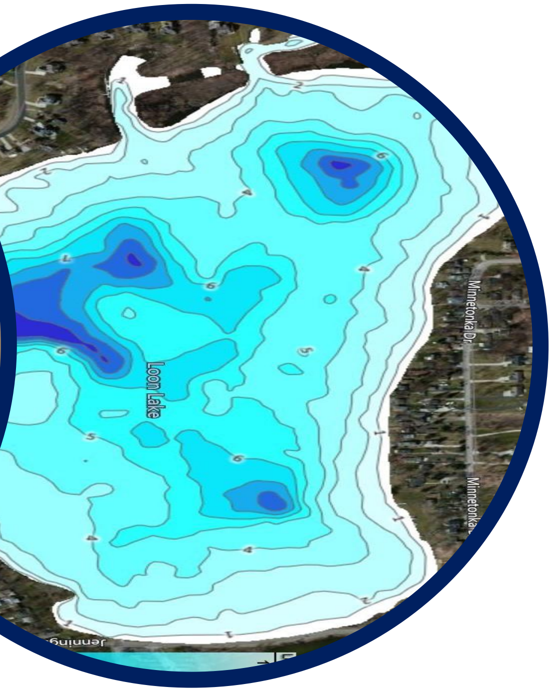
Loon Lake Improvement Study and Management Plan
Genesee County, Michigan



Provided for: Loon Lake Association Board

Prepared by: Restorative Lake Sciences
Jennifer L. Jermalowicz-Jones, PhD
Water Resources Director
18406 West Spring Lake Road
Spring Lake, Michigan 49456
www.restorativelakesciences.com

TABLE OF CONTENTS

SECTION **PAGE**

LIST OF FIGURES

LIST OF TABLES

Loon Lake Improvement Study and Management Plan
Genesee County, Michigan

December 2019

1.0 EXECUTIVE SUMMARY

Loon Lake is located in Fenton Township in Genesee County, Michigan (T.5N, R.6E). The lake is comprised of 162.6 acres (RLS, 2019). The lake is of glacial origin with an inlet from Crane Lake and an outlet to Squaw Lake. The average mean depth of the lake is approximately 5.6 feet and the maximum depth is approximately 10.5 feet (RLS, 2019 bathymetric scan data). The lake also has a fetch (longest distance across the lake) of around 0.8 miles (RLS, 2019).

Loon Lake has an approximate water volume of 664.1 acre-feet (RLS, 2019 bathymetric data) and contains some springs. Loon Lake lies within the Shiawassee River watershed which is within the larger Saginaw Bay watershed which drains to Saginaw Bay and Lake Huron. The immediate watershed, which is the area directly draining into the lake, is approximately 978 acres which is about 6 times the size of the lake and is moderate in size.

Based on the current study, Loon Lake contains two emergent invasive aquatic plant species including (*Phragmites*) and Purple Loosestrife as well as two submersed invasive species such as Eurasian Watermilfoil and Starry Stonewort. Recommendations for treatment and prevention of these invasives are offered later in this management plan report. There are a total of 7 submersed, 2 floating-leaved, and 4 emergent native aquatic plant species in Loon Lake that were present during the lake survey on September 30, 2019 with the most dominant being the White waterlily.

The overall water quality of Loon Lake was measured as good with moderate nutrients such as phosphorus (TP) and nitrogen (TKN) but low water clarity. The pH of the lake indicates that it is a neutral lake. The TP concentrations in the lake deep basins ranged from 0.017-0.027 mg/L which is below or just at the eutrophic threshold. Additionally, the bioavailable TP (SRP) concentrations were all below detection at <0.010 mg/L which is favorable. The TKN concentrations in the lake deep basins ranged from 0.7-1.2 mg/L which is moderate. The lake N:P ratio is 43 which means that the lake is P-limited with 43 times more nitrogen. Total suspended solids (TSS) in the lake were all below detection at <10 mg/L which is favorable.

The conductivity of the lake ranged from 617-629 mS/cm which is moderately high and indicative of an urban watershed. The water clarity (secchi transparency) ranged from 3.6-3.7 feet which is low and indicates turbid waters. The total alkalinity was around 150 mg/L which is moderately hard water. The chlorophyll-a, which is a measure of algal pigment, ranged from 1.8-3.0 µg/L, which is moderate. Dissolved oxygen concentrations were all favorable among the basins. Sediments were moderately low in organic matter and ranged from low to high in sediment phosphorus. The lake is very well mixed and oxygenated. At this time, laminar flow aeration is not needed for the lake. However, intense algal blooms may benefit from addition of beneficial bacteria to outcompete less desirable algae.

Loon Lake has multiple land uses such as wetlands, beaches, and riparian properties. It is recommended that the Loon Lake community implement Best Management Practices (BMP's) discussed in the report to reduce the nutrient and sediment loads being transported into the lake from areas with soil ponding (mucks).

Lastly, 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. This is an event that could be conducted by RLS in the near future.

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 the reader with a more thorough understanding of the forthcoming lake management recommendations for Loon Lake.

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 which 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. Loon Lake may be categorized as a drainage lake since it has an inlet and outlet.

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 Watersheds and Land Use

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 since 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 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.

3.0 LOON LAKE PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Loon Lake Basin

Loon Lake is located in Fenton Township in Genesee County, Michigan (T.5N, R.6E; Figure 1). The lake is comprised of 162.6 acres (RLS, 2019). The lake has nearly 2.62 miles of shoreline. The average mean depth of the lake is approximately 5.6 feet and the maximum depth is approximately 10.5 feet (RLS, 2019 bathymetric scan data; Figure 2). The lake also has a fetch (longest distance across the lake) of around 0.8 miles (RLS, 2019).

Loon Lake has an approximate water volume of 664.1 acre-feet (RLS, 2019 bathymetric data). The immediate watershed, which is the area directly draining into the lake, is approximately 978 acres which is about 6 times the size of the lake and is moderate in size. A bottom sediment hardness scan was conducted of the entire lake bottom on September 30, 2019. The bottom hardness map shows (Figure 3) that most of the lake bottom consists of fairly consolidated sediment throughout the lake with only a few small areas with soft organic bottom. This is not surprising given the amount of sandy loams in the region which contribute to lake geology. Table 1 below shows 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. This scale does not mean that any of the lake contains a truly “hard” bottom but rather a bottom that is more coherent and not flocculent.

Table 1. Loon Lake relative hardness of the lake bottom by category or hardness and percent over of each category (relative cover; September 30, 2019).

Lake Bottom Relative Hardness Category	# GPS Points in Each Category (Total = 6,333)	% Relative Cover of Bottom by Category
0.0-0.1	16	0.3
0.1-0.2	50	0.8
0.2-0.3	478	7.7
0.3-0.4	3632	58.6
>0.4	2027	36.7

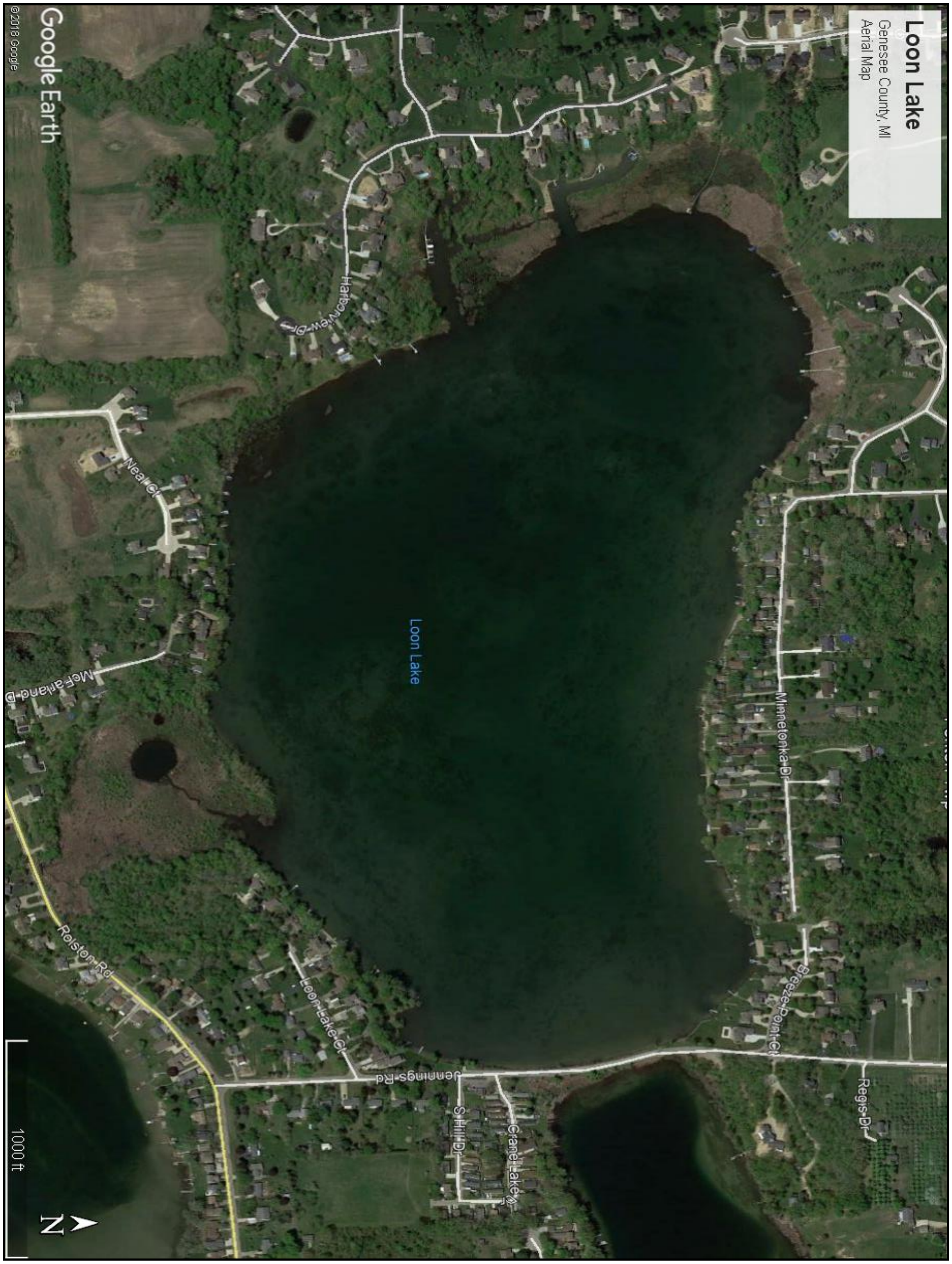


Figure 1. Loon Lake Aerial Photo, Genesee County, Michigan.

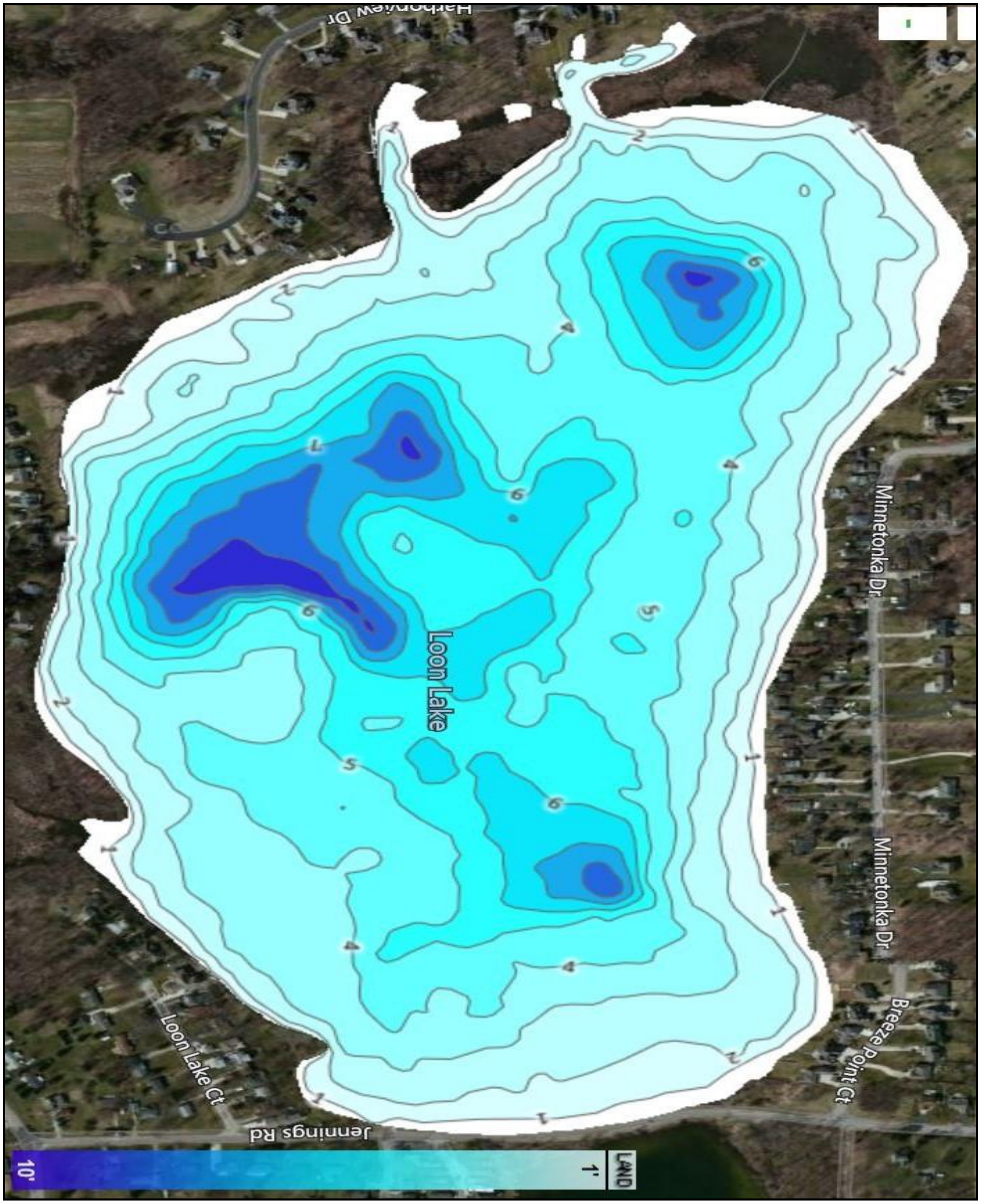


Figure 2. Loon Lake Depth Contour Map, Genesee County, Michigan.

Figure 3. Loon Lake Sediment Hardness Map, Genesee County, Michigan.

3.2 Loon Lake Extended and Immediate Watershed and Land Use Summary

A watershed is defined as a region surrounding a lake that contributes water and nutrients to a waterbody through drainage sources. Watershed size differs greatly among lakes and also significantly impacts lake water quality. Large watersheds with much development, numerous impervious or paved surfaces, abundant storm water drain inputs, and surrounding agricultural lands, have the potential to contribute significant nutrient and pollution loads to aquatic ecosystems.

Loon Lake is located within the Shiawassee River extended watershed (HUC 0408203) which drains into the Saginaw River which then enters Saginaw Bay in Lake Huron. This watershed includes 5.5 mi^2 of lakes and over 234 miles of drains, creeks, and rivers. The largest issue currently facing this watershed is the rapid conversion of agricultural lands to urban and residential land. 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 Loon Lake community.

The immediate watershed of Loon Lake consists of the area around the lake that directly drains to the lake and measures approximately 978 acres in size (Figure 4; RLS, 2019). The immediate watershed is about 6 times the size of the lake, which is considered a moderate-sized watershed. The lakefront itself has a diverse application of land uses such as wetlands beachfront for swimming, and urban lands. Thus, management options should also consider all of these land uses and preserve their unique functions. Soil ponding and nutrient runoff and invasive species are the largest threats to the water quality of Loon Lake.

Some of the areas around the lake are of high slope and are prone to erosion. Best Management Practices (BMP’s) for water quality protection are offered in the watershed improvement section of this report.

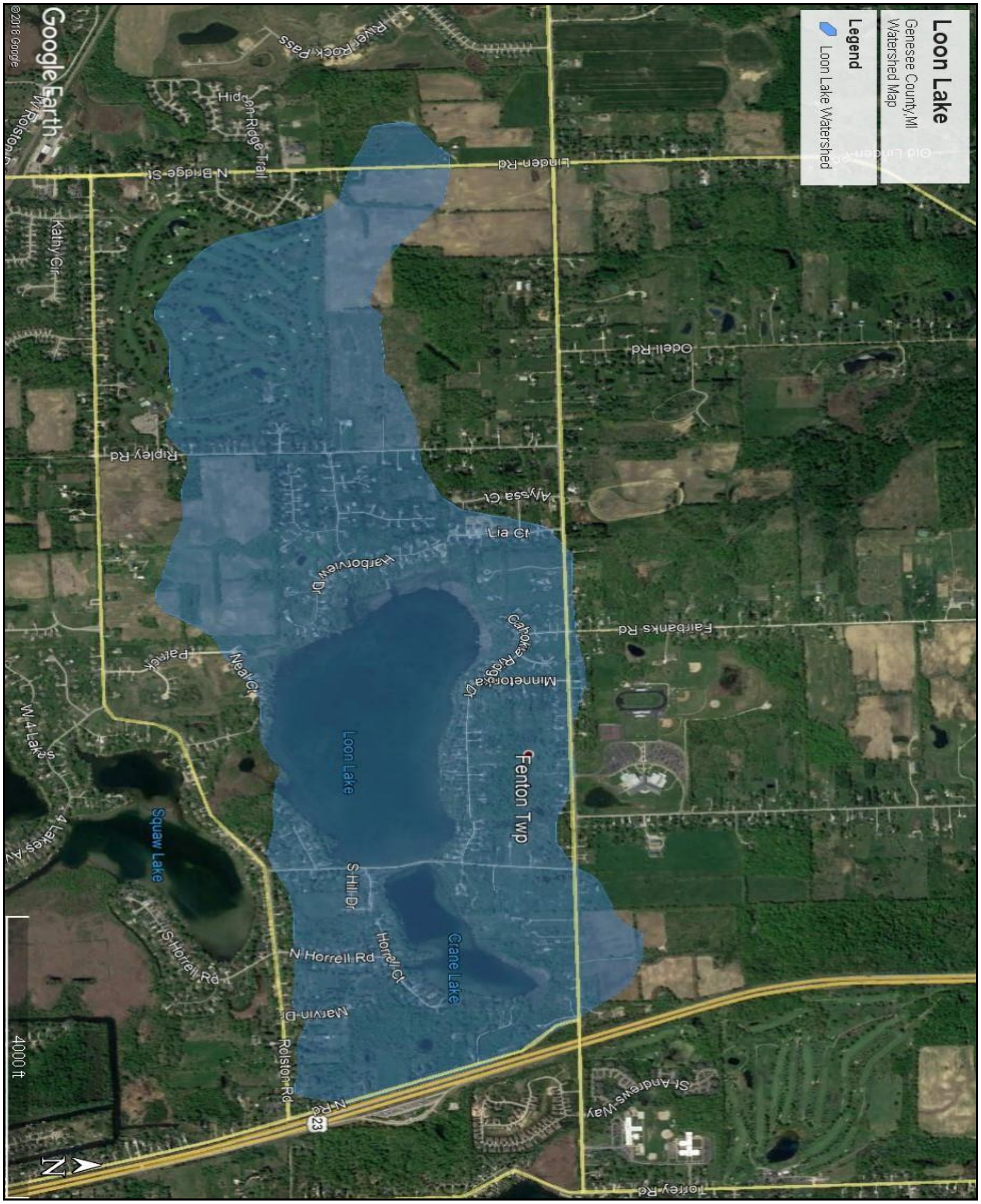


Figure 4. Immediate Watershed draining into Loon Lake, Genesee County, Michigan (Restorative Lake Sciences, 2019).

3.3 Loon Lake Shoreline Soils

There are 5 major soil types immediately surrounding Loon Lake which may impact the water quality of the lake and may dictate the particular land use activities within the area. The denotes a lake with fairly complex geology; Figure 5 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service, 1999) demonstrates the precise soil types and locations around Loon Lake. Major characteristics of the dominant soil types directly surrounding the Loon Lake shoreline are discussed below. The locations of each soil type are listed in Table 2 below.

Table 2. Loon Lake Shoreline Soil Types (USDA-NRCS data).

USDA-NRCS Soil Series	***Loon Lake Soil Type Location***
Cd-Carlisle & Linwood mucks	NW, W, S, E shores
MoC-Wawasee loams, 6-12% slopes	N shore
CVraaB-Conover loam, 0-4% slopes	E, SE, S shores
MoE-Miami loam, 18-25% slopes	E shore
OkB-Oakville fine sand, loamy, 0-6% slopes	SW shore

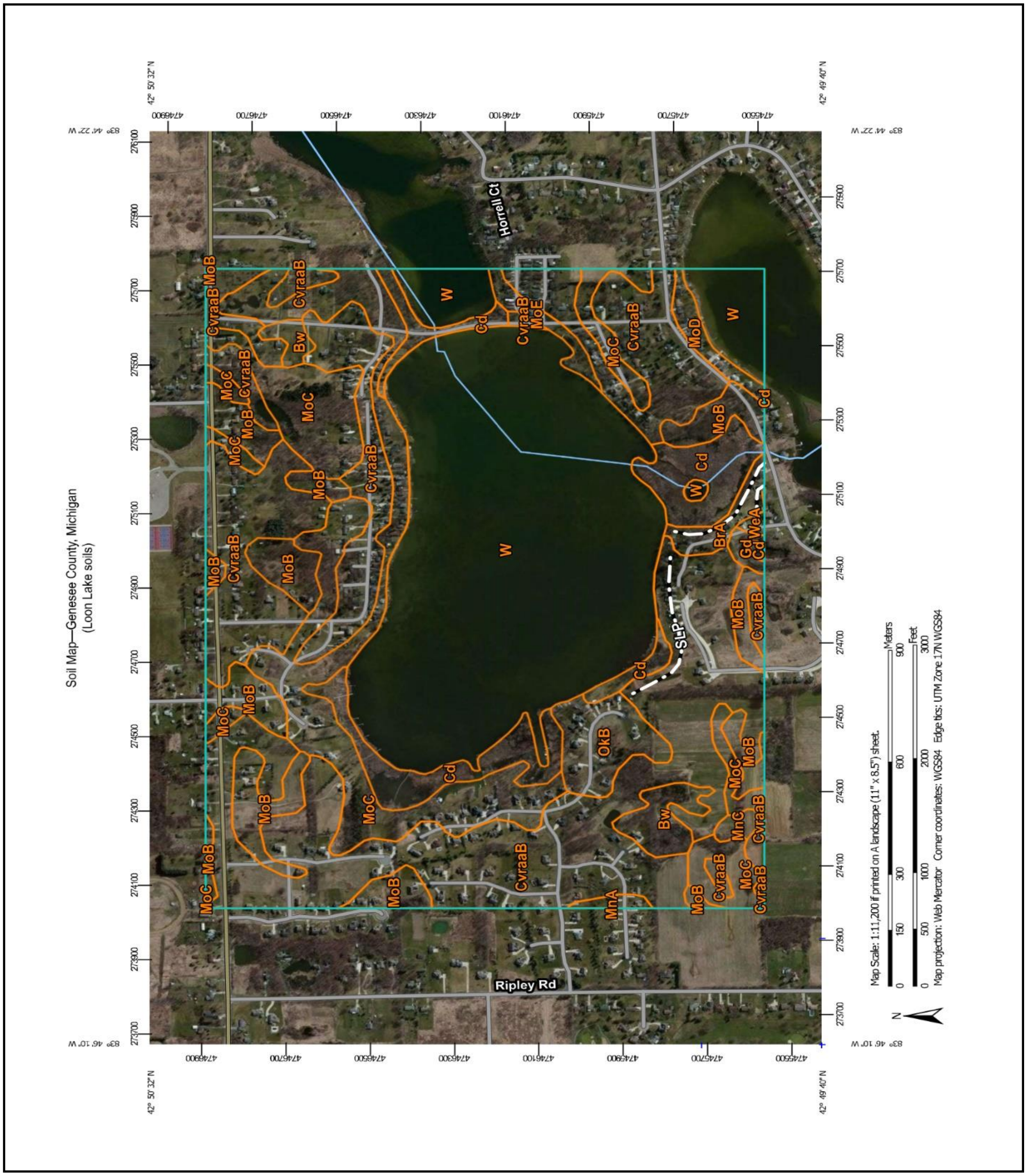


Figure 5. NRCS-USDA soils map for Loon Lake shoreline soils.

The majority of the soils around Loon Lake are very deep, poorly drained mucky soils with the potential for ponding. Ponding occurs when water cannot permeate the soil and accumulates on the ground surface which then many 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 also become ponded during extended rainfall and the wetlands can serve as a source of nutrients to the lake. When the solids of the wetland are not saturate, the wetland can serve as a sink for nutrients and the nutrients are filtered by wetland plants.

4.0 LOON LAKE 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; 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. Loon Lake is classified as a eutrophic (nutrient-enriched) lake due to the moderate nutrients and low Secchi transparency as well as common submersed aquatic vegetation (Figure 6).

Table 3. General Lake Trophic Status Classification Table.

Lake Trophic Status	*Total Phosphorus ($mg\ L^{-1}$)*	*Chlorophyll-a ($\mu g\ L^{-1}$)*	*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

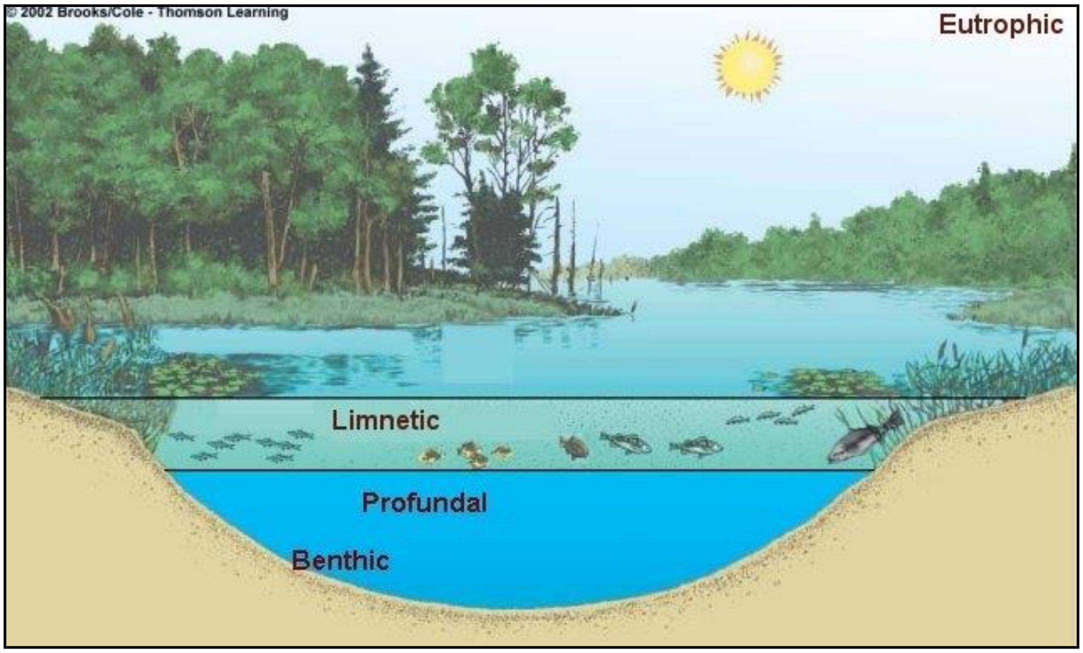


Figure 6. Diagram showing a eutrophic or nutrient-enriched lake ecosystem (photo adapted from Brooks/Cole Thomson learning online).

4.1 Water Quality Parameters

Parameters such as dissolved oxygen (in mg L^{-1}), water temperature (in °C), specific conductivity (mV), turbidity (NTU's), total dissolved solids (mg L^{-1}), total dissolved solids (mg L^{-1}), pH (S.U.), total alkalinity (mg $CaCO_3$ L^{-1}), total phosphorus and ortho-phosphorus (also known as soluble reactive phosphorus or SRP measured in mg L^{-1}), total Kjeldahl nitrogen (in mg L^{-1}), chlorophyll-a (in µg L^{-1}), and Secchi transparency (in feet). All of these parameters respond to changes in water quality and consequently serve as indicators of change. The deep basin results are discussed below and are presented in Tables 4-9.

A map showing the sampling locations for all water quality samples is shown below in Figure 7. All water samples and readings were collected at the four deepest basins on September 30, 2019 with the use of a Van Dorn horizontal water sampler and calibrated Eureka Manta II® multi-meter probe with parameter electrodes, respectively. All samples were taken to a NELAC-certified laboratory for analysis. In addition, 8 sediment samples were collected using an Ekman hand dredge (Figure 8). That data is shown below in Table 10. Sediment samples were analyzed for sediment total phosphorus and organic matter percentage in mg/kg.

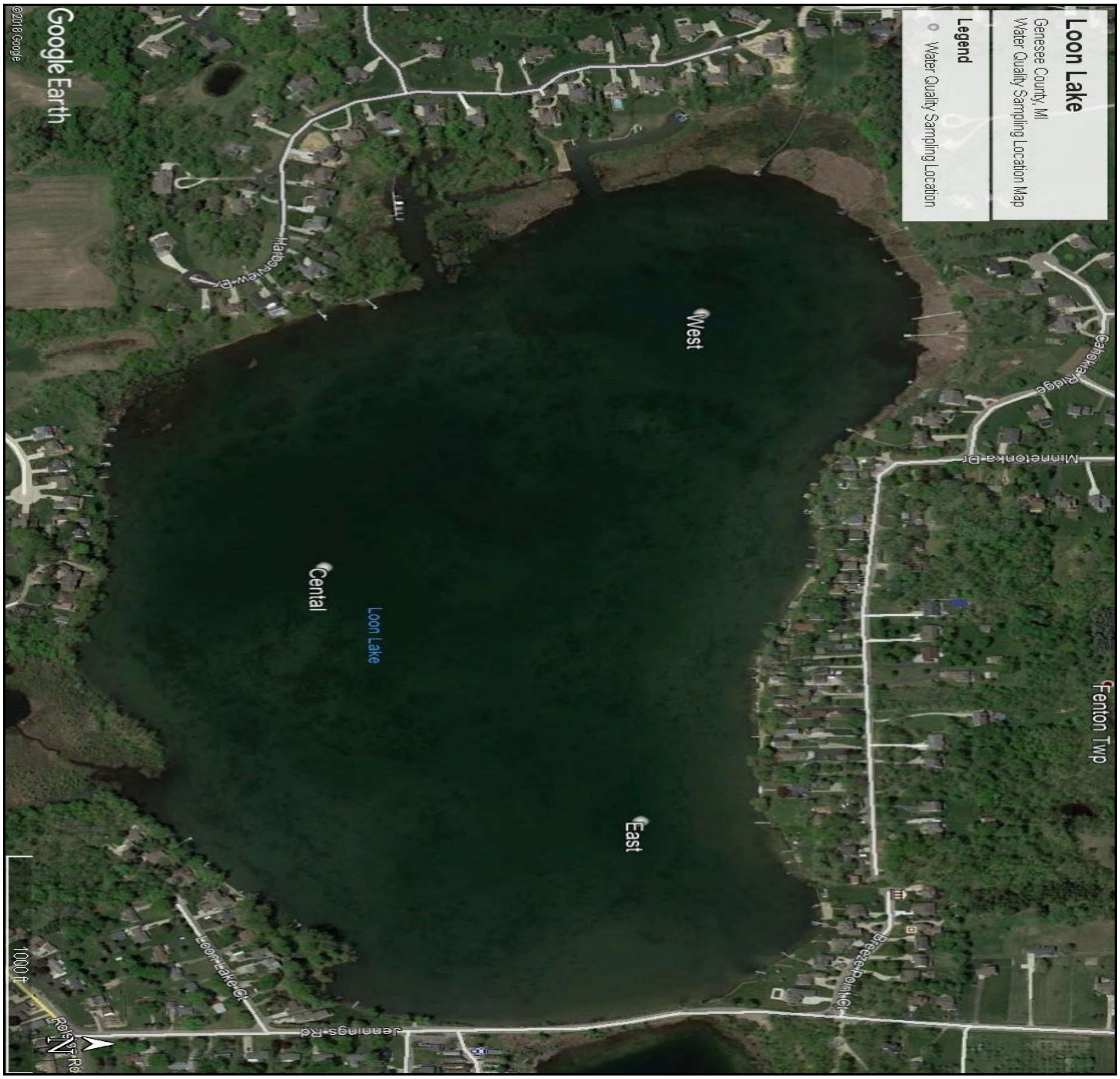


Figure 7. Locations for water quality sampling of the deep basins in Loon Lake (September 30, 2019).

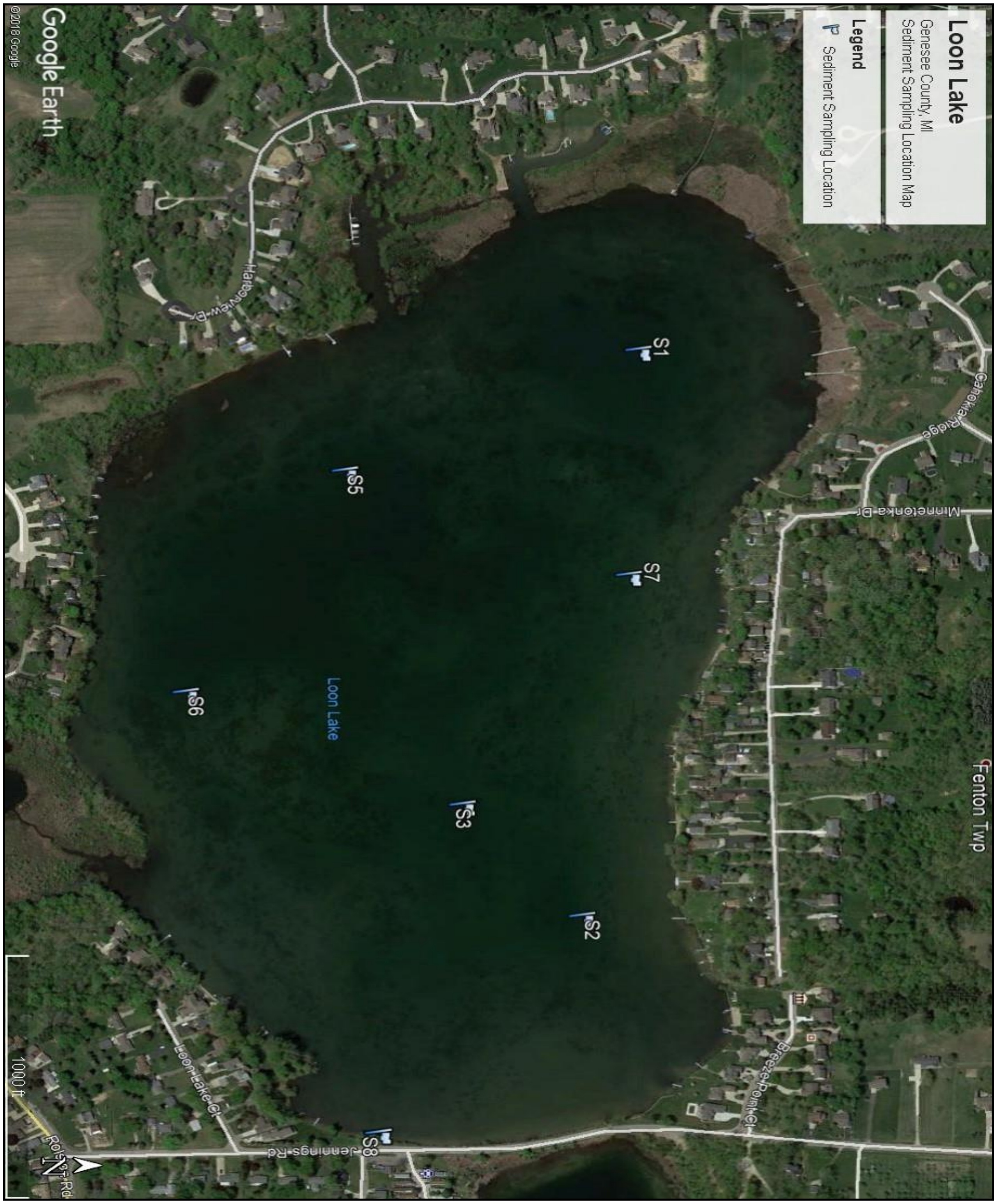
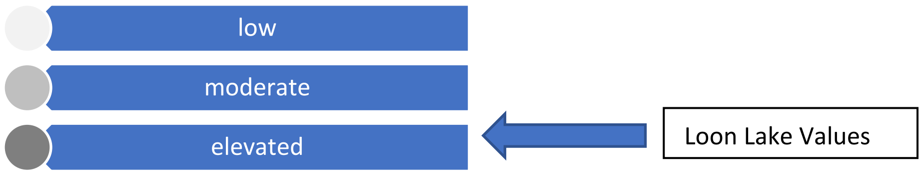


Figure 8. Locations for sediment sampling in Loon Lake (September 30, 2019).

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. Dissolved oxygen (DO) concentrations ranged from 8.5-9.0 mg/L, with the highest values at deep basin #3. The lake is very well mixed with healthy dissolved oxygen levels.



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 9). In general, shallow lakes will not stratify and deeper lakes may experience single or multiple turnover cycles. Water temperature was measured in degrees Celsius (ºC) with the use of a calibrated Eureka Manta II® submersible thermometer. The September 30, 2019 water temperatures of Loon Lake demonstrated strong thermoclines and is indicative of a seasonally mixed (dimictic) lake that mixes completely around twice per year (spring and fall). On the day of sampling, water temperatures ranged from 18.5°C at the surface to 17.4°C at the bottom of the three deep basins. This also represents a well-mixed lake system.

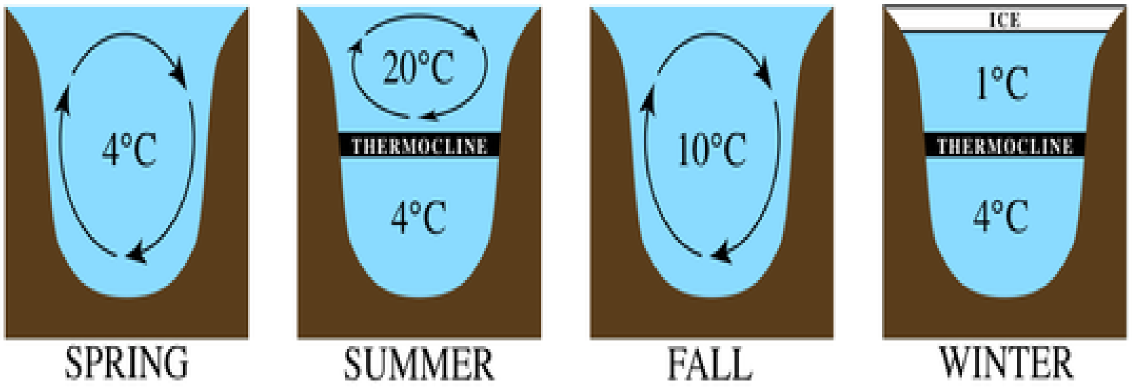
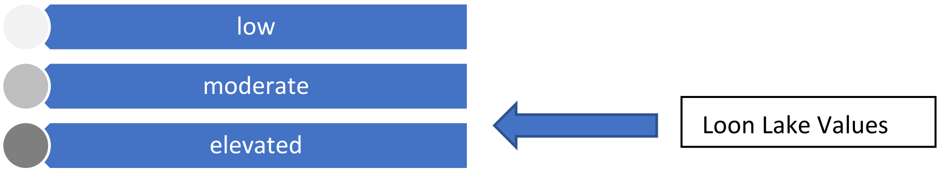


Figure 9. The lake thermal stratification process.

4.1.3 Conductivity

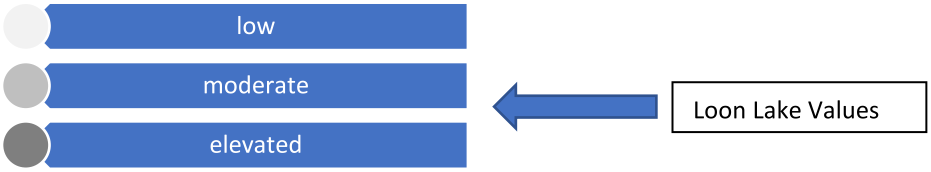
Conductivity is a measure of the amount of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Conductivity was measured in micro Siemens per centimeter (µS/cm) with the use of a calibrated Eureka Manta II® conductivity probe and meter. Conductivity values for Loon Lake were variable among depths at the deep basins and ranged from 617-629 mS/cm which are moderate to high values. Since these values are moderately high for an inland lake, the lake water contains ample 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 Loon Lake 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 Turbidity, Total Dissolved Solids, and Total Suspended Solids

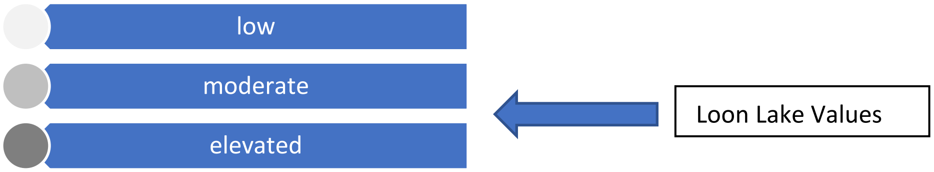
Turbidity

Turbidity is a measure of the loss of water transparency due to the presence of suspended particles. The turbidity of water increases as the number of total suspended particles increases. Turbidity may be caused by erosion inputs, phytoplankton blooms, storm water discharge, urban runoff, re-suspension of bottom sediments, and by large bottom-feeding fish such as carp. Particles suspended in the water column absorb heat from the sun and raise water temperatures. Since higher water temperatures generally hold less oxygen, shallow turbid waters are usually lower in dissolved oxygen. Turbidity was measured in Nephelometric Turbidity Units (NTU's) with the use of a calibrated Lutron® turbidity meter. The World Health Organization (WHO) requires that drinking water be less than 5 NTU's; however, recreational waters may be significantly higher than that. The turbidity of Loon Lake was moderate and ranged from 5.0-6.7 NTU's during the September 30, 2019 sampling event. On the day of sampling, the winds were calm, and turbidity was not likely influenced by much re-suspension of sediments. Spring values would likely be higher due to increased watershed inputs from spring runoff and/or from increased algal blooms in the water column from resultant runoff contributions. These numbers also correlate with the measured low transparency and elevated chlorophyll-a concentrations.



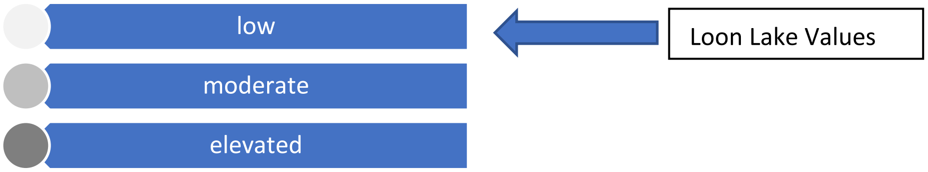
Total Dissolved Solids

Total dissolved solids (TDS) are the 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 TDS in Loon Lake on September 30, 2019 ranged from391-401 mg/L for the deep basins which is moderately high for an inland lake and correlates with the measured moderately high conductivity.



Total Suspended Solids (TSS)

Total suspended solids are the 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 TSS concentrations in Loon Lake on September 30, 2019 and were all below detection at <10 mg/L which is 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 pH of Loon Lake water ranged from 8.4-8.5 S.U. during the September 30, 2019 sampling event. This range of pH is neutral to 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.

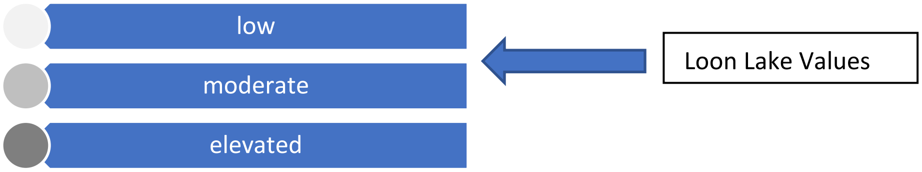
4.1.6 Total Alkalinity

Total alkalinity is the 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 an acid titration Method SM 2320 B-11. Total alkalinity in the deep basins were around 150 mg/L of $CaCO_3$ during the sampling event, which represents a moderately high 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.

4.1.7 Total Phosphorus and Ortho-Phosphorus (SRP)

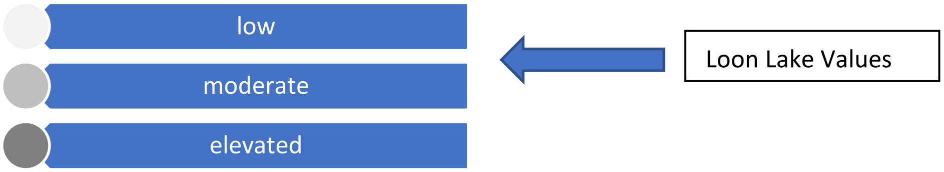
Total Phosphorus

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 which 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 total phosphorus (TP) concentrations in the lake ranged from 0.017-0.027 mg/L during the September 30, 2019 sampling event. The highest concentration was measured near the bottom of deep basin #1 but all concentrations are fairly low for a shallow inland lake. The sediment phosphorus is discussed in the next few pages and that is elevated which means that most of the submersed aquatic plants get their nutrients from the sediments.



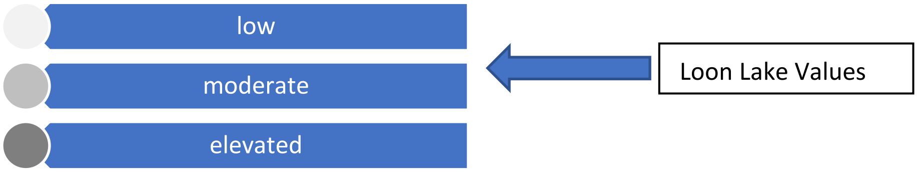
Ortho-Phosphorus

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 P used by all aquatic life. The SRP concentrations were all below detection at <0.010 mg/L which is favorable.



4.1.8 Total Kjeldahl Nitrogen

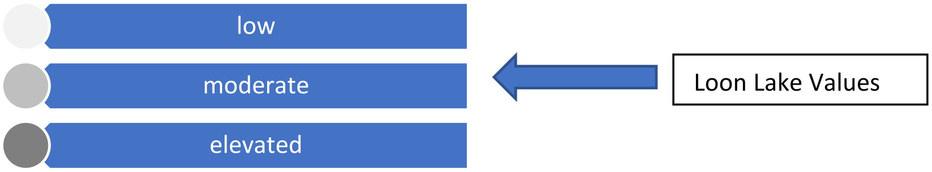
Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. TKN was measured with Method EPA 351.2 (Rev. 2.0). Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. 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. Loon Lake contained low to moderate concentrations of TKN at all depths (0.7-1.2 mg/L), which are normal for an inland lake of similar size. Thus, any additional inputs of either nutrient will further enhance algae growth.



4.1.9 Chlorophyll-a and Algae

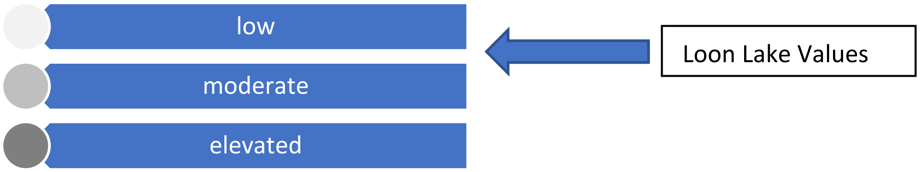
Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. High chlorophyll-a concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg/L are found in eutrophic or nutrient-enriched aquatic 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 the use of Turner Designs® hand-held *in situ* fluorimeter. The chlorophyll-*a* concentrations in Loon Lake were determined by collecting a composite sample of the algae throughout the water column at the deep basin site from just above the lake bottom to the lake surface. The chlorophyll-*a* concentration in the deep basins ranged from 1.8-3.0 µg/L during the September 30, 2019 sampling event. These elevated concentrations are due to the presence of numerous green algae.

Algal genera from a composite water sample collected from the deep basins of Loon Lake were analyzed under a compound brightfield microscope. The genera present included the Chlorophyta (green algae): *Rhizoclonium* sp., *Ulothrix* sp., *Chlorella* sp., *Scenedesmus* sp., *Spirogyra* sp., *Closterium* sp., *Mougeotia* sp., *Zygnema* sp., and *Chloromonas* sp. the Cyanophyta (blue-green algae): *Gleocystis* sp. and *Oscillatoria* sp.; the Bascillariophyta (diatoms): *Rhiocosphenia* sp., *Synedra* sp., *Navicula* sp., and *Fragilaria* sp. The aforementioned species indicate a moderately diverse algal flora and represent a relatively balanced freshwater ecosystem, capable of supporting a strong zooplankton community in favorable water quality conditions. The green algae generally were the most abundant, followed by the diatoms and the blue-green algae.



4.1.10 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. 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 12). 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 Secchi transparency of Loon Lake was measured on September 30, 2019 and ranged from 3.6-3.7 feet over the deep basins which are low readings. Measurements were collected during light wind conditions (winds out of the southwest at 5-10 mph). This transparency indicates that an abundance of solids such as suspended particles and algae are present throughout the water column which increases turbidity and reduces 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.



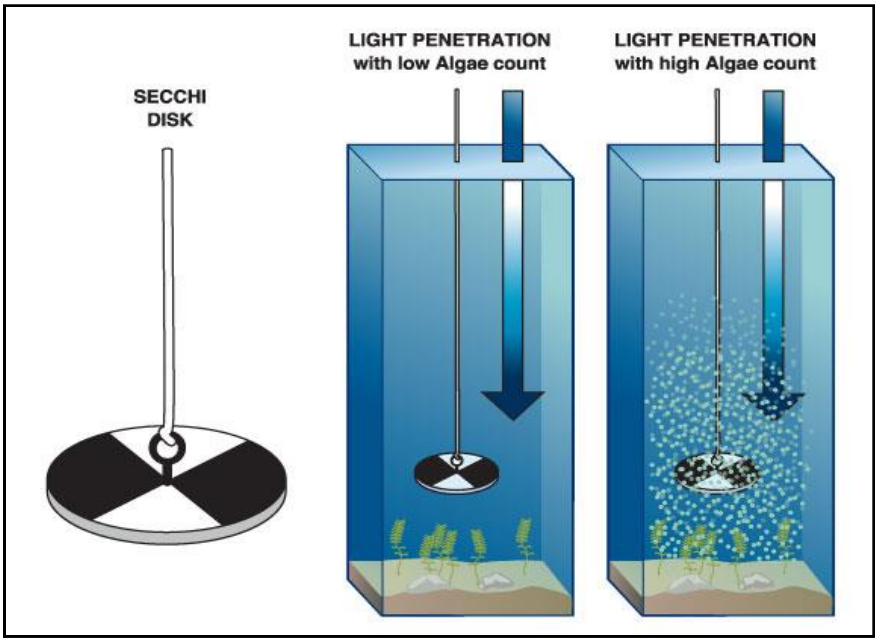


Figure 10. Measurement of water transparency with a Secchi disk.

4.1.11 Sediment Total Phosphorus

Sediment total phosphorus (TP) is a measure of the amount of phosphorus present in the lake sediment. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. The TP concentrations in lake sediments are often up to several times higher than those in the water column since phosphorus tends to adsorb onto sediment particles and sediments thus act as a "sink" or reservoir of nutrients. TP concentrations are usually higher at increased depths due to higher release rates of phosphorus from lake sediments under low oxygen (anoxic) conditions. Sediment TP was measured in milligrams per kilogram (mg kg^{-1}) with EPA Method 6010B. The sediment total phosphorus in the lake sediments ranged from 100-960 mg kg^{-1}. This represents a high variability in the concentrations of sedimentary phosphorus and may explain some variation in the abundance of rooted, submersed aquatic vegetation throughout Loon Lake. These concentrations are much higher than those in the water column which indicates that the sediments are the primary source of P for the aquatic vegetation.

4.1.12 Sediment Organic Matter

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 ranged from 0.5-31%, which is highly variable and not uncommon in post-glacial lakes and is also quite low and indicates the presence of silt and mineral sediments as the dominant sediment geology. Site S1 had the highest percentage of organic matter, followed by site S4.

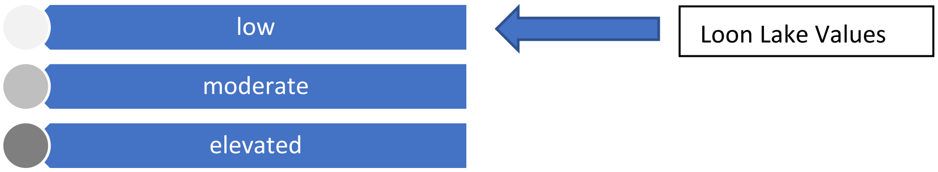


Table 4. Loon Lake physical water quality parameter data collected at west deep basin #1 (September 30, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	Secchi Depth (ft)
0	18.1	8.7	8.5	626	6.7	3.6
1.5	17.8	8.8	8.5	625	6.1	
3.0	17.8	8.6	8.4	624	6.0	

Table 5. Loon Lake chemical water quality parameter data collected at west deep basin #1 (September 30, 2019).

Depth (m)	TKN (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	TDS (mg/L)	Chl-a (µg/L)	Talk (mg CaCO3/L)
0	1.1	<10	0.023	<0.010	401	3.0	150
1.5	1.1	<10	0.026	<0.010	400		150
3.0	1.1	<10	0.027	<0.010	399		150

Table 6. Loon Lake physical water quality parameter data collected at central deep basin #2 (September 30, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	Secchi Depth (ft)
0	18.5	8.7	8.5	621	5.8	3.6
2.0	17.5	8.5	8.5	622	5.0	
3.3	17.4	8.5	8.5	620	6.2	

Table 7. Loon Lake chemical water quality parameter data collected at central deep basin #2 (September 30, 2019).

Depth (m)	TKN (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	TDS (mg/L)	Chl-a (µg/L)	Talk (mg CaCO3/L)
0	0.8	<10	0.017	<0.010	391	1.8	150
2.0	1.2	<10	0.023	<0.010	398		150
3.3	1.2	<10	0.025	<0.010	400		150

Table 8. Loon Lake physical water quality parameter data collected at east deep basin #3 (September 30, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	Secchi Depth (ft)
0	18.3	8.9	8.4	629	5.7	3.7
1.0	18.3	9.0	8.4	622	6.0	
2.5	18.2	9.0	8.4	617	6.0	

Table 9. Loon Lake chemical water quality parameter data collected at east deep basin #3 (September 30, 2019).

Depth (m)	TKN (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	TDS (mg/L)	Chl-a (µg/L)	Talk (mg CaCO3/L)
0	0.9	<10	0.022	<0.010	401	2.7	150
1.0	0.7	<10	0.023	<0.010	397		150
2.5	1.1	<10	0.022	<0.010	395		150

Table 10. Loon Lake sediment nutrient data collected at n= 8 locations (September 30, 2019).

Site	TP (mg/kg)	% OM
S1	960	31
S2	680	20
S3	630	24
S4	900	27
S5	510	26
S6	380	24
S7	200	24
S8	100	0.5

4.2 Loon 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.

A whole-lake scan of the aquatic vegetation in Loon Lake was conducted on September 30, 2019 with a WAAS-enabled Lowrance HDS 9 GPS with variable frequency transducer. This data which included 6, 333 data points was then uploaded into a cloud software program to reveal maps that displayed depth contours, sediment hardness, and aquatic vegetation biovolume (Figure 11). On this scan map, 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 lake that contain low-growing plants like Chara or Coontail. 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. Table 12 shows the biovolume categories by plant cover on September 30, 2019.

The Aquatic Vegetation Assessment Site (AVAS) 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, the littoral zone areas of the lakes are divided into lakeshore sections approximately 100 - 300 feet in length. Each AVAS segment is sampled using visual observation, dependent on water clarity, and weighted rake tows to verify species identification. The species of aquatic macrophytes present and density of each macrophyte are recorded onto an MDEQ AVAS data sheet. Each separate plant species found in each AVAS segment 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). In addition to the particular species observed (via assigned numbers), density information above was used to estimate the percent cumulative coverage of each species within the AVAS site. If shallow areas were present in the open waters of the lakes, then individual AVAS segments were sampled at those locations to assess the macrophyte communities in offshore locations. This is particularly important since exotics often expand in shallow island areas located offshore in many lakes.

The AVAS survey of Loon Lake was conducted on September 30, 2019 and consisted of 274 sampling locations around the littoral zone (Figure 12). 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.

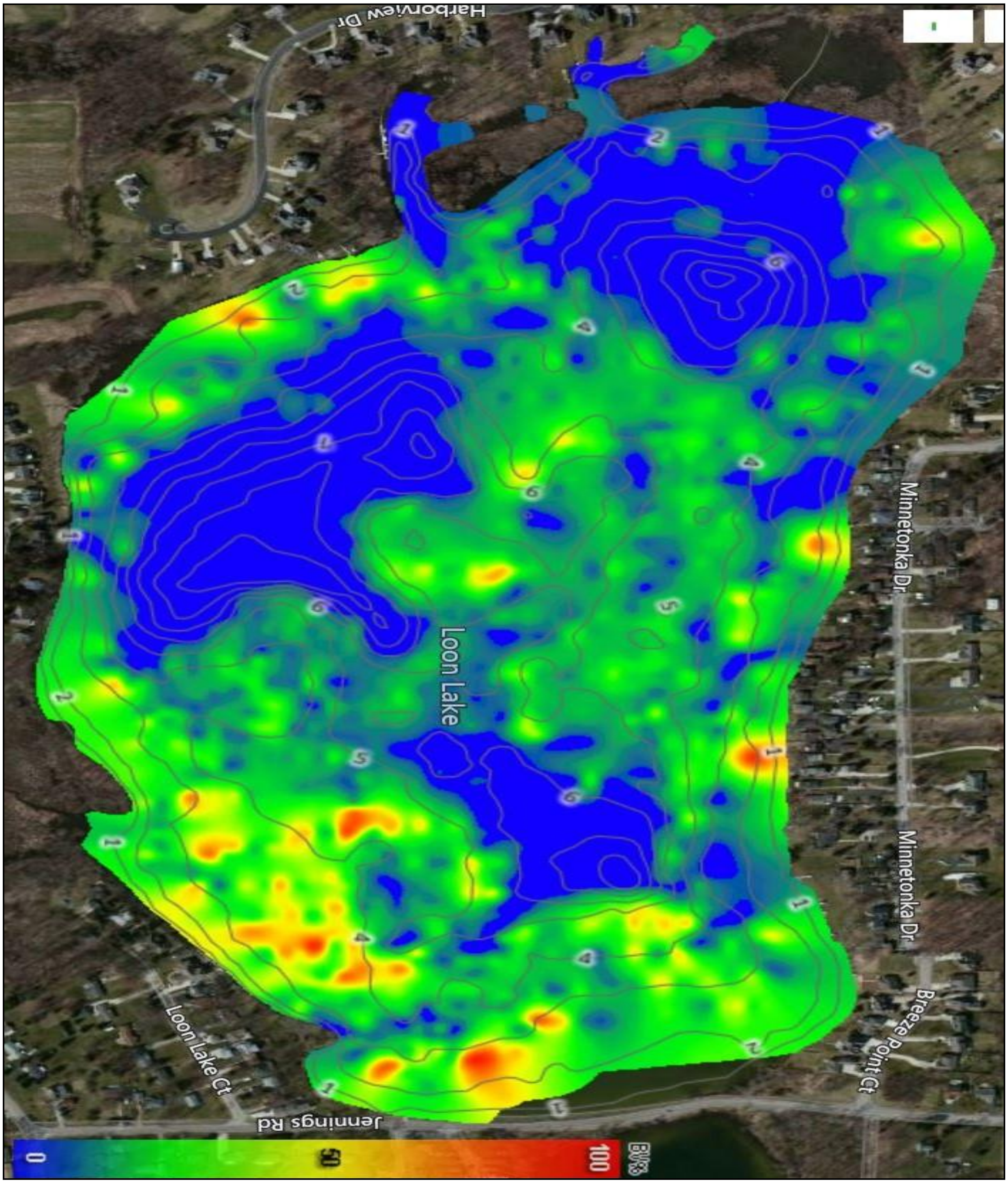


Figure 11. Aquatic plant biovolume of all aquatic plants in Loon Lake, Genesee County, Michigan (September 30, 2019). Note: Red color denotes high-growing aquatic plants, green color denoted low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

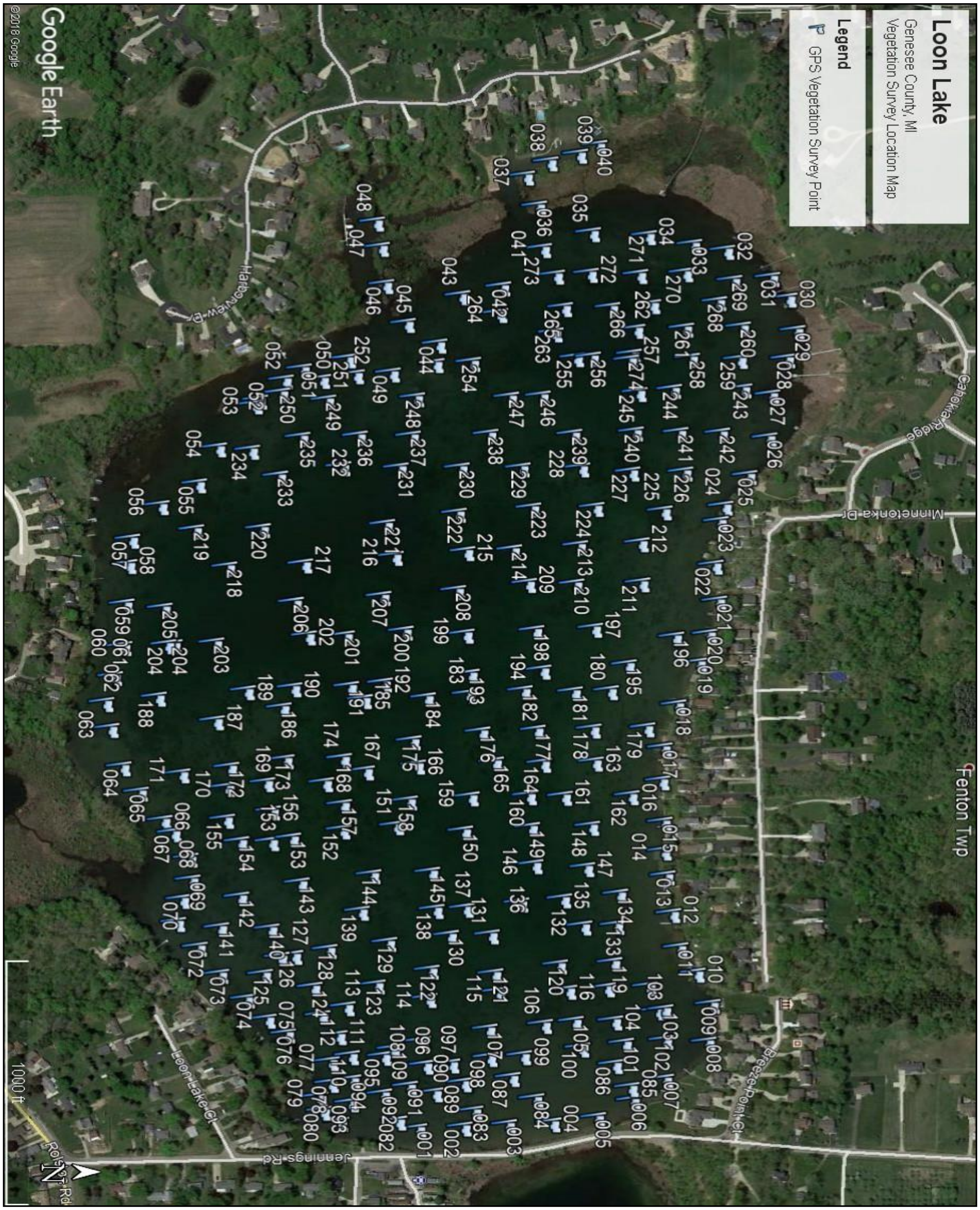


Figure 12. Aquatic vegetation sampling locations in Loon Lake (September 30, 2019).

Table 11. Loon Lake aquatic vegetation biovolume by category percent over of each category (relative cover on September 30, 2019).

Biovolume Cover Category	% Relative Cover of Bottom by Category
0-5%	67.0
5-20%	15.2
20-40%	9.2
40-60%	4.0
60-80%	2.3
>80%	2.3

4.2.1 Loon Lake 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.

Loon Lake contained 7 native submersed, 2 floating-leaved, and 4 emergent aquatic plant species, for a total of 13 native aquatic macrophyte species (Table 12). Photos of all native aquatic plants are shown below in Figures 13-25. The majority of the emergent macrophytes may be found along the shoreline of the lake. Additionally, the majority of the floating-leaved macrophyte species can be found near the shoreline and wetland areas. This is likely due to enriched sediments and shallower water depth with reduced wave energy, which facilitates the growth of aquatic plants with various morphological forms.

The dominant aquatic plants in the main part of the lake included the White waterlily, Thin-leaf Pondweed, and Illinois Pondweed. 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. The emergent plants, such as (Cattails), and *Schoenoplectus acutus* (Bulrushes) are critical for shoreline stabilization as well as for wildlife and fish spawning habitat.

Table 12. Loon Lake native aquatic plants (September 30, 2019).

Native Aquatic Plant Species Name	***Aquatic Plant Common Name***	***% Cover Loon Lake***	***Aquatic Plant Growth Habit***
Chara vulgaris	Muskgrass	2.6	Submersed, Rooted
Potamogeton pectinatus	Thin-leaf Pondweed	3.3	Submersed, Rooted
Potamogeton illinoensis	Illinois Pondweed	2.9	Submersed, Rooted
Vallisneria americana	Wild Celery	0.4	Submersed, Rooted
Ceratophyllum demersum	Coontail	0.1	Submersed, Non-Rooted
Utricularia vulgaris	Bladderwort	0.5	Submersed, Non-Rooted
Najas guadalupensis	Southern Naiad	2.1	Submersed, Rooted
Nymphaea odorata	White Waterlily	4.2	Floating-Leaved
Nuphar variegata	Yellow Waterlily	0.1	Floating-Leaved
Typha latifolia	Cattails	2.3	Emergent
Schoenoplectus acutus	Bulrushes	0.6	Emergent
Decodon verticillatus	Swamp Loosestrife	0.6	Emergent
Pontedaria cordata	Pickerelweed	0.3	Emergent

Figure 13. Chara (Muskgrass) ©RLS

Figure 14. Thin-leaf Pondweed ©RLS

Figure 15. Illinois Pondweed ©RLS

Figure 16. Wild Celery ©RLS

Figure 17.   Coontail ©RLS

Figure 18. Bladderwort ©RLS

Figure 19. Southern Naiad ©RLS

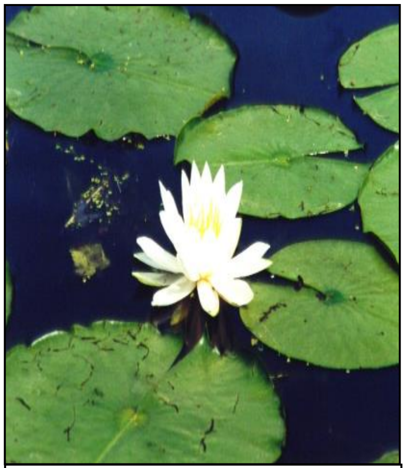


Figure 20. White Waterlily ©RLS

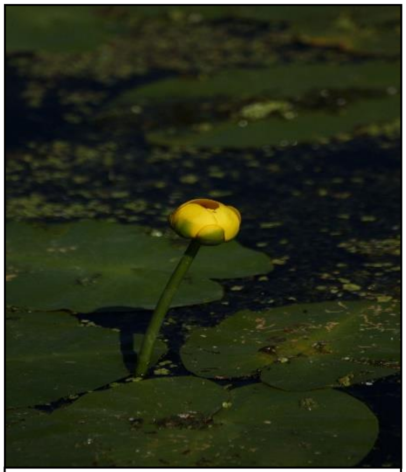


Figure 21. Yellow Waterlily ©RLS

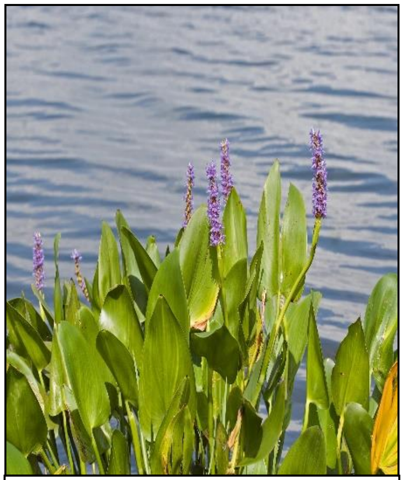


Figure 22. Pickerelweed ©RLS

Figure 23. Cattails ©RLS

Figure 24. Bulrushes ©RLS

Figure 25. Swamp Loosestrife ©RLS

4.2.2 Loon Lake 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 26) 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 27) 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).

Figure 28 shows the distribution of Eurasian Watermilfoil growth in Loon Lake which is capable of producing dense surface canopies. The species of invasive aquatic plants present, and relative abundance of each plant are recorded and then the amount of cover in the littoral zone is calculated. Exotic aquatic plant species that have been found in Loon Lake are shown in Table 13 below and discussions of key invasives also follow below.

Figure 26. Hybrid Eurasian Watermilfoil plant with seed head and fragments (©RLS).

Figure 27. Hybrid Eurasian Watermilfoil Canopy on an inland lake (©RLS).

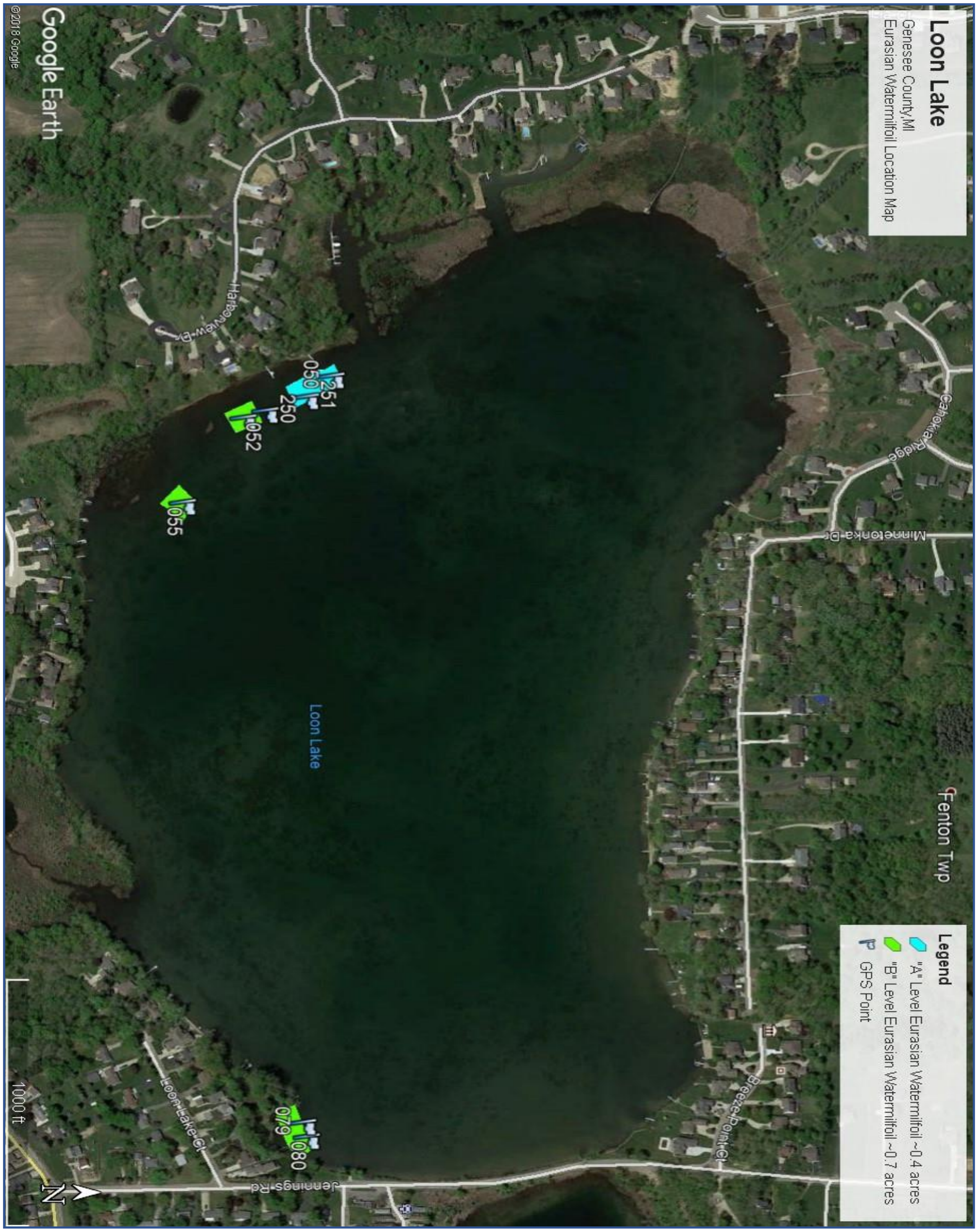


Figure 28. Distribution of EWM in Loon Lake, Genesee County, MI (September 30, 2019).

Starry Stonewort (*Nitellopsis obtusa*; Figure 29) 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 3.0 acres of Loon Lake (Figure 30).

Figure 29. A fragment of Starry Stonewort (©RLS).

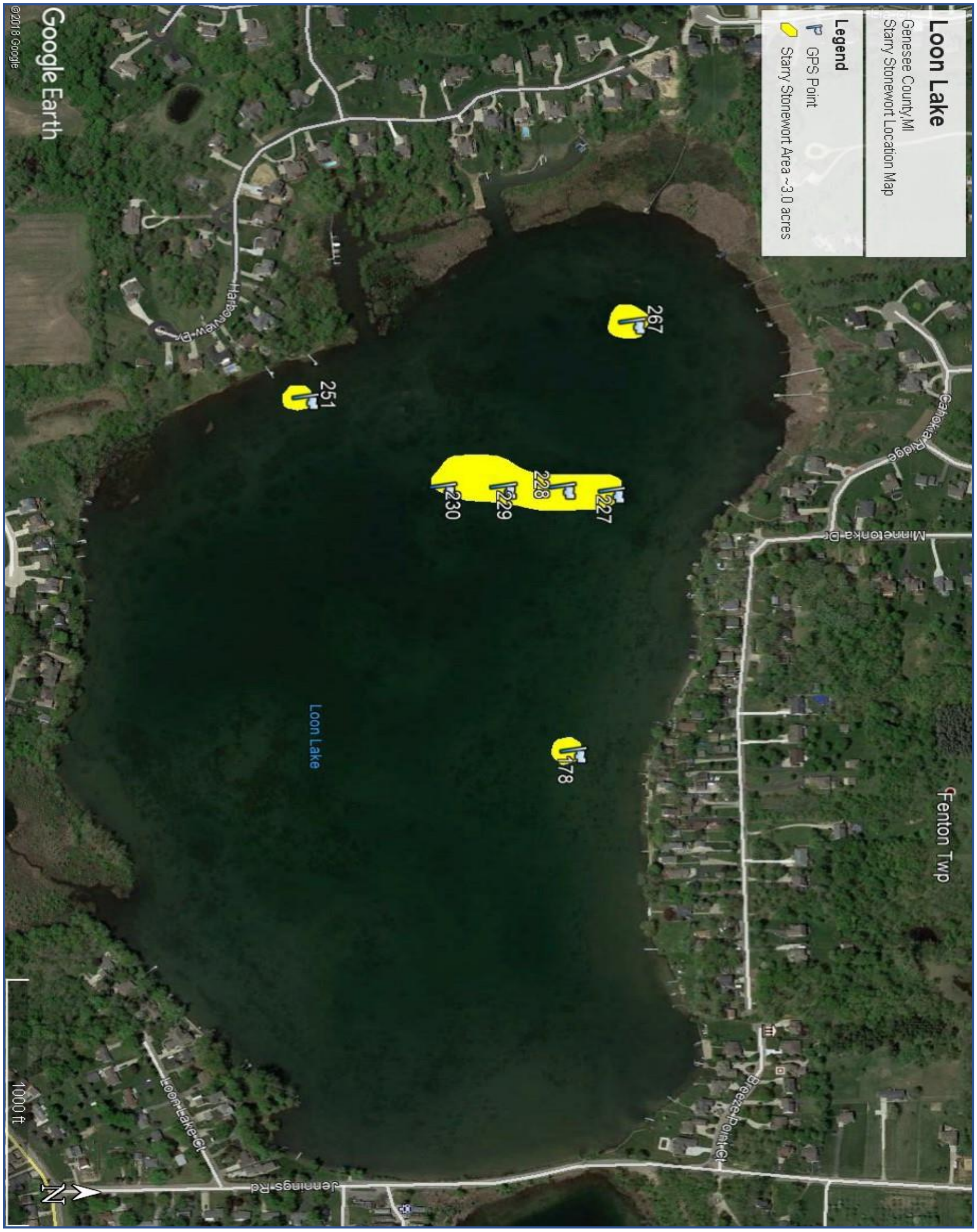


Figure 30. Distribution of Starry Stonewort in Loon Lake, Genesee County, MI (September 30, 2019).

Purple Loosestrife (*Lythrum salicaria*; Figure 31) is an invasive (i.e. exotic) emergent aquatic plant that inhabits wetlands and shoreline areas and was found in one area on the west side of the lake in the wetland between the lake and canal off of Harborview Drive. *L. salicaria* has showy magenta-colored flowers that bloom in mid-July and terminate in late September. The seeds are highly resistant to tough environmental conditions and may reside in the ground for extended periods of time. It exhibits rigorous growth and may out-compete other favorable native emergents such as Cattails (*Typha latifolia*) and thus reduce the biological diversity of localized ecosystems. The plant is spreading rapidly across the United States and is converting diverse wetland habitats to monocultures with substantially lower biological diversity. It should be removed promptly if found (i.e. by hand pulling or using a shovel to remove the roots and then discarding the plant into the garbage) to avoid further infestation. If the plant is not promptly removed by hand, it could dominate in wetland areas and require larger-scale systemic herbicide treatments.

Figure 31. The invasive emergent Purple Loosestrife (©RLS).

The Giant Common Reed (*Phragmites australis*; Figure 32) is an imminent threat to the surface area and shallows of the lake since it may grow submersed in water depths of ≥ 2 meters (Herrick and Wolf, 2005), thereby drying up wetland habitat and reducing lake surface area. In addition, large, dense stands of *Phragmites* accumulate sediments, reduce habitat variability, and impede natural water flow (Wang et *al*., 2006). This plant was found around 0.5 acres of the lake in the north and northwest regions (Figure 33).

Figure 32. The invasive emergent Phragmites (©RLS).

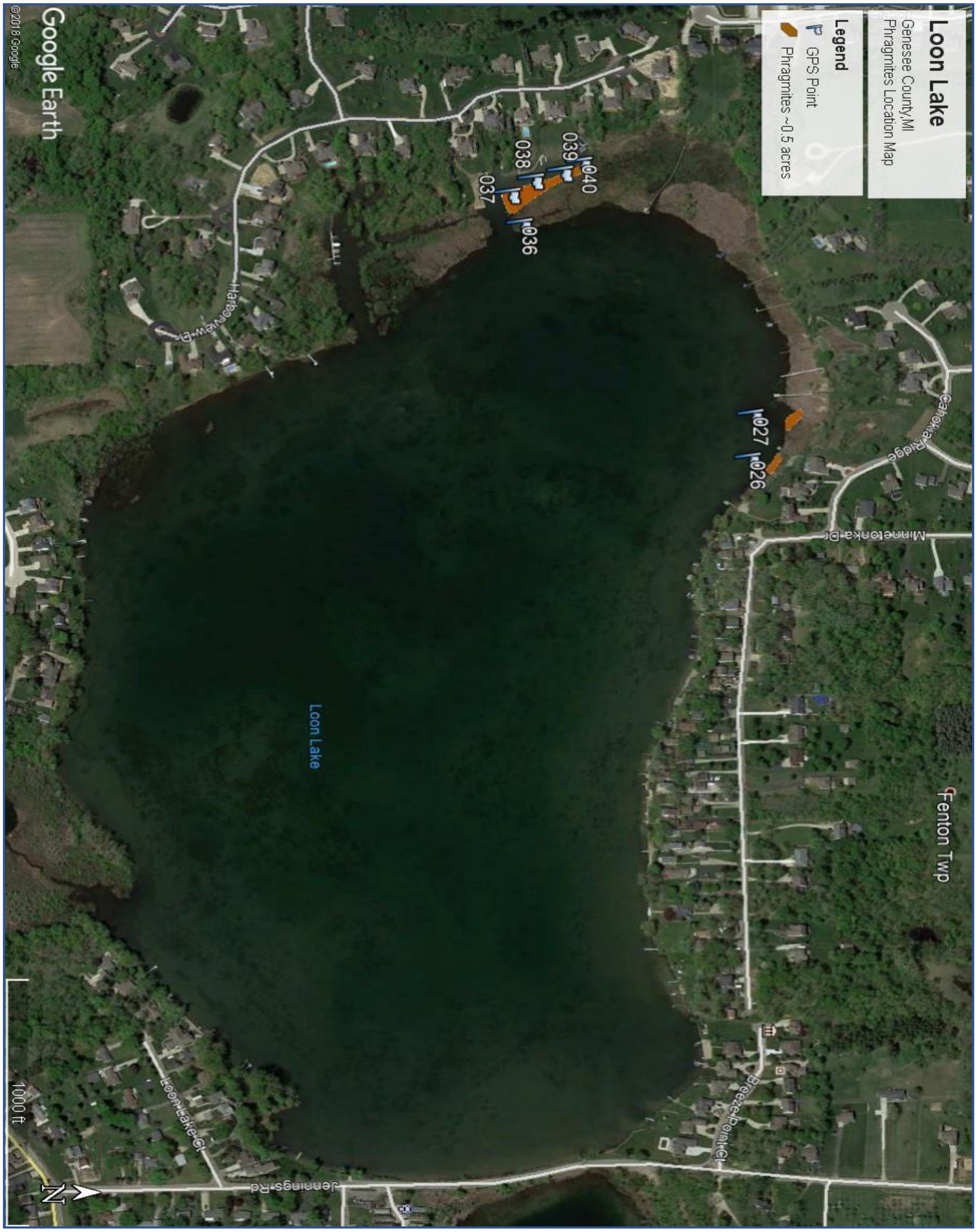


Figure 33. Distribution of Phragmites around Loon Lake, Genesee County, MI (September 30, 2019).

Table 13. Loon Lake exotic aquatic plant species (September 30, 2019).

Exotic Aquatic Plant Species	***Common Name***	***Growth Habit***	***Abundance in or around Loon Lake***
Phragmites australis	Giant Reed	Emergent	0.5 acres
Lythrum salicaria	Purple Loosestrife	Emergent	1 location
Myriophyllum spicatum	Eurasian Watermilfoil	Submersed	1.1 acres
Nitellopsis obtusa	Starry Stonewort	Submersed	3.0 acres

4.3 Loon Lake 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.

Lake Zooplankton

A zooplankton tow using a Wildco® pelagic plankton net with collection jar (Figure 34) was conducted by RLS scientists on September 30, 2019 over the deep basins of Loon Lake. Plankton sub-samples (in 1 ml aliquots) were analyzed under a Zeiss® dissection scope with the use of a Bogorov counting chamber. The most abundant zooplankton genera included cladocerans such as *Daphnia* and the rotifers *Keratella* and *Asplanchna*, and the copepod *Cyclops* (Table 14). Figures 35 and 36 show two common zooplankton found in Loon Lake.

Table 14. Zooplankton taxa and count data from Loon Lake (September 30, 2019).

Cladocerans	Count	Copepods	Count	Rotifers	Count
Daphnia	23	***Cyclops***	7	***Keratella***	16
				Asplanchna	2

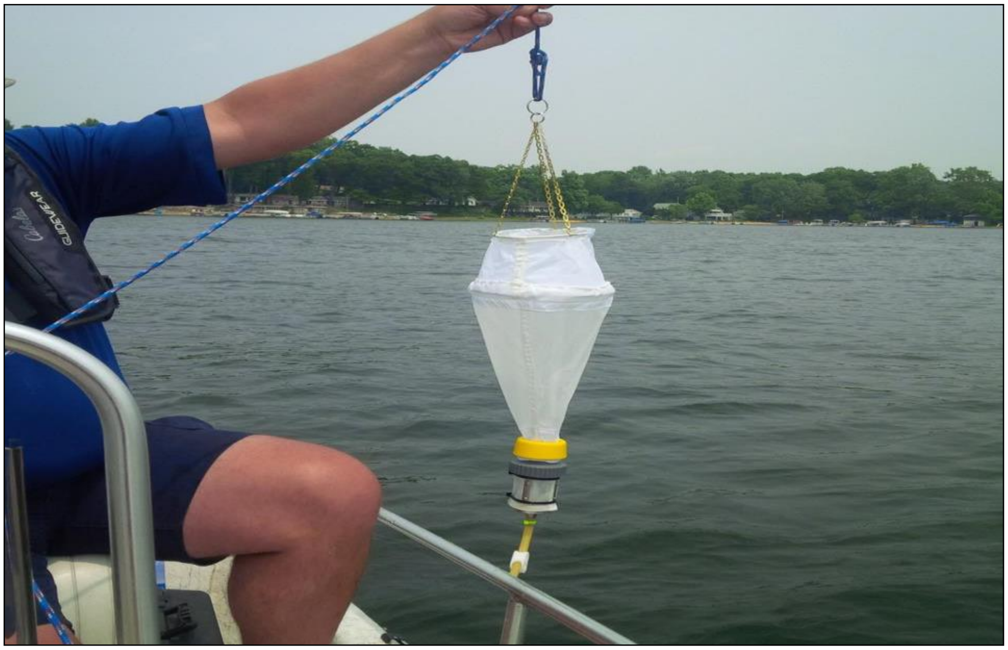


Figure 34. A zooplankton collection tow net (©RLS).

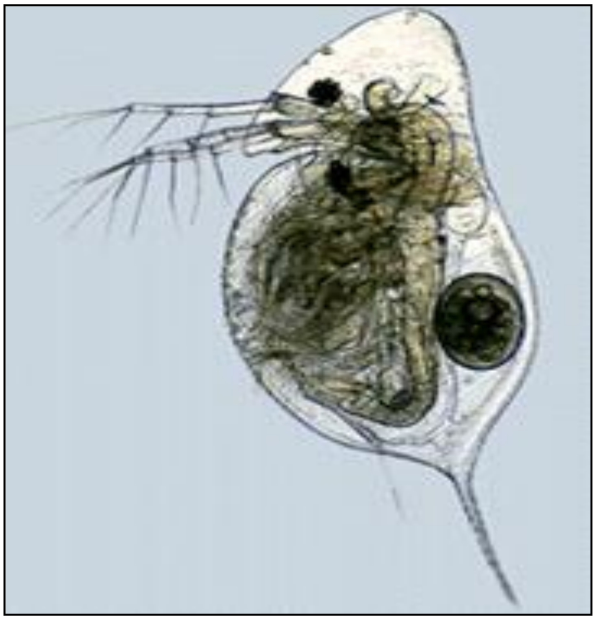


Figure 35. ***Daphnia*-A Zooplankton (photo courtesy of the EPA).**

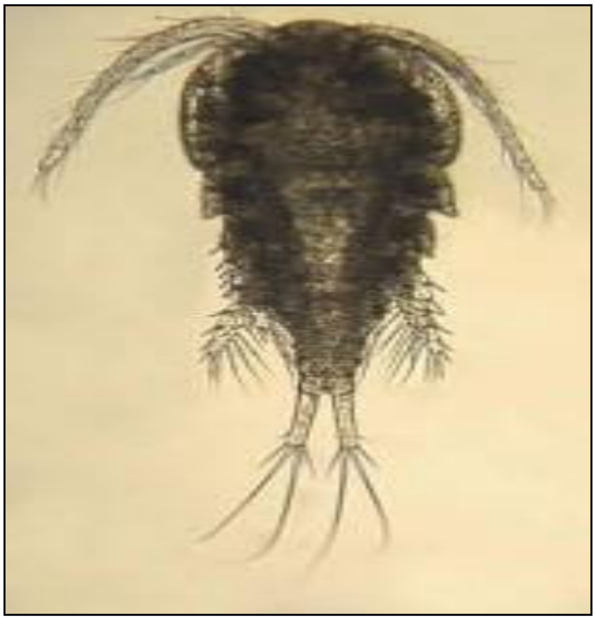


Figure 36. A Copepod Zooplankton (photo courtesy of the USGS).

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 each of the deep basin locations using an Ekman hand dredge sampler (Figure 37) on September 30, 2019 (Table 15). 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 Loon Lake sediment samples included midges (Chironomindae), Jute snails (Pleuroceridae), Wheel snails (Planorbidae), and Zebra Mussels (Dreisseniidae). Of all the species found, all were native except for the Zebra Mussels. While the majority of the species were native, some 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).

Figure 37. 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 Loon Lake may allow for growth of Zebra Mussels since they need ample alkalinity (calcium carbonate) for their shells.

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 and 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 15. Macroinvertebrates found in Loon Lake, Genesee County, MI (September 30, 2019).

Site West	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae		6	Jute snails
	Chironimidae	*Chironomus spp.*	11	Midges
	Planorbidae		6	Wheel snails
	Dreisseniidae		1	Zebra mussels
	Spheriidae		1	Fingernail clams
		Total	**25**	
Site Central	**Family**	**Genus**	**Number**	**Common name**
	Planorbidae		7	Wheel snails
	Chironomidae	*Chironomus spp.*	13	Midges
	Pleuroceridae		6	Jute snails
		Total	**26**	
Site East	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae		4	Jute snails
	Lymnaeidae		5	Dextrel pond snails
	Planorbidae		10	Wheel snails
		Total	**19**	

5.0 LOON LAKE IMPROVEMENT METHODS

Lake improvement methods consist of strategies to reduce invasive aquatic plants, reduce the transport of invasive species, reduction of nuisance algae, improvements in water clarity, and proper immediate watershed management (land use). The following sections offer useful and effective methods for improving the overall condition of Loon Lake.

5.1 Loon Lake Aquatic Plant Management

Improvement strategies, including the management of exotic aquatic plants are available for Loon Lake. The lake management components involve both within-lake (basin) and around-lake (watershed) solutions to protect and restore complex aquatic ecosystems such as Loon Lake. 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.

The management of submersed nuisance invasive aquatic plants is necessary in Loon Lake due to 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. Implementation of more growth of favorable native aquatic plants (especially the low growing native plants) in Loon Lake to provide for a healthier lake is recommended though this may require significant increases in water clarity along with reductions in invasive plant cover. All aquatic vegetation should be managed with solutions that will yield the longest-term results.

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 Loon Lake is awareness and education (Figures 38 and 39). 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 Loon Lake through the use of a professionally developed educational newsletter such as one distributed by the Association.

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. Once a boat washing station is in place on Loon Lake, the Association and MDNR 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 $15,000-$20,000 but lower cost ones are available for private lakes with restricted access (e.g. hand-held sprayer units; Figure 40).

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 38. An aquatic invasive prevention sign for public access sites.

Figure 39. An aquatic invasive prevention sign for public access sites.

Figure 40. A public boat washing station for boat access sites.

Zebra Mussels

Zebra Mussels (*Dreissena polymorpha*; Figure 41) were first discovered in Lake St. Clair in 1988 and likely arrived in ballast water or on shipping vessels from Europe (McMahon 1996). They are easily transferred to other lakes because they inherit a larval (nearly microscopic) stage where they can easily avoid detection. The mussels then grow into the adult (shelled) form and attach to substrates (i.e. boats, rafts, docks, pipes, aquatic plants, and lake bottom sediments) with the use of byssal threads. The fecundity (reproductive rate) of female Zebra Mussels is high, with as many as 40,000 eggs laid per reproductive cycle and up to 1,000,000 in a single spawning season (Mackie and Schlosser 1996). Although the mussels only live 2-3 years, they are capable of great harm to aquatic environments. In particular, they have shown selective grazing capabilities by feeding on the preferred zooplankton food source (green algae) and expulsion of the non-preferred blue green algae (cyanobacteria). Additionally, they may decrease the abundance of beneficial diatoms in aquatic ecosystems (Holland 1993). Such declines in favorable algae, can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations. Zebra Mussels are viewed by some as beneficial to lakes due to their filtration capabilities and subsequent contributions to increased water clarity. However, such water clarity may allow other photosynthetic aquatic plants to grow to nuisance levels (Skubinna et *al*. 1995).

The recommended prevention protocols for introduction of zebra mussels includes steam-washing all boats, boat trailers, jet-skis, and floaters prior to placing them into Loon Lake. Fishing poles, lures, and other equipment used in other lakes (and especially the Great Lakes) should also be thoroughly steam-washed before use in Loon Lake.

Additionally, all solid construction materials (if recycled from other lakes) must also be steam-washed. Boat transom wells must always be steam-washed and emptied prior to entry into the lake. Excessive waterfowl should also be discouraged from the lake since they are a natural transportation vector of the microscopic zebra mussel larvae or mature adults.

Figure 41. Zebra Mussels (Photo courtesy of USGS).

Invasive Aquatic Plants

In addition to Eurasian Watermilfoil (*M. spicatum*), many other invasive aquatic plant species have been introduced into waters of the North Temperate Zone. The majority of exotic aquatic plants do not depend on high water column nutrients for growth, as they are well-adapted to using sunlight and minimal nutrients for successful growth but excess nutrients often result in exacerbated growth. These species have similar detrimental impacts to lakes in that they decrease the quantity and abundance of native aquatic plants and associated macroinvertebrates and consequently alter the lake fishery. Such species include *Hydrilla verticillata* (Figure 42) and *Trapa natans* (Water Chestnut; Figure 43). *Hydrilla* was introduced to waters of the United States from Asia in 1960 (Blackburn et *al*. 1969) and is a highly problematic submersed, rooted, aquatic plant in tropical waters. Many years ago, *Hydrilla* was found in Lake Manitou (Indiana, USA) and the lake public access sites were immediately quarantined in an effort to eradicate it. *Hydrilla* retains many physiologically distinct reproductive strategies which allow it to colonize vast areas of water and to considerable depths, including fragmentation, tuber and turion formation, and seed production. Currently, the methods of control for *Hydrilla* include the use of chemical herbicides, rigorous mechanical harvesting, and Grass Carp (*Ctenopharyngodon idella* Val.), with some biological controls currently being researched.

Water Chestnut (*Trapa natans*) is a non-native, annual, submersed, rooted aquatic plant that was introduced into the United States in the 1870's yet may be found primarily in the northeastern states. The stems of this aquatic plant can reach lengths of 12-15 feet, while the floating leaves form a rosette on the lake surface.

Seeds are produced in July and are extremely thick and hardy and may last for up to 12 years in the lake sediment. If stepped on, the seed pods may even cause deep puncture wounds to those who recreate on the lakes. Methods of control involve the use of mechanical removal and chemical herbicides. Biological controls are not yet available for the control of this aquatic plant.

Figure 42. Hydrilla from a Florida lake (©RLS).

Figure 43. Water Chestnut from a northeastern lake.

5.1.2 Aquatic Herbicides and Applications

The use of aquatic chemical herbicides is regulated by the Michigan Department of Natural Resources and requires a permit. Aquatic herbicides are generally applied via an airboat or skiff equipped with mixing tanks and drop hoses (Figure 44). 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.

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 Loon Lake, the use of contact herbicides (such as diquat and flumioxazin) would be recommended only for nuisance submersed native aquatic plant growth which is rare.

Systemic herbicides such as 2, 4-D and triclopyr are the two primary systemic herbicides used to treat milfoil that occurs in a scattered distribution. 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 objective of a fluridone treatment is to selectively control the growth of milfoil in order to allow other native aquatic plants to germinate and create a more diverse aquatic plant community. Loon Lake does not contain enough milfoil to warrant a fluridone treatment and the milfoil should therefore be managed with systemic herbicides such as triclopyr nearshore and 2,4-D offshore.

Figure 44. A boat used to apply aquatic herbicides in inland lakes (©RLS).

5.1.3 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 45). 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. Fortunately, Loon Lake does not contain enough biomass to necessitate mechanical harvesting.

Figure 45. 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 46) or Weed Rollers (Figure 47) 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 Loon Lake and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth if it becomes prevalent in future years.

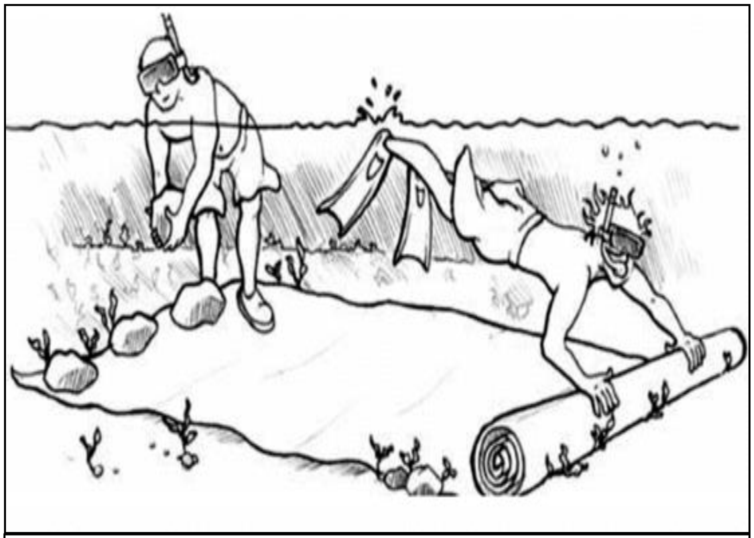


Figure 46. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.

Figure 47. A Weed Roller.

5.1.5 Diver Assisted Suction Harvesting (DASH)

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 48) 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.

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.

Figure 48. A DASH boat used for aquatic plant removal (©RLS).

5.2 Loon Lake Water Quality Improvements

In addition to lake improvement methods that improve the aquatic plant communities (both invasive and nuisance native), there are methods to improve the water quality within the lake basin. These methods are often large 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 Laminar Flow Aeration (LFA) and Bioaugmentation

Laminar flow aeration systems (Figure 49) are retrofitted to a particular site and account for variables such as water depth and volume, contours, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute dissolved oxygen throughout the lake sediments for efficient microbial utilization.

A laminar flow aeration (LFA) system utilizes diffusers which are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help to purge the lake sediment pore water of gases such as benthic carbon dioxide (CO_2) and hydrogen sulfide (H_2S). In addition to the placement of the diffuser units, the concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment.

Beutel (2006) found that lake oxygenation eliminates release of NH_3+ from sediments through oxygenation of the sediment-water interface. Allen (2009) demonstrated that NH_3+ oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry wt. day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt. day^{-1} in controls. Although this is a relatively new area of research, recent case studies have shown promise on the positive impacts of laminar flow aeration systems on aquatic ecosystem management with respect to organic matter degradation and resultant increase in water depth, and rooted aquatic plant management in eutrophic ecosystems (Jermalowicz-Jones, 2010; 2011). Toetz (1981) found evidence of a decline in *Microcystis* algae (a toxin-producing blue-green algae) in Arbuckle Lake in Oklahoma. Other studies (Weiss and Breedlove, 1973; Malueg et *al.*, 1973) have also shown declines in overall algal biomass.

Conversely, a study by Engstrom and Wright (2002) found no significant differences between aerated and non-aerated lakes with respect to reduction in organic sediments. This study was however limited to one sediment core per lake and given the high degree of heterogeneous sediments in inland lakes may not have accurately represented the conditions present throughout much of the lake bottom. The philosophy and science behind the laminar flow aeration system is to reduce the organic matter layer in the sediment so that a significant amount of nutrient is removed from the sediments and excessive sediments are reduced to yield a greater water depth.

Benefits and Limitations of Laminar Flow Aeration

In addition to the reduction in toxic blue-green algae (such as *Microcystis* sp.) as described by Toetz (1981), aeration and bioaugmentation in combination have been shown to exhibit other benefits for the improvements of water bodies. Laing (1978) showed that a range of 49-82 cm of organic sediment was removed annually in a study of nine lakes which received aeration and bioaugmentation. It was further concluded that this sediment reduction was not due to re-distribution of sediments since samples were collected outside of the aeration "crater" that is usually formed. A study by Turcotte et *al*. (1988) analyzed the impacts of bioaugmentation on the growth of Eurasian Watermilfoil and found that during two four-month studies, the growth and re-generation of this plant was reduced significantly with little change in external nutrient loading. Currently, it is unknown whether the reduction of organic matter for rooting medium or the availability of nutrients for sustained growth is the critical growth limitation factor and these possibilities are being researched. A reduction of Eurasian Watermilfoil is desirable for protection of native plant biodiversity, recreation, water quality, and reduction of nutrients such as nitrogen and phosphorus upon decay (Ogwada et *al*., 1984).

Furthermore, bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979) so the concomitant addition of microbes to lake sediments will accelerate that process.

A reduction in sediment organic matter would likely decrease Eurasian Watermilfoil growth as well as increase water depth and reduce the toxicity of ammonia nitrogen to overlying waters. A study by Verma and Dixit (2006) evaluated aeration systems in Lower Lake, Bhopal, India, and found that the aeration increased overall dissolved oxygen, and reduced biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total coliform counts.

The LFA system has some limitations including the inability to break down mineral sediments, the requirement of a constant Phase I electrical energy source to power the units, and possible unpredictable response by various species of rooted aquatic plants (currently being researched by RLS). Due to the high amount of sand and mineral sediments in Loon Lake, the reduction of sediment muck or organics would be limited to areas with >20% organic content. Aeration would not be needed for the dissolved oxygen as the concentrations are very healthy in the lake. However, the addition of bio augmentation may be successfully used to reduce nuisance algal blooms by competing with nuisance algae and is thus recommended.

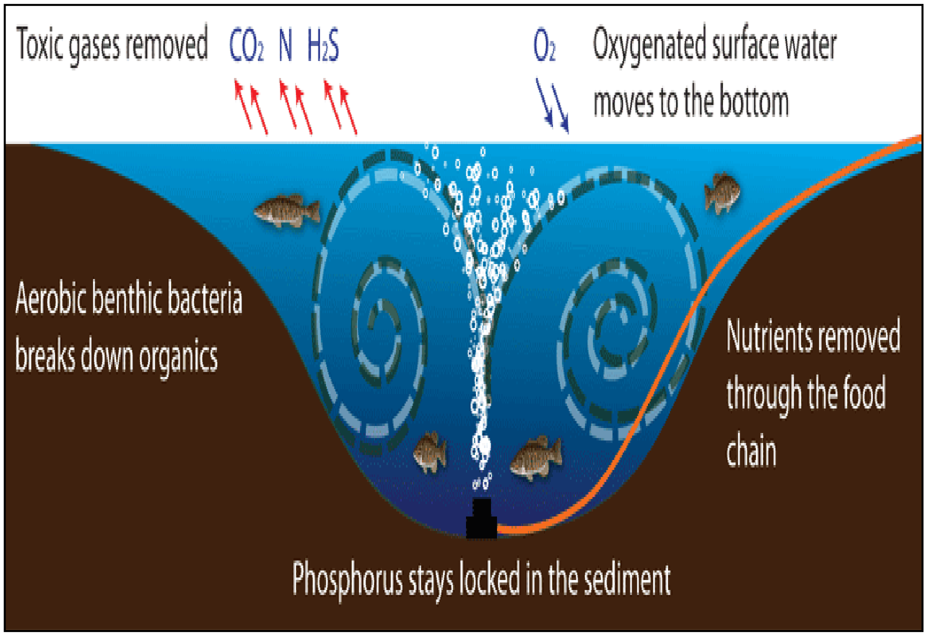


Figure 49. Diagram of laminar flow aeration. ©RLS

5.2.2 Nutrient Inactivation

There are a few products on the lake improvement market 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, 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 such as Loon Lake with a very large catchment of 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) are demonstrating favorable results with alum application in hypereutrophic waters that are also experiencing high external nutrient loads. At this time this method and aeration are not needed for Loon Lake.

5.2.3 Dredging

Dredging is a lake management option used to remove accumulated lake sediments to increase accessibility for navigation and recreational activities. Dredging is subject to permitting by the U.S. Army Corps of Engineers (USACE), and Michigan Department of Environment, Great Lakes, and Energy (EGLE).

The two major types of dredging include hydraulic and mechanical. A mechanical dredge usually utilizes a backhoe and requires that the disposal site be adjacent to the lake (Figure 50).

In contrast, a hydraulic dredge removes sediments in an aqueous slurry and the wetted sediments are transported through a hose to a confined disposal facility (CDF). Selection of a particular dredging method and CDF should consider the environmental, economic, and technical aspects involved. The CDF must be chosen to maximize retention of solids and accommodate large quantities of water from the dewatering of sediments. It is imperative that hydraulic dredges have adequate pumping pressure which can be achieved by dredging in waters greater than 3 foot of depth.

Dredge spoils cannot usually be emptied into wetland habitats; therefore, a large upland area is needed for lakes that are surrounded by wetland habitats. 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.

In addition, proposed sediment for removal must be tested for metal contaminants before being stored in a CDF. Dredging is a very costly operation with an average dredging cost of $28-40 per cubic yard. Dredging is also not needed in Loon Lake at this time.

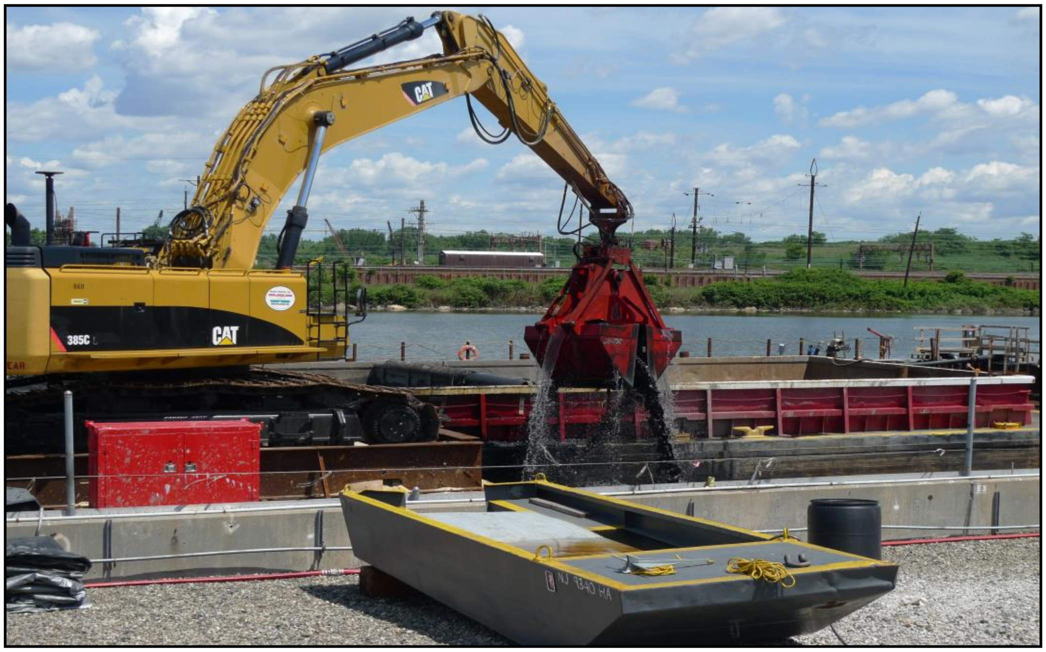


Figure 50. A mechanical dredge for sediment removal in inland waters.

5.2.4 Fishery Habitat Enhancement

Fish spawning habitat is very important for lakes. 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.

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 wash off 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 and helped sustain healthy fish populations. Within a few years, the water gets murkier from fertilizer runoff, and, lacking bulrushes and other 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.

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. A growing number of lakeshore owners are learning that 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. Such a process as 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 lake. 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 in lakes with low dissolved oxygen. 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. Fish spawning habitat in many shallow lakes has been destroyed by 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 from surrounding farm fields. Nutrients and other contaminated runoff flow into lakes from distant farms, parking lots, streets, and lawns. The nutrients fuel blooms of algae, which, when they die, consume oxygen 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. Habitat characteristics were measured at each nesting site and compared with those measured at 75 randomly selected sites. In Lake Cochrane, mean water depth of spawning colonies was 1.0 m.

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 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, 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 12 or less inches deep. Due to predation by insects and other fish including the Northern Pike itself, the number of eggs and fry will be reduced 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 inhabits 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. 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 actually 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 near shore 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.

5.3 Loon Lake Watershed Management

Protection of the lake watershed is imperative for long-term improvement of water quality in Loon Lake. There are many practices that individual riparians as well as the local municipalities can adopt to protect the land from erosion and flooding and reduce nutrient loading to the lake. The following sections offer practical Best Management Practices (BMP's) commonly followed to protect water quality.

5.3.1 Loon Lake Erosion and Sediment Control

In addition to the proposed protection of native aquatic plants and control of invasives in Loon Lake, it is recommended that BMP's be implemented to improve the lake's water quality. 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 (those > 6%; see above soil table; Table 2)
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
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 Loon Lake or the region) around the lake since they are most likely to establish and thrive than those not acclimated to growing in the area soils. A local horticultural supply center would likely have a list of these species.
6) 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.
7) Any wetland areas around Loon Lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat.
8) Erosion of soils into the water may lead to increased turbidity and nutrient loading to the lake. Seawalls should consist of riprap (stone, rock), rather than metal or concrete, 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 Loon Lake. The emergent aquatic plant bulrushes present around Loon Lake offers satisfactory stabilization of shoreline sediments and assists in the minimization of sediment release into the lake.

Erosion Control/Shoreline Survey:

RLS conducted a survey of erosion around the Loon Lake shoreline on September 30, 2019 and noted one area of erosion on the south section of the lake near the outlet. This erosion can negatively impact numerous resources including public use areas; water quality from the soils eroding into the lake; fisheries and wildlife habitat being diminished from both turbidity and a lack of suitable vegetative cover.

Fetch, the distance across a body of water to produce a wind driven wave, ranges from less than ½ mile to nearly 2 miles in some cases, primarily from the south. Sustained southerly wind speeds could produce waves that are between 1.5-2.5-ft high. Shoreline bathymetry also plays a big part in determining the degree of erosion at a particular shoreline site. Sites with straight shorelines and exposed points that are exposed to long wind fetches from prevailing wind directions are vulnerable to more frequent and higher waves. Additionally, where the water deepens abruptly and there is less resistance or bottom roughness to influence the wave, exposed shorelines are susceptible to larger waves. Lastly, heavy human foot traffic and mowed areas, all contribute to substantial shoreline erosion in certain reaches of the lake. A loss of vegetative cover in these locations accelerates erosion and sedimentation.

These findings suggest that a combination of the above factors such as long fetches and high winds produce significant wave heights. Water manipulation and exposed shorelines with abrupt and deep lake depths adjacent to them contribute to substantial shoreline erosion.

Figure 51 demonstrates an area around the lake with bank erosion and Figure 52 demonstrates a well-vegetated and stabilized shoreline.

Figure 51. A photograph of shoreline erosion on Loon Lake with lake bank undercutting (RLS, 2019).

Figure 52. A photograph of a well-vegetated and stabilized shoreline a lake (RLS, 2019).

5.3.2 Loon Lake Nutrient Source Control

Based on the high ratio of nitrogen to phosphorus (i.e. N: P = 47), any additional inputs of phosphorus to the lake are likely to create additional algal and aquatic plant growth. Accordingly, RLS recommends the following procedures to protect the water quality of Loon Lake:

1) 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. Education of riparians on this issue is important as is understanding what they may use for fertilizers and where they are purchased. The best strategy is to water all lawns with lake water.

2) Preserve riparian vegetation buffers around of the Woods (such as those that consist of Cattails, Bulrushes), since they act as a filter to catch nutrients and pollutants that occur on land and may run off into the lake. 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.

3) 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.

4) Assure that all areas that drain into the lake from the surrounding land are vegetated and that no fertilizers are used in areas with saturated soils (see soil table above).

5) NEVER dump any solvents, chemicals, or debris into the lake. These can all harm fish, wildlife, and humans!

6) Never dump leaves or chemicals into storm drains as these often lead to waterways.

7) At a minimum, have annual or bi-annual septic tank and drain field inspections. Septic systems and drain fields can contribute high nutrient and bacteria loads to the lake which then are costly to mitigate.

8) Allow trees to grow near the shoreline for erosion control but be sure to rake away leaves in the fall. Do not rake leaves into the lake and dispose of leaves as yard waste.

9) Do not feed any waterfowl. Although this is enjoyable, they have plenty of food in the lake and their feces are all high in nutrients and bacteria.

10) Do not allow any rubber from water balloons, firework debris, plastic, Styrofoam, or food containers to enter the lake. Most of this will require hundreds of years to break down and is harmful to the lake.

11) Be a responsible lake steward! Attend lake association meetings and learn about issues on the Loon Lake.

6.0 LOON LAKE PROJECT CONCLUSIONS & RECOMMENDATIONS

Loon Lake is quite healthy overall but is facing significant issues that degrade the lake balance and health which include invasive aquatic plant species, low water clarity, algae blooms, and elevated conductivity from stormwater runoff. Although the nutrients are moderate, they have led to increased algal concentrations (chlorophyll-a) which reduces light to all aquatic plants and favors an algal-dominated state over time. The result of the overabundance of algae is higher turbidity, lower water clarity, and fewer aquatic plants. The soils around the lake consist primarily of mucks that are prone to ponding and flooding and can act as a direct source of nutrients and soils to the lake if not properly vegetated.

Improvements would include the assurance that all areas around the lake are vegetated at all times and with proper erosion stabilization techniques.

At this time, aeration is not needed for the lake due to the very healthy dissolved oxygen concentrations. However, the abundance of green algae may benefit from a whole lake bioaugmentation/enzyme addition at least once per season.

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 Loon Lake is critical. The lake manager should oversee all management activities and would be responsible for the creation of aquatic plant management survey maps, direction of the harvester or herbicide applicator to target-specific areas of aquatic vegetation for removal, implementation of watershed best management practices, administrative duties such as the processing of contractor invoices, and lake management education.

A complete list of recommended lake improvement options for this proposed lake management plan can be found in Table 16 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 16. List of Loon Lake proposed 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 lake	Reduce long-term use of herbicides in lake	Entire lake where invasives present
Bioaugmentation/Enzymes	Reduce all algae	Promote beneficial algae growth	Entire lake at least twice per season
Bi-annual water quality monitoring of lake and drains	Monitor efficacy of BMP's implemented, including any bioaugmentation, herbicides, etc.	Evaluate trends in improvements over time	Entire Lake
Annual lake surveys pre- and post-treatment	To determine efficacy of herbicide treatments on invasives	To determine ability of native aquatic vegetation biodiversity to recover post-management implementation	Entire lake
Riparian/Community Education	To raise awareness of lake/drain 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 MDNR and other stakeholders

6.1 Cost Estimates for Loon Lake Improvements

The proposed lake improvement and management program for Loon Lake is recommended to begin as soon as possible in 2020. Since bioaugmentation is likely to be the costliest improvement, it may be conducted over a period of five years or more to reduce annual cost. A breakdown of estimated costs associated with the various proposed treatments in Loon Lake is presented in Table 17.

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.

Table 17. Loon Lake proposed lake improvement program costs. NOTE: Items with asterisks are estimates only and are likely to change based on acquisition of formal quotes from qualified vendors.

Proposed Loon Lake Improvement Item	**Year 1 Costs**	**Years 2-5 (Annual) Costs**[4]
Systemic herbicides for invasives[1]	\$8,000	\$8,000
Professional services (limnologist management of lake, treatment oversight, water quality monitoring, education)[2]	\$16,000	\$16,500
Bioaugmentation[3]	\$35,000	\$35,000
Contingency[4]	\$5,900	\$5,950
Total Annual Estimated Cost	\$64,900	\$65,450

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

[2] Professional services includes comprehensive management of the lake with two annual GPS-guided, aquatic vegetation surveys, pre and post-treatment surveys for aquatic plant control methods, oversight and management of the aquatic plant control program and all management activities, all water quality monitoring and evaluation of all improvement methods, processing of all invoices from contractors and others billing for services related to the improvement program, education of local riparians through the development of a high-quality, scientific newsletter (can be coordinated with an existing lake newsletter), and attendance at up to three regularly scheduled annual board meetings.

[3] A formal bioaugmentation cost should be requested from qualified company to apply solution to entire lake. This cost may vary among years based on product demand, availability, and scope.

[4] Contingency is 10% of the total project cost, to assure that extra funds are available for unexpected expenses. Note: Contingency may be advised and/or needed for future treatment years. Contingency funds may also be used for other water quality improvements and watershed management.

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.

Allen, J. 2009. Ammonia oxidation potential and microbial diversity in sediments from experimental bench-scale oxygen-activated nitrification wetlands. MS thesis, Washington State University, Department of civil and Environmental Engineering.

Barbiero, R., R.E. Carlson, G.D. Cooke, and A.W. Beals. 1988. The effects of a continuous application of aluminum sulfate on lotic benthic macroinvertebrates. *Lake and Reservoir Management* 4(2):63-72.

Blackburn, R.D., L.W. Weldon, R.R. Yeo, and T.M. Taylor. 1969. Identification and distribution of certain similar-appearing submersed aquatic weeds in Florida. *Hyacinth Control Journal* 8:17-23.

Beutel, M.W. 2006. Inhibition of ammonia release from anoxic profundel sediments in lakes using hypolimnetic oxygenation. *Ecological Engineering* 28(3): 271-279.

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.

Engstrom, D.R., and D.I. Wright. 2002. Sedimentological effects of aeration-induced lake circulation. *Lake and Reservoir Management* 18(3):201-214.

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

Gosch, N. J. C., Phelps, Q. E. and D.W. Willis. 2006. Habitat characteristics at bluegill spawning colonies in a South Dakota glacial lake. *Ecology of Freshwater Fish*, 15: 464–469. doi: 10.1111/j.1600-0633.2006.00178. x.

Halstead, J.M., J. Michaud, and S, Hallas-Burt. 2003. Hedonic analysis of effects of a non-native invader (*Myriophyllum heterophyllum*) on New Hampshire (USA) lakefront properties. *Environmental Management* 30 (3): 391-398.

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

Herrick, B.M., and Wolf, A.T. 2005. Invasive plant species in diked vs. undiked Great Lakes wetlands. *Journal of Great Lakes Research*., Internat. Assoc. Great. Lakes. Res. 31(3): 277-287.

Holland, R.E. 1993. Changes in planktonic diatoms and water transparency in Hatchery Bay, Bass Island Area, Western Lake Erie since the establishment of the zebra mussel, *Journal of Great Lakes Research* 19:617-624.

Jermalowicz-Jones, J.L. 2009-2018. Evaluation studies of laminar flow aeration efficacy on various water quality parameters in Michigan inland lakes. *Unpublished data.*

Laing, R.L. 1978. Pond/Lake Management organic waste removal through multiple inversion. In house report. Clean-Flo Lab, Inc.

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.

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.

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.

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

Mackie, G.L., and D.W. Schloesser. 1996. Comparative biology of Zebra Mussels in Europe and North America: An Integrative and Comparative Biology 36(3):244-258.

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.

Malueg, K., J. Tilstra, D. Schults, and C. Powers. 1973. Effect of induced aeration upon stratification and eutrophication processes in an Oregon farm pond. *Geophysical Monograph Series* 17: 578-587. American Geophysical Union. Washington DC.

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.

McMahon, R.F., and C.J. Williams. 1986. A reassessment of growth rate, life span, life cycles, and population dynamics in a natural population dynamics in a natural population and field caged individuals of *Corbicula fluminea* (Müller) (Bivalvia: Corbicula). Am. Malacol. Bull. Spec. ed. No. 2:151-166.

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.

Ogwada, R.A., K.R. Reddy, and D.A. Graetz. 1984. Effects of aeration and temperature on nutrient regeneration from selected aquatic macrophytes. *Journal of Environmental Quality* 13(2):239-243.

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.

Price, J.D., and C.C. Long. 2010. Loon Lake, Genesee County, Michigan 2008-2009 walleye evaluations. Michigan Department of Fish and Wildlife.

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.

Rinehart, K.L., M. Namikoshi, and B. W. Choi. 1994. Structure and biosynthesis of toxins from blue-green algae (cyanobacteria). *Journal of Applied Phycology* 6: 159-176.

Skelton, 1997. Loon Lake tributary macroinvertebrate study. Biology and Environmental Science Department. St. Norbert College. 19 pp.

Skubinna, J.P., T.G. Coon, and T.R. Batterson. 1995. Increased abundance and depth of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Michigan. *Journal of Great Lakes Research* 21(4): 476-488.

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.

Toetz, D.W., 1981. Effects of whole lake mixing on water quality and phytoplankton. *Water Research* 15: 1205-1210.

Turcotte, A.C., C.V. Déry, and K.F. Ehrlich. 1988. Manipulation of microbial ecosystems to control the aquatic plant Eurasian Watermilfoil. Preprint paper. Département de Biologie, Université de Sherbrooke, Sherbrooke, Québec, CANADA J1K 2R1.

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.

Verma, N. and S. Dixit. 2006. Effectiveness of aeration units in improving water quality of Lower Lake, Bhopal, India. *Asian Journal of Experimental Science* 20(1): 87-95.

Weiss, C., and B. Breedlove. 1973. Water quality changes in an impoundment as a consequence of artificial destratification. 216 pp. Water Resources Research Institute. University of North Carolina. Raleigh.

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