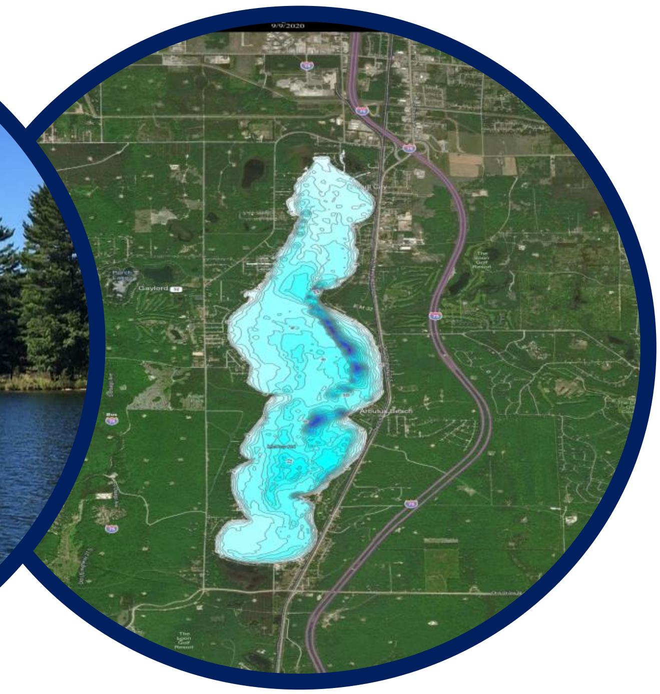
Otsego Lake Improvement Study and Management Plan Otsego County, Michigan



Provided for: Otsego Lake Association (OLA) Board

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Otsego Lake Improvement Study and Management Plan
Otsego County, Michigan

December, 2020

1.0 EXECUTIVE SUMMARY

Otsego Lake is located in Sections 4,5,8,20,21,29,32, and 33 of Otsego Lake (at the south) and Bagley (at the north) Townships (T. 29-30N, R.3W) in Otsego County, Michigan, and is a natural glacial lake. **The lake is comprised of 2,029.1 acres (RLS, 2020) which includes the area of all canals. A legal lake level was established by Circuit Court Order in 1972 (Circuit Court Case No. 136-2). The legal lake level was established at a maximum of 1,273.5 feet above mean sea level (MSL) and minimum of 1,273.0 feet above mean sea level. There is an artificial drain on the eastern shore that empties water into the north branch of the Au Sable River during excessively high water levels. This drain is operated by the Otsego County Road Commission. The lake has no inlet or outlet and thus is considered a seepage lake that receives the majority of its water from groundwater aquifers. Previous estimates of residence time are around 3.6 years (U M 1980 study). The lake elevation is 1,273 feet above sea level.**

The mean depth of the lake is approximately 6.4 feet and the maximum depth is approximately 20.2 feet (RLS, 2020 bathymetric scan data). The lake also has a fetch (longest distance across the lake) of around 4.6 miles (RLS, 2020), a maximum width of 1.1 miles, and a shoreline length of 13.5 miles which includes the length of the canal shorelines.

Otsego Lake has an approximate water volume of 14,362.5 acre-feet (RLS, 2020 bathymetric data) and contains some springs. Otsego Lake lies within the Au Sable River watershed which drains to Lake Huron. The immediate watershed, which is the area directly draining into the lake, is approximately 14,750 acres which is about 7.1 times the size of the lake and is considered to be a medium-sized immediate watershed.

Based on the current study, **Otsego Lake contains three invasive submersed aquatic plant species including approximately 12 acres of Eurasian Watermilfoil (*Myriophyllum spicatum*) and approximately 0.5 acres of invasive Curly-leaf Pondweed (*Potamogeton crispus*), and 2.8 acres of Starry Stonewort.** The Starry Stonewort was only found in the canals and the Curly-leaf Pondweed was scarce at the south end of the lake. All of these species may increase in some years with certain environmental conditions. Recommendations for prevention and treatment of invasives are offered later in this management plan report.

Otsego Lake contained 17 native submersed, 2 floating-leaved, and 5 emergent aquatic plant species, for a total of 24 native aquatic macrophyte species during the lake survey on September 9-11, 2020. Although this biodiversity is favorable, the relative abundance of each plant genus was sparse to moderate overall and thus protection of native biodiversity is critical.

A detailed, Early Detection- Rapid Response Protocol for future invasives that may enter the lake is recommended to be compiled ASAP for the lake community. Furthermore, a professional limnologist/lake manager from RLS should perform regular GPS-guided whole-lake surveys each summer/early fall to monitor the growth and distribution of all invasives 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 Otsego 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 herbicide applicator to target-specific areas of aquatic vegetation for removal, implementation of watershed best management practices, administrative duties such as the review and approval of contractor invoices, and lake management education.

Lake weed treatments should consist only of early spring contact herbicides for any nuisance-level Curly-leaf Pondweed (CLP) and systemic herbicides for Eurasian Watermilfoil (EWM). Algal treatments should only be used on very dense filamentous green algae and should consist of chelated copper only to avoid bioaccumulation in lake sediments. RLS should be present to oversee all lake treatments to assure objectivity and evaluate performance.

The lake has an overall low abundance of zooplankton and macroinvertebrates which form the base of the lake food chain. The reason for the lower macroinvertebrates is likely due to the flocculent nature of many areas of the lake sediments that make colonization by macros difficult. Additionally, these organisms are sensitive to pollution and incoming solids which is why erosion control is important nearshore. A multitude of areas around the lake were found to have shoreline erosion and these areas should be stabilized with rip-rap or soft shoreline emergent vegetation. Guidance for these procedures was offered in Section 5.0 of this report.

Otsego Lake is a relatively soft-water lake. Otsego Lake has overall low to moderate nutrient concentrations and is not burdened by tributary inputs. Dissolved oxygen declined with depth and this could lead to release of TP from the lake bottom which could fuel increased aquatic plant and algae growth with time. Reduction of nutrients should come from proper septic tank maintenance also discussed in section 5.0 of this report as well as erosion control improvements.

A whole-lake shoreline erosion survey was conducted on September 9, 2020 and determined that 72 locations around the lake have significant erosion problems. An erosion control program is highly recommended for the lake with recommendations that are site-specific. RLS could prepare a program for the community upon request. Control of this observed erosion is critical for water quality by reducing turbidity, solids, and nutrients.

Lastly, a riparian education program is recommended through the development of this management plan and through holding future educational workshops. Such workshops may include dispersal of relevant lake information and also identification of local lake biota so that residents know to be vigilant of certain invasives or other lake issues. The local community can request information on Gaylord area lakes by downloading a brochure at: https://www.gaylordmichigan.net/get-outdoors/a-water-wonderland/.

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 Otsego 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. **Otsego Lake is a seepage lake since it lacks an inlet or true outlet and receives the majority of its water from groundwater seepage.**

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 ecosystem, 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 OTSEGO LAKE PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Otsego Lake Basin

Otsego Lake is located in Sections 4,5,8,20,21,29,32, and 33 of Otsego Lake (at the south) and Bagley (at the north) Townships (T. 29-30N, R.3W) in Otsego County, Michigan, and is a natural glacial lake. **The lake is comprised of 2,029.1 acres (RLS, 2020) which includes the area of all canals.**

A legal lake level was established by Circuit Court Order in 1972 (Circuit Court Case No. 136-2). The legal lake level was established at a maximum of 1,273.5 feet above mean sea level (MSL) and minimum of 1,273.0 feet above mean sea level. There is an artificial drain that empties water into the north branch of the Au Sable River during excessively high water levels. The lake has no inlet or outlet and thus is considered a seepage lake that receives the majority of its water from groundwater aquifers. Previous estimates of residence time are around 3.6 years (UM 1980 study). The lake elevation is 1,273 feet above sea level.

The mean depth of the lake is approximately 6.4 feet and the maximum depth is approximately 20.2 feet (RLS, 2020 bathymetric scan data). The lake also has a fetch (longest distance across the lake) of around 4.6 miles (RLS, 2020), a maximum width of 1.1 miles, and a shoreline length of 13.5 miles which includes the length of the canal shoreline.

Otsego Lake has an approximate water volume of 14,362.5 acre-feet (RLS, 2020 bathymetric data) and contains some springs. Otsego Lake lies within the Au Sable River watershed which drains to Lake Huron. The immediate watershed, which is the area directly draining into the lake, is approximately 14,750 acres which is about 7.1 times the size of the lake and is considered to be a medium-sized immediate watershed.

A bottom sediment hardness scan with 44,744 GPS soundings was conducted of the entire lake bottom on September 9, 2020. **The bottom hardness map shows (Figure 3) that most of the lake bottom consists of fairly sandy sediments throughout the shallow areas of the lake with larger areas of soft organic deposits in the deeper waters**. 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 cohesive and not flocculent. The lake was used for logging in the late 1800s and early 1900s with 4 sawmills once operating on the lake. It has been estimated that up to 23 feet of organic sediments were deposited in the south basin from these activities (MDNR, 2009).

Table 1. Otsego Lake relative hardness of the lake bottom on September 9, 2020 by category or hardness and percent over of each category (relative cover).

Lake Bottom Relative Hardness Category	# GPS Points in Each Category (Total =47,744)	% Relative Cover of Bottom by Category
0.0-0.1	253	0.6
0.1-0.2	2661	6.0
0.2-0.3	17337	38.8
0.3-0.4	9073	20.3
>0.4	15420	34.5

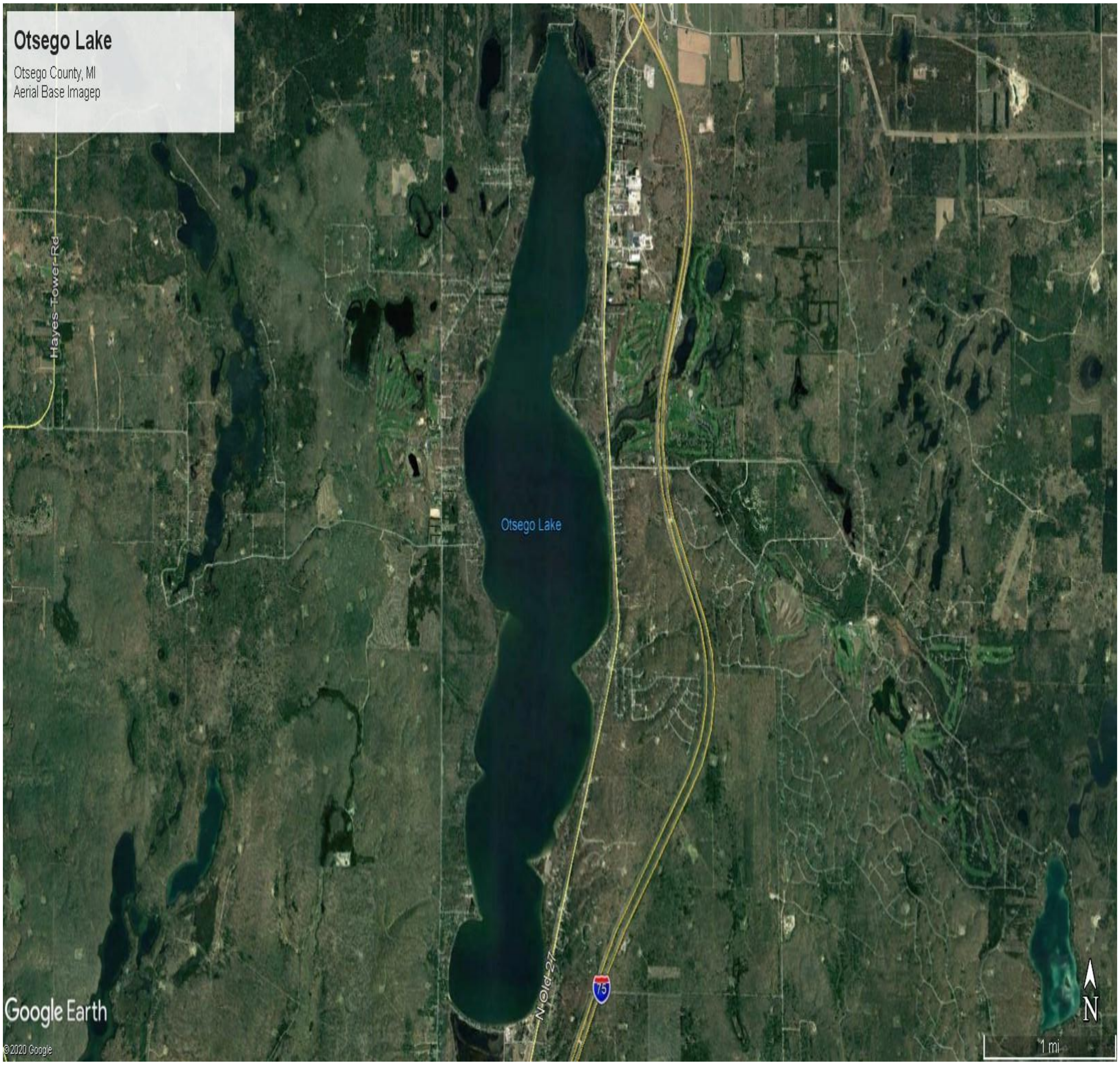


Figure 1. Otsego Lake Aerial Photo, Otsego County, Michigan.

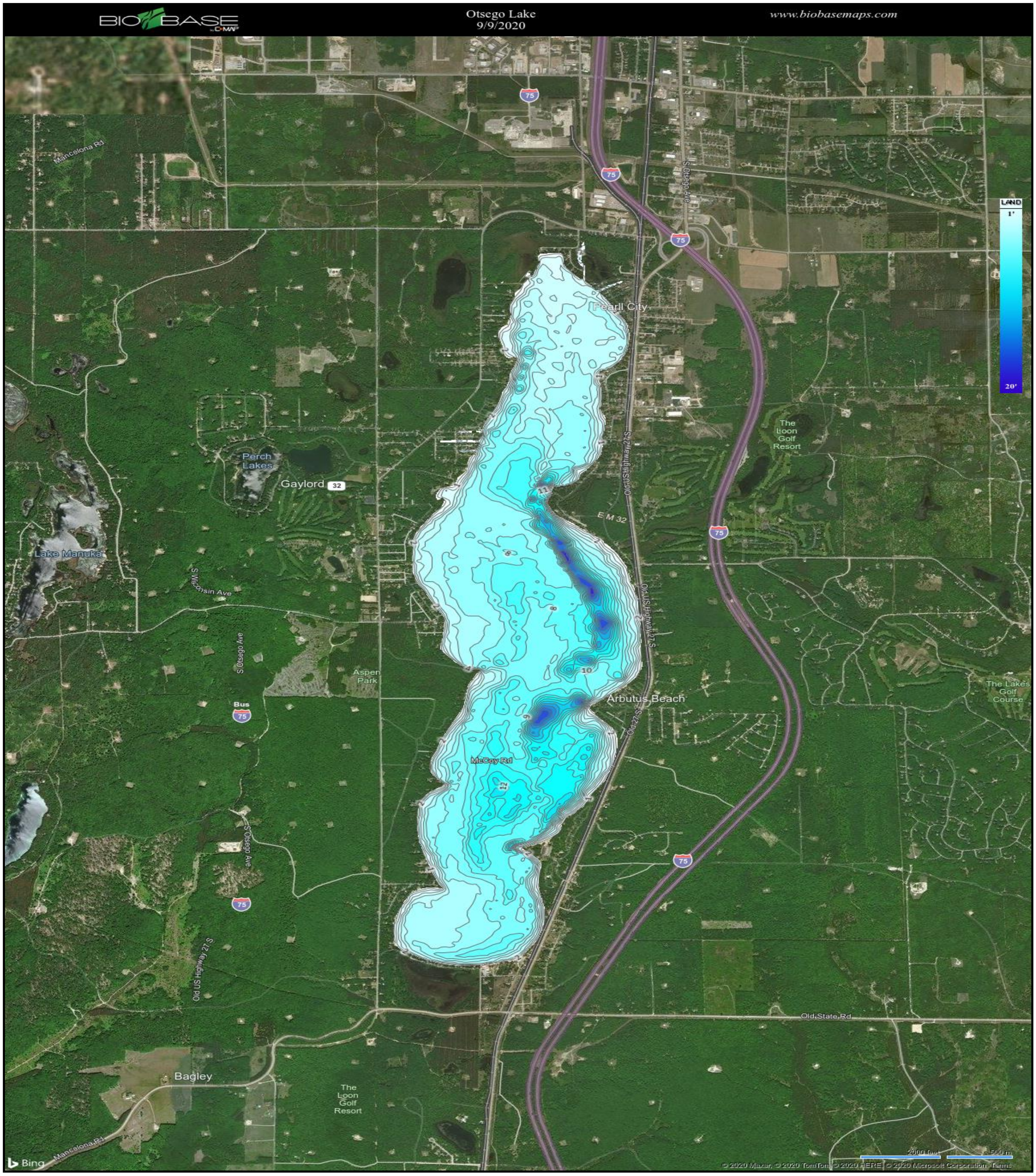


Figure 2. Otsego Lake Depth Contour Map, Otsego County, Michigan (September 9, 2020).

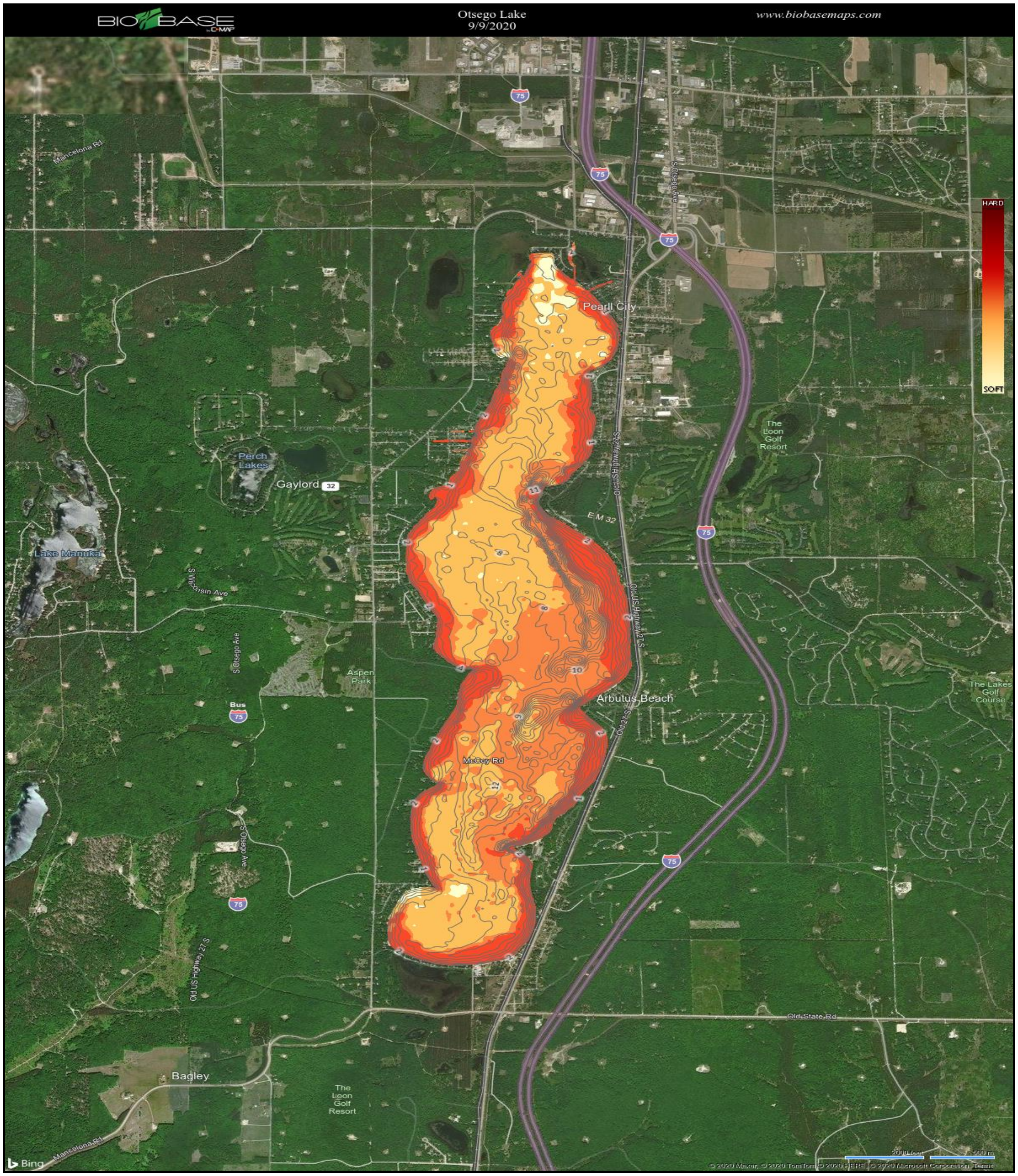


Figure 3. Otsego Lake Sediment Hardness Map, Otsego County, Michigan (September 9, 2020).

3.2 Otsego 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.

Otsego Lake is located within the Au Sable River extended watershed. **The Au Sable River extended watershed (HUC 04070007) which covers an area of approximately 1,932 mi^2 in eight counties that include Otsego, Crawford, Montmorency, Roscommon, Ogemaw, Oscoda, Iosco, and Alcona.** The Au Sable River eventually drains into Lake Huron near the town of Oscoda. The watershed is characterized predominately by forest, urban land, agriculture, grasslands, and wetland land uses (current MIRIS data). 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 Otsego Lake community.

The immediate watershed of Otsego Lake consists of the area around the lake that directly drains to the lake and measures approximately 14,751 acres in size (Figure 4; RLS, 2020). The immediate watershed is about 7.1 times the size of the lake, which is considered a medium-sized immediate watershed. The lakefront itself has a diverse application of land uses such as beachfront for swimming, wetlands, and forested lands. Thus, management options should also consider all of these land uses and preserve their unique functions. **Erosion is the current largest threat to the water quality of Otsego Lake next to septic systems. Some of the areas around the lake are also of high slope or unstable shorelines and are prone to erosion.** Best Management Practices (BMP's) for water quality protection are offered in the watershed improvement section of this report.

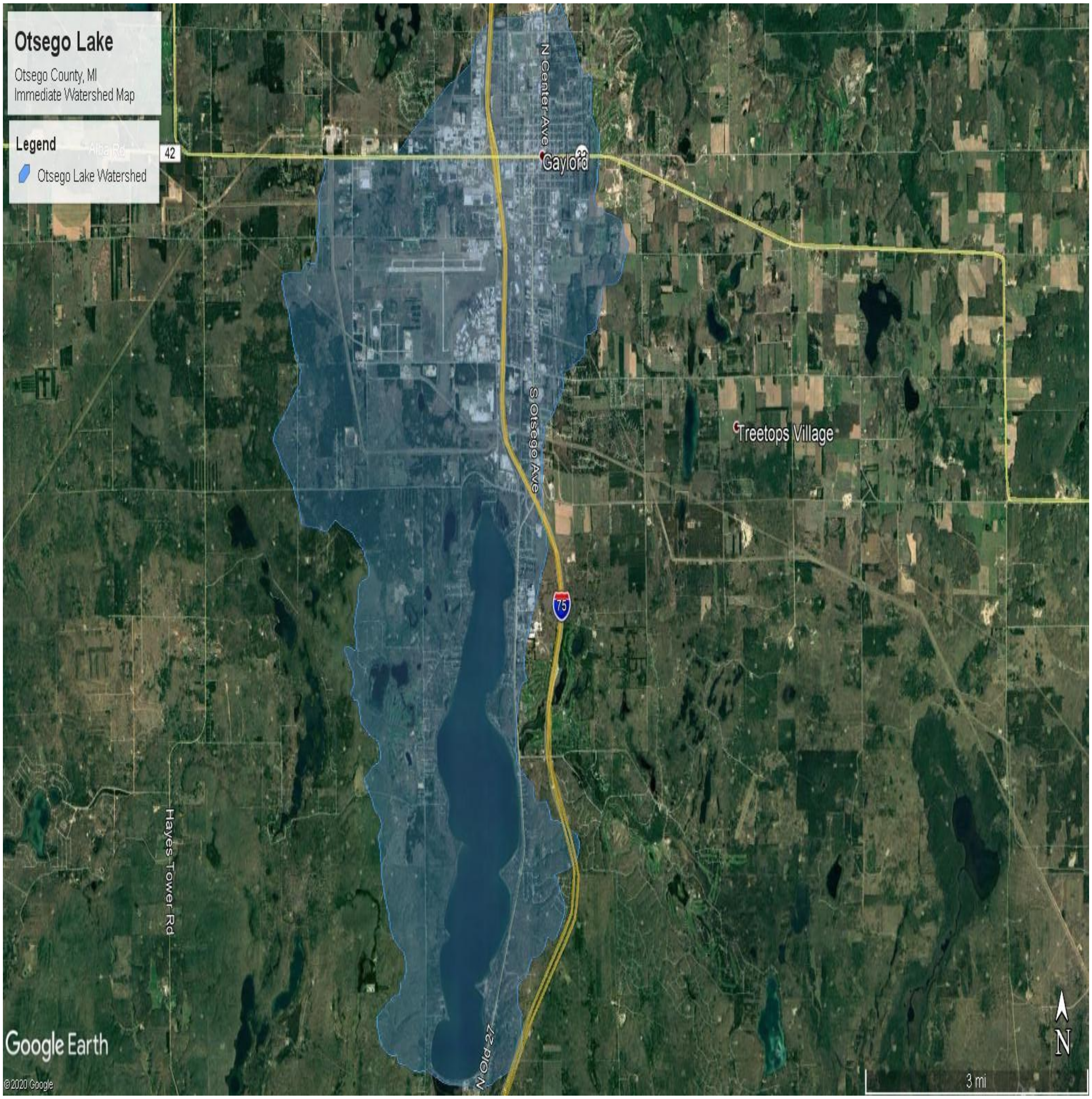


Figure 4. Immediate Watershed draining into Otsego Lake, Otsego County, Michigan (Restorative Lake Sciences, 2020).

3.3 Otsego Lake Shoreline Soils

There are 11 major soil types (defined as occupying a greater surface area near the lake shoreline) immediately surrounding Otsego Lake which may impact the water quality of the lake and may dictate the particular land use activities within the area (Table 2). This denotes a lake with fairly complex geology; Figure 5 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service) demonstrates the precise soil types and locations around Otsego Lake. Major drainage characteristics of the dominant soil types directly surrounding the Otsego Lake shoreline are discussed below.

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

USDA-NRCS Soil Series	***Drainage Characteristics***
CsWaaA: Croswell sand; 0-6% slopes (W,S)	Moderately well-drained
18A: Au Gres sand; 0-3% slopes (W, N)	Somewhat poorly drained
15A: Croswell Au Gres sands; 0-3% slopes (W, E, S)	Moderately well-drained
147B: Lindquist sand; 0-6% slopes (W)	Excessively drained
14: Dawson Loxley peat (SW, E, NW)	Poorly drained
24A: Kinross Au Gres complex; 0-6% slopes (SW)	Poorly drained
86: Histosols and Aquents, ponded (S, NW, NE)	Poorly drained
75B: Rubicon sand; 0-6% (E, NW)	Excessively drained
49B: Kalkaska sand; 0-6% (E)	Somewhat excessively drained
368A: Au Gres-Deford complex; 0-6% slopes (NW)	Poorly drained
369: Deford muck (NW)	Poorly drained

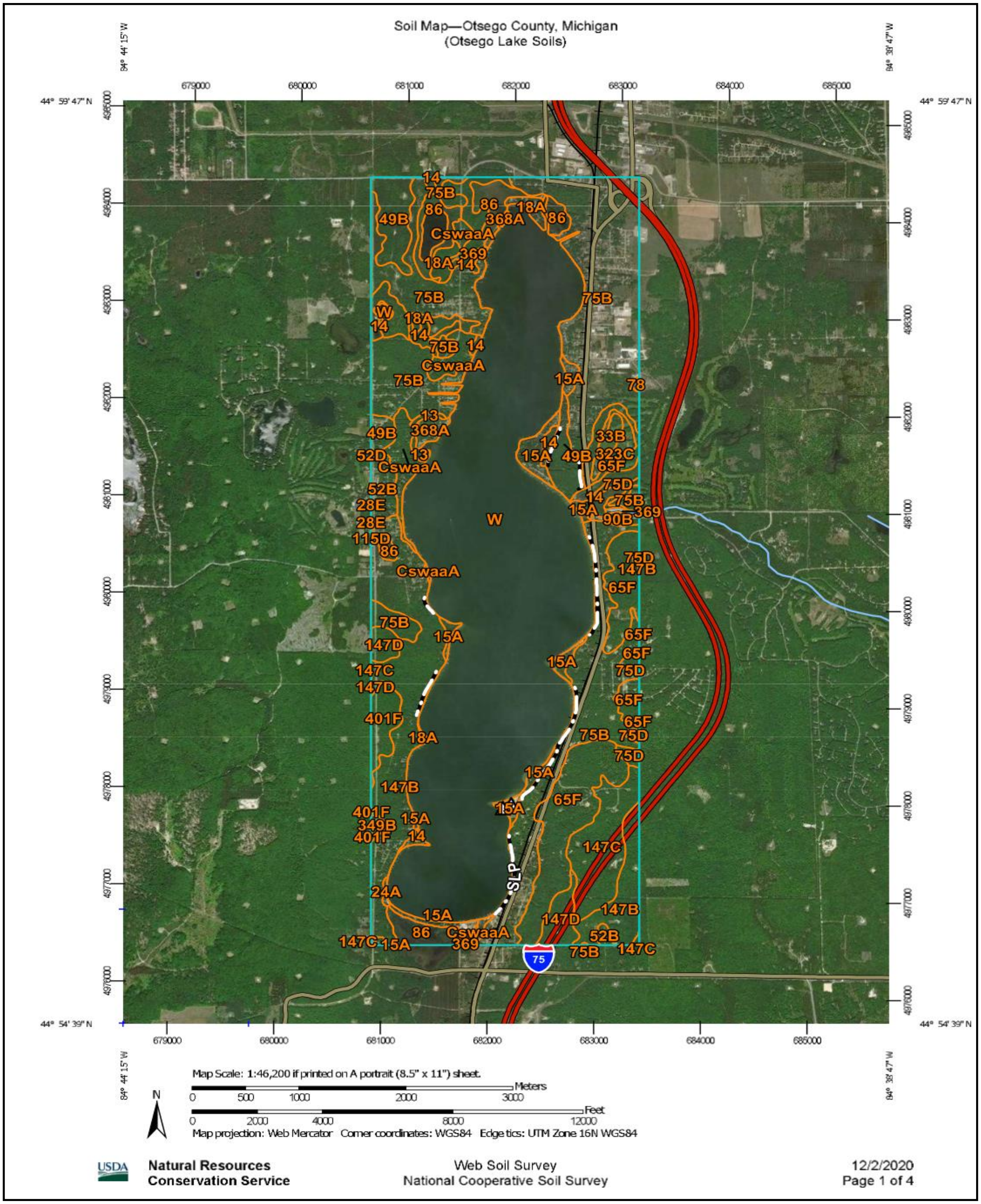


Figure 5. NRCS-USDA soils map for Otsego Lake shoreline soils.

The majority of the soils around Otsego Lake are Croswell and Au Gres sands which are very deep soils with the former being moderately well drained and the latter being somewhat poorly drained soils. Although most areas around the lake have relatively low slopes (<6%), many areas are prone to erosion due to long-standing high water levels which allow many areas of unstable shoreline to empty into the lake shallows. Proper erosion control management is paramount and discussed later in this report.

There are also organic saturated soils such as the Dawson and Loxley peats and Deford mucks, present around the lake that are very deep, very poorly drained 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 become ponded during extended rainfall and the wetlands can serve as a source of nutrients to the lake. When the soils of the wetland are not saturated, the wetland can serve as a sink for nutrients and the nutrients are filtered by wetland plants.

4.0 OTSEGO 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 Otsego 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. **Otsego Lake is classified as a meso-eutrophic (moderately nutrient-rich) lake due to the low to moderate nutrients, low to moderate Secchi transparency, and low to moderate chlorophyll-a concentrations.**

Table 3. General Lake Trophic Status Classification.

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

4.1 Water Quality Parameters

Water quality parameters were measured and included dissolved oxygen (in mg/L), water temperature (in °C), specific conductivity (mS/cm), turbidity (NTU's), total suspended solids (mg/L), total dissolved solids (mg/L), pH (S.U.), total alkalinity (mg $CaCO_3$/L), total phosphorus and ortho-phosphorus (also known as soluble reactive phosphorus or SRP measured in mg/L), total inorganic nitrogen (in mg/L), chlorophyll-a (in µg/L), 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 4-10. A map showing the sampling locations for all water quality samples is shown below in Figure 6. All water samples and readings were collected at the three deepest basins on September 9, 2020 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 collected with new bottles, placed on ice, and taken to a NELAC (EPA)-certified laboratory for analysis. Turbidity was measured with a calibrated Lutron® turbidity meter and chlorophyll-a was measured in situ with a calibrated Turner Designs® fluorimeter. Sediment samples were collected with an Ekman hand dredge on September 9, 2020 and placed in glass jars and transported to the laboratory on ice (Figure 7). Whenever possible, historical data comparisons were made for certain parameters that utilized similar periods and methods as those used in this study. Water quality data in the same deep basins and using the same EPA methods was scarce but comparisons were made when possible.

For information on Otsego Lake water levels, daily water level data can be found online at the following USGS website:
https://waterdata.usgs.gov/mi/nwis/uv/?site_no=445512084415301&PARAmeter_cd=00065,62615

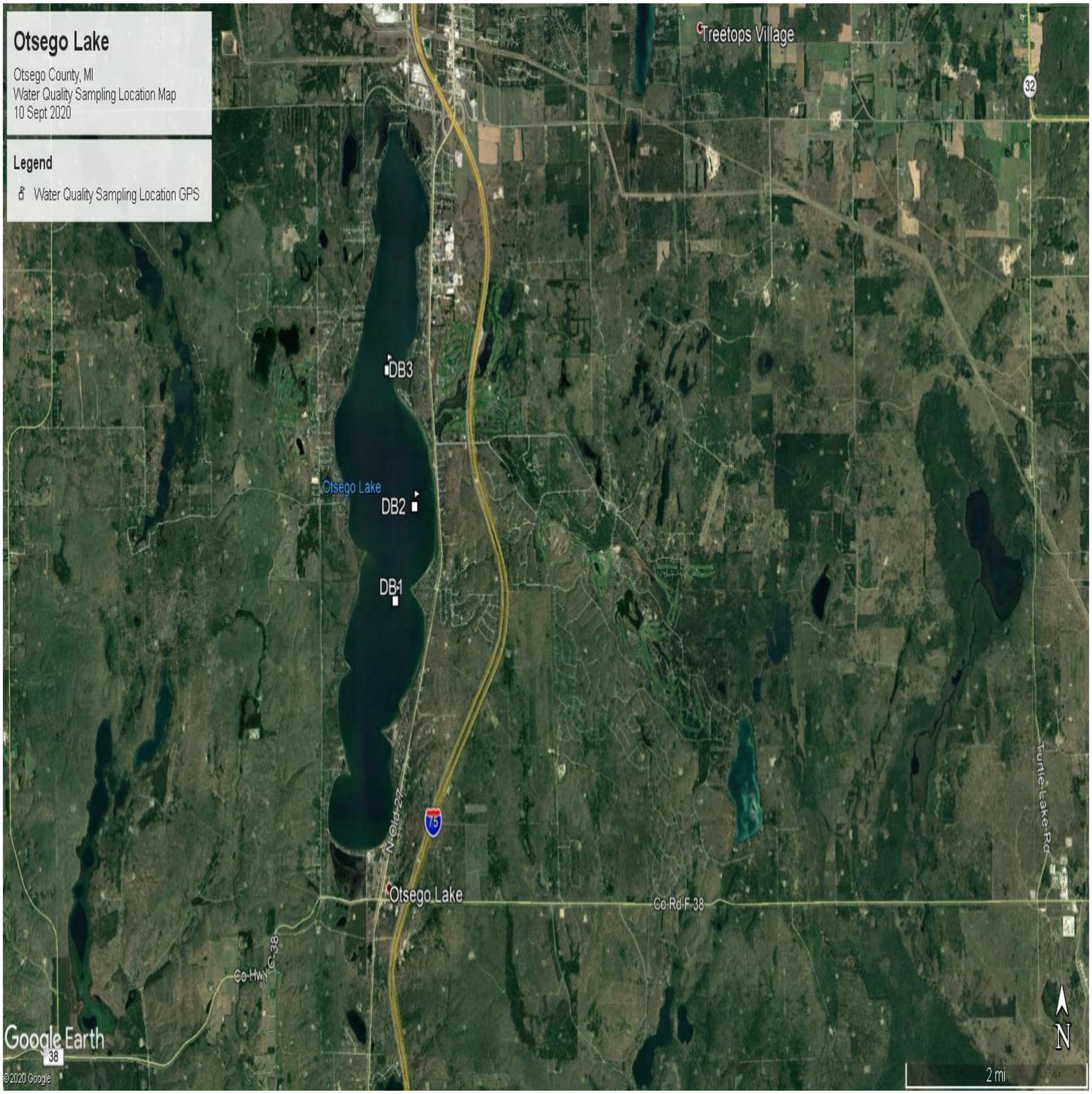


Figure 6. Locations for deep basin water quality sampling in Otsego Lake (September 9, 2020).

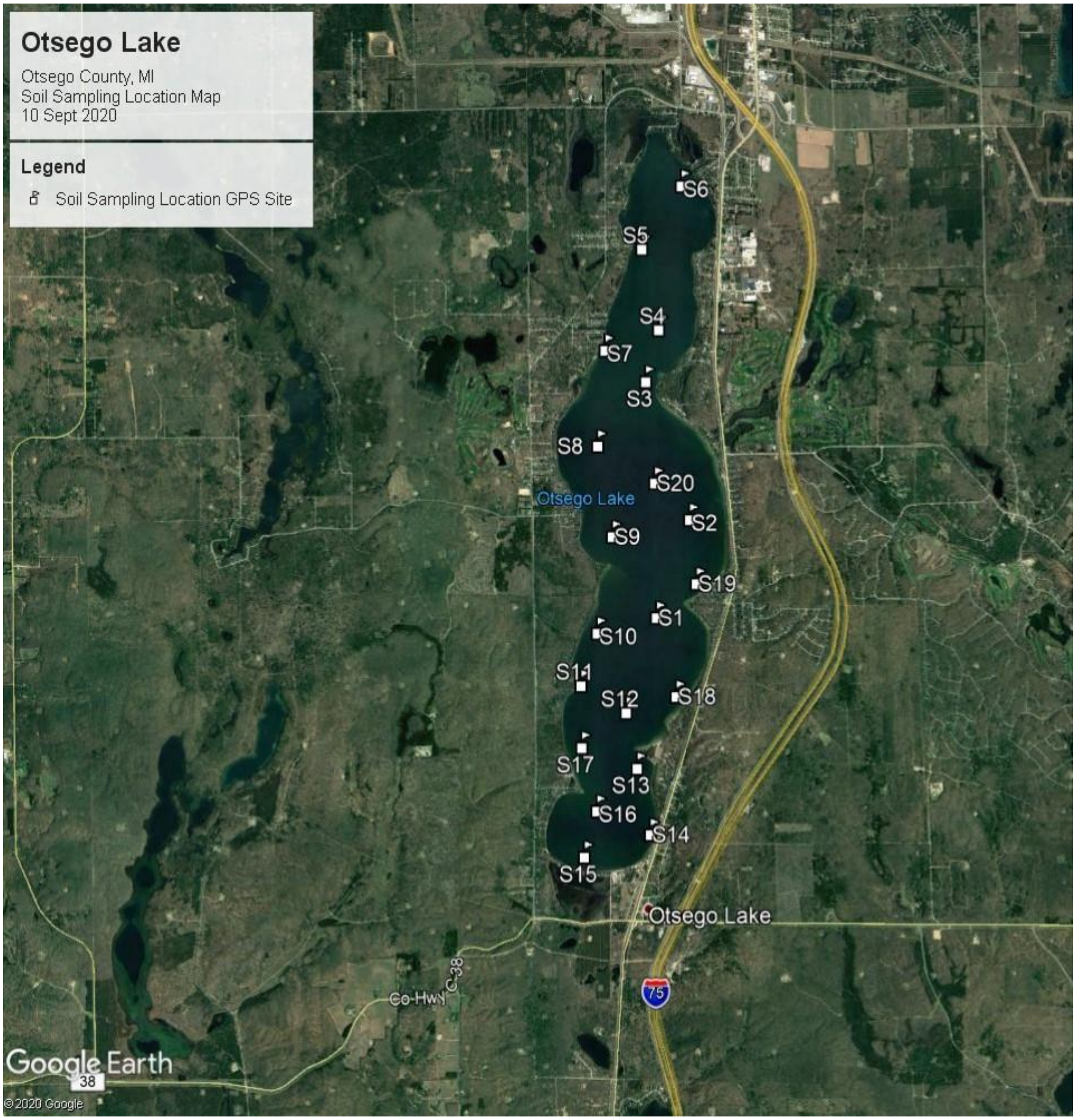
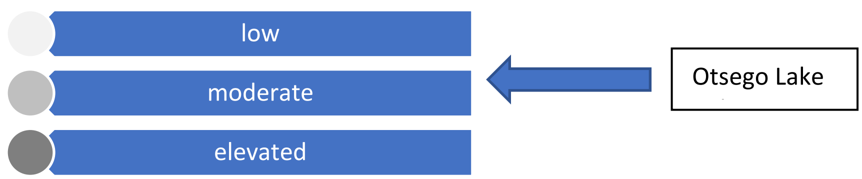


Figure 7. Locations for sediment organic matter sampling in Otsego Lake (September 9, 2020).

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 and even higher around 6 mg/L for trout. 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 in the deep basins ranged from 5.7-9.0 mg/L on September 9, 2020, with the highest values measured at the surface and lowest values near the lake bottom.** The bottom of the lake produces a biochemical oxygen demand (BOD) due to microbial activity attempting to break down high quantities of organic plant matter, which reduces dissolved oxygen in the water column at depth. Furthermore, the lake bottom is distant from the atmosphere where the exchange of oxygen occurs. A decline in the dissolved oxygen concentrations to near zero may result in an increase in the release rates of phosphorus (P) from lake bottom sediments. All of the deep basins experienced some loss of DO with depth, but Deep Basin #3 experienced the least depletion. A previous study by the MDNR (2008) determined the surface to bottom DO concentrations to range from 9.8-6.2 mg/L, which are similar to the concentrations measured during this evaluation.



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 8). 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 9, 2020 water temperatures of Otsego Lake demonstrated a lack of thermoclines and are indicative of a continually mixed (polymictic) lake that mixes multiple times per year due to the overall shallow depths.**

On the day of sampling, water temperatures ranged from 16.7°C at the surface to 16.4°C at the bottom of the three deep basins. The MDNR (2008) study also reported the lack of a thermocline. Deep basin #3 exhibited the most difference with a water temperature difference of 0.2°C.

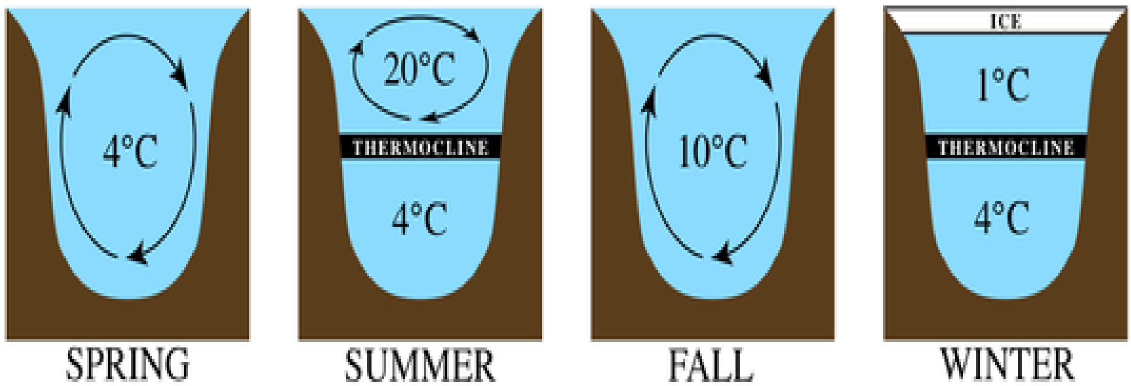
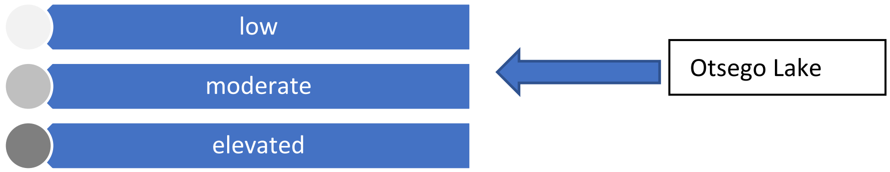


Figure 8. The lake thermal stratification process.

4.1.3 Specific Conductivity

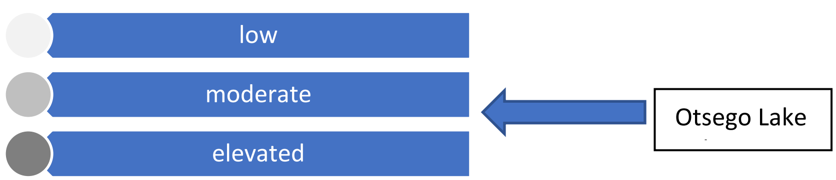
Specific conductivity is a measure of the number of mineral ions present in the water, especially those of salts and other dissolved inorganic substances that can conduct an electrical current. Specific conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Specific conductivity was measured in micro Siemens per centimeter (µS/cm) with the use of a calibrated Eureka Manta II® specific conductivity probe and meter. **Specific conductivity values for Otsego Lake were variable among depths at the deep basins on September 9, 2020 and ranged from 215-408 mS/cm which are low to moderate values. The highest specific conductivity values were recorded in deep basin #2 which had the highest specific conductivity at the lake bottom of 408 mS/cm.** Since these values are moderate 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 specific conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Otsego 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*

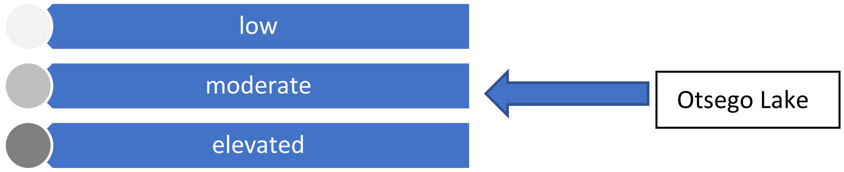
Turbidity

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 Otsego Lake was moderate and ranged from 4.0-8.0 NTU's during the September 9, 2020 sampling event.** On the day of sampling, the winds were calm in the morning, and turbidity was not likely influenced by much re-suspension of sediments although bottom samples are usually higher in turbidity due to fine particle re-suspension.



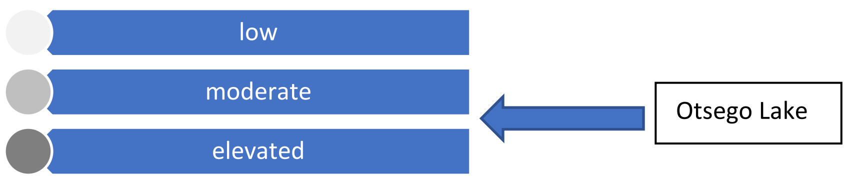
Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the amount of dissolved organic and inorganic particles in the water column. Particles dissolved in the water column absorb heat from the sun and raise the water temperature and increase conductivity. Total dissolved solids were measured with the use of a calibrated Eureka Manta II® meter in mg/L. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. **The TDS in Otsego Lake on September 9, 2020 ranged from 137-248 mg/L for the deep basins which is moderate for an inland lake and correlates with the measured moderate conductivity.**



Total Suspended Solids (TSS)

Total suspended solids is a measure of the number of suspended particles in the water column. Particles suspended in the water column absorb heat from the sun and raise the water temperature. Total suspended solids were measured in mg/L and analyzed in the laboratory with Method SM 2540 D-11. The lake bottom contains many fine (flocculent) 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 Otsego Lake on September 9, 2020, ranged from <10-28 mg/L, with the highest concentrations located throughout deep basin #3.** Ideally values should be < 10 mg/L.



4.1.5 pH

pH is a 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 Otsego Lake water ranged from 8.1-8.3 S.U. during the September 9, 2020 sampling event.** This range of pH is neutral to slightly alkaline on the pH scale and is ideal for an inland lake and is similar to the value of 8.4 S.U. recorded by the MDNR in 2007. 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

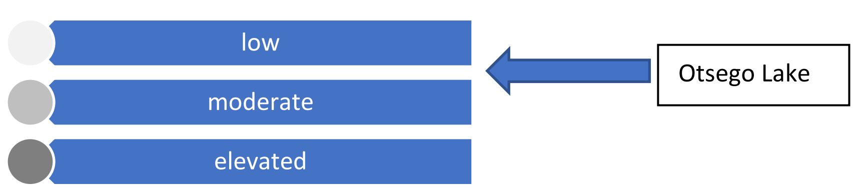
Total alkalinity is a measure of the pH-buffering capacity of lake water. Lakes with high alkalinity (> 150 mg/L of $CaCO_3$) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of $CaCO_3$ and are categorized as having "hard" water.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

Total alkalinity in the deep basins ranged from 68-70 mg/L of $CaCO_3$ during the September 9, 2020 sampling event, which represents a moderately low alkalinity (slightly soft water) 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. This range of total alkalinity was similar to those previously measured by the MDNR (2009) and U of M (1980).

4.1.7 Total Phosphorus and Ortho-Phosphorus (SRP)

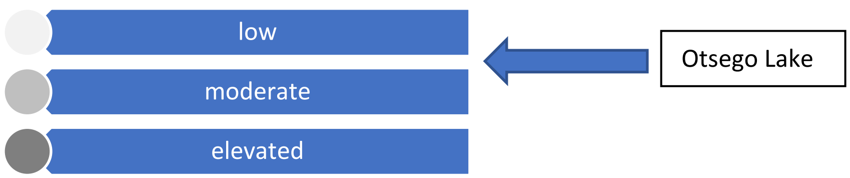
Total Phosphorus

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 (or 20 µg/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 deep basins ranged from 0.012-0.025 mg/L during the September 9, 2020 sampling event. The highest concentration was measured near the bottom of deep basin #3, but this value is still considered at the eutrophic threshold. Surface water TP concentrations are almost always lower than middle and bottom depth concentrations.**



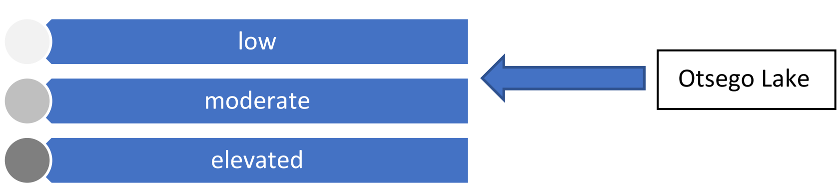
Ortho-Phosphorus

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 ranged from <0.010-0.015 mg/L on September 9, 2020 which is variable but low and favorable. The highest concentrations were found at the bottom of deep basin #2 but this value is below the eutrophic threshold.**



4.1.8 Total Inorganic Nitrogen

Total Inorganic Nitrogen (TIN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), and ammonia (NH_4^+), nitrogen forms in freshwater systems. TIN was measured with Method EPA 351.2 (Rev. 2.0) and Total Inorganic Nitrogen (TIN) was calculated based on the aforementioned three different forms of nitrogen. 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, which is correct for Otsego Lake. 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. **Otsego Lake contained low concentrations of TIN at all depths (≤ 0.120 mg/L), which is normal for an inland lake of similar size and favorable.** In the absence of dissolved oxygen, nitrogen is usually in the ammonia form and will contribute to rigorous submersed aquatic plant growth if adequate water transparency is present. **All of the TIN present in the Otsego Lake samples was in the ammonia form and the nitrate and nitrate were both below detection.**

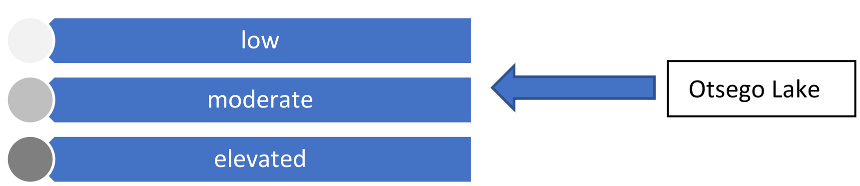


4.1.9 Chlorophyll-a and Algal Communities

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 Method SM 10200H. The chlorophyll-*a* concentrations in Otsego Lake were determined by collecting a composite sample of the algae throughout the water column at the deep basin sites from just above the lake bottom to the lake surface. **The chlorophyll-*a* concentrations in the deep basins ranged from 2.0-3.0 µg/L during the September 9, 2020 sampling event.** These concentrations were favorable and are within the previously reported ranges from MDNR (2009) and U of M (1980). Chlorophyll-a concentrations may significantly fluctuate with changes in air and water temperatures and with storm-driven runoff.

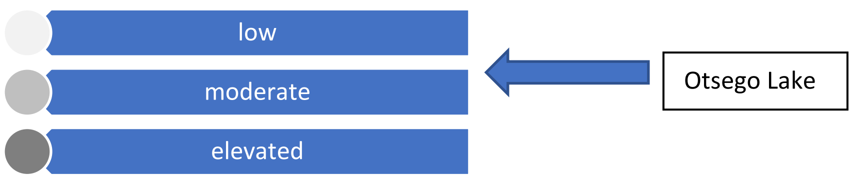
Algal genera from a composite water sample collected from the deep basins of Otsego Lake were analyzed under a Zeiss® compound brightfield microscope. **The genera present included the Chlorophyta (green algae): *Chlorella* sp., *Rhizoclonium* sp., *Spirogyra* sp., *Mougeotia* sp., *Scenedesmus* sp., *Cosmarium* sp., *Staurastrum* sp., *Botryococcus* sp., and *Pediastrum* sp.; the Cyanophyta (blue-green algae): *Microcystis* sp., *Dichlicospermum* sp., *Chroococcus* sp., and *Oscillatoria* sp; the Bascillariophyta (diatoms): *Navicula* sp., *Synedra* sp., *Fragilaria* sp., *Tabellaria* sp., and *Cymbella* sp., and; the Chrysophyta (golden algae) *Dinobryon* 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 and diatoms were the most abundant, followed by the blue-green algae.** Algal blooms, including blue-green algae have been historically reported on Otsego Lake with time (U of M study, 1980; MDNR, 2009).



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 9). 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 Otsego Lake was measured on September 9, 2020 and ranged from 7.5-7.8 feet over the deep basins which are fair measurements.** Measurements were collected during calm conditions. This transparency indicates a moderate quantity of suspended particles and algae throughout the water column which would result in reduced 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. Secchi transparency has fluctuated throughout time and ranged from 9.0-14.8 feet (U of M study 1980; MDNR, 2008) and is likely correlated with lake use and wind and storm events as well as the concentrations of algae and solids.



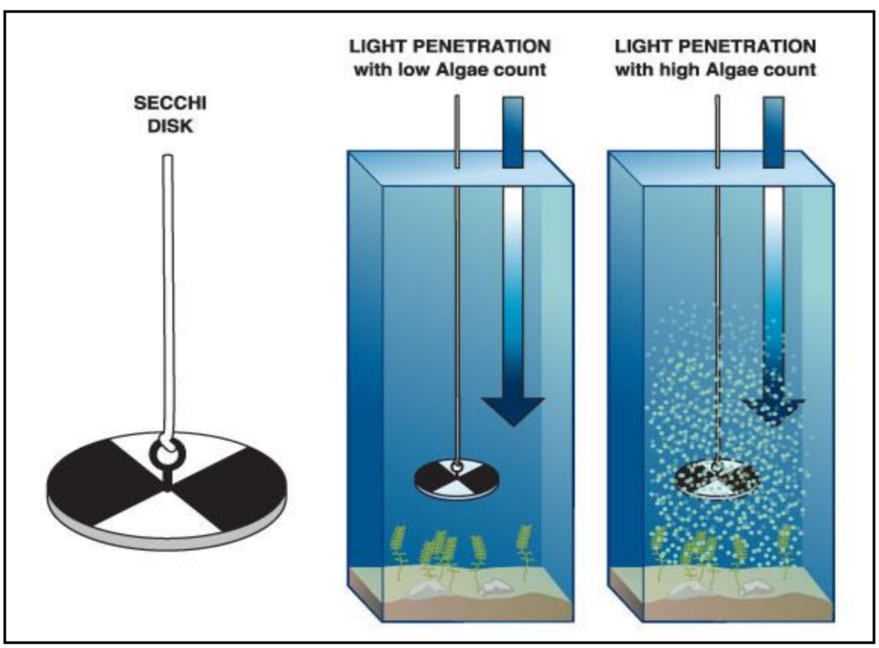


Figure 9. Measurement of water transparency with a Secchi disk.

4.1.11 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. A total of 20 lake sediment samples were collected with an Ekman hand dredge. 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.

The organic content in the Otsego Lake sediments ranged from 1.6-77% organic matter, which is variable with most samples containing over 50% organic matter. This indicates that the lake has overall highly organic sediments (Table 4). These may be attributed to inputs from bordering wetlands, erosion of shoreline soils, and previous lumber remnants from the logging industry.

Table 4. Otsego Lake sediment nutrients (% OM) collected from 20 locations throughout the lake on September 9, 2020.

Sediment Site	*% Organic Matter*
S1	63
S2	74
S3	68
S4	74
S5	62
S6	62
S7	11
S8	11
S9	72
S10	58
S11	65
S12	68
S13	72
S14	36
S15	36
S16	66
S17	65
S18	1.6
S19	55
S20	77

Table 5. Otsego Lake physical water quality parameter data collected in deep basin #1 (September 9, 2020).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	16.5	8.7	8.2	231	146	5.0	7.5
0.5	16.5	8.7	8.2	231	146	5.0	
1.0	16.5	8.6	8.1	225	141	6.0	
1.5	16.5	8.6	8.1	215	137	6.0	
2.0	16.5	8.4	8.1	215	137	6.0	
2.5	16.5	8.1	8.1	219	139	7.0	
3.0	16.5	7.9	8.1	224	141	6.0	
3.5	16.5	7.5	8.1	229	145	6.0	
4.0	16.5	7.0	8.1	232	147	6.0	
4.5	16.5	6.7	8.1	250	157	6.0	
5.0	16.4	6.5	8.1	250	157	7.0	
5.5	16.4	6.3	8.1	250	157	8.0	
6.0	16.4	6.3	8.1	250	157	8.0	

Table 6. Otsego Lake chemical water quality parameter data collected in deep basin #1 (September 9, 2020).

Depth (m)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	TSS (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.059	0.014	<0.010	0.059	<0.10	<0.10	<10	3.0	70
3.0	0.072	0.016	<0.010	0.072	<0.10	<0.10	16	--	70
6.0	0.076	0.017	<0.010	0.076	<0.10	<0.10	<10	--	68

Table 7. Otsego Lake physical water quality parameter data collected in deep basin #2 (September 9, 2020).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	16.5	8.9	8.3	215	137	5.0	7.5
0.5	16.5	8.9	8.3	215	137	5.0	
1.0	16.5	8.8	8.3	215	137	5.0	
1.5	16.5	8.7	8.3	226	144	5.0	
2.0	16.5	8.6	8.3	251	155	6.0	
2.5	16.5	7.2	8.2	335	204	6.0	
3.0	16.5	6.5	8.1	377	230	6.0	
3.5	16.5	5.7	8.1	408	248	7.0	

Table 8. Otsego Lake chemical water quality parameter data collected in deep basin #2 (September 9, 2020).

Depth (m)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	TSS (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.120	0.012	<0.010	0.120	<0.10	<0.10	24	2.0	69
1.5	0.066	0.012	<0.010	0.066	<0.10	<0.10	<10	--	69
3.0	0.072	0.015	0.015	0.072	<0.10	<0.10	<10	--	68

Table 9. Otsego Lake physical water quality parameter data collected in deep basin #3 (September 9, 2020).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	16.7	9.0	8.2	215	138	4.0	7.8
0.5	16.7	9.0	8.2	215	138	4.0	
1.0	16.7	8.9	8.2	215	138	5.0	
1.5	16.7	8.7	8.2	216	138	5.0	
2.0	16.7	8.7	8.2	218	139	6.0	
2.5	16.7	8.6	8.2	218	140	6.0	
3.0	16.6	8.6	8.2	219	140	7.0	
3.5	16.5	8.6	8.1	221	140	7.0	
4.0	16.5	8.1	8.1	221	141	7.0	

Table 10. Otsego Lake chemical water quality parameter data collected in deep basin #3 (September 9, 2020).

Depth (m)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	TSS (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.061	0.013	<0.010	0.061	<0.10	<0.10	10	3.0	69
2.0	0.062	0.015	<0.010	0.062	<0.10	<0.10	12	--	68
4.0	0.074	0.025	<0.010	0.074	<0.10	<0.10	28	--	68

4.2 Otsego 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. **Otsego Lake currently has a favorable quantity of submersed aquatic vegetation but there are still many areas of the lake that lack aquatic vegetation and thus preservation of native aquatic plants is important.**

A whole-lake scan of the aquatic vegetation biovolume in Otsego Lake was conducted on September 9, 2020 with a WAAS-enabled Lowrance HDS 9® GPS with variable frequency transducer. This data included 43,777 GPS data sounding points which were uploaded to a cloud software program to reveal maps that displayed depth contours, sediment hardness, and aquatic vegetation biovolume (Figure 10). On the biovolume 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 Naiad. For this reason, the scans are conducted in conjunction with a whole lake GPS Point Intercept survey to account for individual species identification of all aquatic plants in the lake. Table 11 shows the biovolume categories by plant cover on September 9, 2020.

The GPS Point Intercept survey is sometimes used with an Aquatic Vegetation Assessment Site (AVAS) Survey method to assess the relative abundance 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 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. Where shallow areas were present in the open waters of the lake, 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 GPS Point-Intercept/AVAS survey of Otsego Lake was conducted on September 9-11, 2020 and consisted of 1,304 sampling locations around the littoral zone (Figure 11). 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. The majority of the lake contained low-growing aquatic plants that were within the 0-5% cover and 5-20% cover categories (a total of 93.5% of the lake area).

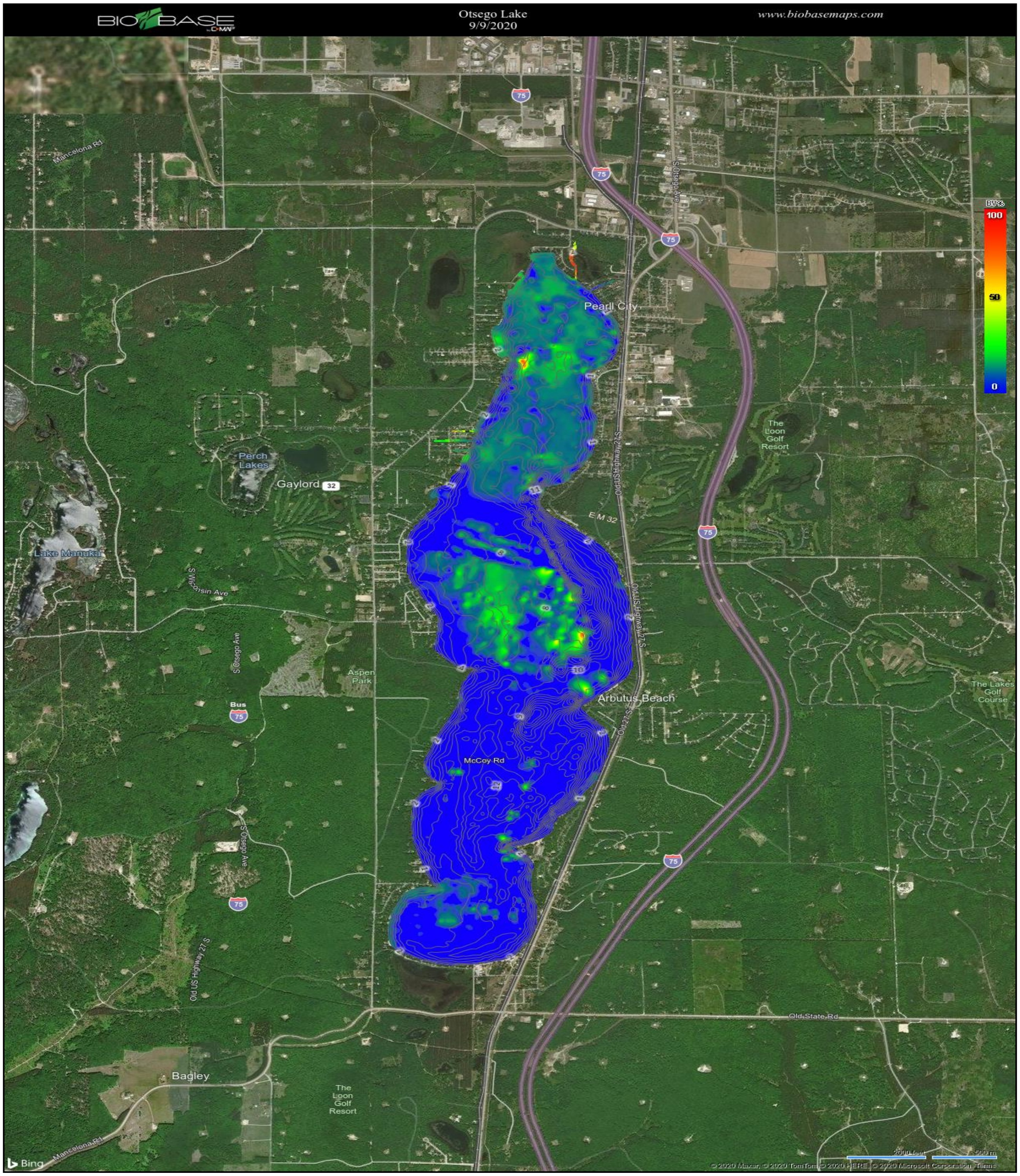


Figure 10. Aquatic plant biovolume of all aquatic plants in Otsego Lake, Otsego County, Michigan (September 9, 2020). Note: Red color denotes high-growing aquatic plants, green color denoted low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

Table 11. Otsego Lake aquatic vegetation biovolume by bottom cover category (relative cover on September 9, 2020).

Aquatic Vegetation Biovolume Cover Category	% Relative Cover of Bottom by Category
0-5%	79.8
5-20%	13.7
20-40%	3.8
40-60%	1.6
60-80%	0.5
>80%	0.7

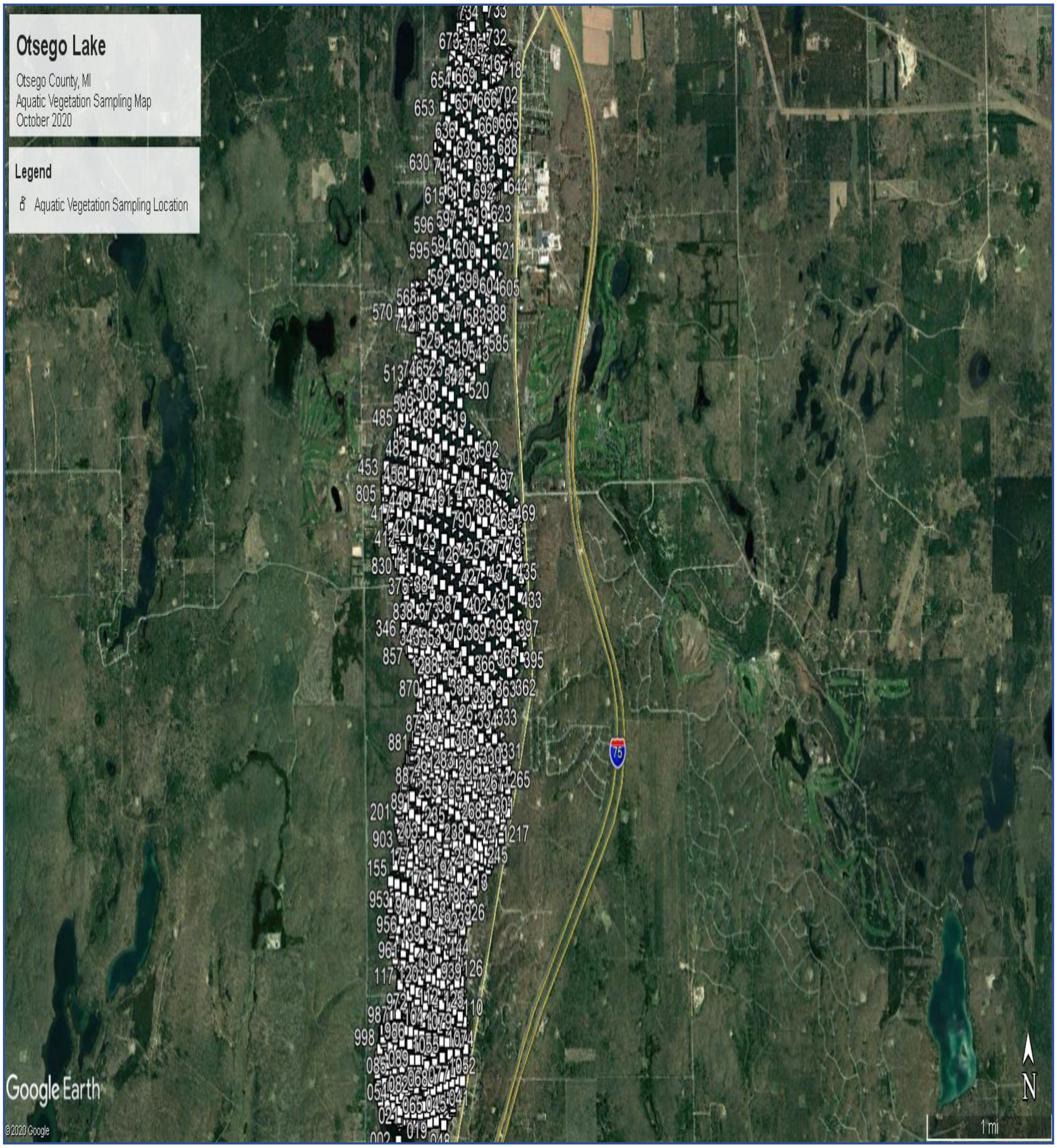


Figure 11. Aquatic vegetation sampling locations in Otsego Lake (September 9-11, 2020).

4.2.1 Otsego 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.

Otsego Lake contained 17 native submersed, 2 floating-leaved, and 5 emergent aquatic plant species, for a total of 24 native aquatic macrophyte species (Table 12). Relative abundance for each aquatic plant species is shown in Table 13. Photos of all native aquatic plants are shown below in Figures 12-35. The emergent macrophytes were found along the shoreline areas of the lake. The rare emergent Wild Rice (*Zizania aquatica*) was found in a few areas of the lake and should be protected. Additionally, the lower-growing species were found throughout the littoral zone and the higher-growing pondweeds were present in the deeper waters of the littoral zone where they were protected from wave action.

The dominant aquatic plants in the main part of the lake included the Clasping-leaf Pondweed (17.3% of the sampling locations), the macro alga Chara (6.4 % of the sampling locations), and the floating-leaved White Waterlily (4.4% of the sampling locations). The pondweeds grow tall in the water column and serve as excellent fish cover. Protection of all native aquatic plant species is critical for the lake ecosystem especially since the relative abundance is overall low for most native aquatic plant species.

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

Table 12. Otsego Lake native aquatic vascular plants and frequency (September 9-11, 2020).

Native Aquatic Plant Species Name	*Native Aquatic Plant Common Name*	*Growth Form*	*% Frequency*
Chara vulgaris	Muskgrass	Submersed	6.4
Stuckenia pectinatus	Sago Pondweed	Submersed	2.1
Potamogeton zosteriformis	Flat-stem Pondweed	Submersed	0.3
Potamogeton robbinsii	Fern-leaf Pondweed	Submersed	0.4
Potamogeton illinoensis	Illinois Pondweed	Submersed	0.8
Potamogeton richardsonii	Clasping-leaf Pondweed	Submersed	17.3
Potamogeton natans	Floating-leaf Pondweed	Submersed	0.8
Potamogeton praelongus	White-stem Pondweed	Submersed	0.3
Potamogeton amplifolius	Large-leaf Pondweed	Submersed	4.3
Myriophyllum sibiricum	Northern Watermilfoil	Submersed	1.5
Zosterella dubia	Water Stargrass	Submersed	0.3
Elodea canadensis	Common Waterweed	Submersed	1.4
Utricularia vulgaris	Bladderwort	Submersed	0.8
Utricularia minor	Mini Bladderwort	Submersed	0.2
Vallisneria americana	Wild Celery	Submersed	3.8
Najas guadalupensis	Southern Naiad	Submersed	1.1
Najas flexilis	Slender Naiad	Submersed	1.6
Nymphaea odorata	White Waterlily	Floating-Leaved	4.4
Nuphar advena	Yellow Waterlily	Floating-Leaved	0.1
Schoenoplectus acutus	Bulrushes	Emergent	1.4
Pontedaria cordata	Pickerelweed	Emergent	0.2
Typha latifolia	Cattails	Emergent	0.3
Eleocharis sp.	Spikerush	Emergent	0.2
Zizania aquatica	Wild Rice	Emergent	0.2

Table 13. Otsego Lake native aquatic vascular plants and relative abundance (September 9-11, 2020).

Native Aquatic Plant Species Name	*"a" Level*	*"b" Level*	*"c" Level*	*"d" Level*
Chara vulgaris	73	3	4	4
Stuckenia pectinatus	13	8	0	6
Potamogeton zosteriformis	0	2	0	2
Potamogeton robbinsii	1	3	0	1
Potamogeton illinoensis	4	6	0	0
Potamogeton richardsonii	117	46	21	41
Potamogeton natans	3	4	0	4
Potamogeton praelongus	4	0	0	0
Potamogeton amplifolius	43	11	2	0
Myriophyllum sibiricum	13	4	0	2
Zosterella dubia	0	4	0	0
Elodea canadensis	4	2	0	12
Utricularia vulgaris	1	10	0	0
Utricularia minor	1	1	0	0
Vallisneria americana	48	1	0	0
Najas guadalupensis	6	7	0	1
Najas flexilis	20	1	0	0
Nymphaea odorata	38	17	1	1
Nuphar advena	1	0	0	0
Schoenoplectus acutus	10	8	0	0
Pontedaria cordata	1	1	0	0
Typha latifolia	2	2	0	0
Eleocharis sp.	2	0	1	0
Zizania aquatica	2	1	0	0

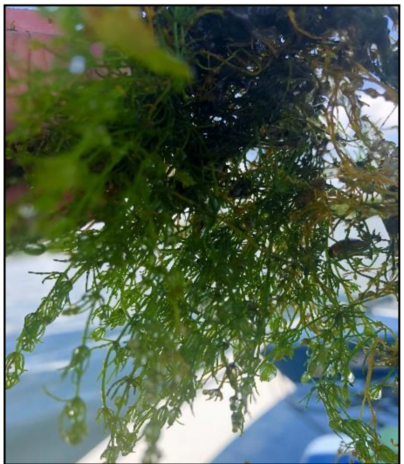


Figure 12. Chara (Muskgrass)

Figure 13. Sago Pondweed

Figure 14. Flat-stem Pondweed

Figure 15. Fern-leaf Pondweed

Figure 16. Illinois Pondweed

Figure 17. Clasping-Leaf Pondweed

Figure 18. Floating-leaf Pondweed

Figure 19. White-stem Pondweed

Figure 20. Large-leaf Pondweed

Figure 21. Northern Watermilfoil

Figure 22. Water Stargrass

Figure 23. Common Waterweed (Elodea)

Figure 24. Common Bladderwort

Figure 25. Mini Bladderwort

Figure 26. Wild Celery

Figure 27. Slender Naiad

Figure 28. Southern Naiad

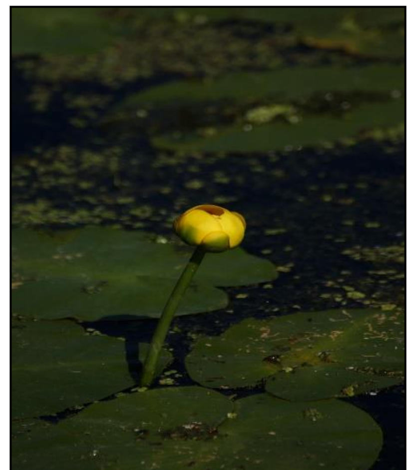


Figure 29. Yellow Waterlily

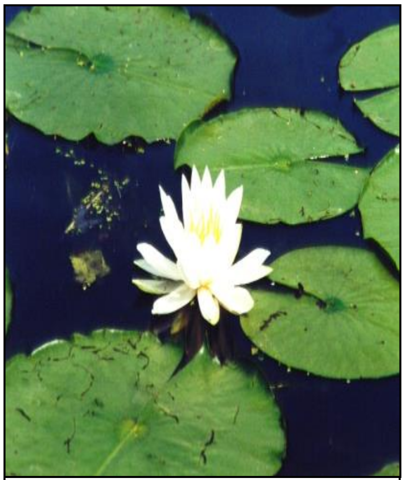


Figure 30. White Waterlily

Figure 31. Cattails

Figure 32. Spikerush

Figure 33. Pickerelweed

Figure 34. Bulrushes

Figure 35. Wild Rice

4.2.2 Otsego Lake Exotic Aquatic Macrophytes

Exotic aquatic plants (macrophytes) are not native to a particular site and 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 36) 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 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).

Approximately 12 acres of Eurasian Watermilfoil were found in Otsego Lake during the September 9-11, 2020 survey. An intensive management program is proposed below. Eurasian Watermilfoil growth in Otsego Lake is capable of producing dense surface canopies in shallow areas as well as in deeper waters due to the sometimes high light penetration. In addition, it could hybridize with the native northern watermilfoil and create a highly herbicide-resistant strain.

There were approximately 0.5 acres of invasive Curly-leaf Pondweed found in a few areas at the southern region of the lake. Curly-leaf Pondweed (*Potamogeton crispus*; Figure 37) is an exotic, submersed, rooted aquatic plant that was introduced into the United States in 1807 but was abundant by the early 1900's. It is easily distinguished from other native pondweeds by its wavy leaf margins. It grows early in the spring and as a result may prevent other favorable native aquatic species from germinating. The plant reproduces by the formation of fruiting structures called turions. It does not reproduce by fragmentation as invasive watermilfoil does; however, the turions may be deposited in the lake sediment and germinate in following seasons. Curly-leaf Pondweed is a pioneering aquatic plant species and specializes in colonizing disturbed habitats. It is highly invasive in aquatic ecosystems with low biodiversity and unique sediment characteristics.

Lastly, approximately 2.8 acres of invasive Starry Stonewort (Figure 38) were found only in the canals. Starry Stonewort (*Nitellopsis obtusa*) 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. Although it prefers alkaline waters, it can thrive in most clear waters and especially in shallow canals.

The species of invasive aquatic plants present, and relative abundance of each plant were recorded and then the amount of cover in the littoral zone was calculated. **Exotic aquatic plant species that were found in Otsego Lake on September 9-11, 2020 are shown in Table 14 below and discussions of key invasives also follow below.** Figures 39-42 display the locations where each invasive aquatic plant was located during the survey.

Figure 36. Hybrid Eurasian Watermilfoil plant with seed head and fragments.

Figure 37. Curly-leaf Pondweed found at the South end of Otsego Lake (September 9-11, 2020).

Figure 38. Starry Stonewort found in the Otsego Lake canals (September 9-11, 2020).

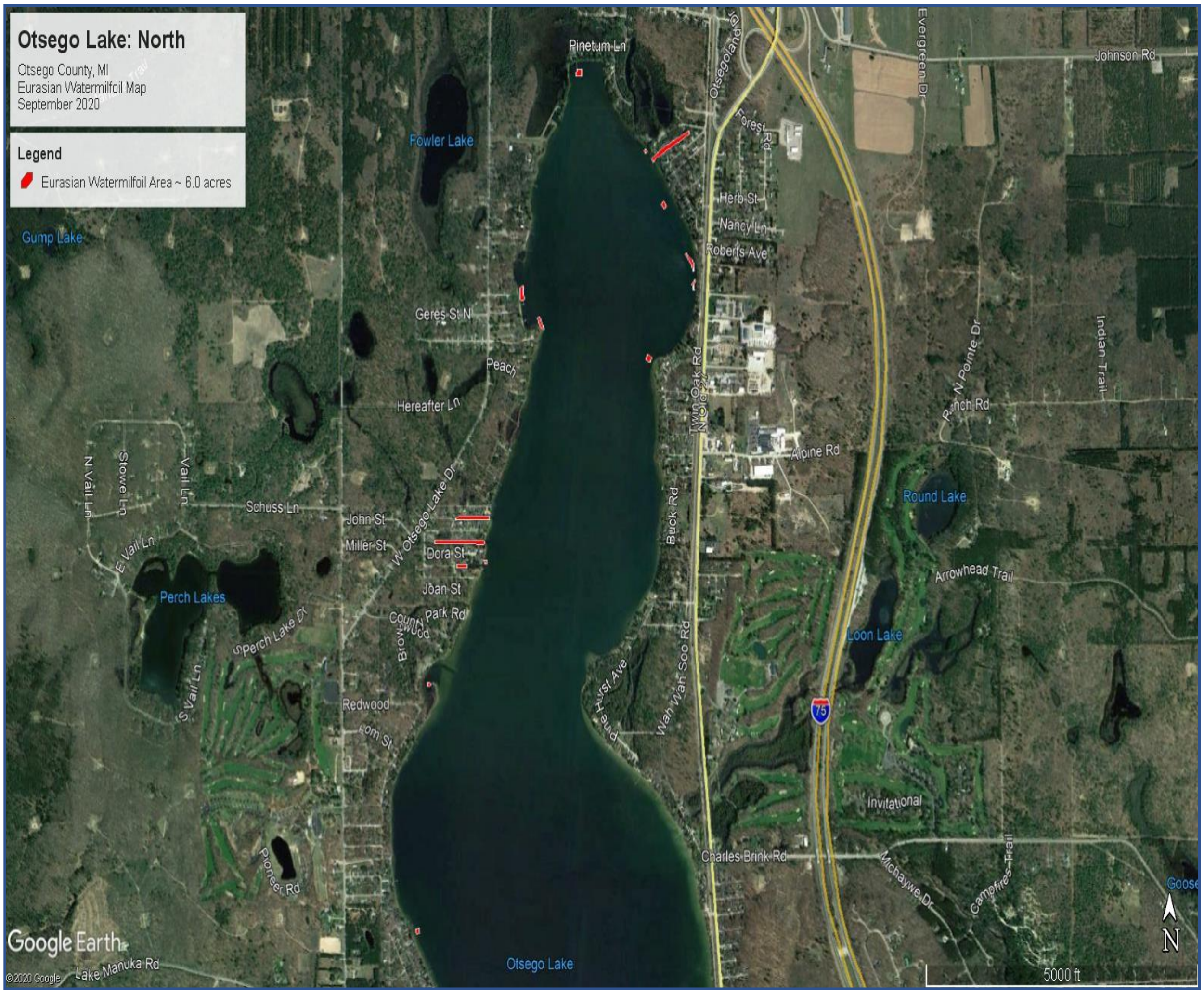


Figure 39. EWM distribution in Otsego Lake -North (September 9-11, 2020).

Figure 40. EWM distribution in Otsego Lake-South (September 9-11, 2020).

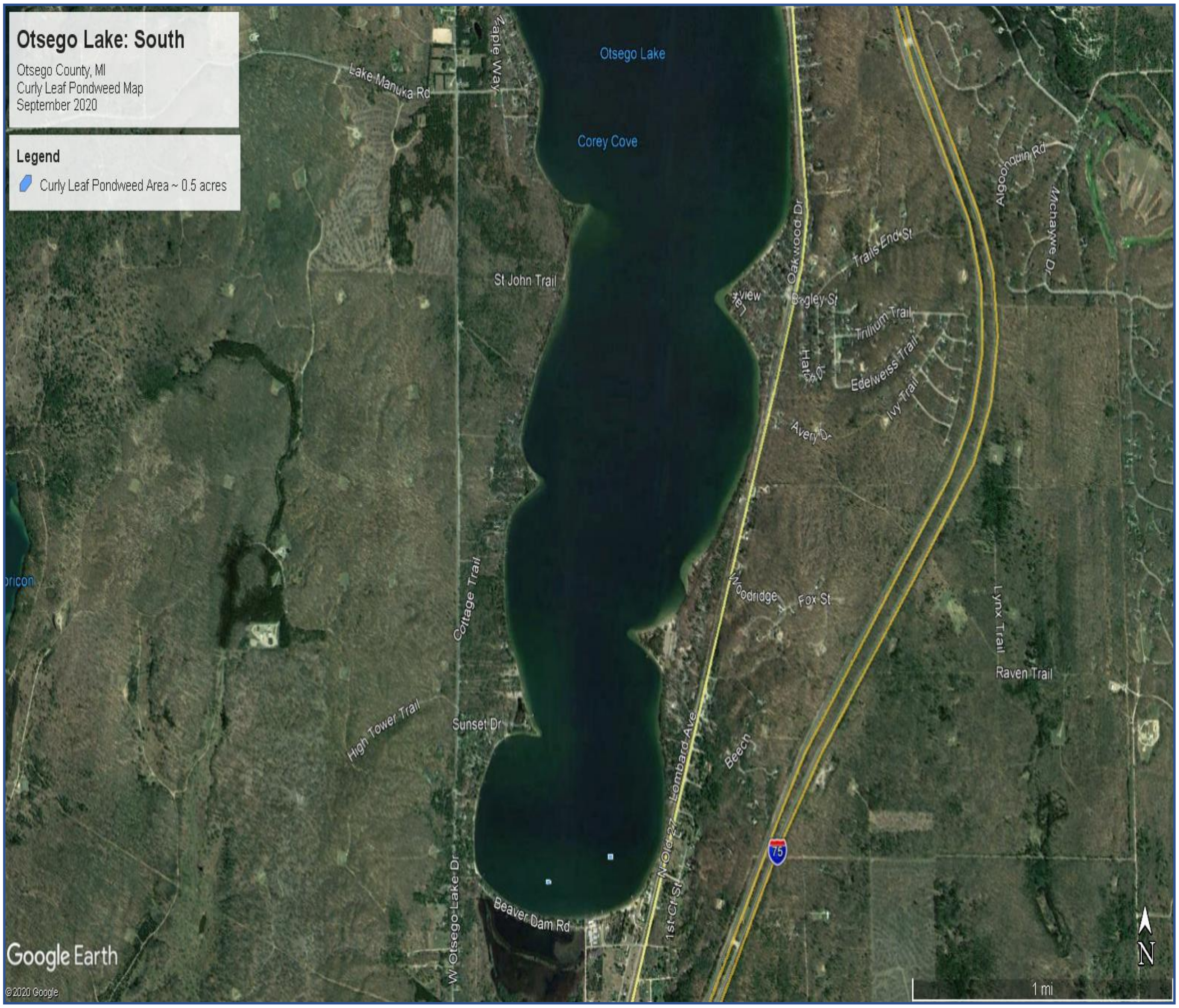


Figure 41. CLP distribution in Otsego Lake-South (September 9-11, 2020).

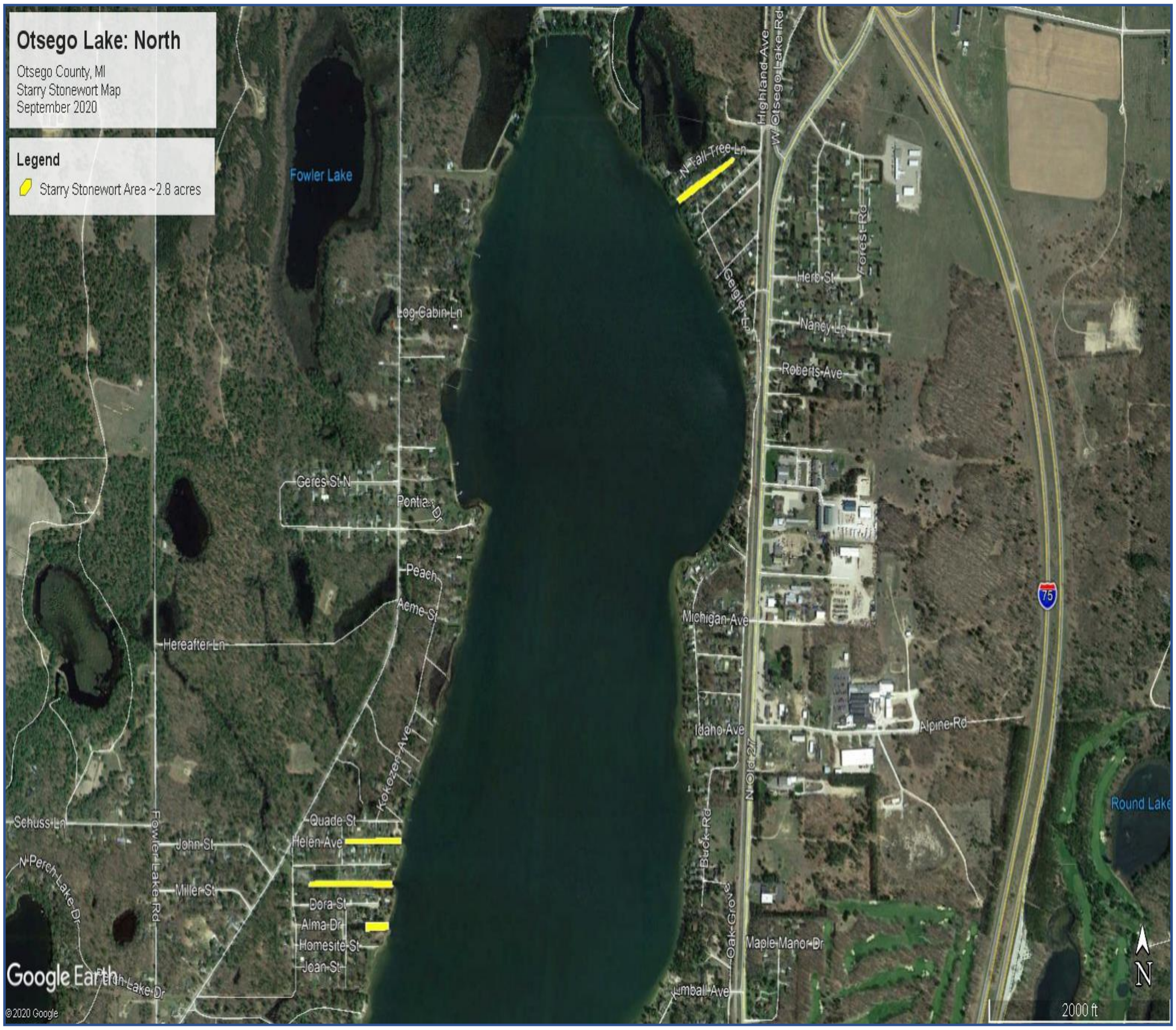


Figure 42. Starry Stonewort distribution in Otsego Lake Canals (September 9-11, 2020).

Table 14. Otsego Lake exotic aquatic plant species (September 9-11, 2020).

Exotic Aquatic Plant Species	*Exotic Aquatic Plant Common Name*	*Exotic Aquatic Plant Growth Habit*	*Abundance in Otsego Lake*
Myriophyllum spicatum	Eurasian Watermilfoil	Rooted, Submersed	~12 acres
Potamogeton crispus	Curly-leaf Pondweed	Rooted, Submersed	~0.5 acres
Nitellopsis obtusa	Starry Stonewort	Rooted, Submersed	~2.8 acres

4.3 Otsego Lake Food Chain: 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 (63 micrometer) with collection jar (Figure 43) was conducted by RLS scientists on September 9, 2020 in the 3 deep basins of Otsego Lake. The plankton net was left at depth for 30 seconds and then raised slowly to the surface at an approximate rate of 4 feet/second. The net was then raised above the lake surface and water was splashed on the outside of the net to dislodge any zooplankton from the net into the jar. The jar was then drained into a 125-mL bottle with a CO_2 tablet to anesthetize the zooplankton. The sample was then preserved with a 70% ethyl alcohol solution. Plankton sub-samples (in 1 ml aliquots) were analyzed under a Zeiss® dissection scope with the use of a Bogorov counting chamber. **Taxa were keyed to genus and are shown in Tables 15-17 below.**

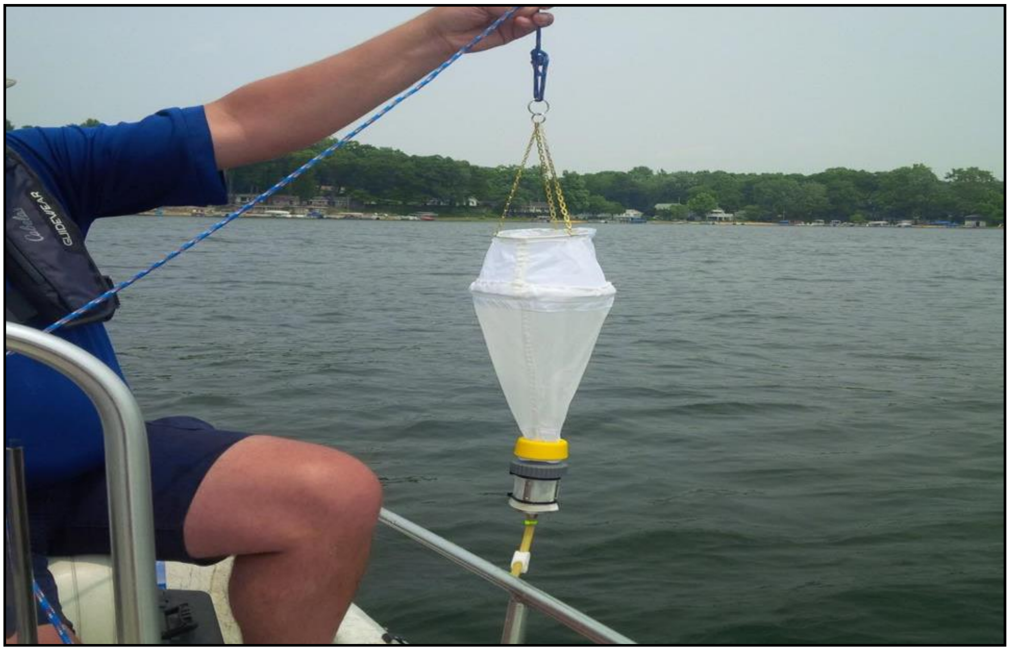


Figure 43. A zooplankton collection tow net.

Table 15. Zooplankton taxa and count data from Otsego Lake Deep Basin #1 (September 9, 2020).

Cladocerans	Count	Copepods	Count	Rotifers	Count
***Daphnia* sp.**	3	***Cyclops* sp.**	1	***Keratella* sp.**	6
***Chydorus* sp.**	9	***Nauplius* sp.**	2	***Tricocerca* sp.**	2
***Bosmina* sp.**	1	***Diaptomus* sp.**	6	***Asplanchna* sp.**	4

Table 16. Zooplankton taxa and count data from Otsego Lake Deep Basin #2 (September 9, 2020).

Cladocerans	Count	Copepods	Count	Rotifers	Count
***Daphnia* sp.**	5	***Cyclops* sp.**	3	***Keratella* sp.**	2
***Chydorus* sp.**	8	***Diaptomus* sp.**	6	***Asplanchna* sp.**	4
***Bosmina* sp.**	2	***Nauplius* sp.**	5	***Tricocerca* sp.**	5

Table 17. Zooplankton taxa and count data from Otsego Lake Area #3 (September 9, 2020).

Cladocerans	Count	Copepods	Count	Rotifers	Count
***Daphnia* sp.**	8	***Cyclops* sp.**	8	***Keratella* sp.**	5
***Bosmina* sp.**	2	***Nauplius* sp.**	4	***Asplanchna* sp.**	4
***Diaphanasoma* sp.**	2	***Diaptomus* sp.**	7	***Kellicottia* sp.**	1
***Chydorus* sp.**	4				
***Holopedium* sp.**	1				

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 algae 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 five locations (Figure 44) using an Ekman hand dredge sampler (Figure 45) on September 9, 2020 (Table 18). Macroinvertebrate samples were placed in small plastic buckets and analyzed in the RLS wet laboratory within 48 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 Otsego Lake sediment samples included midges (Chironomindae), Wheel snails (Planorbidae), Left-handed snails (Physidae), and Water mites. RLS did not find evidence of Zebra Mussels in the macroinvertebrate samples. Numerous finger-nail clams were also noted throughout the lake but were not collected in the samples. While all 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).

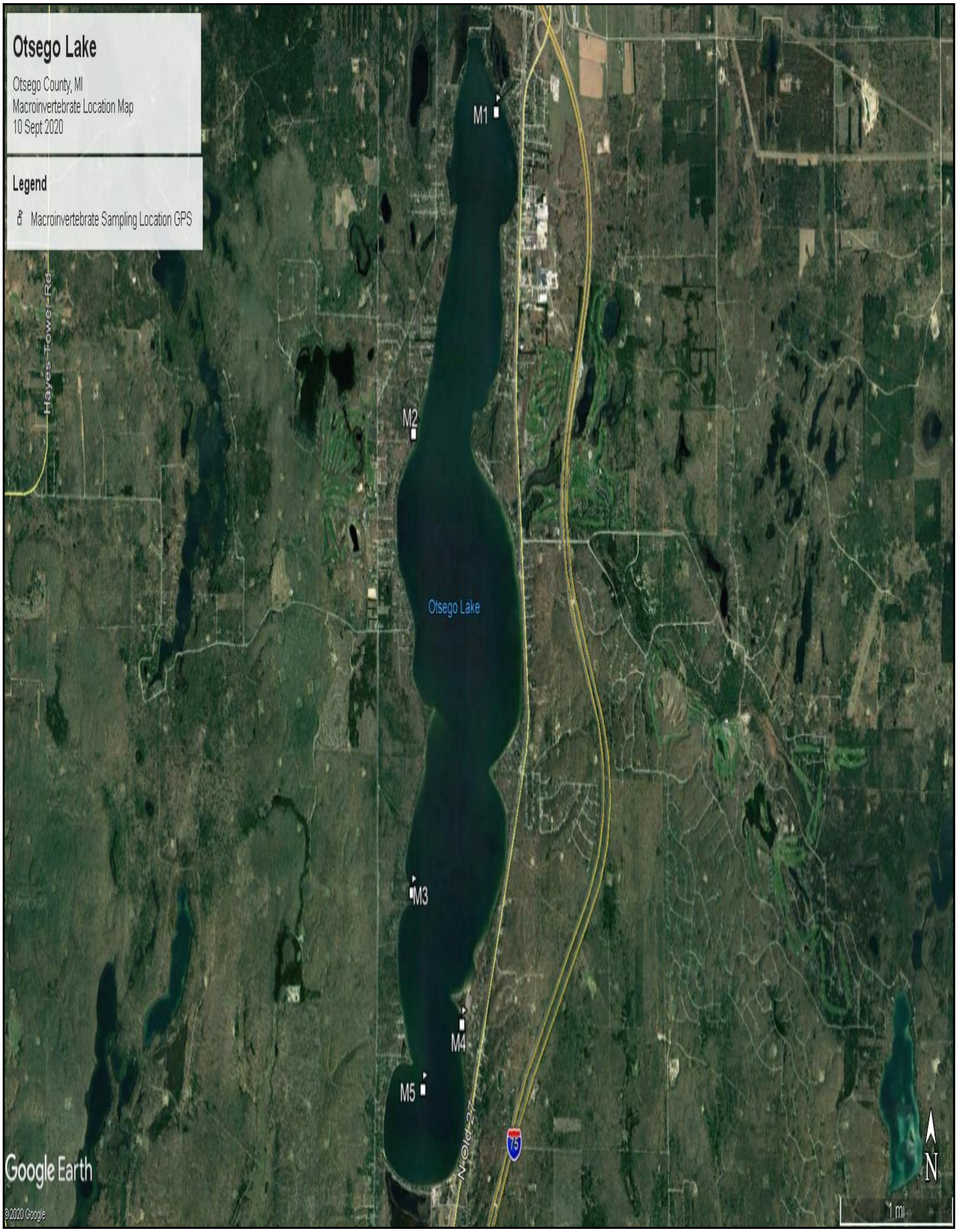


Figure 44. Sampling locations for macroinvertebrates in Otsego Lake (September 9, 2020).

Figure 45. An Ekman hand dredge for sampling lake sediments.

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 moderately low alkalinity of Otsego Lake could allow for some growth of Zebra Mussels; however, they need ample alkalinity (calcium carbonate) which is lower than desirable in Otsego Lake, for their shells to become prevalent throughout the lake.**

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 18. Macroinvertebrates found in Otsego Lake, Otsego County, MI (September 9, 2020).

Site 1	**Family**	**Genus or Species**	**Number**	**Common name**
	Chironomidae	*Chironomus* spp.	5	Midges
	Planorbidae	*Planorbis* sp.	2	Wheel snails
		Total	**7**	
Site 2	**Family**	**Genus**	**Number**	**Common name**
	Planorbidae	*Planorbis* sp.	2	Wheel snails
	Chironomidae	*Chironomus* sp.	8	Midges
	Physidae	*Physa* sp.	1	Left-handed snail
		Total	**11**	
Site 3	**Family**	**Genus**	**Number**	**Common name**
	Chironomidae	*Chironomus* spp.	6	Midges
	Hydrachnidae	*Hydrachnidia* sp.	1	Water mites
		Total	**7**	
Site 4	**Family**	**Genus**	**Number**	**Common name**
	Chironomidae	*Chironomus* spp.	6	Midges
		Total	**6**	
Site 5	**Family**	**Genus**	**Number**	**Common Name**
	Chironomidae	*Chironomus* spp.	4	Midges
	Hydrachnidae	*Hydrachnidia* sp.	2	Water mites
		Total	**6**	

4.4 Otsego Lake Fishery

Currently, Otsego Lake has healthy populations of panfish, Walleye, Smallmouth Bass, Northern Pike and many others. The MDNR (Michigan Department of Natural Resources) has an extensive stocking history in Otsego Lake that includes Walleye, Northern Pike, Tiger Muskellunge, and Lake Sturgeon for the years indicated in Table 19 below. The table displays the stocking history with the quantity and average length of fish stocked during each year. Recommendations for fishery habitat improvement are offered in Section 5.2.2 below.

Table 19. Fish stocking history in Otsego Lake (MDNR, 1953-2019).

Year(s)	Fish Stocked	# Fish Stocked	Average Length Range (inches)
1953-4; 1959; 1960-1	Northern Pike	2,592	NA
1979	Tiger Muskellunge	6,000	5.2
1980	--	--	--
1981	Northern Pike; Tiger Muskellunge	1,000; 5,000	2.7; 6.7
1982	Lake Sturgeon; Northern Pike	235; 400	NA; 4.4
1983	Tiger Muskellunge; Lake Sturgeon; Tiger Muskellunge	3,000; 834; 3,000	6.9; NA; 6.9
1984	Northern Pike	60,000	2.0
1985	Tiger Muskellunge; Northern Pike; Tiger Muskellunge	3,497; 90,000; 3,496	10.8; 2.0; 10.8
1986	Northern Pike	100,000	2.0
1987	Tiger Muskellunge; Northern Pike; Tiger Muskellunge	3,000;10,000; 3,000	9.9;2.0; 9.9
1988	Northern Pike	18,000	2.0
1989	Tiger Muskellunge; Northern Pike; Tiger Muskellunge	3,025; 20,000; 4,640	8.7; 2.0; 8.6
1990	Northern Pike	60,000	2.0
1991	Northern Pike; Walleye; Tiger Muskellunge; Lake Sturgeon; Tiger Muskellunge	50,000; 2,000,000; 4,000; 7,062; 4,000	2.5; 0.2; 9.3; 2.7; 9.3
1992	Northern Pike; Lake Sturgeon; Walleye; Walleye	40,000; 2,751; 2,000,000; 2,000	2.5; 5.4; 0.2; 5
1993	Northern Pike; Lake Sturgeon; Walleye; Walleye	51,000; 1,998; 1,000,000; 300,000	3.0; 4.9; 3.9; 0.2; 0.2
1994	Northern Pike; Walleye	60,000; 36,900	3.0; 1.5-1.9
1995	Northern Pike; Walleye; Walleye	30,000; 1,650,000; 3,650,000	2.5; 0.4; 0.4
1996	Northern Pike	30,000	3.0
1997	Walleye; Walleye	2,000,000	0.4; 0.4

1998	Walleye	2,000,000	0.1
1999	Northern Pike; Walleye; Walleye	15,000; 43,050; 28,170	3.0; 2.1; 3.6
2000	Northern Pike; Walleye; Walleye	1,500; 750,000; 1,000,000	3.0; 0.4; 0.1
2001	Northern Pike	800	2.2
2002	Walleye; Walleye; Walleye; Walleye; Lake Sturgeon; Lake Sturgeon	71,500; 5,863; 38,250; 71,500; 26; 500	1.2; 1.4; 1.6; 1.2; 19.9; 7.2
2003	Northern Pike; Walleye	3,000; 52,426	3.0; 1.4
2004	Walleye; Walleye; Walleye; Walleye	13,000; 15,500; 6,000; 17,000	1.3; 1.3; 1.7; 1.8
2005	Walleye; Walleye	2,125; 14,600	2.2; 1.7
2006	Lake Sturgeon; Muskellunge; Walleye	180; 20,431; 2,954,100	3.2; 2.6; 0.1
2007	Northern Pike	5,000	2.0
2008	Northern Pike; Muskellunge	50,000; 6,990	2.0; 9.7
2009	Northern Pike	6,000	2.0
2010	Northern Pike	4,662	2.8
2011	Northern Pike; Walleye; Walleye	2,592; 38,717; 30,308	3.0; 1.5; 1.9
2012	Northern Pike; Muskellunge	7,500; 3,951	2.5; 9.8
2013	Northern Pike; Lake Sturgeon; Muskellunge; Walleye; Walleye	2,500; 3,585; 2,958; 6,914; 68,818	2.3; 1.2; 8.6; 1.5; 2.1
2014	Lake Sturgeon; Lake Sturgeon; Walleye	198; 2,102; 64,316	15.8; 1.2; 1.4
2015	Lake Sturgeon; Lake Sturgeon; Lake Sturgeon; Lake Sturgeon; Muskellunge	514; 149; 17; 349; 2,952	4.5; 5.9; 3.5; 6.9; 9.6
2016	Lake Sturgeon; Lake Sturgeon; Walleye	21; 413; 52,580	7.8; 2.0; 1.4
2017	Walleye; Walleye	2,300,000; 855,000	0.1; 0.2
2018	Lake Sturgeon; Lake Sturgeon; Lake Sturgeon; Muskellunge; Walleye	244; 189; 3; 2,958; 111,723	2.1; 6.4; 18.9; 9.3; 1.2
2019	Lake Sturgeon; Lake Sturgeon	50; 1	4.9-5.0; 18.9

5.0 OTSEGO LAKE MANAGEMENT METHODS

This section offers methods to reduce the transport as well as the quantity of invasive aquatic plants. Aquatic invasive species (AIS) prevention methods are discussed below along with justifications for specific recommendations.

5.1 Otsego Lake Aquatic Plant Management

The management of submersed nuisance invasive aquatic plants is necessary in Otsego 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. Protection of native aquatic plant species (especially the low growing native plants) in Otsego Lake to provide for a healthier lake is recommended to maintain and improve lake health. All aquatic vegetation should be managed with solutions that will yield the longest-term results. A detailed Early Detection Rapid Response Protocol is recommended for Otsego Lake for each invasive species and to prevent others from entering the lake or becoming problematic. The following sections detail invasive species prevention and community education.

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 Otsego Lake is awareness and education (Figures 46 and 47). The exotic species of concern have been listed in this report. Other exotic species on the move could be introduced to the riparians around Otsego Lake through the use of a professionally developed educational newsletter or through public workshops on the health of the Otsego Lake ecosystem.

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.

Boat washing stations offer opportunities for collaborative efforts between lake groups, the MDNR, and EGLE. Figures 48-49 demonstrate the use of a boat washing station to prevent the spread of invasives into lakes with public access which is applicable to Otsego Lake.

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

Recently, MSU partnered with EGLE to study the various forms of boat washing stations (including the innovative CD3 units) on lakes to analyze effectiveness of invasive removal, behavior patterns and preference for use, and short and long-term cost effectiveness of each system. This will assist in the placement of specific types of wash stations around specific portals of entry around lakes. Boat washing stations and invasive species prevention signs are recommended at all public entry sites where practical, especially since enforcement is not required and is lacking.

Figure 46. An aquatic invasive prevention sign for public access sites.

Figure 47. An aquatic hitchhiker (milfoil) on a boat trailer.

Figure 48. A public boat washing station on Higgins Lake, Michigan.

Figure 49. A responsible boat owner using a boat washing station.

Zebra Mussels and Quagga Mussels

Although these were not found by RLS in September, 2020, proper protocols for their prevention are offered below.

Zebra Mussels (*Dreissena polymorpha*; Figure 50) 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).

Quagga Mussels (*Dreissena bugensis;* Figure 50) are native the Ukraine and have created an economical burden to the Great Lakes fishery due to their great ability to alter the planktonic food chain in the lakes. They currently outrank the Zebra Mussels in abundance in the Great Lakes and are capable of filtering larger quantities of water and therefore assimilating more plankton. These mussels were shown to be highly selective in choosing naked flagellates such as Rhodomonas as well as larger diatoms (NOAA research; noaa.gov).

The recommended prevention protocols for further introduction of mussels includes steam-washing all boats, boat trailers, jet-skis, and floaters prior to placing them into Otsego 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 Otsego 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.

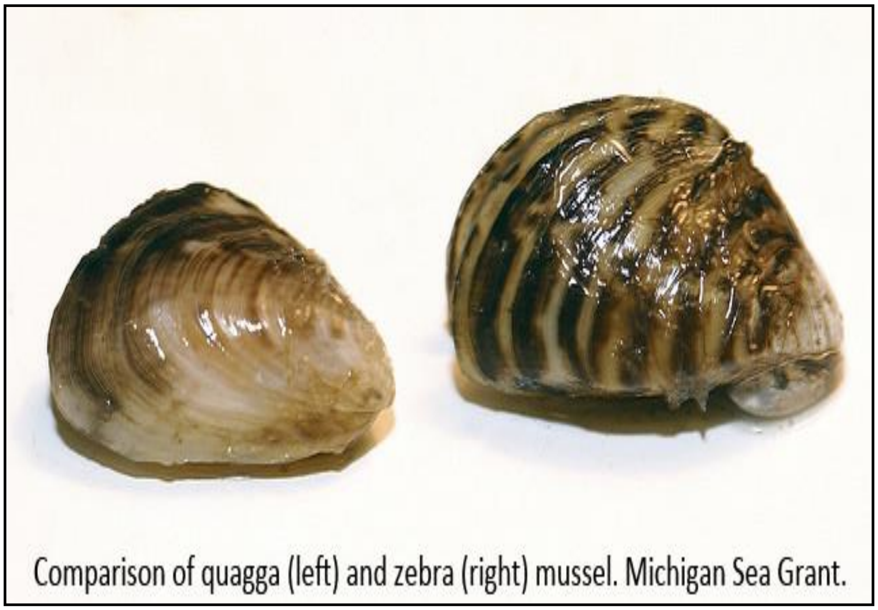


Figure 50. Zebra Mussels and Quagga Mussels (Photo courtesy of Michigan Sea Grant).

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 51) and *Trapa natans* (Water Chestnut; Figure 52). *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 invasive plant.

Figure 51. Hydrilla from a Florida lake.

Figure 52. 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 Environment, Great Lakes, and Energy (EGLE) and requires a permit. Aquatic herbicides are generally applied via an airboat or skiff equipped with mixing tanks and drop hoses (Figure 53). 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. The permit also requires notification of the Loon protection program if nesting Loons are present on the lake. 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 Otsego Lake, the use of contact herbicides (such as diquat and flumioxazin) would be highly discouraged for native aquatic plants but may be used for curly-leaf pondweed as there is currently no systemic herbicides for Curly-leaf Pondweed. Contact herbicides offer short-term control of plants since they do not kill plant roots.**

Algaecides such as copper sulfate should also be avoided on Otsego Lake as copper accumulates in lake sediments and bio-persists over time. It is harmful to sediment biota and can be released into the water column with sediment perturbations. There is also evidence that over-use of algaecides can exacerbate blue-green algae when blooms are present. The reduction of algae usually depends upon long-term nutrient reductions from the immediate watershed (septic tanks) and lake shoreline erosion.

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. **Due to the scattered abundance of milfoil in Otsego Lake (given its size), the use of fluridone is not recommended. The use of other systemic herbicides such as triclopyr or 2,4-D that may be used for spot-treatments are recommended.**

Figure 53. A boat used to apply aquatic herbicides in inland lakes.

5.1.3 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 54). 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. Additionally, it is often not practical for very large lakes, given the long transfer times to offload harvested vegetation. Due to the distribution of invasives in open water areas, mechanical harvesting is not recommended or needed for Otsego Lake.

Figure 54. A mechanical harvester used to remove aquatic plants.

5.1.4 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 55) or Weed Rollers (Figure 56) 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 Otsego Lake and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth if it becomes prevalent in future years.

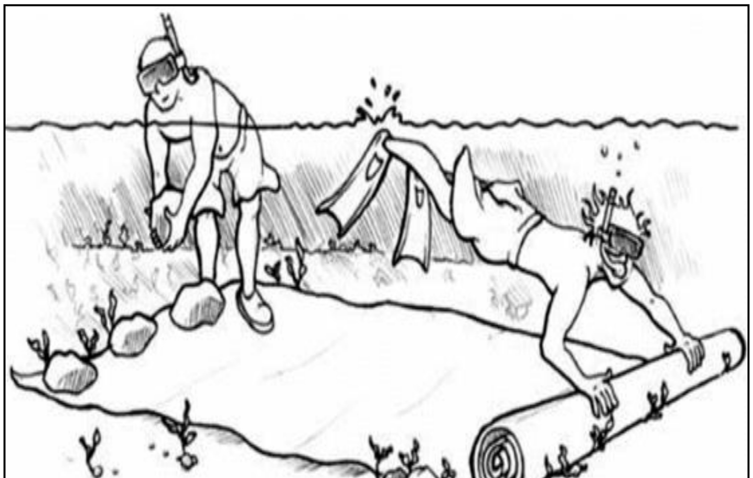


Figure 55. A Benthic Barrier. ***Photo courtesy of Cornell Cooperative Extension.***

Figure 56. A Weed Roller.

5.1.5 Diver Assisted Suction Harvesting (DASH)

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 57) 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 costly on a large scale and so it used on a spot-removal basis or in small areas. It has been used to remove nuisance invasive aquatic vegetation in inland lakes and requires a joint permit with EGLE and the U.S. Army Corps of Engineers (USACE).

Because this activity may cause re-suspension of sediments (Nayar et *al*., 2007), increased turbidity and reduced clarity of the water can occur. Permitting requirements include the use of a turbidity curtain that reduce the transport of solids to locations outside of treatment areas and also help define areas where intensive aquatic vegetation removal efforts are being implemented. **This method may be feasible for small areas of milfoil removal once herbicides have reduced the cover, or small areas that become resistant to aquatic herbicides. It could also be used for the Starry Stonewort in the canals.**

Figure 57. A DASH boat used in a lake for aquatic plant removal.

5.1.6 Ultraviolet (UV) Light:

Short-wave electromagnetic radiation light (UV-C) damages the DNA and cellular structure of aquatic plants. This method was used in 2017 in Lake Tahoe in California and Nevada, USA. It reduced aquatic plant percent cover, mean aquatic plant height, and aquatic plant density and was used to reduce invasive watermilfoil and curly-leaf pondweed as an alternative to chemical herbicides. Effective control may require multiple UV treatments and eradication may not be possible, but this is the case for most management methods. This technology requires very clear water to be effective, as treatment areas should be closely monitored as the boat moves over individual weed beds. Treatment is also more effective when the plant beds are not yet at mature height and are lower in density. **This treatment would require a unique EGLE permit and would also possibly damage other preferred native aquatic plants. Because of these challenges, it is not recommended at this time. An experimental area could be considered in the future if EGLE and MDNR approve of such an experiment.**

5.2 Otsego Lake Water Quality Improvements

In addition to lake improvement methods that improve the aquatic plant communities through prevention and control of invasive aquatic plant species, there are methods to improve the water quality within the lake basin. A discussion on septic systems and their impacts on inland waters follows below in Section 5.2.1. **In lakes such as Otsego Lake where a lake-wide sewer system may not be practical, adherence to proper septic tank and drain field maintenance is strongly recommended.**

5.2.1 Septic System and Drain Field Maintenance

Nutrient pollution of inland lakes from septic systems and other land use activities is not a modern realization and has been known for multiple decades. The problem is also not unique to Michigan Lakes and was first described in Montreal Canada by Lesauteur (1968) who noticed that summer cottages were having negative impacts on many water bodies. He further noted that a broader policy was needed to garner control of these systems because they were becoming more common over time. Many of our inland lakes are in rural areas and thus sewer systems or other centralized wastewater collection methods are not practical. Thus, septic systems have been common in those areas since development on inland lakes began. Septic systems have four main components consisting of a pipe from the residence, a septic tank or reservoir, a drainage field, and the surrounding soils Figure 58).

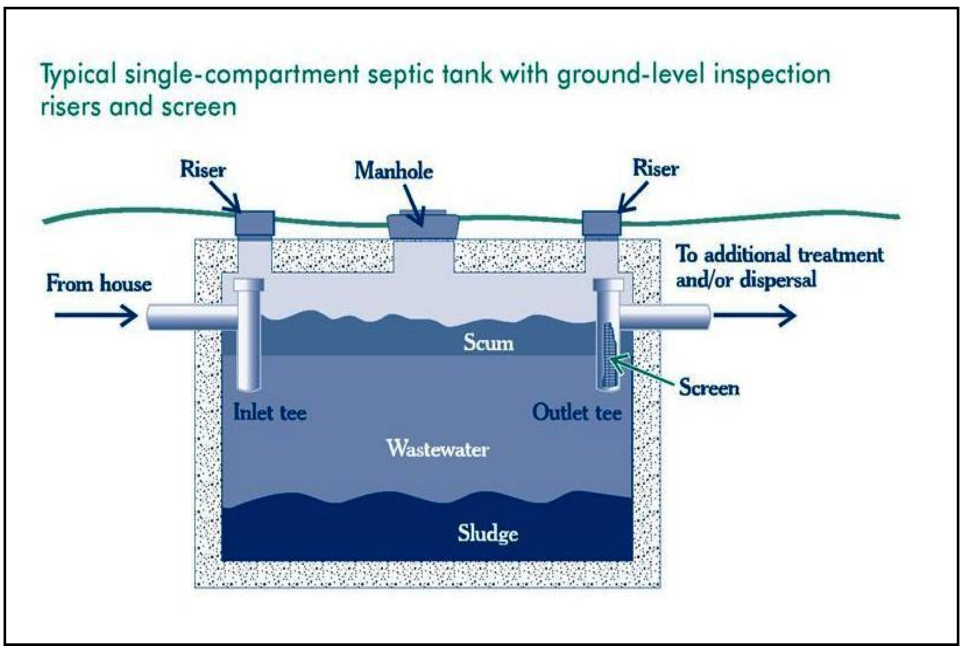


Figure 58. Diagram of essential septic tank components (US EPA).

On ideal soil types, microbes in the soil are able to decompose nutrients and reduce the probability of groundwater contamination. However, many lakes in Michigan contain soils that are not suitable for septic systems. **Such soils that are not very permeable, prone to saturation or ponding, and have mucks exist around many lakes and currently have properties with septic systems. There are many areas around Otsego Lake that have mucky soils, and this was discussed in the soil type Section 3.3 of this report.**

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

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

Spence-Cheruvelil and Soranno (2008) studied 54 inland lakes in Michigan and found that total aquatic plant cover (including submersed plants) was most related to secchi depth and mean depth. However, they also determined that man-made land use activities are also predictors of aquatic plant cover since such variables can also influence these patterns of growth. Prior to changes in offshore aquatic plant communities, an additional indicator of land use impacts on lake water quality in oligotrophic lakes (lakes that are low in nutrients) includes changes in periphytic algae associated with development nearshore. **Such algae can determine impacts of septic leachate before other more noticeable changes offshore are found (Rosenberger et *al*., 2008). The green filamentous algae, *Cladophora* was noted along many areas of the Otsego Lake shoreline and is often related to septic nutrients.**

Development in the watershed also may influence the relative species abundance of individual aquatic plant species. Sass et *al*. (2010) found that lakes associated with rigorous development in surrounding watersheds had more invasive species and less native aquatic plant diversity than less developed lakes. Thus, land use activities such as failing septic systems may not only affect aquatic plant biomass and algal biomass, but also the composition and species richness of aquatic plant communities.

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

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

The utilization of septic systems by riparians is still quite common around inland lake shorelines. A basic septic system typically consists of a pipe leading from the home to the septic tank, the septic tank itself, the drain field, and the soil. The tank is usually an impermeable substance such as concrete or polyethylene and delivers the waste from the home to the drain field. The sludge settles out at the tank bottom and the oils and buoyant materials float to the surface. Ultimately the drain field receives the contents of the septic tank and disperses the materials into the surrounding soils. The problem arises when this material enters the zone of water near the water table and gradually seeps into the lake bottom.

This phenomenon has been noted by many scholars on inland waterways as it contributes sizeable loads of nutrients and pathogens to lake water. Lakebed seepage is highly dependent upon water table characteristics such as slope (Winter 1981).

The higher the rainfall, the more likely seepage will occur and allow groundwater nutrients to enter waterways—this is especially significant for a seepage lake such as Otsego Lake. Seepage velocities will different greatly among sites and thus failing septic systems will have varying impacts on the water quality of specific lakes**. Lee (1977) studied seepage in lake systems and found that seepage occurs as far as 80 meters from the shore. This finding may help explain the observed increases in submersed aquatic plant and algae growth near areas with abundant septic tank systems that may not be adequately maintained.** Loeb and Goldman (1978) found that groundwater contributes approximately 44% of the total soluble reactive phosphorus (SRP) and 49% of total nitrates to Lake Tahoe from the Ward Valley watershed. Additionally, Canter (1981) determined that man-made (anthropogenic) activities such as the use of septic systems can greatly contribute nutrients to groundwater.

5.2.2 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 on many lakes. 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. Eventually, the water gets turbid 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 the conversion of 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.

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 currents clear 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 while 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 and 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 inhabit Lake Mendota, Wisconsin has changed since 1900. A diverse assemblage that included several environmentally sensitive species has been replaced by an assemblage dominated by a single species, the Brook Silverside, whose abundance fluctuates dramatically from year to year. Their decline was associated with the invasion and explosive increase in abundance of an exotic macrophyte, 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 with shorelines graded, or altered with riprap, sand blankets, or sea walls.

Ultimately, suitability for fish spawning habitat had decreased. **This is why preservation of the emergent and floating-leaved aquatic plants in and around Otsego Lake are so important.**

The largest factors affecting the fishery habitat of Otsego Lake include shoreline erosion and reductions in nearshore emergent vegetation.

5.3 Otsego Lake Watershed Management

Protection of the lake watershed is imperative for long-term improvement of water quality in Otsego 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 Otsego Lake Drainage System and Maintenance

Although there is not a formal outlet for Otsego Lake, there is a constructed "artificial drain" that was created in 1972 after Circuit Court Case No. 136-2. The drain was created to normalize excessively high lake levels and connects the lake to the North Branch of the Au Sable River. It is located at the eastern shore of the lake and is regulated by the Otsego Country Road Commission to maintain an ideal lake level of 1,273.5 feet. The drain may be open for a maximum of 90 days if needed from the period of March 15 to June 5 of each year. This structure should be regularly inspected in case it is needed for periods of flooding such as those that occurred in 2014. Periods of intense rain and/or snow are likely to create higher than acceptable water levels which can further the erosion issues around the lake and also impact septic drain fields and individual yards and lakefront properties.

5.3.2 Otsego Lake Erosion and Sediment Control

In addition to the proposed protection of native aquatic plants and control of invasives in Otsego 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%)
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 native genotype plants (those native to Otsego 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) All wetland areas around Otsego 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 rip-rap (stone, rock), rather than metal or concrete, due to the fact that rip-rap offers a more favorable habitat for lakeshore organisms, which are critical to the ecological balance of the lake ecosystem. Rip-rap should be installed in front of areas where metal seawalls are currently in use. The rip-rap should extend into the water to create a presence of microhabitats for enhanced biodiversity of the aquatic organisms within Otsego Lake. Planting of emergent aquatic plants around Otsego Lake may offer stabilization of shoreline sediments and assist in protection of areas prone to erosion.

Erosion Control/Shoreline Survey:

RLS conducted a lake-wide shoreline erosion survey around the Otsego Lake shoreline on September 9, 2020 (Table 20). Seventy-two areas with impaired erosion conditions were observed within Otsego Lake's shoreline that are typical of recreational lakes (Figures 59-60). Erosion was overall moderate to slightly severe. This erosion negatively impacts numerous resources such as public use areas through water quality degradation from the soils eroding into the lake, fisheries and wildlife habitat being diminished from turbidity, and a lack of suitable vegetative cover.

The fetch in Otsego Lake, which is the distance across the greatest length of the lake to produce a wind-driven wave, is approximately 4.6 miles which can lead to waves with heights exceeding 3.0 feet. Shoreline bathymetry also plays a big part in determining the degree of erosion at a particular shoreline site. Sites with straight shorelines and 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.

Additional steps for evaluating all areas around the lake with erosion could include a detailed assessment in order to prioritize sites based on severity, feasibility, costs, landowner willingness, and other factors. There is a wide range of erosion control methods that can be used in a cost-effective manner to address the shoreline erosion problems. Higher priority should go to sites where structures or amenities are threatened.

Table 20. Areas of erosion or lack of shoreline stabilization around the shoreline of Otsego Lake (September 9, 2020).

Location	Description of Impaired Shoreline Erosion
6	Point just north of boat launch low herbaceous vegetation
7	500-600 feet sand beach at state park
8	120 feet of landscape block retaining wall
9	State Park 2’ foot tall 100 foot long sand bank
10	State Park near ramp 150’ sand beach 15” high.
11	State Park 2 ‘tall, 400’ landscaping block retaining wall
12	Seawall
13	60’ sand erosion 3-4’ tall
14	60’ rock riprap private stabilization
15	300 foot sand beach
16	80’ sand beach with 2’ field stone retaining wall
17	Pine St. road end, native grass & shrubs
18	Long areas of sand beach ~40’ wide, which under windy conditions will contribute sand erosion
19	20’ bank 10’ high at Township Park
20	120’ wood retaining wall 8 to 10” high
21	100’ 6’ high wood retaining wall with sandbags at base
22	75’ unprotected area showing erosion
23	40’ plastic tarp covering potentially falling seawall
24	150’ of sand unprotected beach showing signs of erosion
25	300’ sand beach with 6” to 8” erosion line
26	Road end with 30’ sand to water.
27	Road end (Michigan Ave), eroding beach 30’ long and 3’ high

28	Road end (Stonewood St), failing concrete seawall. Road end is 3’ higher than lake effecting seawall
29	Undercut grass bank in canal.
30	Dock put in sand bank 30’ long 3 foot high.
31	Wild rice at canal entrance
32	Undercut white pine and sand beach 3’ high
33	80’ undercut bank
34	Water control and overflow structure for marsh. (Old pike fish hatchery?)
35	40’ apparent ice push damage
36	80’ sand area, possible seaplane launch
37	200’ undercut grass
38	800’ unprotected sand shoreline, slow erosion
39	300’ long 18” tall sand beach
40	100’ beach area 2’ tall signs of sheet erosion
41	Rock riprap failing seawall 60’
42	Launch site with wood seawall and cover
43	Well protected native shoreline
44	60’ slumping sand beach between seawalls
45	Failing concrete wall by canal
46	Undermined failing rock riprap seawall
47	Road end with 3’ high sand erosion
48	Undercut wooded bank in canal
49	Sand fill with not much vegetation, eroding into lake
50	75’ of ice lift damage
51	100’ of 18” tall sand cut bank
52	80’ undercut grass area adjacent to township boat launch

53	80’ of undercut concrete seawall
54	150’ of undercut grass bank
55	40’ long 2’ high sand gravel bank
56	Road end with rutted erosion (Bluewater Ave)
57	40’ sand bank 18” high
58	200’ long sand beach
59	60’ sand beach with gully erosion
60	80’ undercut bank
61	200’ undercut wooded bank
62	1000’ of low undercut bank w/ no slumpage
63	At point 100’ long 2’ high sand bank showing active erosion
64	200’ undercut bank
65	Fieldstone seawall with metal and sandbag reinforcement
66	All sand landscaping with erosion rill and gully erosion
67	No Notes
68	Sand beach undercut around tree roots
69	Wide sand beach with 6” undercut near water
70	Extensive sand beach with rill erosion
71	100’ sand beach with gully erosion
72	1000’ wide sandy beach contributing sand during storm events
73	60’ sand bank at edge of seawall near RR
74	30’ sand bank at bottom of stairs
75	Foot trail to lake10’
76	10’ sand bank where dock put in
77	State park 30’ at south end

78	State park stairwell washout
79	State park stairwell washout

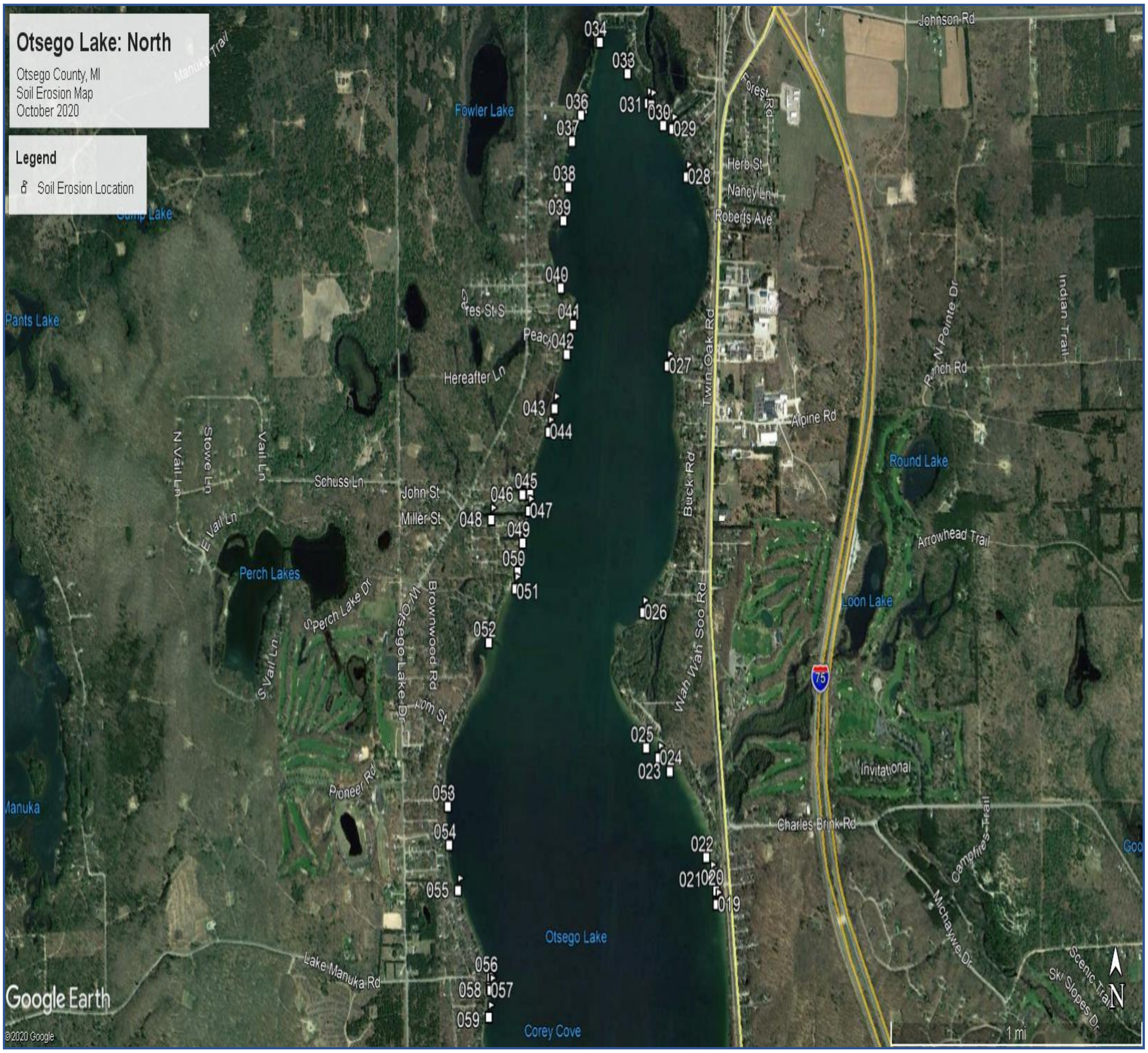


Figure 59. Otsego Lake shoreline soil erosion sites (north end) on September 9, 2020.

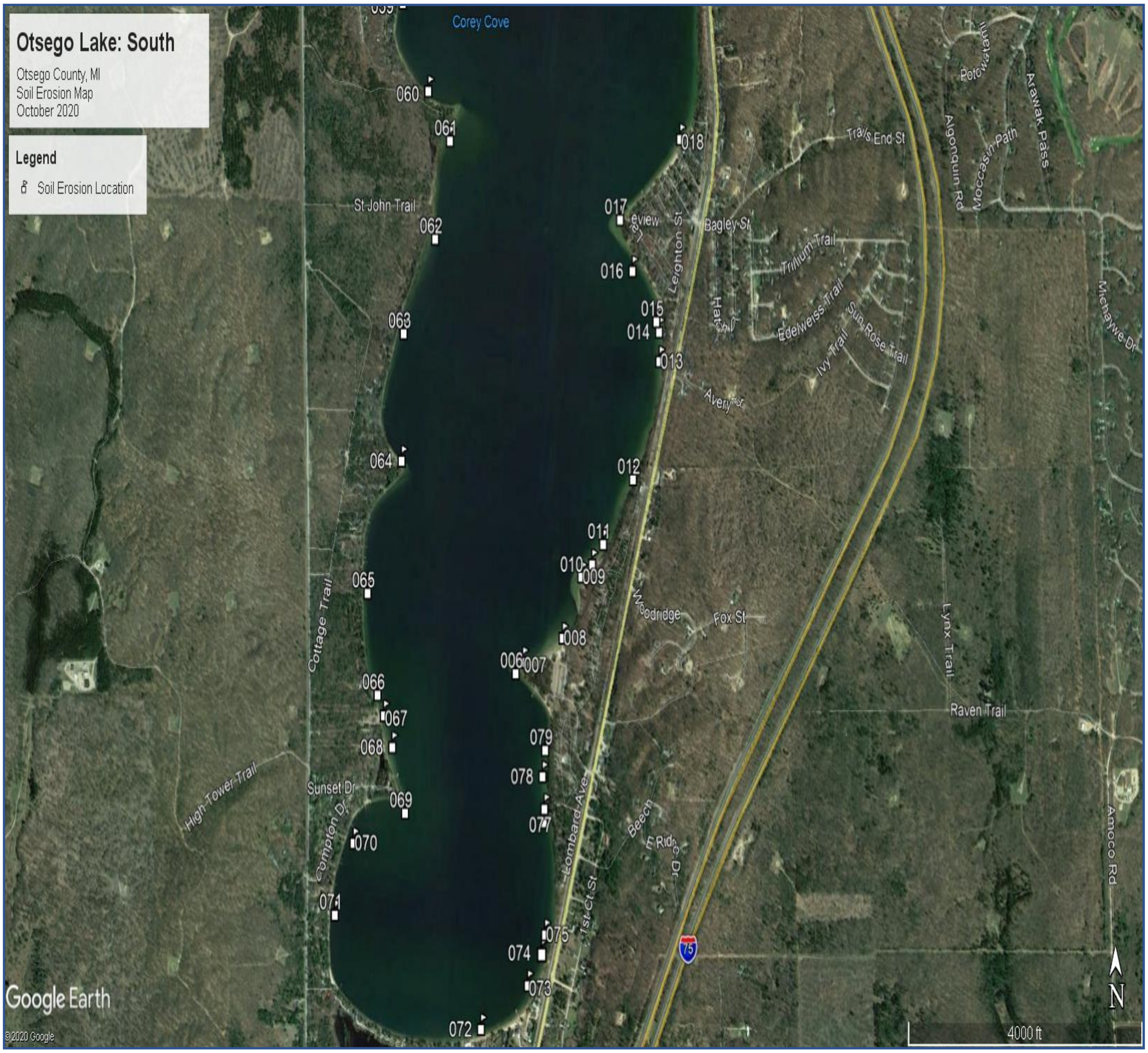


Figure 60. Otsego Lake shoreline soil erosion sites (south end) on September 9, 2020.

Figure 61. Erosion Site #6

Figure 62. Erosion Site #7

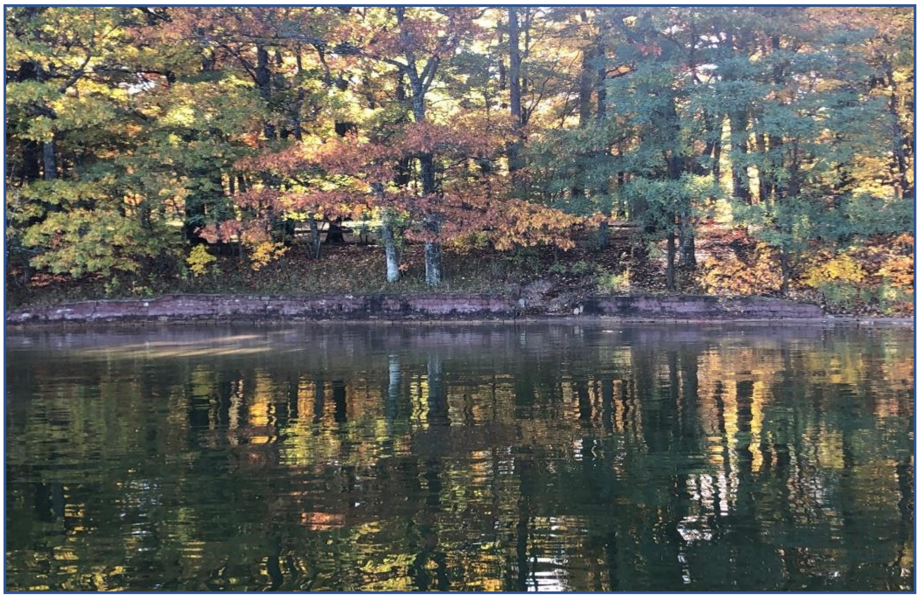


Figure 63. Erosion Site #8

Figure 64. Erosion Site #9

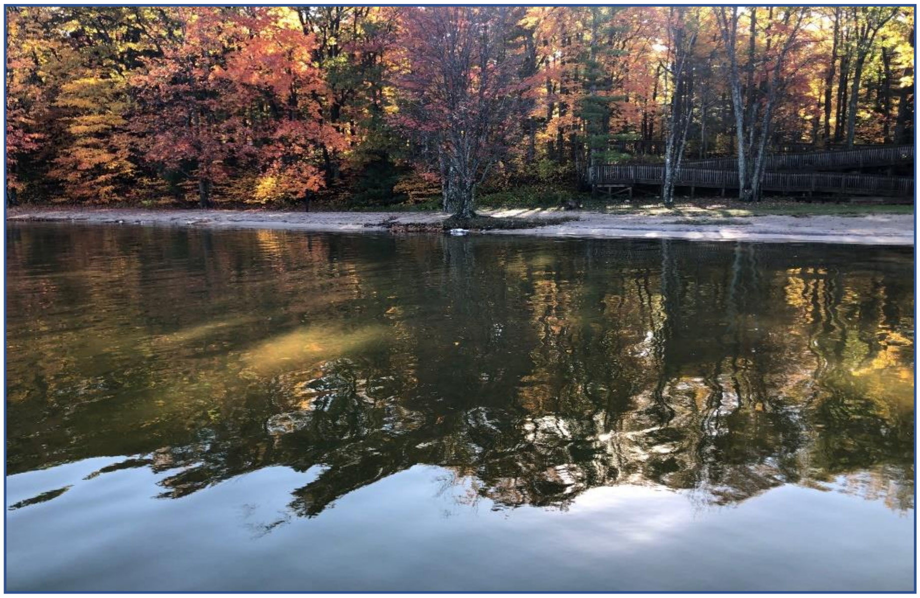


Figure 65. Erosion Site #10

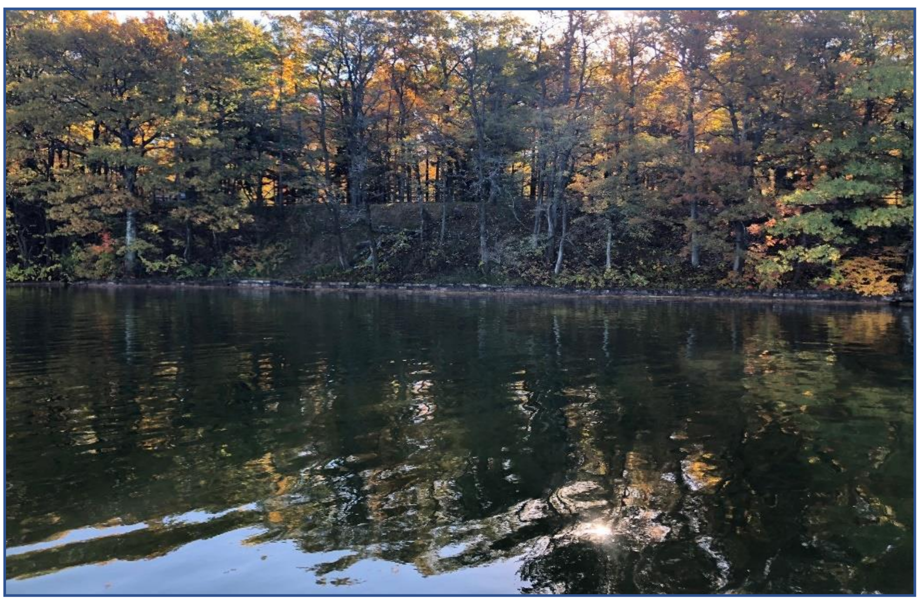


Figure 66. Erosion Site #11

Figure 67. Erosion Site #12

Figure 68. Erosion Site #13

Figure 69. Erosion Site #14

Figure 70. Erosion Site #15

Figure 71. Erosion Site #16

Figure 72. Erosion Site #17

Figure 73. Erosion Site #18

Figure 74. Erosion Site #19

Figure 75. Erosion Site #20

Figure 76. Erosion Site #21

Figure 77. Erosion Site #22

Figure 78. Erosion Site #23

Figure 79. Erosion Site #24

Figure 80. Erosion Site #25

Figure 81. Erosion Site #26

Figure 82. Erosion Site #27

Figure 83. Erosion Site #28

Figure 84. Erosion Site #29

Figure 85. Erosion Site #30

Figure 86. Erosion Site #31

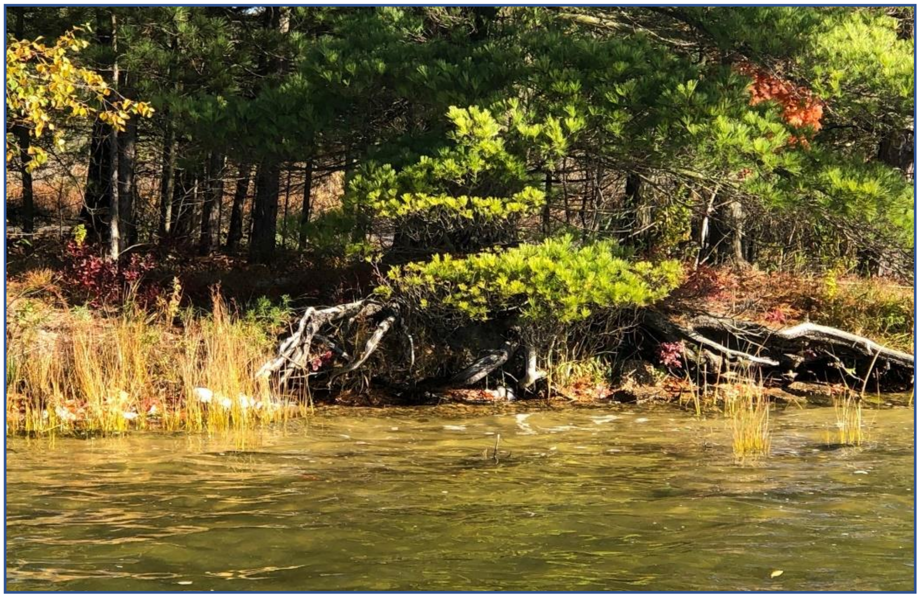


Figure 87. Erosion Site #32

Figure 88. Erosion Site #33

Figure 89. Erosion Site #34

Figure 90. Erosion Site #35

Figure 91. Erosion Site #36

Figure 92. Erosion Site #37

Figure 93. Erosion Site #38

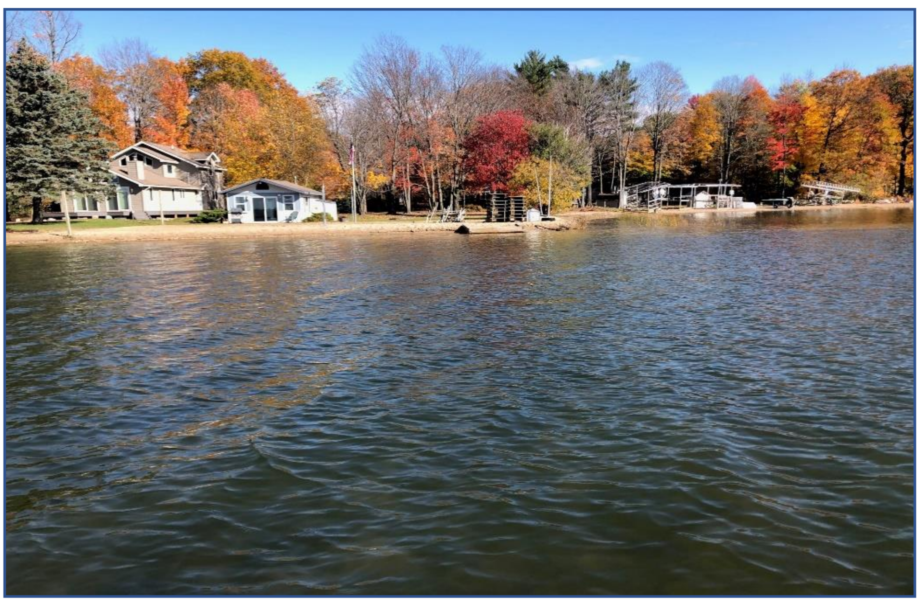


Figure 94. Erosion Site #39

Figure 95. Erosion Site #40

Figure 96. Erosion Site #41

Figure 97. Erosion Site #42

Figure 98. Erosion Site #43 (No erosion present-excellent buffer).

Figure 99. Erosion Site #44

Figure 100. Erosion Site #45

Figure 101. Erosion Site #46

Figure 102. Erosion Site #47

Figure 103. Erosion Site #48

Figure 104. Erosion Site #49

Figure 105. Erosion Site #50

Figure 106. Erosion Site #51

Figure 107. Erosion Site #52

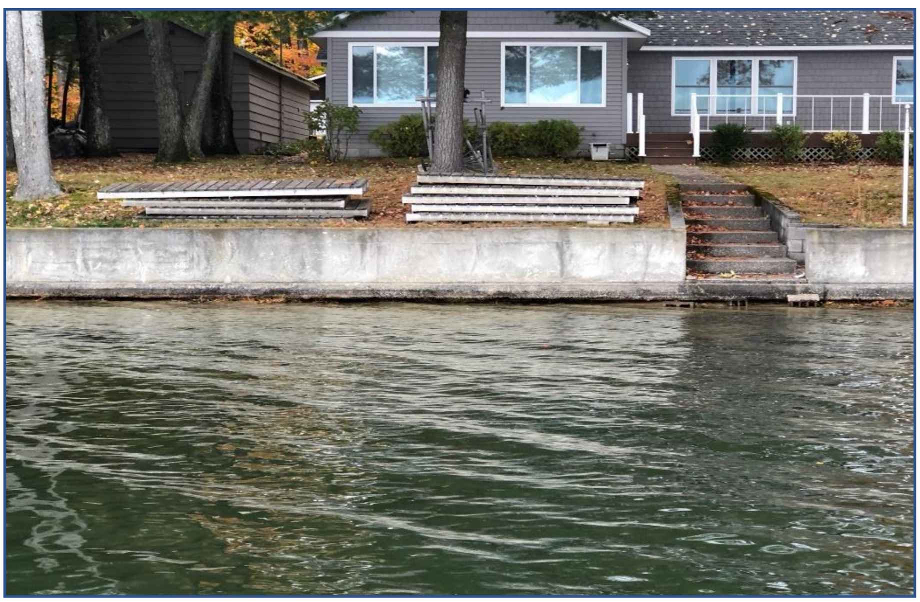


Figure 108. Erosion Site #53

Figure 109. Erosion Site #54

Figure 110. Erosion Site #55

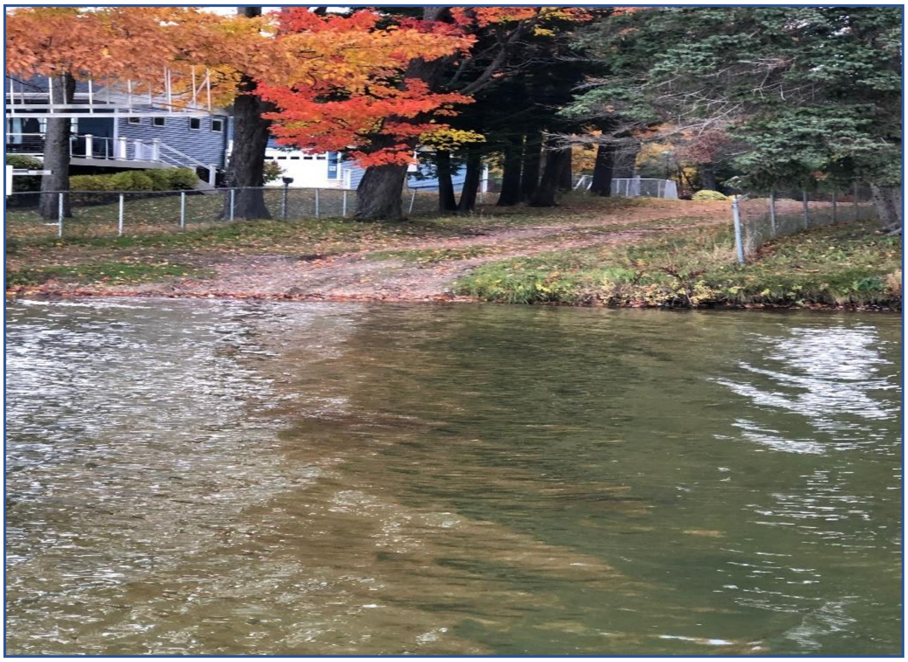


Figure 111. Erosion Site #56

Figure 112. Erosion Site #57

Figure 113. Erosion Site #58

Figure 114. Erosion Site #59

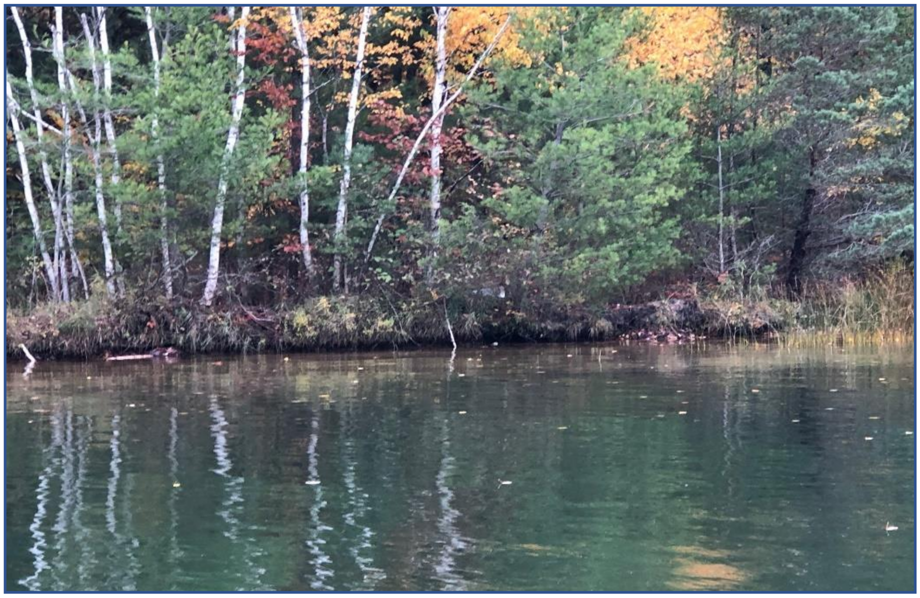


Figure 115. Erosion Site #60

Figure 116. Erosion Site #61

Figure 117. Erosion Site #62

Figure 118. Erosion Site #63

Figure 119. Erosion Site #64

Figure 120. Erosion Site #65

Figure 121. Erosion Site #66

Figure 122. Erosion Site #68

Figure 123. Erosion Site #69

Figure 124. Erosion Site #70

Figure 125. Erosion Site #71

Figure 126. Erosion Site #72

Figure 127. Erosion Site #73

Figure 128. Erosion Site #74

Figure 129. Erosion Site #75

Figure 130. Erosion Site #76

Figure 131. Erosion Site #77

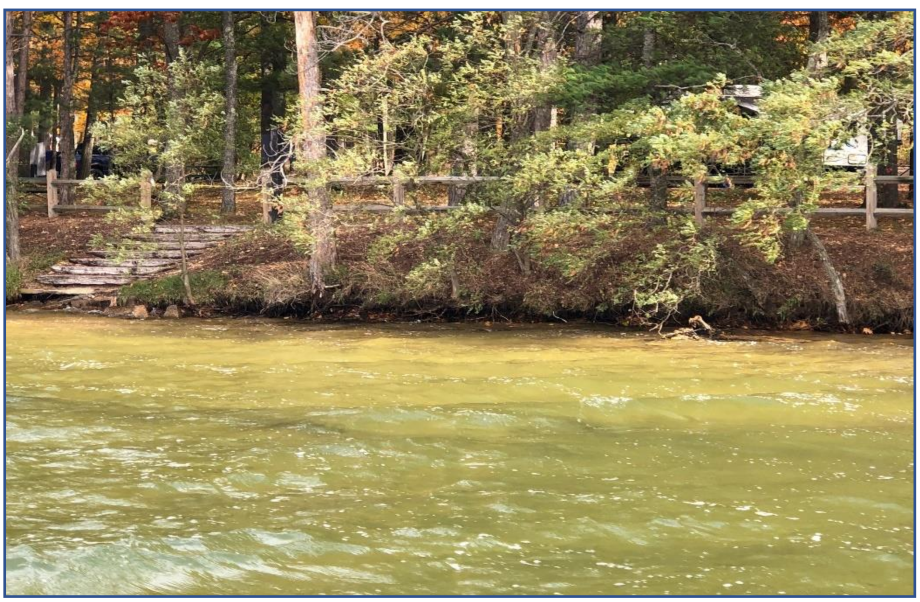


Figure 132. Erosion Site #78

Figure 133. Erosion Site #79

5.3.3 Otsego Lake Nutrient Source Control

Any additional inputs of phosphorus to the lake are likely to create additional algal and aquatic plant growth, especially nearshore. **Accordingly, RLS recommends the following procedures to protect the water quality of Otsego 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 which 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 you must fertilize, 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. Figure 134 demonstrates a lawn that is bright green and lacks a buffer and is likely contributing nutrients to the lake.

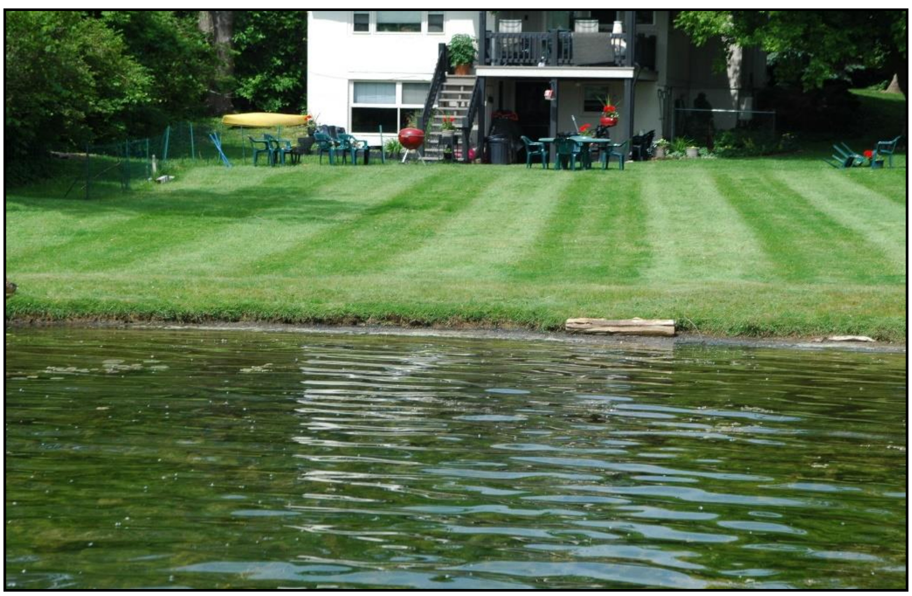


Figure 134. A green lawn leading to a lake with absence of emergent vegetation to reduce nutrient runoff into lake.

2) **Have all septic systems annually inspected if possible or at least every two years.** This includes both the tank and the drain field. Septic inputs have been shown to be the second largest contributor of both nitrogen and phosphorus to Otsego Lake. For more information on septic care, visit the EPA website at: http://www.epa.gov/septic

3) **Preserve riparian vegetation buffers around the shoreline 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. Valuable information can be found on the Michigan Natural Shoreline Partnership website at: www.mishorelinepartnership.org

4) **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.

5) 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.

6) **Never dump any solvents, chemicals, or debris into the lake.** These can all harm fish, wildlife, and humans.

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

8) **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 are costly to mitigate.

9) 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 instead dispose of leaves as yard waste.

10) Preserve all wetlands around the lake as they act as natural filters of runoff nutrients in those areas.

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

12) 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.

13) **Be a responsible lake steward!** Attend lake association meetings and learn about issues on the Otsego Lake Association website at: http://myotsegolake.com/

6.0 OTSEGO LAKE MANAGEMENT PLAN CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Otsego Lake is facing significant issues that may degrade water quality, including inputs of nutrients from septic systems and significant shoreline erosion which leads to a decline in lake health over time. Additionally, invasive species such as Eurasian Watermilfoil (EWM), Curly-leaf Pondweed (CLP), and Starry Stonewort are located in the lake with the latter two present in the south region and canal region of the lake. These invasives pose a serious risk to the native aquatic plant biodiversity and recreational activities in the lake. Protection of the high biodiversity of native aquatic plants is essential for lake health, especially given the low relative abundance of most native aquatic plant species. **Here are the key conclusions and recommendations for successful management of Otsego Lake:**

1. Management of invasive species would be best achieved with aquatic herbicides but could be removed on a smaller scale with DASH technology. EGLE permits treatment of invasive EWM, CLP, and Starry Stonewort with aquatic herbicides. At the current time, there are approximately 12.0 acres of EWM, 0.5 acres of CLP, and 2.8 acres of Starry Stonewort. RLS recommends spot-treating the EWM with granular 2,4-D (offshore) or triclopyr products (nearshore). The product types and doses should rotate each year to lessen the occurrence of herbicide tolerance by EWM in Otsego Lake. Treatment of CLP must also be treated only once per season with contact herbicides prior to June 15. Due to these restrictions, a late May to early June survey is critical for getting a treatment conducted by June 15. The use of copper sulfate should not be used for Otsego Lake since it bioaccumulates in the lake sediments and may harm lake benthos and macroinvertebrates. Chelated copper products could be used only on nuisance green filamentous nearshore algae in the canals. As stated earlier, blue-green algae can be exacerbated by algaecide treatments. **EGLE and USACE also permit the use of DASH for removal of invasives. This would be recommended for all invasives once the acreage is small enough for DASH removal (ideally under 3.0 acres).**

2. A detailed, Early Detection-Rapid Response Protocol for future invasives that may enter the lake is recommended to be compiled ASAP for the Otsego Lake community. This would include current identification and treatment protocols and also those for new invasives that have been appearing in our Midwest lakes.

3. Each year, an independent professional limnologist/aquatic botanist at RLS should perform regular GPS-guided whole-lake surveys each summer/early fall to monitor the growth and distribution of all invasives prior to and after all 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 Otsego 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 applicators to target-specific areas of aquatic vegetation for removal and reviewing all contractor invoices for accuracy.

4. A boat washing station is recommended for the public access site and would require some financial investment. It could consist of a basic sprayer bottle and signs in place of a pricey electronic steam wash unit, but the latter is still preferred. These stations have been effective at educating visitors to clean their boats and trailers and at reducing the spread of invasive aquatic plant species.

5. The lake has a healthy food chain which consists of panfish, walleye, bass, pike, and other fish. In addition, there is an abundance of fingernail clams and healthy zooplankton and macroinvertebrates. All of these organisms are sensitive to high copper use and thus these products should be avoided if possible.

6. Annual water quality monitoring of the three deep basins is recommended to continue to evaluate long-term trends and impacts of management practices. The water quality parameters measured included physical parameters such as water temperature, dissolved oxygen, pH, conductivity, Secchi transparency, and total dissolved solids. In addition, chemical water quality parameters such as total phosphorus (TP) and ortho-phosphorus (SRP), total inorganic nitrogen (TIN), chlorophyll-a, and total suspended solids (TSS) should also be monitored. These should be sampled in the 3 deep basins each summer from late May-September. The 2020 water quality data demonstrated elevated turbidity and solids which may be due to the flocculent nature of the organic lake sediments but also to the high amount of shoreline erosion.

7. Otsego Lake has nutrient concentrations in the deep basins that are near or just below the eutrophic threshold and inputs are likely from septic effluent, runoff, and shoreline erosion. A small amount of phosphorus is deposited in lakes from atmospheric deposition. Since a lake-wide sewer may not be feasible, maintenance of individual septic systems and drain fields is critical. This could be encouraged through a community-wide septic pumping period and education of riparians on the importance of proper septic maintenance.

8. There are seventy-two areas of significant erosion found along the shoreline of Otsego Lake. An erosion control program which offers site-specific improvements is urgently recommended. Reduction of this erosion should result in clearer waters over time.

9. Lastly, a riparian education program is recommended through the development of this management plan and through holding future educational workshops. Such workshops may include dispersal of relevant lake information and also identification of local lake biota so that residents know to be vigilant of certain invasives. This could be done at annual lake association meetings or at a venue during the summer.

A complete list of recommended lake improvement options for this proposed lake management plan can be found in Table 21 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 21. List of Otsego Lake proposed improvement methods with primary and secondary goals and locations for implementation.

Proposed Improvement Method	Primary Goal	Secondary Goal	Where to Implement
Maintenance program for septic systems	To reduce nutrients inputs from septic systems	To improve water quality parameters- especially lake bottom nutrients	Lake-wide
Spot-treatment with systemic herbicides for control of EWM and contacts for CLP and SS	Systemically reduce EWM throughout lake and reduce other invasives	Use less herbicide over time for all invasives	Entire lake where invasive EWM, CLP, SS are present
Bi-annual water quality monitoring of lake	Monitor lake health over time	Use long-term and current data to drive management decisions relative to BMP's	Lake deep basins (n=3)
Development of Early Detection Rapid Response Protocol for new invasives	Generate a clear strategy for dealing with new invasives that may be found in the lake	Allow for less long-term spread of any new invasives with early detection	Entire lake
Shoreline Erosion Control program (site-specific)	To reduce erosion around the lake	To protect and improve water quality	Entire shoreline—impaired areas found
Boat launch washing stations	To reduce entry of invasives into Otsego Lake	To reduce exit of invasives from Otsego Lake	At public access site noted in this report.
Annual lake surveys pre- and post-treatment	To determine efficacy of all treatments on invasives and nuisance plants	To determine ability of native aquatic vegetation biodiversity to recover post-management implementation	Entire lake

Independent and objective oversight of lake treatments or other contractor work	To objectively evaluate treatments for optimum science and future costs	To work with applicators or contractors for optimum lake management solutions	Through treatment season
Riparian/Community Education	To raise awareness of lake issues and empower all to participate in lake protection	Long-term sustainability requires ongoing awareness and action	Entire lake community and those who frequent the lake; may also include other relevant stakeholders

6.1 Proposed Cost Estimates for Otsego Lake Improvements

The proposed lake improvement and management program for Otsego Lake is recommended to begin as soon as possible. A breakdown of estimated costs associated with the various proposed management items in Otsego Lake is presented in Table 22. 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. Any of these could be conducted during different years of a new or existing SAD program. However, it is highly recommended to perform all of these management methods as soon as possible. The annual cost will decline over time with the boat wash station, early detection rapid response protocol, and reductions in invasive aquatic plant species as well as shoreline erosion.

Table 22. Otsego Lake proposed lake management program costs. Note: These items could be implemented over a period of years with professional services and treatment of invasives recommended on an annual basis.

Proposed Otsego Lake Improvement Item	Estimated Itemized Costs
[1]Treatments for EWM and CLP (Systemic herbicides used for EWM and contact herbicides for CLP and Starry Stonewort); NOTE: Future EWM or SS could be removed with DASH once acreage is reduced	$14,000
[2]Professional services (limnologist management of lake, aquatic vegetation surveys, deep basin water quality sampling, oversight of treatments, education, development of Rapid Response Protocol, annual professional report)	$18,000
[3]Boat washing station-basic	~$5,000
[4]Lake workshop in late summer with tips for riparians and handouts of Otsego Lake maps, info.	$7,000
[5]Erosion Control site-specific recommendations report for all found problem areas (RLS)	$15,000
Contingency	$5,900
Total Estimated Cost of all Items	$64,900

[1] This cost is based on an evaluation of previous and current treatments and possible need for higher systemic herbicide doses in the future to adequately control hybrid EWM.
[2] This cost would include all annual professional consulting deliverables from RLS that would include aquatic plant surveys, follow-up surveys, treatment oversights, deep basin water quality sampling, riparian education, development of rapid response protocol, data analysis, professional annual report, and attendance at up to 2 lake Association meetings.

Once the rapid response protocol was completed, the cost of professional services would be reduced to $15,000 per year.

[3] This cost includes signs for the boat wash as well as a simple pump sprayer for use by incoming boats. If vandalism may occur, then signage may be useful for more education of incoming boaters.

[4]This cost would include a three-hour lake workshop at a venue of choice by the OLA and would include handouts on Otsego Lake protection and ecology and also booths from informative sources such as RLS, MSU Extension, MDNR, and EGLE, among others.

[5]This cost would include site-specific recommendations for erosion control of observed areas noted during the 2020 evaluation. This would produce a guidebook of the individual sites with recommendations for erosion control and approximate costs.

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.

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.

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.

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.

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.

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.

Michigan Department of Natural Resources, 2009. Otsego Lake Report 2009-71.

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

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

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

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

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.

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.

United States Environmental Protection Agency (1995). The Great Lakes – An Environmental Atlas and Resource Book, EPA 905-B-95-001, (after Brown).

University of Michigan Biological Station, 1980. A Water quality survey of Otsego Lake, Michigan. Technical Report No. 10. 72 pgs.

University of Nebraska-Lincoln (2010). Canada Goose Management Website. NRES 348 Wildlife Damage Management class, Spring Semester, Scott Hygnstrom, Instructor; Stephen Vantassel, Webmaster.

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

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