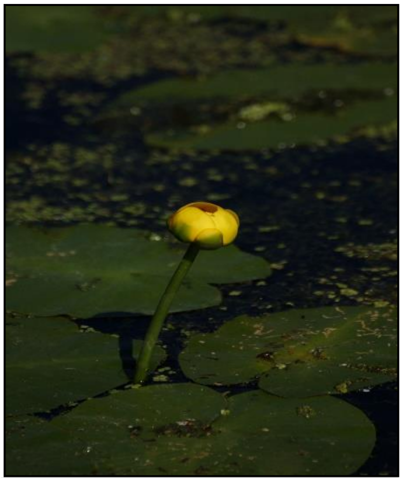


Figure 32. Yellow Waterlily ©RLS

Figure 33. Cattails ©RLS

Figure 34. Swamp Loosestrife ©RLS

Figure 35. Bulrushes ©RLS

Figure 36. Pickerelweed ©RLS

Figure 37. Iris ©RLS

4.2.2 Perch and Crystal Lakes Exotic Aquatic Macrophytes

Exotic aquatic plants (macrophytes) are not native to a particular site, but are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially if the lake has public access sites), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem. Eurasian Watermilfoil (*Myriophyllum spicatum*; Figure 38) is an exotic aquatic macrophyte first documented in the United States in the 1880's (Reed 1997), although other reports (Couch and Nelson 1985) suggest it was first found in the 1940's. In recent years, this species has hybridized with native milfoil species to form hybrid species. Eurasian Watermilfoil has since spread to thousands of inland lakes in various states through the use of boats and trailers, waterfowl, seed dispersal, and intentional introduction for fish habitat. Eurasian Watermilfoil is a major threat to the ecological balance of an aquatic ecosystem through causation of significant declines in favorable native vegetation within lakes (Madsen et *al*. 1991), in that it forms dense canopies (Figure 39) and may limit light from reaching native aquatic plant species (Newroth 1985; Aiken et *al*. 1979). Additionally, Eurasian Watermilfoil can alter the macroinvertebrate populations associated with particular native plants of certain structural architecture (Newroth 1985).

Eurasian Watermilfoil growth in Crystal Lake is capable of producing dense surface canopies, even despite the deeper waters as most of the littoral zone could be infested if not controlled. Figure 40 shows the distribution of milfoil within Crystal Lake (0.6 acres). At the time of the survey, Perch Lake did not have any milfoil present. Tables 24-25 show the various invasives found and their relative abundance in both lakes.

Figure 38. Hybrid Eurasian Watermilfoil plant with seed head and fragments (©RLS).

Figure 39. Hybrid Eurasian Watermilfoil canopy on an inland lake (©RLS).

Figure 40. Distribution of EWM in Crystal Lake (June 13, 2023).

Curly-leaf Pondweed (*Potamogeton crispus*; Figure 41) is an exotic, submersed, rooted aquatic plant that was introduced into the United States in 1807 but was abundant by the early 1900's. It is easily distinguished from other native pondweeds by its wavy leaf margins. It grows early in the spring and as a result may prevent other favorable native aquatic species from germinating. The plant reproduces by the formation of fruiting structures called turions. It does not reproduce by fragmentation as invasive watermilfoil does; however, the turions may be deposited in the lake sediment and germinate in following seasons. Curly-leaf Pondweed is a pioneering aquatic plant species and specializes in colonizing disturbed habitats. It is highly invasive in aquatic ecosystems with low biodiversity and unique sediment characteristics. Curly-leaf pondweed was only found in Crystal Lake (Figure 42) but in low abundance (0.9 acres). It will naturally decay by late July so it could be left alone but there is risk since turions can fall into the sediment and re-germinate the following season.

Figure 41. Curly-leaf Pondweed (©RLS).

Figure 42. Distribution of CLP in Crystal Lake (June 13, 2023).

Starry Stonewort (*Nitellopsis obtusa*; Figure 43) is an invasive macro alga that has invaded many inland lakes and was originally discovered in the St. Lawrence River. The "leaves" appear as long, smooth, angular branches of differing lengths. The alga has been observed in dense beds at depths beyond several meters in clear inland lakes and can grow to heights in excess of a few meters. It prefers clear alkaline waters and has been shown to cause significant declines in water quality and fishery spawning habitat Individual fragments can be transported to the lake via waterfowl or boats. It was found in approximately 0.7 acres of Perch Lake (Figure 44).

Figure 43. A fragment of Starry Stonewort (©RLS).

Figure 44. Distribution of Starry Stonewort in Perch Lake (June 13, 2023).

Table 24. Perch Lake invasive aquatic plants (June 13, 2023).

Aquatic Plant Common Name	Aquatic Plant Latin Name	A level	B level	C level	D level	# Sites Found (% of total)
Starry Stonewort	*Nitellopsis obtusa*	0	12	0	0	4.3

Table 25. Crystal Lake invasive aquatic plants (June 13, 2023).

Aquatic Plant Common Name	Aquatic Plant Latin Name	A level	B level	C level	D level	# Sites Found (% of total)
Hybrid Eurasian Watermilfoil	*Myriophyllum spicatum* var. *sibiricum*	4	4	0	0	3.9
Curly-leaf Pondweed	*Potamogeton crispus*	2	4	0	0	2.9

4.3 Perch and Crystal Lakes Zooplankton and Macroinvertebrates

The zooplankton and macroinvertebrates make up the food chain base in an aquatic ecosystem and thus are integral components. Zooplankton are usually microscopic, but some can be seen with the unaided eye. Macroinvertebrates can be readily seen and are also known as aquatic insects or bugs. The zooplankton migrate throughout the water column of the lake according to daylight/evening cycles and are prime food for the lake fishery. Macroinvertebrates can be found in a variety of locations including on aquatic vegetation, near the shoreline, and in the lake bottom sediments. The biodiversity and relative abundance of both food chain groups are indicative of water quality status and productivity.

Perch and Crystal Lake Zooplankton

A zooplankton tow using a Wildco® pelagic plankton net (63 micrometer) with collection jar (Figure 45) was conducted by RLS scientists on July 25, 2023 in the 2 deep basins of both lakes. The plankton net was left at depth for 30 seconds and then raised slowly to the surface at an approximate rate of 4 feet/second. The net was then raised above the lake surface and water was splashed on the outside of the net to dislodge any zooplankton from the net into the jar. The jar was then drained into a 125-mL bottle with a CO_2 tablet to anesthetize the zooplankton. The sample was then preserved with a 70% ethyl alcohol solution.

Plankton sub-samples (in 1 ml aliquots) were analyzed under a Zeiss® dissection scope with the use of a Bogorov counting chamber. Taxa were keyed to species when possible and are shown in Tables 26-27 below. There is a higher abundance of zooplankton in Crystal Lake which is not uncommon given the greater water volume and depths and larger surface area. All of the taxa below are beneficial and serve as favorable food for the lake fisheries.

Table 26. Zooplankton taxa and count data from Perch Lake (July 25, 2023)

Zooplankton Taxa	DB1	DB2
Cladocerans		
Daphnia sp.	12	9
Simocephalus sp.	5	1
Bosmina sp.	24	11
Chydorus sp.	2	6
Copepods/Cyclopods		
Cyclops sp.	2	4
Rotifers		
Keratella sp.	7	2
Vorticella sp.	5	3

Table 27. Zooplankton taxa and count data from Crystal Lake (July 25, 2023).

Zooplankton Taxa	DB1	DB2
Cladocerans		
Daphnia sp.	16	28
Leptodora sp.	8	2
Bosmina sp.	17	5
Chydorus sp.	3	4
Copepods/Cyclopods		
Cyclops sp.	2	0
Rotifers		
Keratella sp.	1	3
Vorticella sp.	6	2

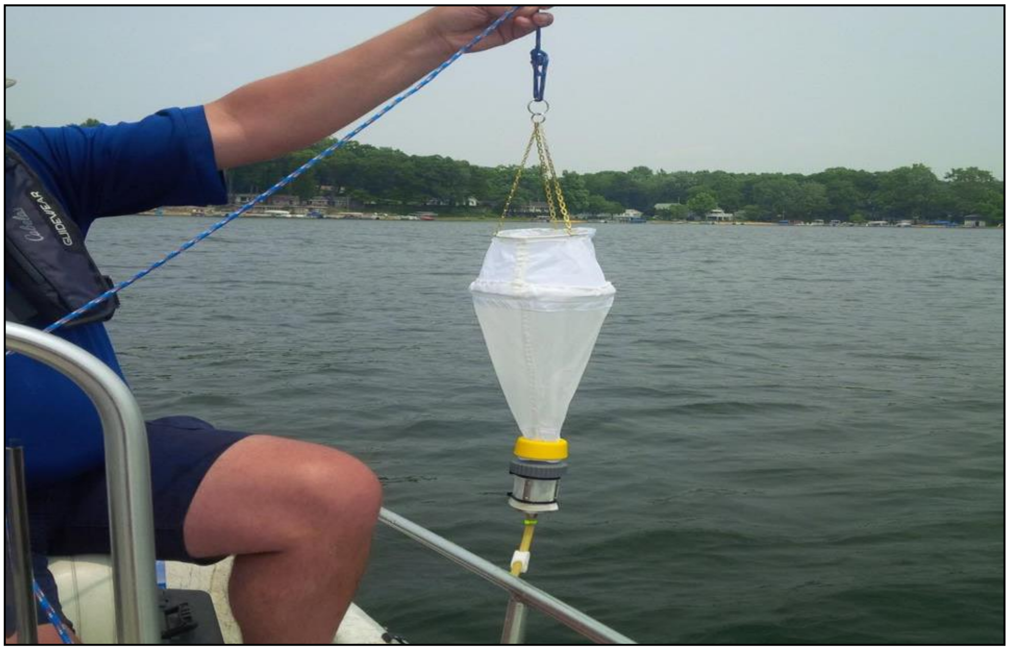


Figure 45. A zooplankton collection tow net (RLS).

Perch and Crystal Lakes Benthic Macroinvertebrates

Freshwater macroinvertebrates are ubiquitous, as even the most impacted lake contains some representatives of this diverse and ecologically important group of organisms. Benthic macroinvertebrates are key components of lake food webs both in terms of total biomass and in the important ecological role that they play in the processing of energy. Others are important predators, graze alga on rocks and logs, and are important food sources (biomass) for fish. The removal of macroinvertebrates has been shown to impact fish populations and total species richness of an entire lake or stream food web (Lenat and Barbour 1994). In the food webs of lakes, benthic macroinvertebrates have an intermediate position between primary producers and higher trophic levels (fish) on the other side. Hence, they play an essential role in key ecosystem processes (food chain dynamics, productivity, nutrient cycling, and decomposition).

Restorative Lake Sciences collected benthic (bottom) aquatic macroinvertebrate samples at the same locations as the sediment samples with the use of an Ekman hand dredge (Figure 46). Macroinvertebrate samples were placed in small plastic buckets and analyzed in the RLS wet laboratory within 24 hours after collection using a hard-plastic sorting tray, tweezers, and a Zeiss® dissection microscope under 1X, 3X, and 10X magnification power. Macroinvertebrates were taxonomically identified using a key from: “The Introduction to the Aquatic Insects of North America”, by Merritt, Cummings, and Berg (2008) to at least the family level and genus level whenever possible. All macroinvertebrates were recorded including larval or nymph forms, mussels, snails, worms, or other “macro” life forms.

Genera found in the Perch and Crystal lakes sediment samples included midges (Chironomindae), jute snails (Pleuroceridae), wheel snails (Planorbidae), pond snails, fingernail clams, and banded Mystery snails. Of all the species found, all were native except for the banded Mystery snails which arrived from China several decades ago. Many of these genera are located universally in low quality and high-quality water. The midge larvae family Chironomidae can be found in both high- and low-quality water (Lenat and Barbour 1994). Tables 28-29 display the taxa and abundance found at the 10 sites.

Perch Lake had higher numbers of macroinvertebrates which was likely attributed to higher productivity and shallower depths where dissolved oxygen was favorable for macroinvertebrates in the lake sediments.

Figure 46. An Ekman hand dredge for sampling lake sediments (RLS).

Native lake macroinvertebrate communities can and have been impacted by exotic and invasive species. A study by Stewart and Haynes (1994) examined changes in benthic macroinvertebrate communities in southwestern Lake Ontario following the invasion of Zebra and Quagga mussels (*Dreissena spp*.). They found that *Dreissena* had replaced a species of freshwater shrimp as the dominant species. However, they also found that additional macroinvertebrates actually increased in the 10-year study, although some species were considered more pollution-tolerant than others. This increase was thought to have been due to an increase in *Dreissena* colonies increasing additional habitat for other macroinvertebrates. The moderate alkalinity of Crystal Lake may allow for growth of Zebra Mussels since they need ample alkalinity (calcium carbonate) for their shells, whereas the alkalinity in Perch Lake is marginal to support robust growth.

In addition to exotic and invasive macroinvertebrate species, macroinvertebrate assemblages can be affected by land-use. Stewart et *al*. (2000) showed that macroinvertebrates were negatively affected by surrounding land-use. They also indicated that these land-use practices are important to the restoration and management of lakes. Schreiber et *al*., (2003) stated that disturbance and anthropogenic land use changes are usually considered to be key factors facilitating biological invasions.

Table 28. Macroinvertebrates found in Perch Lake, Hillsdale County, MI (July 25, 2023).

Site S7	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	10	Jute snails
	Chironomidae	*Chironomus* spp.	7	Midges
	Planorbidae		9	Wheel snails
	Lymnaeidae		3	Dextrel pond snails
	Sphaeriidae	*Pisidium* sp.	2	Fingernail clams
		Total	**31**	
Site S8	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	16	Jute snails
	Planorbidae		8	Wheel snails
	Lymnaeidae		7	Dextrel pond snails
	Sphaeriidae	*Pisidium* sp.	1	Fingernail clams
	Viviparidae	*Viviparus georgianus*	8	Banded mystery snail
	Chironomidae	*Chironomus* spp.	12	Midges
		Total	**52**	
Site S9	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	9	Jute snails
	Planorbidae		15	Wheel snails
	Lymnaeidae		6	Dextrel pond snails
	Chironomidae	*Chironomus* spp.	16	Midges
	Sphaeriidae	*Pisidium* sp.	1	Fingernail clams
		Total	**47**	
Site S10	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	9	Jute snails
	Planorbidae		7	Wheel snails
	Lymnaeidae		9	Dextrel pond snails
	Chironomidae	*Chironomus* spp.	11	Midges
	Sphaeriidae	*Pisidium* sp.	1	Fingernail clams
		Total	**37**	

Table 29. Macroinvertebrates found in Crystal Lake, Hillsdale County, MI (July 25, 2023).

Site S1	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	6	Jute snails
	Chironomidae	*Chironomus* spp.	2	Midges
	Planorbidae		12	Wheel snails
	Lymnaeidae		1	Dextrel pond snails
	Sphaeriidae	*Pisidium* sp.	1	Fingernail clams
		Total	**22**	
Site S2	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	6	Jute snails
	Planorbidae		2	Wheel snails
	Lymnaeidae		7	Dextrel pond snails
	Sphaeriidae	*Pisidium* sp.	1	Fingernail clams
	Chironomidae	*Chironomus* spp.	6	Midges
		Total	**22**	
Site S3	**Family**	**Genus**	**Number**	**Common name**
	Planorbidae		3	Wheel snails
	Lymnaeidae		8	Dextrel pond snails
	Chironomidae	*Chironomus* spp.	13	Midges
		Total	**24**	
Site S4	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	2	Jute snails
	Planorbidae		9	Wheel snails
	Sphaeriidae	*Pisidium* sp.	6	Fingernail clams
		Total	**18**	
Site S5	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	2	Jute snails
	Planorbidae		6	Wheel snails
	Lymnaeidae		2	Dextrel pond snails
	Chironomidae	*Chironomus* spp.	5	Midges
		Total	**15**	
Site S6	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	11	Jute snails
	Planorbidae		2	Wheel snails
	Lymnaeidae		6	Dextrel pond snails
	Chironomidae	*Chironomus* spp.	5	Midges
	Sphaeriidae	*Pisidium* sp.	1	Fingernail clams
		Total	**25**	

5.0 PERCH AND CRYSTAL LAKES IMPROVEMENT METHODS

Lake improvement methods for both lakes consist of strategies to reduce invasive aquatic plants, reduce the transport of invasive species, improve water quality, reduce lake sedimentation and nutrient transport, and facilitate proper immediate watershed management. The following sections offer useful and effective methods for improving the overall condition of Perch and Crystal lakes. The goals of a Lake Management Plan (LMP) such as this are to increase water quality, increase favorable wildlife habitat and aquatic plant and animal biodiversity, optimize recreational use, and protect property values. Regardless of the management goals, all management decisions must be site-specific and should consider the socio-economic, scientific, and environmental components of the LMP such as within this LMP.

5.1 Perch and Crystal Lakes Aquatic Plant Management

The management of submersed invasive aquatic plants is necessary in both lakes due to the potential for accelerated growth and distribution. Management options should be environmentally and ecologically-sound and financially feasible. Options for control of aquatic plants are limited yet are capable of achieving strong results when used properly. All aquatic vegetation should be managed with solutions that will yield the longest-term results. The sections below discuss various aquatic plant management methods to protect the native biodiversity in both lakes.

5.1.1 Aquatic Invasive Species Prevention

An exotic species is a non-native species that does not originate from a particular location. When international commerce and travel became prevalent, many of these species were transported to areas of the world where they did not originate. Due to their small size, insects, plants, animals, and aquatic organisms may escape detection and be unknowingly transferred to unintended habitats.

The first ingredient to successful prevention of unwanted transfers of exotic species to Perch and Crystal lakes is awareness and education (Figure 47). The majority of the exotic species of concern have been listed in this report. Other exotic species on the move could be introduced to the riparians around the lakes through the use of a professionally developed educational newsletter and/or through regular lake seminars or workshops.

Public boat launches are a primary area of vector transport for all invasive species and thus boat washing stations have become more common. With over 13 million registered boaters in the U.S. alone, the need for reducing transfer of aquatic invasive species (AIS) has never been greater. The Minnesota Sea Grant program identifies five major boat wash scenarios which include: 1) Permanent washing stations at launch sites, 2) Portable drive-thru or transient systems, 3) Commercial car washes, 4) Home washing, and 5) Mandatory vs. volunteer washing.

Boat washing stations promote the Clean Waters Clean Boats volunteer education program by educating boaters to wash boating equipment (including trailers and bait buckets) before entry into every lake.

Critical elements of this education include: 1) How to approach boaters, 2) Demonstration of effective boat and trailer inspections and cleaning techniques, 3) The recording of important information, 4) Identification of high-priority invasive species, and 5) Sharing findings with others. If a boat washing station is situated on either of the two lakes, the Association should work together to educate the public and lake users on proper cleaning techniques and other invasive species information. A "Landing Blitz" can be held once the station is in place and the public can be invited to a field demonstration of how to use the washing station. A typical boat washing station typically costs around $30,000 (Figure 48) but lower cost ones are available for private lakes with restricted access (e.g., hand-held sprayer units).

Additional educational information regarding these stations and education can be found on the following websites:

1) USDA: https://www.invasivespeciesinfo.gov/us/Michigan
2) Michigan Wildlife Federation Invasive animals, plants list, and native plants/animals list: https://www.Michiganwildlife.org/wildlife
3) Stop Aquatic Hitchhikers!: www.protectyourwaters.net

Figure 47. An aquatic invasive prevention sign for public access sites.

Figure 48. A public boat washing station for boat access sites.

5.1.2 Aquatic Herbicides and Applications

The use of aquatic chemical herbicides is regulated by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) and requires a permit. Aquatic herbicides are generally applied via an airboat or skiff equipped with mixing tanks and drop hoses (Figure 49). The permit contains a list of approved herbicides for a particular body of water, as well as dosage rates, treatment areas, and water use restrictions. Contact and systemic aquatic herbicides are the two primary categories used in aquatic systems.

Figure 49. A boat used to apply aquatic herbicides in inland lakes (©RLS).

Contact herbicides such as diquat, flumioxazin, and hydrothol cause damage to leaf and stem structures; whereas systemic herbicides are assimilated by the plant roots and are lethal to the entire plant. Wherever possible, it is preferred to use a systemic herbicide for longer-lasting aquatic plant control of invasives. In Perch Lake, the use of contact herbicides (such as diquat and flumioxazin) would be recommended only for Starry Stonewort.

Algaecides should only be used on dense, green, filamentous algal blooms since many treatments can exacerbate blue-green algae blooms. Blue-green algae have numerous gas vesicles, and the algae can thrive at the surface with minimal photo-degradation (breaking down) by the sun. When the sunlight is excessive, the algae can break down and release toxins and lower the dissolved oxygen in the water column. *Microcystis*, a type of blue-green algae, has been shown to overwinter in lake sediments (Fallon et *al.*, 1981). In addition, it may thrive in a mucilage layer with sediment bacteria that can release phosphorus under anaerobic conditions (Brunberg, 1995).

They assume a high volume in the water column (Reynolds, 1984) compared to diatoms and other single-celled green algae. The blue-green algae have been on the planet nearly 2.15 billion years and have assumed strong adaptation mechanisms for survival. In general, calm surface conditions will facilitate enhanced growth of this type of algae since downward transport is reduced. If this algae occurs, the use of PAK27® or SeClear® algaecides is recommended in place of copper sulfate since the latter bioaccumulates in lake sediments and is toxic to benthic macroinvertebrates.

Systemic herbicides such as 2,4-D, triclopyr, and ProcellaCOR® are the primary systemic herbicides used to treat milfoil that occurs in a scattered distribution or low frequency. Fluridone (trade name, SONAR®) is a systemic whole-lake herbicide treatment that is applied to the entire lake volume in the spring and is used for extensive infestations. The invasive milfoil present in Crystal Lake should be treated with systemic herbicides on a localized basis. The goal is to apply minimal herbicide to the lake over time but maintain effective and sustainable control. ProcellaCOR® has shown great efficacy in recent years at reducing variable sizes of milfoil beds. Care should be taken to avoid collateral damage to native milfoil species as much as possible.

5.1.3 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 50). The mechanical harvester collects numerous loads of aquatic plants as they are cut near the lake bottom. The plants are off-loaded onto a conveyor and then into a dump truck. Harvested plants are then taken to an offsite landfill or farm where they can be used as fertilizer. Mechanical harvesting is preferred over chemical herbicides when primarily native aquatic plants exist, or when excessive amounts of plant biomass need to be removed.

Mechanical harvesting is usually not recommended for the removal of Eurasian Watermilfoil since the plant may fragment when cut and re-grow on the lake bottom. It may be considered in future years for Perch Lake if the native aquatic vegetation becomes too prevalent and no invasives that fragment are present. At this time, the communities in Crystal Lake are currently balanced and thus harvesting would not be recommended, although it could be used to reduce dense native vegetation in the future if it becomes a recreational or navigational hazard.

Figure 50. A mechanical harvester used to remove aquatic plants (©RLS).

5.1.4 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 51) or Weed Rollers (Figure 52) have been used to reduce weed growth in small areas such as in beach areas and around docks. The benthic mats are placed on the lake bottom in early spring prior to the germination of aquatic vegetation. They act to reduce germination of all aquatic plants and lead to a local area free of most aquatic vegetation. Benthic barriers may come in various sizes between 100-400 feet in length.

They are anchored to the lake bottom to avoid becoming a navigation hazard. The cost of the barriers varies among vendors but can range from $100-$1,000 per mat. Benthic barrier mats can be purchased online at: www.lakemat.com or www.lakebottomblanket.com. The efficacy of benthic barrier mats has been studied by Laitala et *al.* (2012) who report a minimum of 75% reduction in invasive milfoil in the treatment areas. Lastly, benthic barrier mats should not be placed in areas where fishery spawning habitat is present and/or spawning activity is occurring.

Weed Rollers are electrical devices which utilize a rolling arm that rolls along the lake bottom in small areas (usually not more than 50 feet) and pulverizes the lake bottom to reduce germination of any aquatic vegetation in that area. They can be purchased online at: www.crary.com/marine or at: www.lakegroomer.net.

Both methods are useful in recreational lakes such as Perch and Crystal lakes and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth if it becomes prevalent in future years.

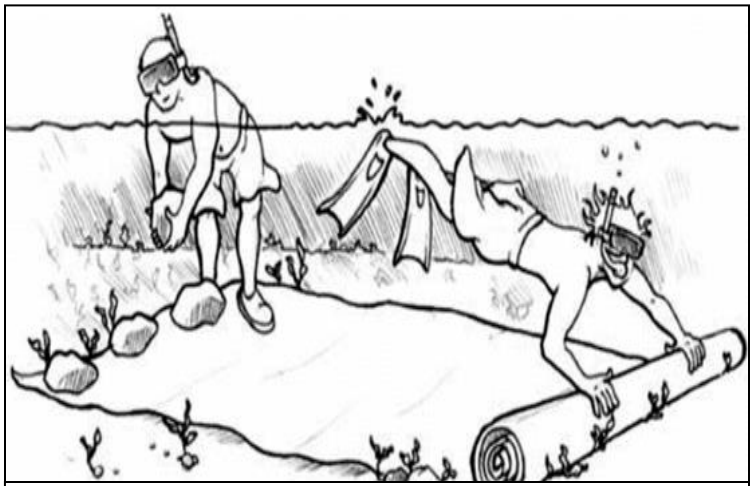


Figure 51. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.

Figure 52. A Weed Roller.

5.1.5 Diver Assisted Suction Harvesting (DASH)

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 53) involves hand removal of individual plants by a SCUBA diver in selected areas of lake bottom with the use of a hand-operated suction hose. Samples are dewatered on land or removed via fabric bags to an offsite location. This method is generally recommended for small (less than 1 acre) spot removal of vegetation since it is costly on a large scale. It may be used in the future to remove small areas of dense growth in shallow areas but is not recommended at this time.

Furthermore, this activity may cause re-suspension of sediments (Nayar et *al*., 2007) which may lead to increased turbidity and reduced clarity of the water. This method is a sustainable option for removal of plant beds in beach areas and areas where herbicide treatments may be restricted. It could be used to very selectively remove small areas of invasive Starry Stonewort or small areas of lily pads that interfere with navigation on either of the lakes. There are some companies that sell these units to associations as long as there are volunteers to operate them or companies that employ commercial divers are available to operate the machines.

Figure 53. A DASH boat used for aquatic plant removal (©RLS).

5.2 Perch and Crystal Lakes Immediate Watershed Improvements

In addition to methods that improve the aquatic plant communities (both invasive and nuisance native), there are methods to improve the water quality within the lake basins. These methods are often larger in scale and costly but are highly effective at increasing water clarity, reducing algae, increasing dissolved oxygen, reducing muck, and allowing for enhanced recreational activities.

5.2.1 Nutrient Inactivation

There are a few products available that aim to reduce phosphorus in the water column and the release of phosphorus from a lake bottom. Such products are usually applied as a slurry by a special dose-metered vessel to the water column or just above the lake bottom. Most of these formulas can be applied in aerobic (oxygenated) or anaerobic (oxygen-deficient) conditions. In lakes that lack ample dissolved oxygen at depth, such as Crystal Lake, this product may help prevent phosphorus release from the sediments. A few disadvantages include cost, inability to bind high concentrations of phosphorus especially in lakes that receive high external loads of phosphorus (i.e., lakes with a large catchment or watershed), and the addition of an aluminum floc to the lake sediments which may impact benthic macroinvertebrate diversity and relative abundance (Pilgrim and Brezonik, 2005). Some formulas utilize a clay base with the P-inactivating lanthanum (Phoslock®) which may reduce sediment toxicity of alum.

If this method is implemented, it is highly recommended that sampling the lake sediments for sediment pore water phosphorus concentrations be conducted to determine internal releases of phosphorus pre-alum and then monitoring post-alum implementation. Additionally, external phosphorus loads must be significantly reduced since these inputs would compromise phosphorus-inactivation formulas (Nürnberg, 2017). Some recent case studies (Brattebo et *al*., 2017) have demonstrated favorable results with alum application in hypereutrophic waters that are also experiencing high external nutrient loads. It is only recommended for the Crystal Lake basin if existing nutrient loads become problematic relative to nuisance algal blooms or fish kills during summer months.

5.2.2 Fishery Habitat Enhancement

Fish habitat is very important for lakes and for improving the water quality. In addition to providing suitable habitat for spawning, lakes also benefit from the fish populations by controlling various types of phytoplankton (algae), zooplankton, and other fish species. Fish also add nutrients in the form of waste to the carbon, nitrogen, and phosphorus cycles for other plants and animals in the lake. Historically, Walleye and Northern Pike were reported stocked in Crystal Lake by the MDNR in 1993 and 1995, respectively.

Habitat degradation around lakes has harmed fish populations. Pesticides, fertilizers, and soil from farm fields drain into lakes and rivers, killing aquatic insects, depleting dissolved oxygen, and smothering fish eggs. Leaves, grass, and fertilizer runoff urban and suburban lawns into sewers, then into lakes, where these excessive nutrients fuel massive algae blooms. The housing boom on fishing lakes is turning native lakeshore and shallow water vegetation into lawns, rocky riprap, and sand beaches. Native plants have been removed in many areas that once helped sustain healthy fish populations. Water becomes turbid from fertilizer runoff, and, with reduced emergent plants in shallows, fish have fewer places to hide and grow. It is important for landowners to realize how important aquatic and emergent lake vegetation can be to the lake ecology of both lakes.

To restore the natural features of lakeshores that provide fish habitat, a new approach replaces some or all lakeside lawns and beaches with native wildflowers, shrubs, grasses, and aquatic plants. Restoring natural vegetation can cut maintenance costs, prevent unwanted pests such as Canada geese, attract butterflies and songbirds, and improve fish spawning habitat in shallow water. Preventing erosion and sedimentation around lakes is also important because excess sediment can smother fish eggs. Converting plowed land along the lake edge into grassy strips can filter runoff and stabilize banks. Vegetative plantings on steep banks can prevent erosion and excess nutrients from reaching the lakes. Adding additional natural features such as boulders can also improve fish spawning habitat in a lake. In Minnesota's Lake Winni, more than 4.5 miles of the lakeshore has been reinforced since 1989 and Walleye are now spawning in the improved habitat. In addition, altering water levels in marshy areas used by northern pike for spawning can create more favorable conditions for reproduction.

Lake aeration can also improve fish populations. Every few winters, most or all fish in many shallow lakes die for lack of oxygen. When plants die, they decompose and use up dissolved oxygen needed by fish. Adding oxygen to the lake using an aeration system can help prevent winterkill in lakes where depletion is present (i.e., Crystal Lake at depth). Fish spawning habitat in many shallow lakes has been destroyed by Common Carp and Black Bullhead. These fish root in the silty lake bottoms and stir up nutrient-laden sediment. The murky water blocks sunlight from reaching aquatic plants that stabilize the lake bottom and provide oxygen and habitat for game fish. Bluegill and Bass numbers have been shown to plummet while these fish species thrive. The sediment that carp and bullheads stir up is loaded with nutrients. Nutrients and other contaminated runoff flow into lakes from distant farms, parking lots, streets, and lawns. The nutrients fuel blooms of algae, which consume oxygen upon decay, needed by fish and underwater insects.

A few specific fish species spawning habitat examples:

Numerous fish species utilize different types of habitat and substrate to spawn**.** Gosch et *al*. (2006) examined Bluegill spawning colonies in South Dakota (Lake Cochrane). Habitat characteristics were measured at each nesting site and compared with those measured at 75 randomly selected sites. In Lake Cochrane, the mean water depth of spawning colonies was 1.0 meter.

Every Bluegill nest site contained gravel substrate, despite the availability of muck, sand and rock. Additionally, Bluegills selected nesting locations with relatively moderate dissolved oxygen levels. Lake Cochrane Bluegill nest sites consisted of shallow, gravel areas with short, low-density, live submergent *Chara* vegetation. Walleye generally spawn over rock, rubble, gravel and similar substrate in rivers or windswept shallows in water 1 to 6 feet deep, where current clears away fine sediment and will cleanse and aerate eggs. Male Walleye move into spawning areas in early spring when the water temperature may be only a few degrees above freezing while the larger females arrive later. Spawning culminates when the water temperature ranges from 42 to 50 degrees. For Walleye, the success of spawning can vary greatly year to year depending on the weather. Rapidly warming water can cause eggs to hatch prematurely. Prolonged cool weather can delay and impair hatching. A cold snap after the hatch can suppress the production of micro crustaceans that Walleye fry eat.

Largemouth Bass spawning activities begin when water temperatures reach 63° to 68°F. The male moves into shallow bays and flats and sweeps away debris from a circular area on a hard bottom. The male remains to guard the nest and the female heads for deeper water to recover. Northern Pike begin to spawn as soon as the ice begins to break up in the spring, in late March or early April. The fish migrate to their spawning areas late at night and the males will congregate there for a few days before spawning actually begins. Marshes with grasses, sedges, rushes or aquatic plants and flooded wetlands are prime spawning habitat for Northern Pike. Mature females move into flooded areas where the water is ≤1 foot deep. Due to predation by insects and other fish including the Northern Pike itself, the number of eggs and fry will be reduced by over 99% in the months that follow spawning.

The eggs hatch in 12 to 14 days, depending on water temperature, and the fry begin feeding on zooplankton when they are about 10 days old.

Impacts to Fish Spawning from Invasive Species:

Lyons (1989) studied how the assemblage of small littoral-zone fishes that inhabit Lake Mendota, Wisconsin has changed since 1900. A diverse assemblage that included several environmentally sensitive species has been replaced by an assemblage dominated by a single species, the Brook Silverside, whose abundance fluctuates dramatically from year to year.

Their decline was associated with the invasion and explosive increase in abundance of an exotic macrophyte, the Eurasian Watermilfoil (*Myriophyllum spicatum*), in the mid-1960's. This is another reason why continued successful management of milfoil in Crystal Lake is critical. Changes in the assemblage of small littoral-zone fishes in Lake Mendota indicate environmental degradation in the near shore area and may have important implications for the entire fish community of the lake including fish spawning habitat availability.

Lillie and Budd (1992) examined the distribution and architecture of Eurasian Watermilfoil in Fish Lake, Wisconsin. They showed that temporal changes in the architecture of milfoil during the growing season and differences in architecture within one macrophyte bed in Fish Lake were substantial and may have influenced spawning habitat use by fish and macroinvertebrates. Eiswerth et *al*. (2000) looked at the potential recreational impacts of increasing populations of Eurasian Watermilfoil. They determined that, unless the weed is controlled, significant alterations of aquatic ecosystems including spawning habitat for native fish, with associated degradation of natural resources and economic damages to human uses of those resources, may occur. In contrast, Valley and Bremigan (2002) studied how changes in aquatic plant abundance or architecture, caused by invasion and/or removal of exotic plants, may affect age-0 Largemouth Bass growth and recruitment. They showed that selective removal of Eurasian Watermilfoil did not have a significant positive effect on age-0 Largemouth Bass growth. In this lake, factors influencing age-0 Bluegill availability to age-0 Largemouth Bass appear more related to size structure of Largemouth Bass and Bluegill populations than to plant cover, but plants still are needed to provide habitat and spawning cover.

Impacts from Natural Shoreline Degradation:

Lakeshore development can also play an important role in how vegetation abundance can impact fish spawning habitat. Vegetation abundance along undeveloped and developed shorelines of Minnesota lakes was compared to test the hypothesis that development has not altered the abundance of emergent and floating-leaf vegetation (Radomski and Goeman 2001). They found that vegetative cover in littoral areas adjacent to developed shores was less abundant than along undeveloped shorelines. On average, there was a 66% reduction in vegetation coverage with development. Significant correlations were also detected between occurrence of emergent and floating-leaved plant species and relative biomass and mean size of Northern Pike, Bluegill, and Pumpkinseed.

Margenau et *al*. (2008) showed that a loss of nearshore habitat has continued at an increased rate as more lake homes are built and shorelines graded, and altered with riprap, sand blankets, or sea walls. Ultimately, suitability for fish spawning habitat had decreased.

5.2.3 Perch and Crystal Lakes Immediate Watershed Improvements

Septic Systems and Other Non-Point Source Inputs

Nutrient pollution of inland lakes from septic systems and other land use activities is not a modern realization and has been known for multiple decades. The problem is also not unique to Michigan Lakes and was first described in Montreal Canada by Lesauteur (1968) who noticed that summer cottages were having negative impacts on many water bodies. He further noted that a broader policy was needed to garner control of these systems because they were becoming more common over time. Many of our inland lakes are in rural areas and thus sewer systems or other centralized wastewater collection methods are not practical. Thus, septic systems have been common in those areas since development on inland lakes began. Septic systems have four main components consisting of a pipe from the residence, a septic tank or reservoir, a drainage field, and the surrounding soils (Figure 54).

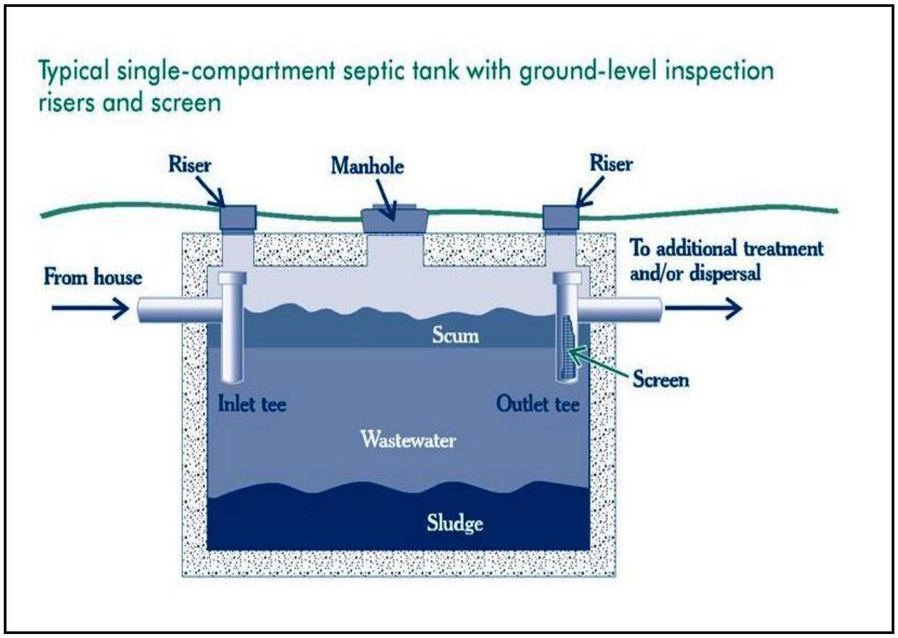


Figure 54. Diagram of essential septic tank components (US EPA).

On ideal soil types, microbes in the soil are able to decompose nutrients and reduce the probability of groundwater contamination. However, many lakes in Michigan contain soils that are not suitable for septic systems. Soils that are not very permeable, prone to saturation or ponding, and have mucks exist around many lakes and currently have properties with septic systems.

In fact, soils that are saturated may be associated with a marked reduction in phosphorus assimilation and adsorption (Gilliom and Patmont, 1983; Shawney and Starr, 1977) which leads to the discharge of phosphorus into the groundwater, especially in areas with a high water table. In the study by Gilliom and Patmont (1983) on Pine Lake in the Puget Sound of the western U.S., they found that it may take 20-30 years for the phosphorus to make its way to the lake and cause negative impacts on water quality.

Typical septic tank effluents are rich in nutrients such as phosphorus and nitrogen, chlorides, fecal coliform, sulfates, and carbon (Cantor and Knox, 1985). Phosphorus and nitrogen have long been identified as the key causes of nuisance aquatic plant and algae growth in inland lakes. Although phosphorus is often the limiting growth factor for aquatic plant growth, nitrogen is often more mobile in the groundwater and thus is found in abundance in groundwater contributions to lakes. A groundwater seepage study on submersed aquatic plant growth in White Lake, Muskegon County, Michigan, was conducted in 2005 by Jermalowicz-Jones (MS thesis, Grand Valley State University) and found that both phosphorus and nitrogen concentrations were higher in developed areas than in undeveloped areas. This helped to explain why the relatively undeveloped northern shore of White Lake contained significantly less submersed aquatic plant growth than the developed southern shoreline. The research also showed that more nutrients were entering the lake from groundwater than in some of the major tributaries.

Spence-Cheruvelil and Soranno (2008) studied 54 inland lakes in Michigan and found that total aquatic plant cover (including submersed plants) was most related to secchi depth and mean depth. However, they also determined that man-made land use activities are also predictors of aquatic plant cover since such variables can also influence these patterns of growth. Prior to changes in offshore aquatic plant communities, an additional indicator of land use impacts on lake water quality in oligotrophic lakes (lakes that are low in nutrients) includes changes in periphytic algae associated with development nearshore. Such algae can determine impacts of septic leachate before other more noticeable changes offshore are found (Rosenberger et *al*., 2008). Development in the watershed also may influence the relative species abundance of individual aquatic plant species. Sass et *al*. (2010) found that lakes associated with rigorous development in surrounding watersheds had more invasive species and less native aquatic plant diversity than less developed lakes. Thus, land use activities such as failing septic systems may not only affect aquatic plant biomass and algal biomass, but also the composition and species richness of aquatic plant communities.

A groundwater investigation of nutrient contributions to Narrow Lake in Central Alberta, Canada by Shaw and Prepas, 1990, utilized mini-piezometers and seepage meters to measure contributions of groundwater flow to the lake. They estimated that groundwater was a significant source of water to the lake by contributing approximately 30% of the annual load to the lake. Additionally, phosphorus concentrations in the sediment pore water were up to eight times higher than groundwater from nearby lake wells.

It is estimated that Michigan has over 1.2 million septic systems currently installed with many of them occurring in rural areas around inland lakes. Currently only seven counties in Michigan (Benzie, Grand Traverse, Macomb, Ottawa, Shiawassee, Washtenaw, and Wayne) require a septic system inspection prior to a property being sold. The number of septic systems that are a risk to the aquatic environment is unknown which makes riparian awareness of these systems critical for protection of lake water. Construction of new septic tanks require notification and application by the homeowner to the county Department of Public Health and also that soils must be tested to determine suitability of the system for human health and the environment. It is recommended that each septic tank be inspected every 2-3 years and pumped every 1-2 years or sooner depending upon usage. The drain field should be inspected as well and only grasses should be planted in the vicinity of the system since tree roots can cause the drain field to malfunction. Additionally, toxins should not be added to the tank since this would kill beneficial microbes needed to digest septic waste. Areas that contain large amounts of peat or muck soils may not be conducive to septic tank placement due to the ability of these soils to retain septic material and cause ponding in the drain field. Other soils that contain excessive sands or gravels may also not be favorable due to excessive transfer of septage into underlying groundwater. Many sandy soils do not have a strong adsorption capacity for phosphorus and thus the nutrient is easily transported to groundwater. Nitrates, however, are even more mobile and travel quickly with the groundwater and thus are also a threat to water quality.

The utilization of septic systems by riparians is still quite common around inland lake shorelines. A basic septic system typically consists of a pipe leading from the home to the septic tank, the septic tank itself, the drain field, and the soil. The tank is usually an impermeable substance such as concrete or polyethylene and delivers the waste from the home to the drain field. The sludge settles out at the tank bottom and the oils and buoyant materials float to the surface. Ultimately the drain field receives the contents of the septic tank and disperses the materials into the surrounding soils. The problem arises when this material enters the zone of water near the water table and gradually seeps into the lake bottom. This phenomenon has been noted by many scholars on inland waterways as it contributes sizeable loads of nutrients and pathogens to lake water. Lakebed seepage is highly dependent upon water table characteristics such as slope (Winter 1981). The higher the rainfall, the more likely seepage will occur and allow groundwater nutrients to enter waterways. Seepage velocities will differ greatly among sites and thus failing septic systems will have varying impacts on the water quality of specific lakes. Lee (1977) studied seepage in lake systems and found that seepage occurs as far as 80 meters from the shore. This finding may help explain the observed increases in submersed aquatic plant growth near areas with abundant septic tank systems that may not be adequately maintained. Loeb and Goldman (1978) found that groundwater contributes approximately 44% of the total soluble reactive phosphorus (SRP) and 49% of total nitrates to Lake Tahoe from the Ward Valley watershed. Additionally, Canter (1981) determined that man-made (anthropogenic) activities such as the use of septic systems can greatly contribute nutrients to groundwater.

Poorly maintained septic systems may also lead to increases in toxin-producing blue-green algae such as *Microcystis.* This alga is indicative of highly nutrient-rich waters and forms an unsightly green scum on the surface of a water body. Toxins are released from the algal cells and may be dangerous to animals and humans in elevated concentrations. Furthermore, the alga may shade light from underlying native aquatic plants and create a sharp decline in biomass which leads to lower dissolved oxygen levels in the water column. Repeated algae treatments are often not enough to compensate for this algal growth and the problem persists. There are several different methods available to reduce the threat of NPS pollution to inland lakes and each are able to be site-specific.

Riparian Land Use Best Management Practices (BMPs)

The increased developmental pressures and usage of aquatic ecosystems necessitate inland lake management practices as well as watershed Best Management Practices (BMPs) to restore balance within the immediate watershed of Perch and Crystal lakes, especially around the lakeshores. For optimum results, BMP's should be site-specific and tailored directly to the impaired area (Maguire et *al.*, 2009). Best Management Practices (BMPs) can be implemented to improve a lake's water quality. Best Management Practices (BMPs) are land management practices that treat, prevent, or reduce water pollution. Structural BMPs are physical improvements that require construction during installation. Examples of structural BMPs include check dams, detention basins, and rock riprap. BMPs that utilize plants to stabilize soils, filter runoff, or slow water velocity are categorized as Vegetative BMPs. Managerial BMPs involve changing operating procedures to lessen water quality impairments. Conservation tillage and adoption of ordinances are examples of these types of BMPs. For inland lakes, the emphasis should be on BMPs that are designed to reduce storm water volume, peak flows, and/or nonpoint source pollution through proper storm water management and erosion control practices. Below is a summary of BMPs that are designed to meet these requirements. Identifying opportunities for implementation of BMPs is based on several factors including stakeholder willingness/preferences, cost, time, and effectiveness of specific management options.

The guidebook, Lakescaping for Wildlife and Water Quality (Henderson et *al*. 1998) provides the following guidelines:

1) Maintenance of brush cover on lands with steep slopes (>6% slope)
2) Development of a vegetation buffer zone 25-30 feet from the land-water interface with approximately 60-80% of the shoreline bordered with vegetation
3) Limiting boat traffic and boat size to reduce wave energy and thus erosion potential. There is currently a mandated no-wake boating speed for both Perch and Crystal Lakes.
4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion
5) Using only <u>native</u> genotype plants (those native to a particular lake and region) around the lake since they are most likely to establish and thrive than those not acclimated to growing in the area soils

6) Avoid the use of lawn fertilizers that contain phosphorus (P). P is the main nutrient required for aquatic plant and algae growth, and plants grow in excess when P is abundant. When possible, water lawns with lake water that usually contains adequate P for successful lawn growth. If you must fertilize your lawn, assure that the middle number on the bag of fertilizer reads “0” to denote the absence of P. If possible, also use low N in the fertilizer or use lake water.
7) Preserve riparian vegetation buffers around a lake (such as those that consist of Cattails, Bulrushes, and Swamp Loosestrife), since they act as a filter to catch nutrients and pollutants that occur on land and may run off into a lake. Visit the Michigan Natural Shoreline Partnership website to learn more about soft shoreline protection and planting: https://www.shorelinepartnership.org/.

   As an additional bonus, Canada geese (*Branta canadensis*) usually do not prefer lakefront lawns with dense riparian vegetation because they are concerned about the potential of hidden predators within the vegetation. Figure 55 demonstrates a lakefront property with poor management of the shoreline.

Figure 55. An example of poor shoreline management with no vegetation buffer present. ©RLS

8) Do not burn leaves near the lake shoreline since the ash is a high source of P. The ash is lightweight and may become airborne and land in the water eventually becoming dissolved and utilized by aquatic vegetation and algae.
9) Ensure that all areas that drain to a lake from the surrounding land are vegetated and that no fertilizers are used in areas with saturated soils.

10) The construction of impervious surfaces (i.e., paved roads and walkways, houses) should be minimized and kept at least 100 feet from the lakefront shoreline to reduce surface runoff potential. In addition, any wetland areas around a lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat. Construction practices near the lakeshore should minimize the chances for erosion and sedimentation by keeping land areas adjacent to the water stabilized with rock, vegetation, or wood retaining walls. This is especially critical in areas that contain land slopes greater than 6%.
11) In areas where the shoreline contains metal or concrete seawalls, placement of natural vegetation or tall emergent plants around the shoreline is encouraged. Erosion of soils into the water may lead to increased turbidity and nutrient loading to a lake. Seawalls should consist of riprap (stone, rock), rather than metal, due to the fact that riprap offers a more favorable habitat for lakeshore organisms, which are critical to the ecological balance of the lake ecosystem. Riprap should be installed in front of areas where metal seawalls are currently in use. The riprap should extend into the water to create a presence of microhabitats for enhanced biodiversity of the aquatic organisms within a lake. The emergent aquatic plants, *Schoenoplectus* sp. (Bulrushes) or Cattails present around the lakes may offer satisfactory stabilization of shoreline sediments and assist in the minimization of sediment release into a lake.
12) The U.S. Environmental Protection Agency (USEPA) offers excellent educational resources and reference materials that riparians can use to care for their septic systems. To learn more about septic systems and how to care for them, visit the website: http://water.epa.gov/infrastructure/septic/. Some lake associations have created “annual septic pump out” days where septic tank contractors visit individual properties and clean out the septic tanks as well as inspect the drain fields for any issues that may negatively affect water quality. Annual pump out days are a great way to interact with riparian neighbors and learn about the many different types and locations of individual septic systems. Additionally, riparians should always maintain an awareness of the aquatic vegetation and algae in their lake so they can report any significant deviations from the normal observations. An awareness of the ambient lake water quality is also useful since degradations in water quality often occur over a long period of time and can be subtle.

6.0 PERCH AND CRYSTAL LAKES IMPROVEMENT CONCLUSIONS & RECOMMENDATIONS

The largest threats to both Perch and Crystal lakes are erosion of land around the lake and nutrients from septic systems, and invasive aquatic plant species. If erosion is not stabilized, fishery spawning habitat may become impaired by the addition of sediments to the lake and the increased BOD may result in a decline in dissolved oxygen with depth throughout Crystal Lake. In addition, soils entering the lakes further contribute nutrients over time that may continue to increase at the lake bottoms. Crystal Lake in particular is vulnerable to the release of phosphorus since its dissolved oxygen concentrations decline significantly with depth. Over time, high nutrients may lead to increased aquatic plant growth and even blue-green algal blooms that secrete toxins such as microcystins that are a public and pet health hazard and result in lake advisories and use restrictions.

Only invasive aquatic vegetation should be managed and treated as the native biodiversity is needed to support the lake fishery and compete with any invasives over time. Only systemic herbicides should be used for milfoil and Curly-leaf Pondweed should either be left to die naturally or could be treated with a contact herbicide. It is best to reduce the amount of herbicide needed over time. Starry Stonewort must be addressed soon before it becomes abundant. The best approach for that plant is either DASH or the use of SeClear® or flumioxazin herbicides.

Additional improvements would include the assurance that all areas around the lake are vegetated at all times and with proper erosion stabilization techniques. In addition, RLS recommends a lake-wide septic system maintenance program be developed where residents can have an annual septic tank pump-out week and the Association can keep a log of residents that participate.

An aquatic invasive species (AIS) educational program should also be developed and possibly enriched with the placement of signs and boat washing stations at key access locations. A major goal is to reduce the transfer of invasives into both lakes over time as many new invasive species have been found in the Midwest and are moving north.

Furthermore, a professional limnologist/aquatic botanist should perform regular GPS-guided whole-lake surveys each spring and late summer/early fall to monitor the growth and distribution of all invasives and nuisance aquatic vegetation growth prior to and after treatments to determine treatment efficacy. Continuous monitoring of the lake for potential influxes of other exotic aquatic plant genera (i.e., *Hydrilla*) that could also significantly disrupt the ecological stability of both lakes is critical. An independent lake professional should be responsible for the creation of unbiased aquatic plant management survey maps, and direction of the harvester or herbicide applicator to target-specific areas of aquatic vegetation for removal.

A complete list of recommended lake improvement options for this proposed lake management plan can be found in Table 30 below. It is important to coordinate these methods with objectives so that baseline conditions can be compared to post-treatment/management conditions once the methods have been implemented.

Table 30. List of Perch and Crystal Lake improvement methods with primary and secondary goals and locations for implementation.

Proposed Improvement Method	Primary Goal	Secondary Goal	Where to Implement
Systemic herbicide spot-treatments for invasives	Reduce invasives in both lakes	Reduce long-term use of herbicides in lakes	Entire lake where invasives present
Boat washing station and/or AIS prevention	To reduce the transfer of invasive aquatic species into or out of both lakes	To continue to improve biodiversity of native species in both lakes	At access sites
Annual water quality monitoring of lake	Determine the trends in all water quality parameters with time	Compare baseline water quality and drain data to modern data to view trends for data-driven management	Both lake basins in two locations
Annual whole-lake aquatic vegetation surveys	To inventory where the invasive species are located for necessary treatment	To determine treatment efficacy and assure that native biodiversity can thrive	Both lakes, entire lake basins
Annual septic tank pump out program	To motivate all riparians to annual pump and have septic tank inspected	To reduce nutrient loads to the lakes as septic systems are largest source	All lakefront homes on both lakes
Riparian/community education	To raise awareness of lake issues and empower all to participate in lake protection	Long-term sustainability requires ongoing awareness and action	Entire lake community and those who frequent the lake; may also include relevant stakeholders

6.1 Cost Estimates for Perch and Crystal Lake Improvements

The proposed lake improvement and management program for Perch and Crystal Lakes is recommended to begin as soon as possible. A breakdown of estimated costs associated with the various proposed improvements to the lakes is presented in Table 31. It should be noted that proposed costs are estimates and may change in response to changes in environmental conditions (i.e., increases in aquatic plant growth or distribution, or changes in herbicide costs). Note that this table is adaptive and is likely to change and may be executed over many years.

Table 31. Perch and Crystal Lakes proposed lake improvement program costs.

Management Item	Proposed Cost 2024	Predicted Cost 2025-2026
Systemic herbicides[1] for EWM and contacts for CLP and/or Starry Stonewort	$5,000	$6,000
Boat washing station[2]	$30,000	$1,000 (maintenance)
Water quality monitoring[3]of lake (in addition to abbreviated CLMP program)	$5,800	$6,000
Whole lake aquatic vegetation surveys[4]	$4,500	$4,800
Septic tank program[5] (includes educational materials and seminars)	$8,000	$8,000
Riparian education[6] (includes educational information and seminars and workshops)	$5,500	$6,000
TOTAL ANNUAL COST	$58,800	$31,800

[1] Herbicide treatment scope may change annually due to changes in the distribution and/or abundance of aquatic plants.

[2] Boat washing station estimate based on current 2023 market cost for single solar-powered unit.

[3] Water quality monitoring to include scope similar to this evaluation and inclusion of CLMP data into annual report.

[4] Proposed to be two annual GPS-guided, whole-lake aquatic vegetation surveys and scans as presented in this evaluation.

[5] Septic system program for riparians to include education of proper septic system care and coordination of an annual pump out day/week program for nutrient reduction.

[6] Riparian educational workshops to be held annually on lake improvement strategies for water quality, erosion control, septic maintenance, aquatic vegetation identification, and invasive species prevention.

7.0 SCIENTIFIC REFERENCES

Aiken, S.G., P.R. Newroth, and I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. *Canadian Journal of Aquatic Plant Science* 59: 201-215.

Brattebo, S.K., E.B. Welch, H.L. Gibbons, M.K. Burghdoff, G. N. Williams, and J.L. Oden. Effectiveness of alum in a hypereutrophic lake with substantial external loading. *Lake and Reservoir Management* 33(2): 108-118.

Brunberg, A.K. 2995. Microbial activity and phosphorus dynamics in eutrophic lake sediments enriched with *Microcystis* colonies. *Freshwater Biology* 33: 541-555.

Canter, L.W., and R.C. Knox. Septic tank system effluents on groundwater quality. Chelsea, Michigan, Lewis Publications, Inc. 336 p.

Couch, R., and E. Nelson 1985. *Myriophyllum spicatum* in North America. Pp. 8-18. In: Proc. First Int. Symp. On Watermilfoil (*M. spicatum*) and related Haloragaceae species. July 23-24, 1985. Vancouver, BC, Canada. Aquatic Plant Management Society, Inc.

Eiswerth, M.E., S.G. Donaldson, and W.S. Johnson. 2000. Potential environmental impacts and economic damages of Eurasian Watermilfoil (*M. spicatum*) in Western Nevada and Northeastern California. *Weed Technology* 14(3):511-518.

Fenchel, T., and T.H. Blackburn. 1979. Bacteria and mineral cycling. Academic.

Gilliom, R.J., and Patmont, C.R. 1983. Lake phosphorus loading from septic systems by seasonally perched groundwater. *Journal of the Water Pollution Control Federation*. 55(10):1297-1305.

Henderson, C.L., C. Dindorf, and F. Rozumalski. 1998. Lakescaping for Wildlife and Water Quality. Minnesota Department of Natural Resources, 176 pgs.

Laitala, K.L., T.S. Prather, D. Thill, and B. Kennedy. 2012. Efficacy of benthic barriers as a control measure for Eurasian Watermilfoil (*Myriophyllum spicatum*). *Invasive Plant Science* 5(2):170-177.

Lee, D.R. 1977. A device for measuring seepage flux in lakes and estuaries. *Limnology and Oceanography* 22(1):140-147.

Lenat, D.R. and M.T. Barbour. Using benthic macroinvertebrate community structure for rapid, cost-effective, water quality monitoring: rapid bioassessment. Biological monitoring of aquatic systems. Lewis Publishers, Boca Raton, Florida (1994): 187-215.

Lesauteur, T. 1968. Water pollution in summer cottage areas. *Canadian Journal of Public Health* 59(7):276-277.

Lillie, R.A., and J. Budd. 1992. Habitat architecture of *Myriophyllum spicatum* L. as an Index to habitat quality for fish and macroinvertebrates. *Journal of Freshwater Ecology* 7(2): 113-125.

Loeb, S., and C.R. Goldman. 1978. Water and nutrient transport via groundwater from Ward Valley into Lake Tahoe. *Limnology and Oceanography* 24(6):1146-1154.

Lyons, J. 1989. Changes in the abundance of small littoral-zone fishes in Lake Mendota, Wisconsin. *Canadian Journal of Zoology* 67:2910-2916, 10.1139/z89-412.

Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies, *Journal of Aquatic Plant Management* 29, 94-99.

Maguire, R.O., G.H. Rubaek, B.E. Haggard, and B.H. Foy, 2009. Critical evaluation of the implementation of mitigation options for phosphorus from field to catchment scales. *Journal of Environmental Quality* 38(5):1989-1997.

Margenau, T.L., AveLallemant, S.P., Giehtbrock, D., and S. Schram. 2008. Ecology and management of northern pike in Wisconsin. *Hydrobiologia* 601(1):111-123.

Merritt, R., W. Cummins, and M.B. Berg. 2008. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co. 1158 pgs.

Nayar, S., DJ Miller, A. Hunt, BP Goh, and LM Chou. 2007. Environmental effects of dredging on sediment nutrients, carbon, and granulometry in a tropical estuary. *Environmental Monitoring and Assessment* 127(1-3):1-13.

Newroth, P.R. 1985. A review of Eurasian watermilfoil impacts and management in British Columbia. Pp. 139-153. In: Proc. First Int. Symp. On watermilfoil (*M. spicatum*) and related Haloragaceae species. July 23-24, 1985. Vancouver, BC, Canada. Aquatic Plant Management Society, Inc.

Nürnberg, G. 2017. Attempted management of cyanobacteria by Phoslock (lanthanum-modified) clay in Canadian Lakes: Water quality results and predictions. *Lake and Reservoir Management* 33:163-170.

Parsons, J.K., and R.A. Matthews. 1995. Analysis of the camps between macroinvertebrates and macrophytes in a freshwater pond. *Northwest Science* 69: 265-275.

Pilgrim, K.M., and P.L. Brezonik, 2005. Evaluation of the potential adverse effects of lake inflow treatment with alum. *Lake and Reservoir Management* 21(1):77-87.

Radomski, P. and T. J. Goeman. 2001. Consequences of human lakeshore development on emergent and floating-leaf vegetation abundance. *North American Journal of Fisheries Management* 21(1):46-61.

Reed, C.G. 1977. History and disturbance of Eurasian milfoil in the United States and Canada. *Phytologia* 36: 417-436.

Reynolds, C.S. 1984. The Ecology of Freshwater Phytoplankton. Cambridge University Press, Cambridge, UK.

Rosenberger, E.E., Hampton, S.E., Fradkin, S.C., and Kennedy, B.P. 2008. Effects of shoreline development on the nearshore environment in large, deep, oligotrophic lakes. *Freshwater Biology* 53:1673-1691.

Sass. L.L., Bozek, M.A., Hauxwell, J.A., Wagner, K., and Knights, S. 2010. Response of aquatic macrophytes to human land use perturbations in the watersheds of Wisconsin lakes, USA. *Aquatic Botany* 93:1-8.

Sawhney, B.L., and J.L. Starr. 1977. Movement of phosphorus from a septic system drain Field. *Journal of Water Pollution Control Federation* 49(11):2238-2242.

Schreiber, E.S.G., Quinn, G.P. and P.S. Lake. 2003. Distribution of an alien aquatic snail in relation to flow variability, human activities and water quality. *Freshwater Biology*: Vol 48:6, pages 951-961.

Shaw and Prepas, 1990. Groundwater-lake interactions: I. Accuracy of seepage meter estimates of lake seepage. *Journal of Hydrology* 119:105-120.

Spence-Cheruvelil. K. and P.A. Soranno. 2008. Relationships between lake macrophyte cover and lake and landscape features. *Journal of Aquatic Botany* 88(3):219-227.

Stewart, T.W. and J.M. Haynes. 1994. Benthic macroinvertebrate communities of southwestern Lake Ontario following invasion of *Dreissena*. *Journal of Great Lakes Research* 20(2): 479-493.

Stewart, P.M., Butcher, J.T. and T.O. Swinford. 2000. Land use, habitat, and water quality effects on macroinvertebrate communities in three watersheds of a Lake Michigan associated marsh system. *Aquatic Ecosystem Health & Management*: 3(1):179-189.

Valley, R., and M. T. Bremigan. 2002. Effects of selective removal of Eurasian watermilfoil on age-0 largemouth bass piscivory and growth in southern Michigan lakes. *Journal of Aquatic Plant Management* 40: 79-87.

Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Third Edition. Academic Press, 1006 pgs.

Winter, T.C. 1981. Effects of water-table configuration on seepage through lake beds. *Limnology and Oceanography* 26(5):925-934.

8.0 TECHNICAL GLOSSARY

Aerobic: Requiring oxygen to live or occurring in the presence of oxygen.

Anaerobic: The absence of oxygen (also anoxic).

Algae: Simple single-celled (phytoplankton), colonial, or multi-celled, mostly aquatic plants, containing chlorophyll and lacking roots, stems and leaves. Aquatic algae are microscopic plants that grow in sunlit water that contains phosphates, nitrates, and other nutrients. Algae, like all aquatic plants, add oxygen to the water and are important in the fish food chain. Algae is either suspended in water or attached to rocks and other substrates. Algae are an essential part of the lake ecosystem and provide the food base for most lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Algal Bloom: A heavy growth of algae in and on a body of water. This usually is a result of high nitrates and phosphate concentrations entering water bodies.

Benthic: Located on the bottom of a body of water or in the bottom sediments.

Bioaccumulation: The process by which the concentration of a substance is increased through successive links in a food chain which may result in toxic concentrations at the top of the chain.

Best Management Practices (BMPs): An engineered structure or management activity that eliminates or reduces adverse environmental effects of pollutants.

Buffer Strip: Grass or other vegetation planted between a waterway and an area of intensive land use in order to reduce erosion. This is considered a best management practice.

Chlorophyll-*a*: The green pigment found in plants that are essential to photosynthesis. It is sometimes used to measure the amount of algae in the lake.

Chlorides: Sodium chloride (table salt) is often used to de-ice roadways during winter months. The salt (chloride) may then be washed into nearby lakes and streams resulting in elevated chloride levels in the water body. Elevated chloride levels can have an adverse effect on aquatic plants and animals. In public water supplies the EPA has set a standard that requires chloride levels not to exceed 250 mg/L due to possible health concerns.

Conductivity: A measure of the electrolytes in the water, which may be elevated by the presence of salts resulting from soil composition, faulty septic systems, or road salts.

Cultural Eutrophication: When human activities lead to the premature aging of a lake or pond.

Cyanobacteria (Blue-Green Algae): Bacteria that photosynthesize (use sunlight to produce food) and are blue-green in color. While cyanobacteria occur naturally in all lakes and ponds, elevated nutrient levels may cause cyanobacteria to "bloom" or grow out of control and cover the lake surface. The concern associated with cyanobacteria is that some species produce toxins that may affect domestic animals or humans through skin contact or ingestion.

Dissolved Oxygen: The amount of oxygen in the water. Dissolved oxygen may be produced by algae and aquatic plants or mixed into the water from the air. It is used by fish, aquatic insects, crayfish and other aquatic animals. Dissolved oxygen is usually measured in milligrams per liter.

Ecology: The study of the interactions between organisms and their environments.

Erosion: The gradual wearing away of land surface materials, especially rocks, sediments, and soils, by the action of water, wind, or a glacier. Usually, erosion also involves the transport of eroded material from one place to another.

Eutrophic: Nutrient rich waters, generally characterized by high levels of biological production.

Exotic Species: A plant or animal species introduced to an area from another country or state that is not native to the area.

Food Chain: A succession of organisms in an ecological community that constitutes a continuation of food energy from one organism to another as each consumes a lower member and in turn is preyed upon by a higher member.

Groundwater: (1) water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper surface of the saturated zone is called the water table. (2) Water stored underground in rock crevices and in the pores of geologic materials that make up the Earth's crust.

Headwater: The source and upper reaches of a stream or river.

Impaired: Being damaged or degraded as a result of pollution and therefore unable to meet the designated uses outlined by the State of Michigan.

Internal Loading: The release of phosphorus from the lake bottom sediments into the bottom layer of the water.

Leaching: The process by which soluble materials in the soil, such as salts, nutrients, pesticide chemicals or contaminants, are washed into a lower layer of soil or are dissolved and carried away by water.

Limiting Nutrient: An essential nutrient for plant growth, which has the least abundance in the environment relative to the needs of the plant. Phosphorous is usually the limiting nutrient in freshwater lakes and rivers.

Limnology: The study of the biology, chemistry, and physics of freshwater lakes and ponds.

Littoral: The shoreline zone of a lake where sunlight penetrates to the bottom and is sufficient to support rooted plant growth.

Nonpoint Source Pollution: Pollution that comes from diffuse sources, not an end-of-pipe outlet which is referred to as point source pollution. Typical nonpoint source pollutants include animal manure, storm water runoff, metals, nutrients, organic matter, pathogens, pesticides, petroleum by-products, and sediment.

Nutrients: Inorganic substances required by plants to manufacture food by photosynthesis. Phosphorus is the nutrient that usually limits the amount of aquatic plant growth in lakes.

Pathogens: Human disease causing bacteria or viruses that come from sewage spills, leaking septic tanks, manure runoff from farm fields, and even wildlife that live in the watershed.

pH: The measure of how acidic the water is, on a scale of 1-14; 1 is very acidic, and 14 is very basic.

Phosphorus: The nutrient most necessary for plant and algal growth in Michigan lakes, which comes from many sources including land application of farm animal manure, faulty septic systems, lawn fertilizers, and decaying plant matter.

Phytoplankton: Microscopic plants that float within or on top of lake water. (Refer to Algae)

Pollutant: Any substance of such character and in such quantities that when it reaches a body of water, soil or air, it contributes to the degradation or impairment of its usefulness.

Point Source Pollution: Pollution into a water body from a specific and identifiable source, such as industrial waste or municipal sewers.

Riprap: Large rocks placed along the bank of a waterway to prevent erosion.

Runoff: Water that travels over the land surface and ends up in streams and lakes.

Secchi Disk: An instrument used for measuring the transparency of lakes. It is a 20-cm diameter disk with black and white quadrants.

Sedimentation: The transport and deposition of soil particles by flowing water. Sediment is considered a pollutant.

Stratification (thermal): A process by which a deep lake becomes layered by temperature in the summer months. The layers will separate because colder water sinks to the bottom, leaving warmer water at the surface. Because these layers form chemical and biological barriers, limnologists sample each layer of the lake. During the winter months, when ice forms on the lake, Inverse Thermal Stratification occurs under the ice, in which colder, less dense water overlies warmer, denser water near the maximum density of four degrees Celsius.

Transparency: A measure of water clarity often determined by the depth at which a Secchi disk can be seen below the surface of the water. Transparency may be reduced by the presence of algae and suspended materials such as silt and pollen.

Tributary: A river or stream that flows into a larger river, stream, or lake.

Trophic Classification: Biologically ranking the quality of lakes using a model that incorporates several parameters including; chlorophyll-a, Secchi disk transparency, aquatic plant abundance, and dissolved oxygen.

Trophic State: The trophic state of a lake is a general concept with no precise definition and no well-defined units of measure. In general, trophic state refers to the biological production, both plant and animal life, that occurs in a lake. The level of production that occurs is defined by several factors, but primarily by the phosphorus supply to the lake and the volume and residence time of the water in the lake.

Turbidity: A measure of the particles suspended in the water column which affect the clarity and transparency of the water. These particles may include silt, pollen, and algae.

Water Residence Time: The amount of time required to completely replace the water volume of a lake by incoming water, assuming complete mixing.

Watershed management plan: A document that assesses surface water resources impairments, land use activities, and development in a given watershed in order to provide the framework needed to implement projects and practices to restore, preserve, and sustain healthy watershed services.

Watershed: An area of land in which all the rainfall and snowmelt from that area drains to the lowest point, usually a stream or lake.

Zooplankton: Microscopic animals that live in lakes.