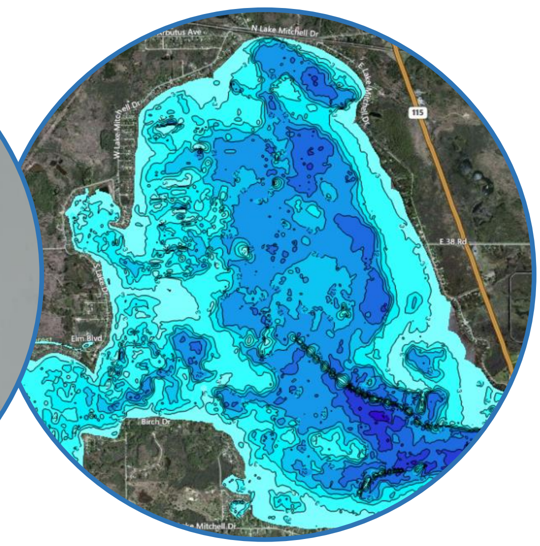
Lake Mitchell Improvement Feasibility Study and Aquatic Vegetation Management Plan
Wexford County, Michigan



Provided for: Lake Mitchell Improvement Board
Pursuant to P.A. 451 of 1994, as amended

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TABLE OF CONTENTS

LIST OF FIGURES

FIGURE		PAGE

LIST OF TABLES

Lake Mitchell Improvement Feasibility Study and Aquatic Vegetation Management Plan

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1.0 EXECUTIVE SUMMARY

Lake Mitchell is a 2,580-acre natural, glacial lake located in Sections 1, 2, 3, 4, 10, 11, 12, 34, 35, and 36 of Cherry Grove and Selma Townships in Wexford County, Michigan (T. 21, 22N, R. 10W). The lake has three major tributaries including Mitchell Creek which enters the lake from the west side of Big Cove, Brandy Brook which enters the lake at the north end of Little Cove, and Gyttja Creek which enters the lake at the north region of the lake.

The lake has approximately 11.4 miles of shoreline and a mean depth of approximately 8.7 feet (Restorative Lake Sciences, 2014). Based on the current study, Lake Mitchell contains approximately 20 acres of invasive hybrid watermilfoil (*Myriophyllum spicatum* var. *sibiricum*); however, that may change significantly within a single season as it has in previous years due to the aggressive and unpredictable growth habit of hybrid watermilfoil. This particular plant threatens the biodiversity of the submersed native aquatic plant (macrophyte) communities, threatens navigation and recreational activities, and also may harbor bacteria and other nuisance algae that are not beneficial to the lake's ecosystem. Furthermore, the plant may reduce waterfront property values. The native aquatic plant diversity in Lake Mitchell is very high with 27 native aquatic plant species present.

The overall water quality of Lake Mitchell was measured as very good with moderate nutrients such as phosphorus and nitrogen and moderate water clarity. The pH and alkalinity of the lake indicate that it is a soft water lake with a neutral pH and low conductivity. The nutrients entering the lake from the three tributaries are higher than the ambient concentrations in the lake and indicate that they are sources of significant nutrient loading to Lake Mitchell. The immediate watershed draining to Lake Mitchell is quite large and approximately 22.6 times the size of Lake Mitchell.

Restorative Lake Sciences (RLS) recommends that selective spot-treatments with highly selective granular systemic aquatic herbicides be used to treat the exotic hybrid watermilfoil within the lake and that strong contact herbicides be used to control the nuisance native aquatic plant and algae overgrowth in the Coves and in Torenta Canal. A reduction in the herbicide treatment areas is projected for ongoing years of the program if no other invasives enter the Lake Mitchell ecosystem. Additionally, RLS recommends continued education of lake riparians on nutrient reduction to the lake and lake protection Best Management Practices (BMP's) that are emphasized in this report.

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 Lake Mitchell.

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 (O'Neil and Soulliere 2006). 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. Lake Mitchell may be categorized as a drainage lake as it receives external water supplies from three significant tributaries (inlets) which include Mitchell Creek which enters Big Cove, Brandy Brook which enters Little Cove, and Gyttja Creek which enters the northern region of the lake in Selma Township. A channel connects Lake Mitchell to Lake Cadillac and an outlet empties both lakes to the Clam River via a dam.

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 LAKE MITCHELL PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Lake Mitchell Basin

Lake Mitchell is located in sections 1, 2, 3, 4, 10, 11, 12, 34, 35, and 36 of Cherry Grove and Selma Townships, (T.21, 22N, R.10W) in Wexford County, Michigan. The lake has a surface area of approximately 2,580 acres and a maximum depth of 25 feet as determined by a modernized whole-lake benthic scan by Restorative Lake Sciences in 2013 (Figure 1). The lake lies at an elevation of 1,289 feet above sea level. Lake Mitchell has a mean (average) depth of approximately 8.7 feet (RLS, 2013). The lake is classified as a eutrophic (nutrient-enriched) aquatic ecosystem with two deep basins of over 20 feet and a moderate-sized littoral (shallow) zone that is capable of supporting rigorous submersed rooted, aquatic plant growth.

The lake bottom consists of pulpy peat in the deep basins and sand in the shallow areas. Lake Mitchell has a lake perimeter of approximately 11.4 miles (Restorative Lake Sciences, 2015). Currently, all of the surrounding homes around the lake utilize a sanitary sewer system for waste management.

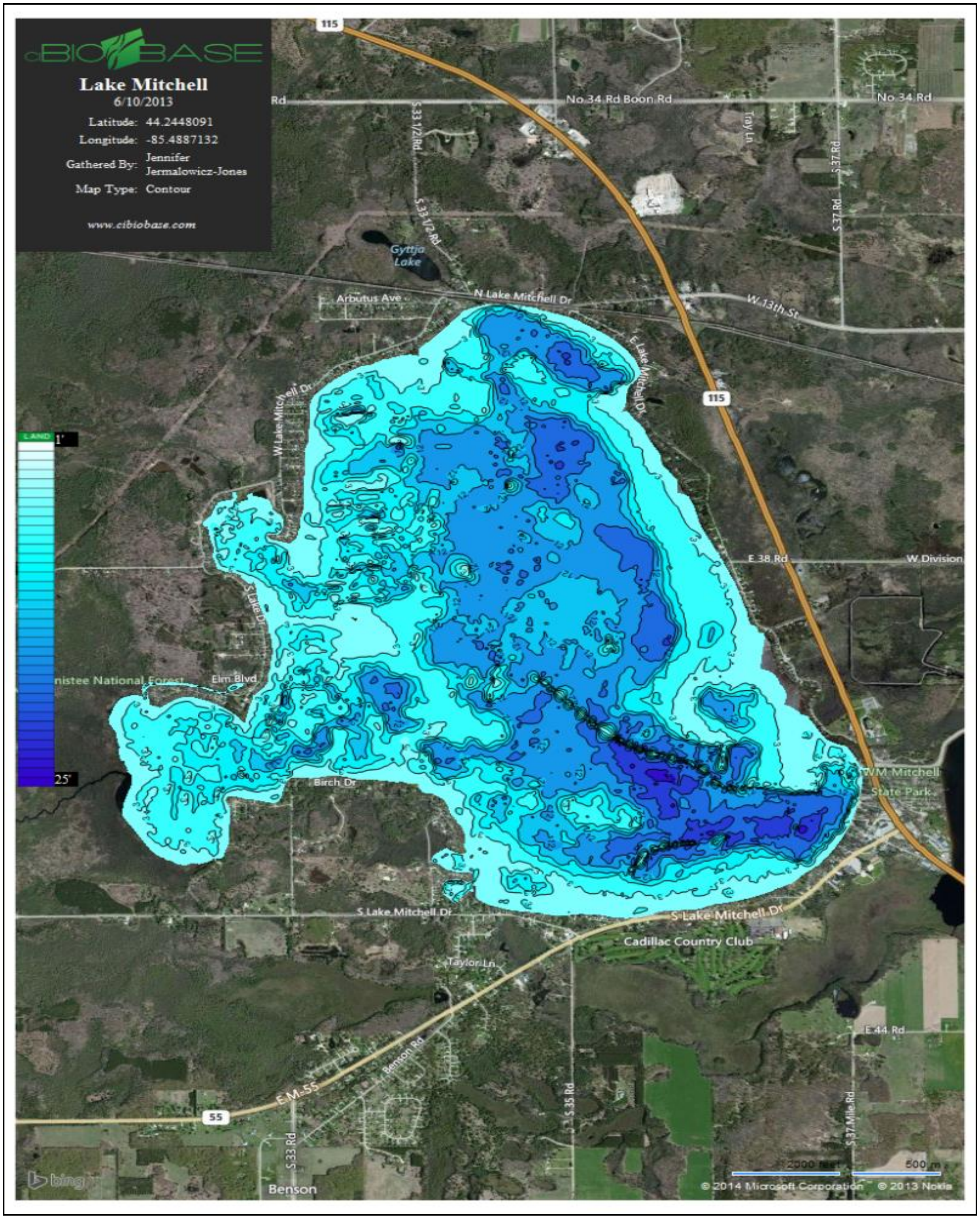


Figure 1. Lake Mitchell, Wexford County, Michigan (RLS, 2013).

3.2 Lake Mitchell 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 high 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. The Lake Mitchell extended watershed (Muskegon River; Figure 2) is approximately 2,700 mi^2 or 1,728,000 acres in area. The Muskegon River Watershed includes 8 counties including Roscommon, Missaukee, Clare, Osceola, Mecosta, Montcalm, Newaygo, and Muskegon Counties. Watershed land use categorizes the many activities and land types that occur within the watershed and often include: residential development, commercial development, agriculture, forested land, open space, and wetlands. The primary land uses present in the Lake Mitchell immediate watershed include forests and wetlands, agriculture, and developed (residential and commercial) land.

The immediate watershed area is approximately 58,256 acres in area (Restorative Lake Sciences, 2015; Figure 3). It is recommended that a modernized study utilize a smaller sub-watershed scale in the future to investigate nutrient inputs on a local scale, while assessing critical source areas (CSA's) at the previous larger scale. It is worth noting that extensive areas of wetlands exist in the immediate watershed and thus anthropogenic (man-made) inputs of phosphorus to upstream waters are unlikely and thus inputs of pollutants such as phosphorus are likely to occur more locally. The immediate watershed is approximately 22.6 times larger than the size of Lake Mitchell, which indicates the presence of a large-sized immediate watershed.

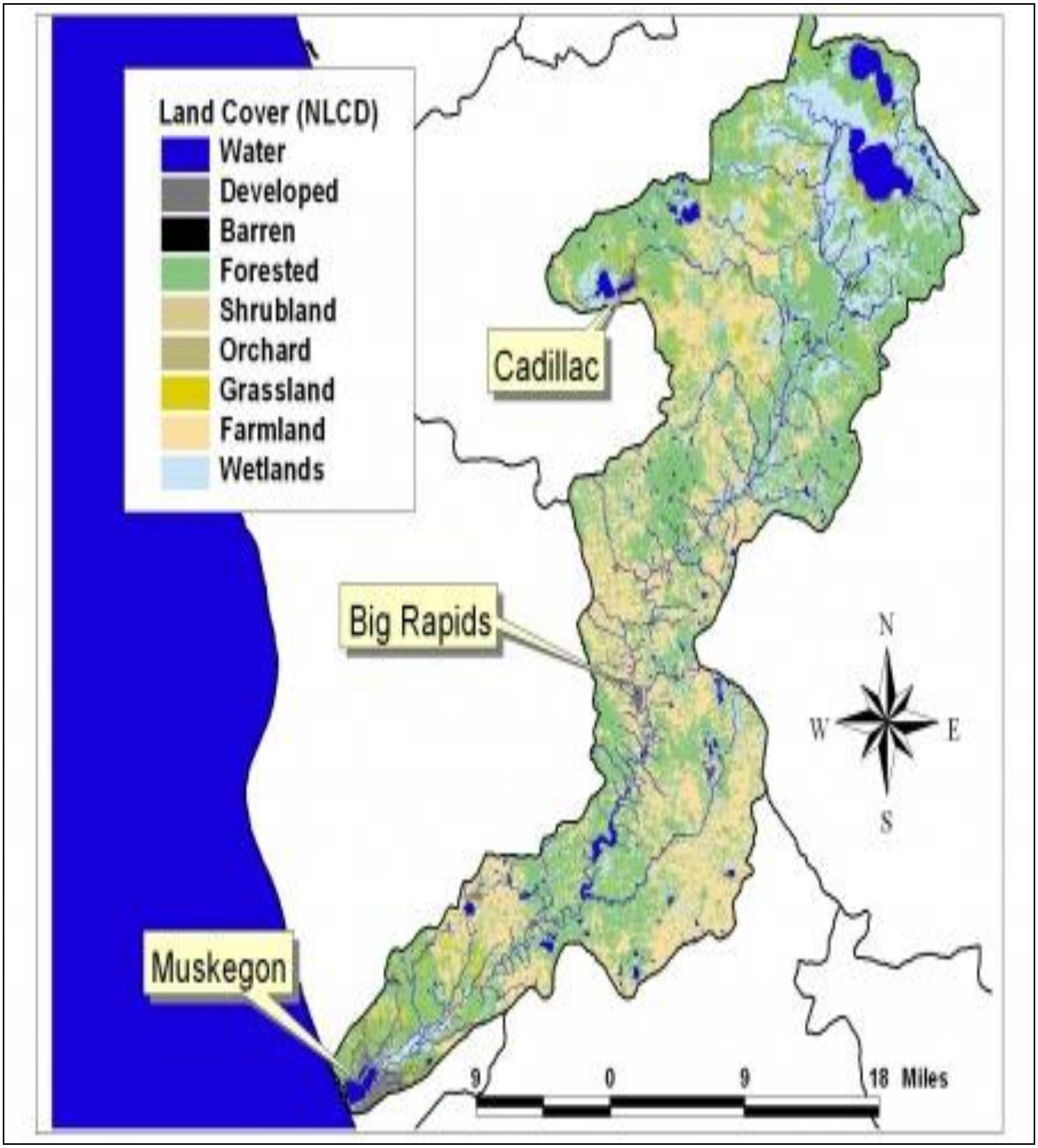


Figure 2. Extended Muskegon River Watershed (www.epa.gov, online resource)

Figure 3. Immediate Watershed draining into Lake Mitchell, Wexford County, Michigan (Restorative Lake Sciences, 2016)

3.3 Lake Mitchell Shoreline Soils

There are 8 major soil types immediately surrounding Lake Mitchell which may impact the water quality of the lake and may dictate the particular land use activities within the area. Figure 4 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service, 1999) demonstrates the precise soil types and locations around Lake Mitchell. Major characteristics of the dominant soil types directly surrounding the Lake Mitchell shoreline are discussed below. The locations of each soil type are listed in Table 1 below.

USDA-NRCS Soil Series	***Shoreline Soil Location***
10A-Au Gres-Finch sands 0-4% slopes	West, northeast, east shores
11A-Croswell sand 0-4% slopes	Northeast, east, southwest, west shores
14A-Allendale loamy sand 0-4% slopes	Southwest shore
8-Loxley peat	Northeast, south, southeast, shores
19-Lupton muck	Northwest, west, southwest shores
20B-Montcalm-Graycalm complex, 0-6% slopes	South, southeast shores
22-Tawas-Roscommon association	West, northwest, north shores
23B-Rubicon sand 0-12% slopes	West, east shores

Table 1. Lake Mitchell Shoreline Soil Types (USDA-NRCS, 1999).

Figure 4. NRCS-USDA soils map for Lake Mitchell shoreline soils (1999 data).

The majority of the soils around Lake Mitchell are well-drained sands with low slopes. There are scattered areas around the lake that contain ponded or mucky soils that may have been problematic in the past for septic systems and may be now for heavy rainfall. Ponding occurs when water cannot permeate the soil and accumulates on the ground surface which then may runoff into nearby waterways 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. Some Best Management Practices (BMP's) are offered later in this study report for those that may reside on properties that have mucky soils or soils that are prone to erosion.

4.0 LAKE MITCHELL WATER QUALITY

Water quality is highly variable among Michigan's inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by both land use practices and climatic events. Climatic factors (i.e. spring runoff, heavy rainfall) may alter water quality in the short term; whereas, anthropogenic (man-induced) factors (i.e. shoreline development, lawn fertilizer use) alter water quality over longer time periods. Since many lakes have a fairly long hydraulic residence time, the water may remain in the lake for years and is therefore sensitive to nutrient loading and pollutants. Furthermore, lake water quality helps to determine the classification of particular lakes (Table 2). 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. Lake Mitchell is classified as eutrophic. Although Lake Mitchell has a fair level of nutrients, the water quality has been traditionally favorable for fish stocking of Walleye (as recently as June, 2014) by the Michigan Department of Natural Resources.

Lake Trophic Status	***Total Phosphorus ($\mu g\ L^{-1}$)***	***Chlorophyll-a ($\mu g\ L^{-1}$)***	***Secchi Transparency (feet)***
Oligotrophic	< 10.0	< 2.2	> 15.0
Mesotrophic	10.0 – 20.0	2.2 – 6.0	7.5 – 15.0
Eutrophic	> 20.0	> 6.0	< 7.5

Table 2. Lake Trophic Status Classification Table (MDNR)

4.1 Water Quality Parameters

Parameters such as, but not limited to, dissolved oxygen, water temperature, oxidative reduction potential, conductivity, turbidity, total dissolved solids, pH, total alkalinity, total phosphorus, chlorophyll-*a*, algal composition, and Secchi transparency, respond to changes in water quality and consequently serve as indicators of change. During the past several years and during the study, RLS collected water samples from within the two lake deep basins and three tributaries for the water quality parameters mentioned above. The results are discussed below and are presented in Tables 3-5. Whenever possible, historical trend data are displayed to show the changes in a particular water quality parameter with time. A map showing the sampling locations for all water quality samples is shown below in Figure 5. All water samples and readings were collected on August 28, 2015 with the use of a Van Dorn horizontal water sampler and calibrated Hanna® multi-meter probe with parameter electrodes, respectively.

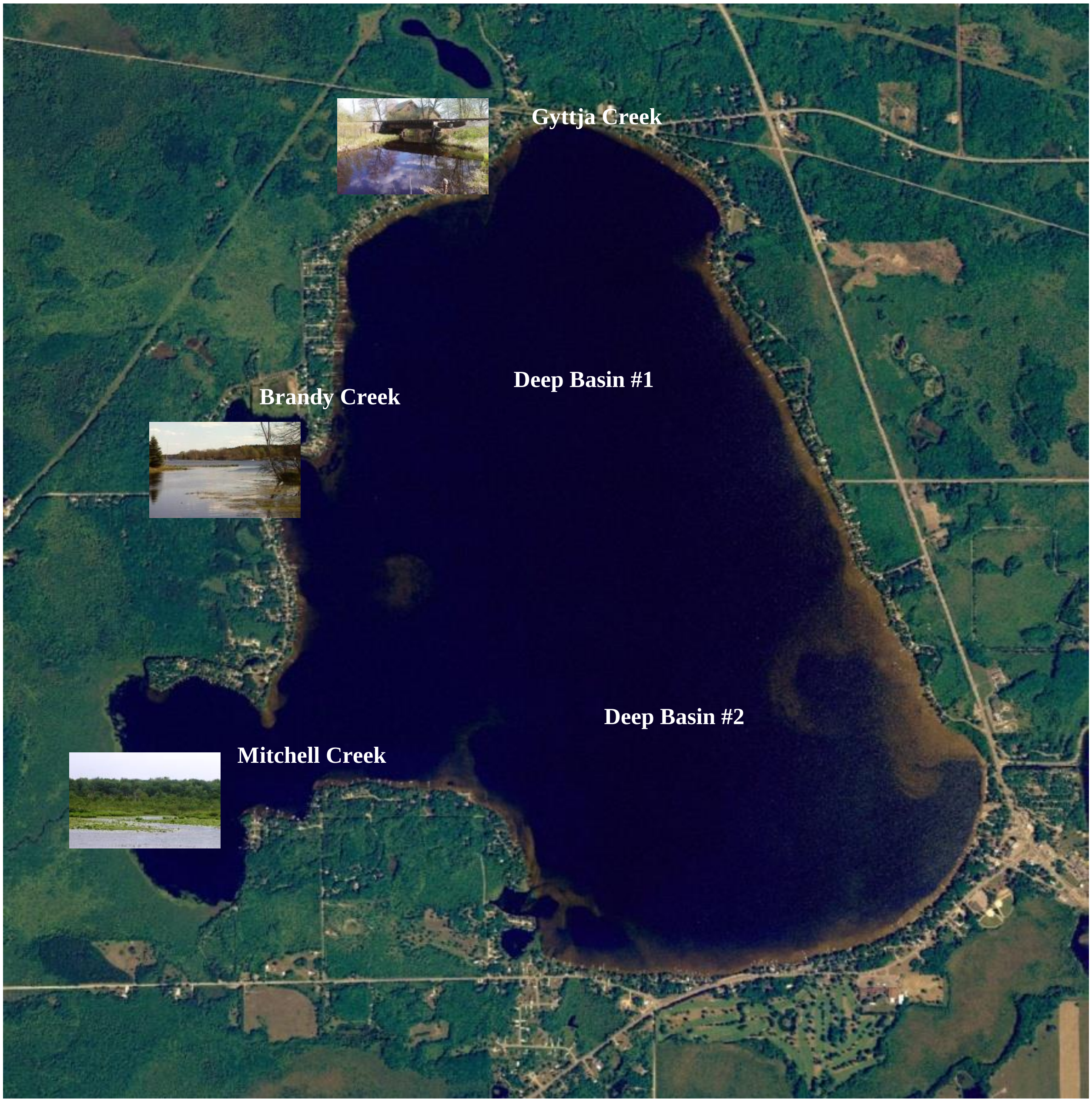


Figure 5. Locations for water quality sampling of the deep basins and tributaries in Lake Mitchell (August 28, 2015 and historically).

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^{-1} to sustain a healthy warm-water fishery. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. Dissolved oxygen was measured in milligrams per liter (mg L^{-1}) with the use of a calibrated dissolved oxygen meter. Dissolved oxygen concentrations ranged between 8.1-7.4 mg L^{-1}, with concentrations of dissolved oxygen higher at the surface and slightly lower at the bottom. The dissolved oxygen concentrations of the three tributaries were lower than the lake which is not uncommon later in the season when water temperatures are higher and warmer water holds less dissolved oxygen. During the summer months, dissolved oxygen at the surface is generally higher due to the exchange of oxygen from the atmosphere with the lake surface, whereas dissolved oxygen is lower at the lake bottom due to decreased contact with the atmosphere and increased biochemical oxygen demand (BOD) from microbial activity.

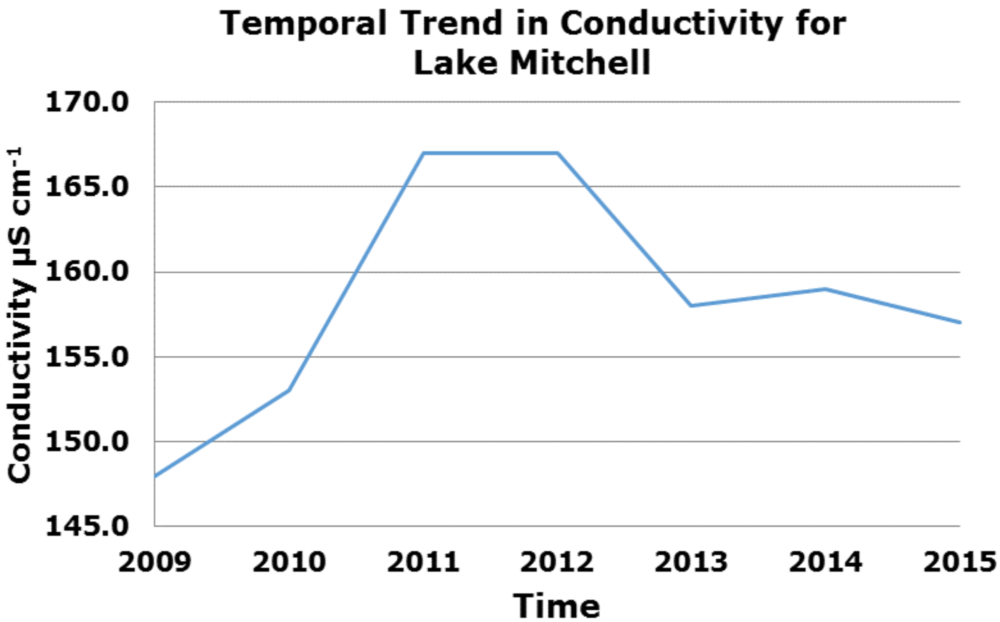
4.1.2 Water Temperature

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". In general, shallow lakes will not stratify and deeper lakes may experience single or multiple turnover cycles. Water temperature is measured in degrees Celsius (ºC) or degrees Fahrenheit (ºF) with the use of a submersible thermometer. The late August, 2015 water temperatures of Lake Mitchell demonstrated a lack of a thermocline and lack of thermal stratification from the surface to the lake bottom in both of the deep basins. This is not an uncommon occurrence for Lake Mitchell and other large, shallow lakes.

4.1.3 Conductivity

Conductivity is a measure of the amount of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Conductivity was measured in micro ohms per centimeter (µmho cm^{-1}) with the use of a calibrated conductivity probe meter.

Conductivity values for Lake Mitchell ranged from 155-160 mS cm^{-1} in the deep basins during late August of 2015. These values are low to moderate for an inland lake and mean that the lake water contains some dissolved metals. The conductivity of the three tributaries ranged from 126-235 mS cm^{-1}. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Lake Mitchell over a long period of time, or to trace the origin of a substance to the lake in an effort to reduce pollutant loading.

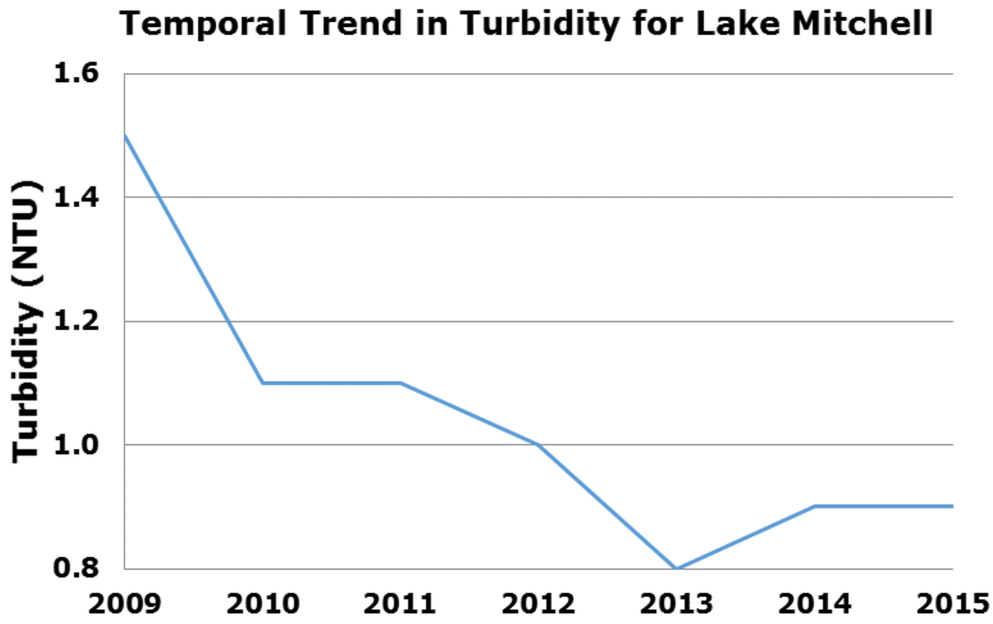


4.1.4 Turbidity & Total Dissolved Solids

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® turbidimeter. 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 Lake Mitchell is quite low and was consistently around 0.9 NTU's during the late August, 2015 sampling event.

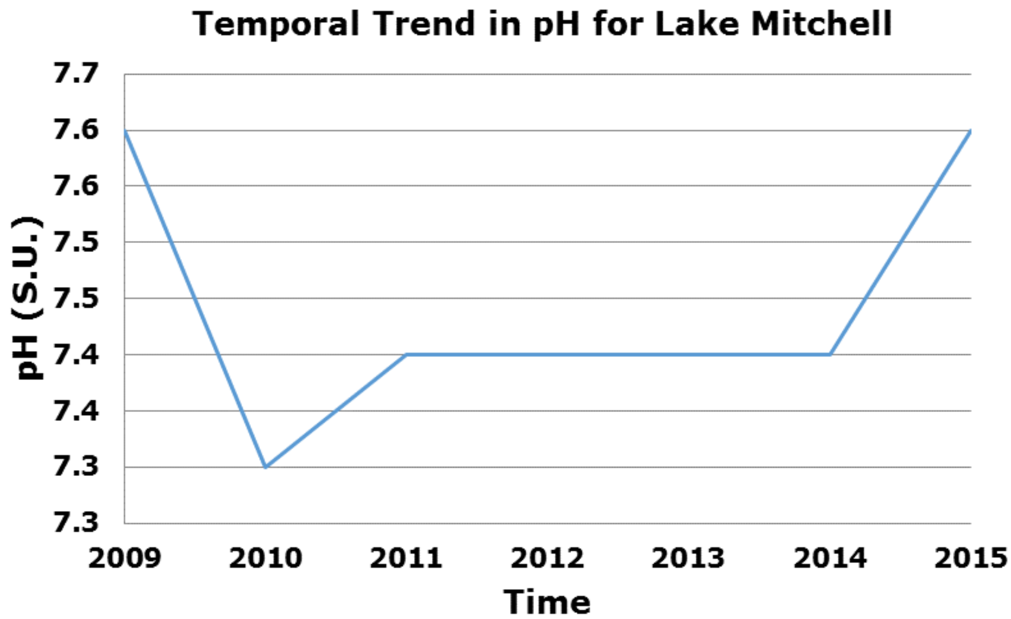
Total Dissolved Solids

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. TDS was measured with the use of a calibrated TDS probe in mg L^{-1}. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The TDS in Lake Mitchell ranged from 52-59 mg L^{-1} for the deep basins in late August of 2015, which is moderate for an inland lake. The TDS of the tributaries ranged from 89-105 mg L^{-1} in late August of 2015.



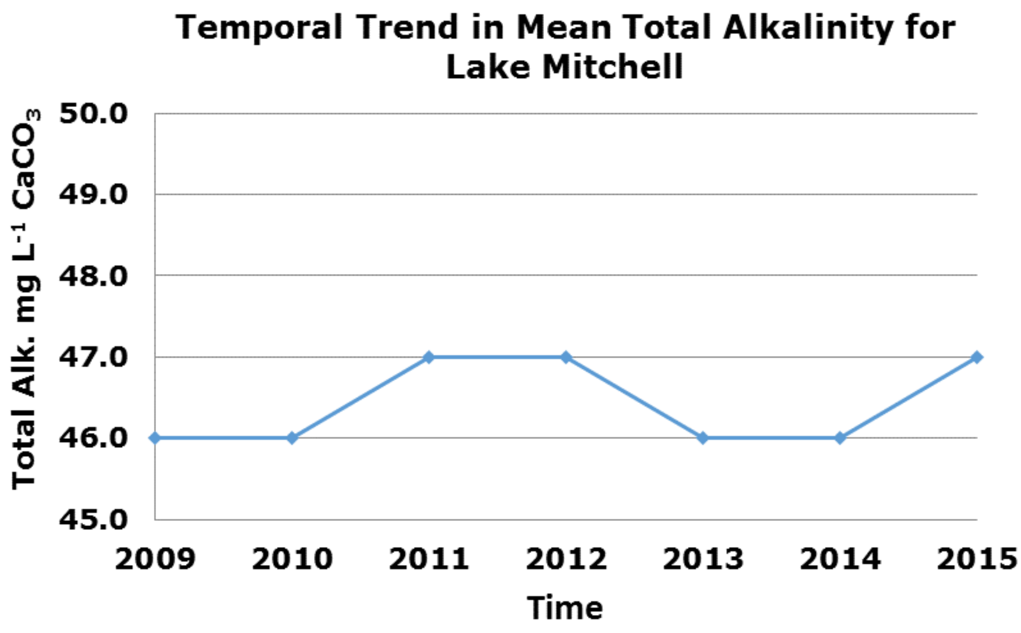
4.1.5 pH

pH is the measure of acidity or basicity of water. pH was measured with a calibrated 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 6.5 to 9.5. 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 Lake Mitchell water ranged from 7.5 – 7.6 S.U. during the late August, 2015 sampling event. This range of pH is neutral on the pH scale. The pH of the tributary waters ranged from 7.4-7.5 S.U.



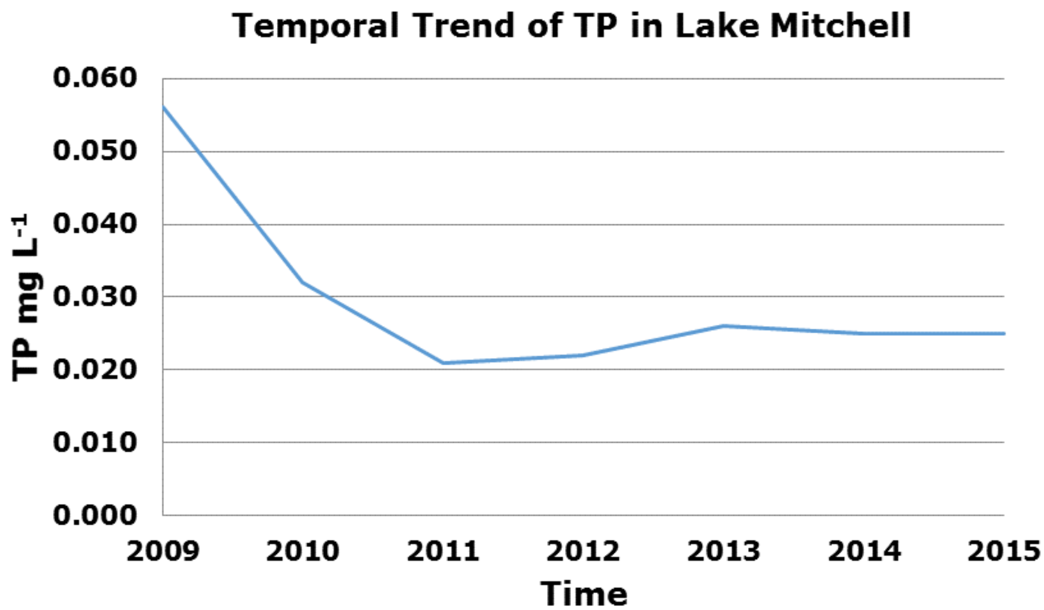
4.1.6 Total Alkalinity

Total alkalinity is the measure of the pH-buffering capacity of lake water. Lakes with high alkalinity (> 150 mg L^{-1} of $CaCO_3$) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of $CaCO_3$ and are categorized as having "hard" water. Total alkalinity was measured in milligrams per liter of $CaCO_3$ through an acid titration method. The total alkalinity of Lake Mitchell is considered "low" (< 60 mg L^{-1} of $CaCO_3$), and indicates that the water is rather soft. Total alkalinity in the deep basins ranged from 47-50 mg L^{-1} of $CaCO_3$ during the late August, 2015 sampling event. Total alkalinity may change on a daily basis due to the re-suspension of sedimentary deposits in the water and respond to seasonal changes due to the cyclic turnover of the lake water.



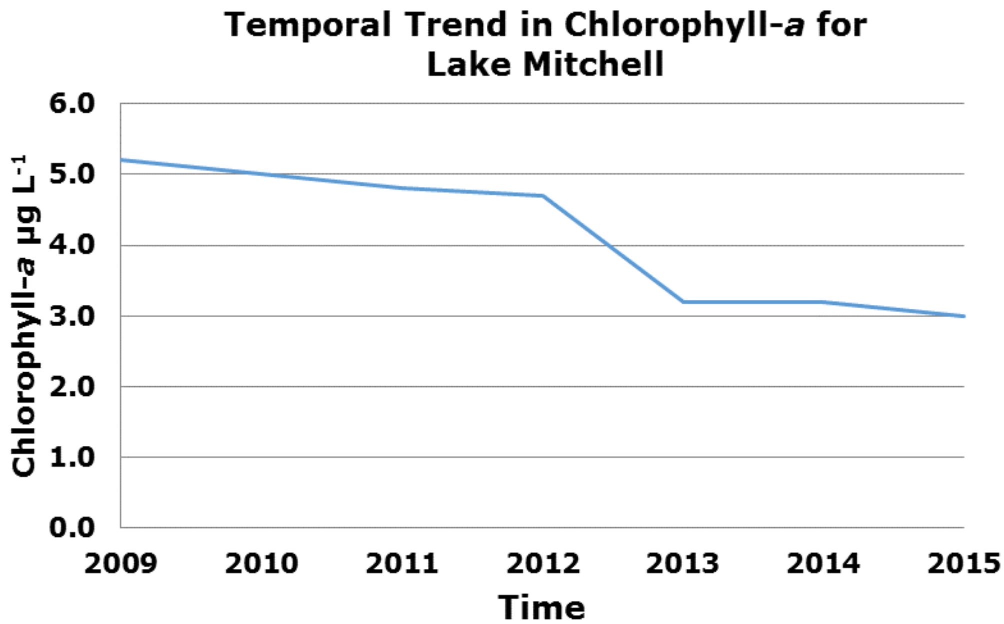
4.1.7 Total Phosphorus

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 0.20 mg L^{-1} 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 is measured in micrograms per liter (µg L^{-1}) with the use of a chemical auto analyzer. The TP concentrations in the deep basins of Lake Mitchell ranged from 0.020-0.030 mg L^{-1} in late August of 2015. The TP concentrations in the tributaries ranged from 0.030-0.040 mg L^{-1} in late August of 2015. The TP concentrations in the tributaries are higher than the lake and thus they serve as sources of nutrients to the lake.



4.1.8 Chlorophyll-a and Algae

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. High chlorophyll-*a* concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg L^{-1} are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg L^{-1} are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* is measured in micrograms per liter (µg L^{-1}) with the use of an acetone extraction method and a spectrometer. The chlorophyll-*a* concentrations in Lake Mitchell were determined by collecting composite samples of the algae throughout the water column at each of the two deep basin sites from just above the lake bottom to the lake surface. The chlorophyll-*a* concentrations in the deep basins were both 3.0 µg L^{-1} in August of 2015, which indicates a fair amount of planktonic algae throughout the water column. It is likely that these values are higher in the spring after spring runoff or in late summer when water temperatures increase and lead to the growth of algae in the water column (planktonic form) or on the surface (filamentous form). These concentrations have been declining over time, likely due to the presence of Zebra Mussels that filter algae from the water and lower the amount of algal pigment in the water.

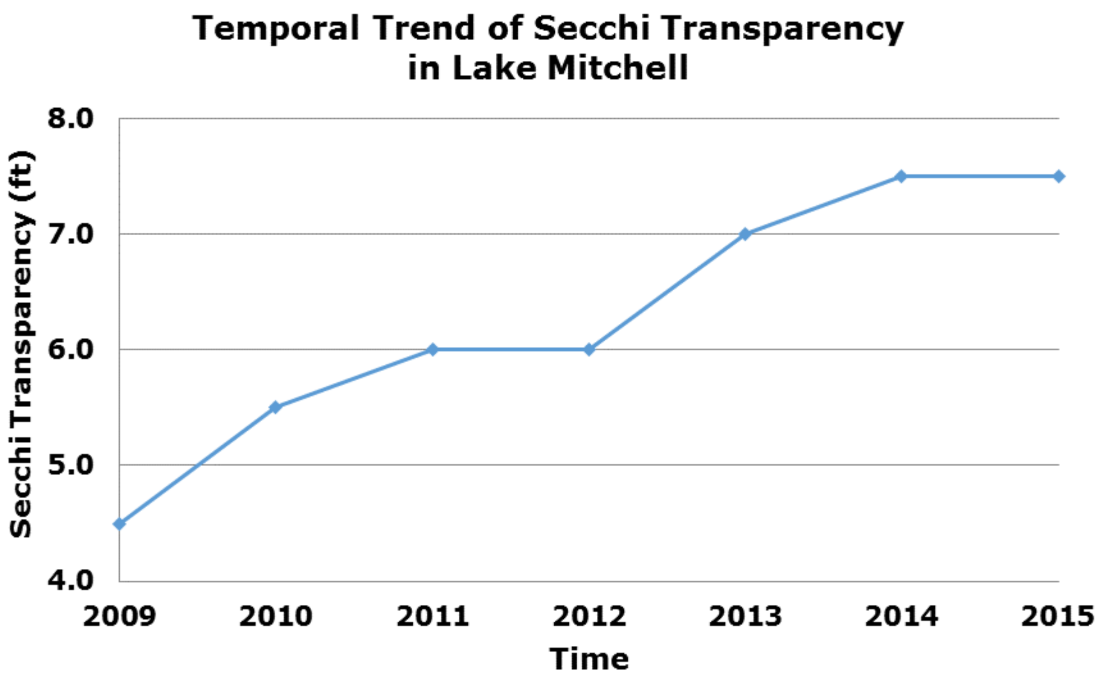


Algal genera from a composite water sample collected over the deep basin of Lake Mitchell were analyzed under a compound brightfield microscope. Genera are listed here in the order of most abundant to least abundant. The genera present included the Chlorophyta (green algae): The dominant genera present included *Haematococcus* sp., *Chloromonas* sp., *Chlorella* sp., *Scenedesmus* sp., *Cladophora* sp., *Hydrodictyon* sp., *Gleocystis* sp., *Micrasterias* sp., *Staurastrum* sp., *Euglena* sp., the Cyanophyta (blue-green algae): *Oscillatoria* sp.,; the Bascillariophyta (diatoms): *Synedra* sp., *Navicula* sp., *Fragilaria* sp., *Asterionella* sp., *Cymbella* sp., *Stephanodiscus* sp., *Pinnularia* sp., and *Diatomella* sp.

The aforementioned species indicate a diverse algal flora and represent a relatively balanced freshwater ecosystem, capable of supporting a strong zooplankton community in favorable water quality conditions. The waters of Lake Mitchell are rich in the Chlorophyta (green algae) and diatoms, which are indicators of productive but healthy waters that would support a robust zooplankton population for a healthy fishery.

4.1.9 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and is measured with the use of an 8-inch diameter standardized Secchi disk. 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. 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 Lake Mitchell averaged 7.5 feet over the deep basins of Lake Mitchell during the 2015 season. This transparency is adequate to allow abundant growth of algae and aquatic plants in the majority of the littoral (shallow) zone of the lake. 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. The Secchi transparency has increased steadily over the past few years which has also allowed more light to penetrate to the lake bottom and increase potential for submersed aquatic plant growth.



Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*ORP mV*	*Total Dissolved Solids mg L^{-1}*	*Total Alk. mg L^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*
0	71.8	8.1	7.5	157	0.9	133.6	58	47	0.020
10	70.6	7.8	7.6	159	0.9	145.7	62	49	0.020
19.5	68.2	7.6	7.5	157	0.9	112.9	69	47	0.030

Table 3. Lake Mitchell water quality parameter data collected over Deep Basin 1 on August 28, 2015.

Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*ORP mV*	*Total Dissolved Solids mg L^{-1}*	*Total Alk. mg L^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*
0	75.2	8.0	7.5	160	0.9	122.8	55	50	0.020
9	73.1	7.6	7.6	158	0.9	146.7	55	47	0.020
20	69.0	7.4	7.6	155	0.9	176.1	57	47	0.030

Table 4. Lake Mitchell water quality parameter data collected over Deep Basin 2 on August 28, 2015.

Tributary	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*ORP mV*	*Total Phos. mg L^{-1}*
Mitchell Creek	79.5	7.5	7.5	235	96	125.4	0.040
Brandy Brook	77.2	7.2	7.4	126	105	135.3	0.030
Gyttja	75.4	6.9	7.4	228	89	127.4	0.040

Table 5. Lake Mitchell tributary water quality parameter data collected on August 28, 2015.

4.2 Lake Mitchell Aquatic Vegetation Communities & Sampling Methods

Aquatic plants (macrophytes) are an essential component in the littoral zones of most lakes in that they serve as 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 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) 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. 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.

The aquatic plant sampling methods used for lake surveys of aquatic plant communities commonly consist of shoreline surveys, visual abundance surveys, transect surveys, AVAS surveys, and Point-Intercept Grid surveys. The Michigan Department of Environmental Quality (MDEQ) prefers that an Aquatic Vegetation Assessment Site (AVAS) Survey, or a GPS Point-Intercept survey (or both) be conducted on most inland lakes following large-scale aquatic herbicide treatments to assess the changes in aquatic vegetation structure and to record the relative abundance and locations of native aquatic plant species. Due to the large size and shallow mean depth of Lake Mitchell, a bi-seasonal GPS Point-Intercept grid matrix survey (Madsen et *al*. 1994; 1996; Figure 6) is conducted to assess all aquatic plants, including submersed, floating-leaved, and emergent species. In 2013-2015, the use of a side-scan sonar GPS device to scan the aquatic plant biovolume of the lake was conducted using a Lowrance® HDS 8 unit with BioBase® software. The scans for 2013-2015 are shown in Figures 7a-c below. Note the substantial reduction of red color in 2015 relative to 2013 and 2014. This represents a reduction in high-growing canopy-forming plants such as milfoil. Blue areas on the map represent lake bottom that lacks vegetation. The sections below describe the invasive and native aquatic vegetation communities present in Lake Mitchell throughout the past few years which related to successful management efforts.

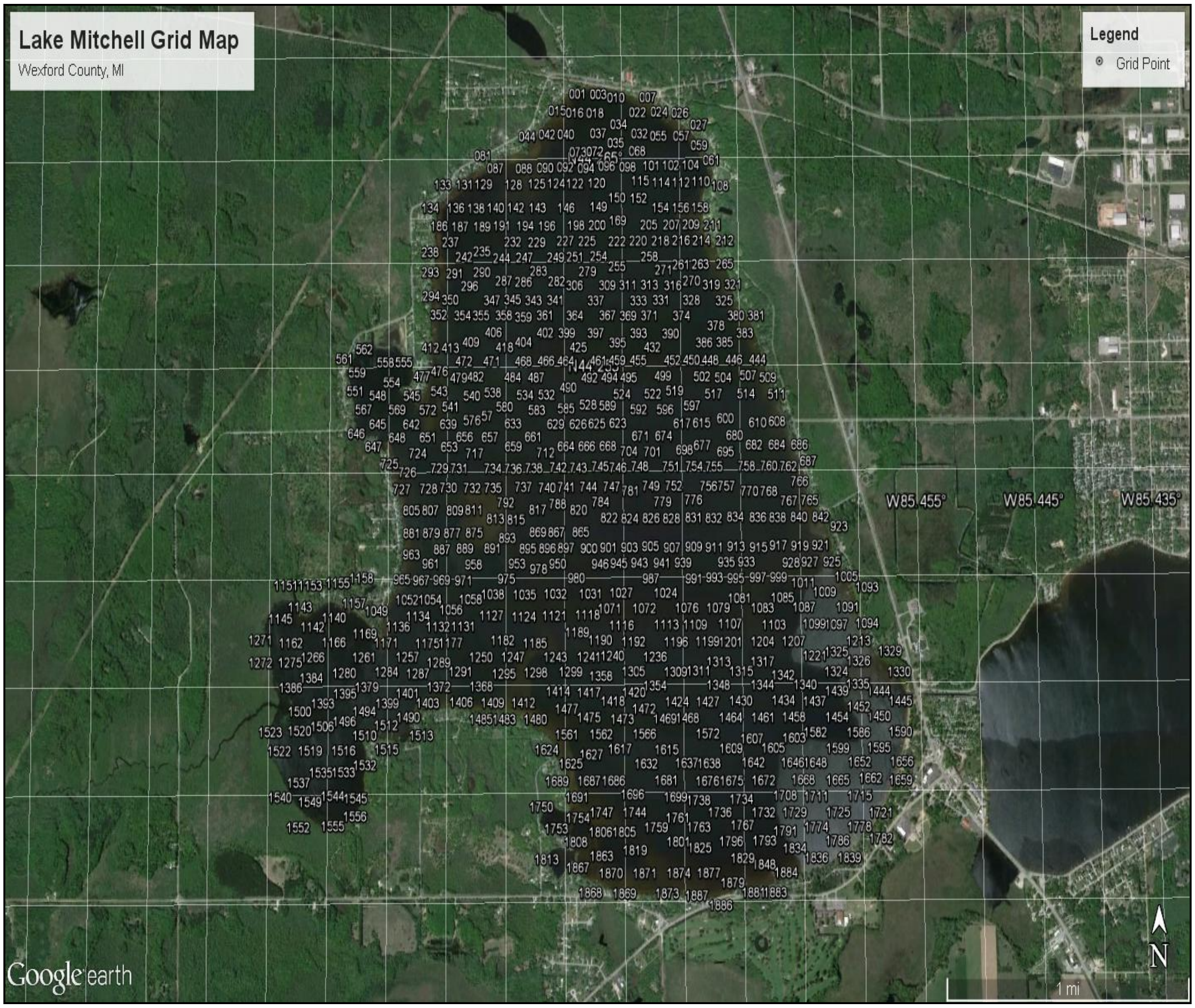


Figure 6. Lake Mitchell GPS Sampling Locations (annual).

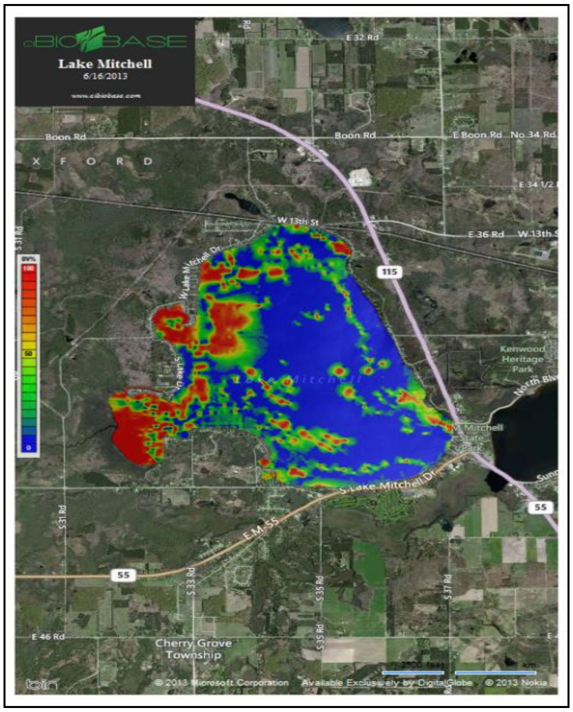


Figure 7 a. Lake Mitchell aquatic plant biovolume, 2013

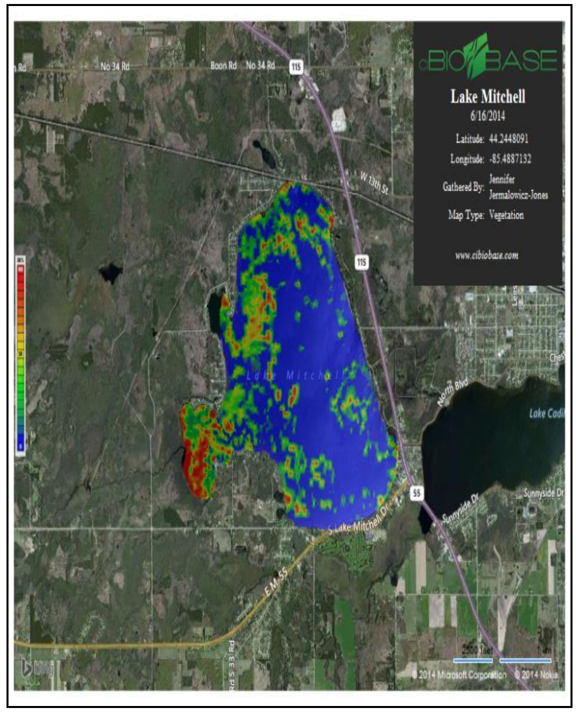


Figure 7 b. Lake Mitchell aquatic plant biovolume, 2014

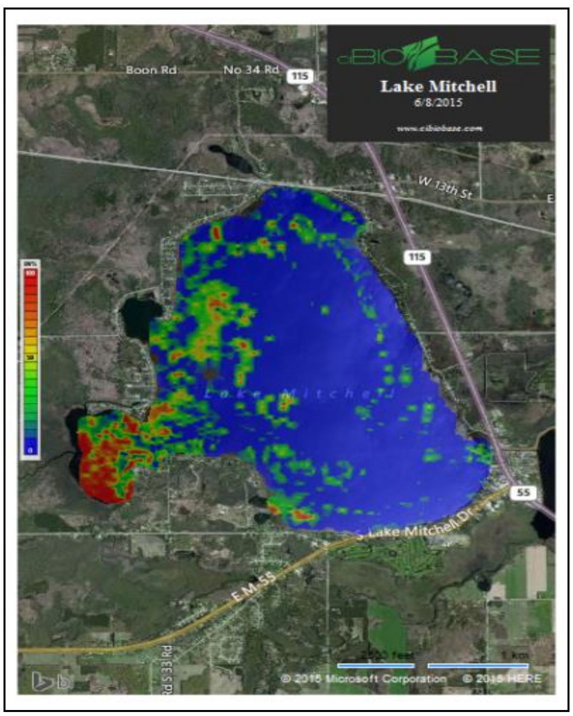


Figure 7 c. Lake Mitchell aquatic plant biovolume, 2015

4.2.1 Lake Mitchell Exotic Aquatic Macrophytes

Exotic aquatic plants (macrophytes) are not native to a particular site, but are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially if the lake has public access sites), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem.

Hybrid watermilfoil (*Myriophyllum spicatum var. sibiricum*; Figure 8) is an exotic aquatic macrophyte that is a serious problem in Michigan inland lakes. A similar watermilfoil species that is considered to be exotic by some scientists (*Myriophyllum heterophyllum*) in New Hampshire was found to have significant impacts on waterfront property values (Halstead et *al*., 2003). Moody and Les (2007) were among the first to determine a means of genotypic and phenotypic identification of the hybrid watermilfoil variant and further warned of the potential difficulties in the management of hybrids relative to the parental genotypes. It is commonly known that hybrid vigor is likely due to increased ecological tolerances relative to parental genotypes (Anderson 1948), which would give hybrid watermilfoil a distinct advantage to earlier growth, faster growth rates, and increased robustness in harsh environmental conditions. In regards to impacts on native vegetation, hybrid watermilfoil possesses a faster growth rate than Eurasian watermilfoil or other plants and thus may effectively displace other vegetation (Les and Philbrick 1993; Vilá et *al*. 2000).

Furthermore, the required dose of 2,4-D for successful control of the hybrid watermilfoil is likely to be higher since there is much more water volume at greater depths it can occupy and also due to the fact that hybrid watermilfoil has shown increased tolerance to traditionally used doses of systemic aquatic herbicides. There has been significant scientific debate in the aquatic plant management community regarding the required doses for effective control of hybrid watermilfoil.

During the summer of 2013, stems of hybrid watermilfoil in Lake Mitchell were collected by the aquatic herbicide manufacturer SePRO® and submitted to the SePRO® laboratory in North Carolina (U.S.A.) to determine which types and doses of aquatic herbicides would best kill the watermilfoil. Additionally, the stems were subjected to the aquatic herbicide fluridone (Sonar®), among others, in order to determine if that herbicide could possibly hold promise in future treatments. There are limitations to this method in that laboratory testing conditions are not the same as exist *in situ* in Lake Mitchell (i.e. the lake water chemistry is likely different from laboratory water chemistry and sediment chelation behavior was not an experimental component measured). Recent results indicate the hybrid watermilfoil within Lake Mitchell is susceptible to Sonar® at a 6 ppb bump 6 ppb dose and may possibly be an effective tool for future hybrid watermilfoil treatment. Fortunately, spot-treatments with systemic granular herbicides have been effective to date on the control of the hybrid watermilfoil but there is another tool available if resistance to these herbicides becomes an issue in the future.

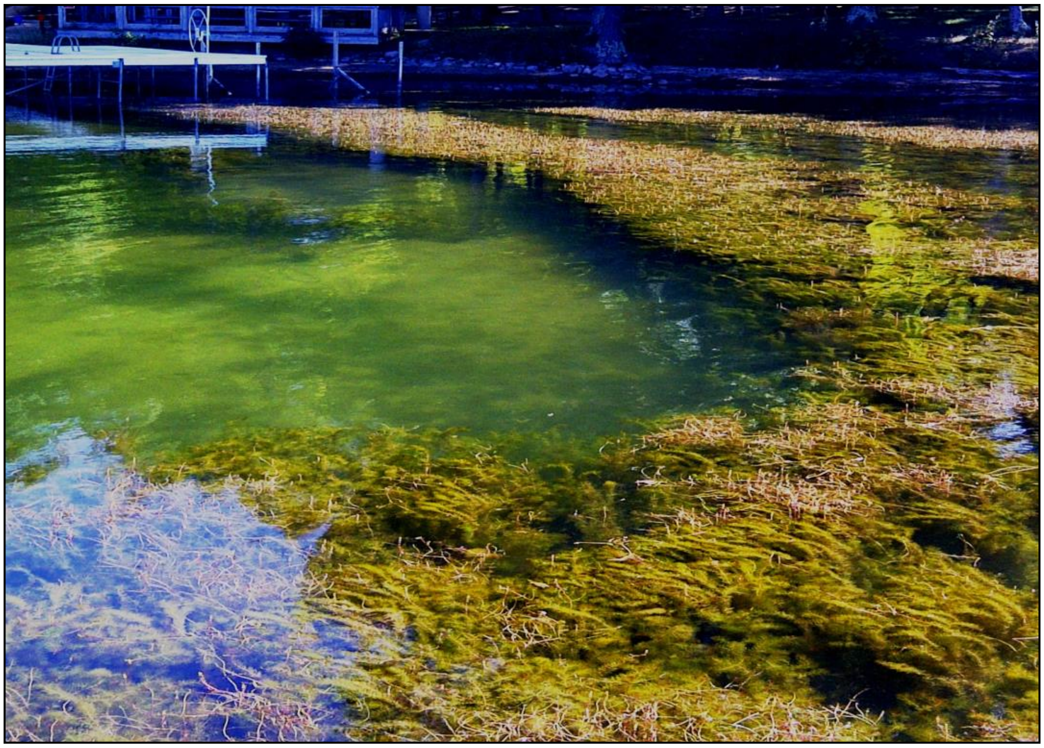


Figure 8. Hybrid watermilfoil (©RLS, 2006).

Curly-leaf Pondweed (*Potamogeton crispus*; Figure 9) 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. Fortunately, the plant naturally declines around mid-July in many lakes and is also amenable to mechanical harvesting. 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. This plant was found only in a few areas of the Franke Coves and Little Cove.

Purple loosestrife (*Lythrum salicaria*; Figure 10) is an invasive (i.e. exotic) emergent aquatic plant that inhabits wetlands and shoreline areas. It has showy magenta-colored flowers that bloom in mid-July and terminate in late September. The seeds are highly resistant to tough environmental conditions and may reside in the ground for extended periods of time. It exhibits rigorous growth and may out-compete other favorable native emergents such as cattails (*Typha latifolia*) or native swamp loosestrife (*Decodon verticillatus*) and thus reduce the biological diversity of Lake Mitchell. The plant is spreading rapidly across the United States and is converting diverse wetland habitats to monocultures with substantially lower biological diversity. This plant was found scattered around the lake shoreline mainly around the Coves and the Torenta Canal. A list of all invasive species found in and around Lake Mitchell in 2015 is shown below in Table 6. The distribution of hybrid watermilfoil in 2015 is shown in Figure 11.

Exotic Aquatic Plant Species	***Common Name***	***Growth Habit***	***Abundance in or around Lake Mitchell***
Myriophyllum spicatum var. sibiricum	Hybrid watermilfoil	Submersed; Rooted	Sparse; Main lake, Coves
Potamogeton crispus	Curly-leaf Pondweed	Submersed; Rooted	Rare, Franke Coves
Lythrum salicaria	Purple Loosestrife	Emergent	Shoreline around Canal and Coves

Table 6. Lake Mitchell exotic aquatic plant species (June, 2015).

Figure 9. Curly-leaf Pondweed (©RLS).

Figure 10. Purple Loosestrife (©RLS).

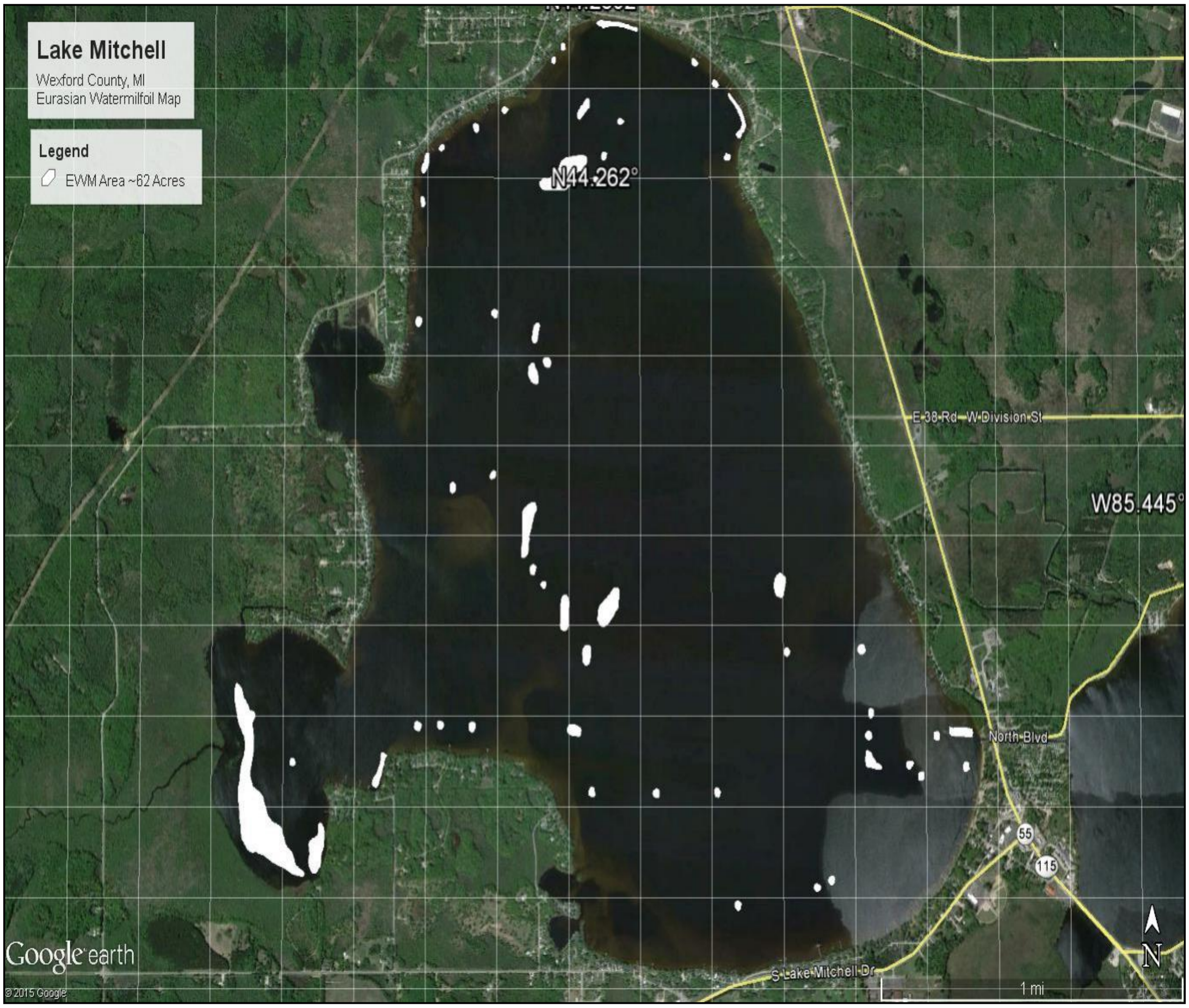


Figure 11. Distribution of Hybrid watermilfoil around Lake Mitchell (June 8-9, 2015).

4.2.2 Lake Mitchell 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 (Watermilfoils). 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.

Lake Mitchell contained 18 native submersed, 4 floating-leaved, and 5 emergent aquatic plant species, for a total of 27 native aquatic macrophyte species (Table 7). Photos of all native aquatic plants are shown below in Figures 12-38. The majority of the emergent macrophytes may be found along the shoreline of the lake. Additionally, the majority of the floating-leaved macrophyte species can be found near the shoreline and in the Coves. This is likely due to enriched sediments and shallower water depth with reduced wave energy that facilitates the growth of aquatic plants with various morphological forms.

The dominant aquatic plants in the main part of the lake included the Pondweeds and Bladderwort. The Pondweeds grow tall in the water column and serve as excellent fish cover. In dense quantities, they can be a nuisance for swimming and boating and can be controlled with selective contact herbicide management. Bladderwort was also very abundant in many areas and lies on the bottom where it traps zooplankton in the water and uses them for a food source for growth since the plant is rootless and cannot obtain nutrient from the sediment.

There were also four floating-leaved macrophyte species, including *Nymphaea odorata* (White-Waterlily), which is critical for housing macroinvertebrates and should be protected and preserved in non-recreational areas to serve as food sources for the fishery and wildlife around the lake, and *Nuphar variegata* (Yellow-Waterlily), which harbors seeds that are eaten by waterfowl, and *Brasenia schreberi* (Watershield) which appears like small "footballs" on a stalk that are covered with mucilage on the underside of the leaf, and the tiny, (Duckweed), *Lemna trisulca* which was noted in the back of the Torenta Canal. The emergent plants, such as (Cattails), and *Scirpus acutus* (Bulrushes) are critical for shoreline stabilization as well as for wildlife and fish spawning habitat. The presence of Purple Loosestrife around the Lake Mitchell shoreline is an imminent threat to the emergent macrophyte populations, which could be displaced if left untreated or removed. Fortunately, biological control has been implemented as a treatment for this invasive and that is discussed later in this report.

Aquatic Plant Species	***Common Name***	***Plant Growth Form***	***% Coverage of Sampled Lake Area (2015)***
Chara vulgaris (macroalga)	Muskgrass	Submersed; Rooted	15
Potamogeton pectinatus	Sago Pondweed	Submersed; Rooted	15
Potamogeton robbinsii	Fern-leaf Pondweed	Submersed; Rooted	61
Potamogeton gramineus	Variable-leaf Pondweed	Submersed; Rooted	27
Potamogeton praelongus	White-stem Pondweed	Submersed; Rooted	42
Potamogeton richardsonii	Clasping-leaf Pondweed	Submersed; Rooted	22
Potamogeton illinoensis	Illinois Pondweed	Submersed; Rooted	16
Potamogeton amplifolius	Large-leaf Pondweed	Submersed; Rooted	19
Myriophyllum sibiricum	Northern Watermilfoil	Submersed; Rooted	6
Megalodonta beckii	Water Marigold	Submersed; Rooted	10
Ceratophyllum demersum	Coontail	Submersed; Non-rooted	9
Elodea canadensis	Common Waterweed	Submersed: Rooted	18
Utricularia vulgaris	Common Bladderwort	Submersed; Non-rooted	33
Utricularia minor	Mini Bladderwort	Submersed; Non-rooted	16
Najas guadalupensis	Southern Naiad	Submersed; Rooted	13
Najas flexilis	Slender Naiad	Submersed; Rooted	24
Myriophyllum tenellum	Leafless Watermilfoil	Submersed; Rooted	36
Potamogeton pusillus	Small-leaf Pondweed	Submersed; Rooted	21
Nymphaea odorata	White Waterlily	Floating-leaved	11
Nuphar variegata	Yellow Waterlily	Floating-leaved	9
Brasenia schreberi	Watershield	Floating-leaved	11
Lemna trisulca	Star Duckweed	Floating-Leaved; Non-rooted	3
Pontedaria cordata	Pickerelweed	Emergent	6
Typha latifolia	Cattails	Emergent	12
Scirpus acutus	Bulrushes	Emergent	40
Decodon verticillatus	Swamp Loosestrife	Emergent	7
Eleocharis acicularis	Spikerush	Emergent	21

Table 7. Lake Mitchell native aquatic plant species (June 8-9, 2015).

Figure 12. Chara (Muskgrass)

Figure 13. Thin-leaf Pondweed

Figure 14. Large-leaf Pondweed ©RLS

Figure 15. Variable-leaf Pondweed ©RLS

Figure 16. Fern-leaf Pondweed ©RLS

Figure 17. White-stem Pondweed ©RLS

Figure 18. Slender Naiad ©RLS

Figure 19. Clasping-leaf Pondweed ©RLS

Figure 20. Mini Bladderwort ©RLS

Figure 21. Leafless Watermilfoil ©RLS

Figure 22. Illinois Pondweed ©RLS

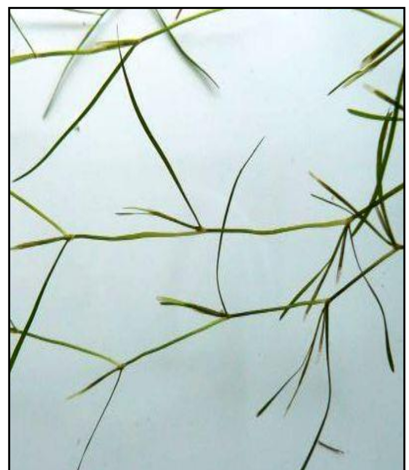


Figure 23. Small-leaf Pondweed ©RLS

Figure 24. Northern Watermilfoil ©RLS

Figure 25. Elodea ©RLS

Figure 26. Water Marigold ©RLS

Figure 27. Coontail ©RLS

Figure 28. Bladderwort ©RLS

Figure 29. Southern Naiad ©RLS

Figure 30. Bulrushes ©RLS

Figure 31. Pickerelweed ©RLS

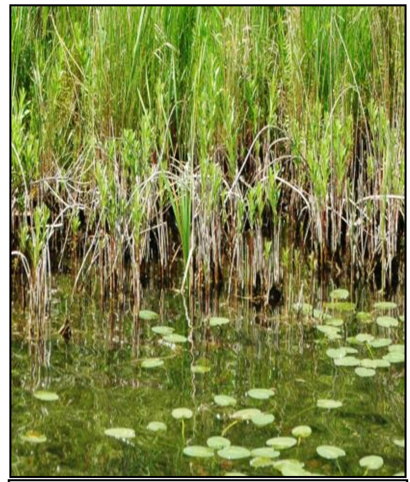


Figure 32. Swamp Loosestrife ©RLS

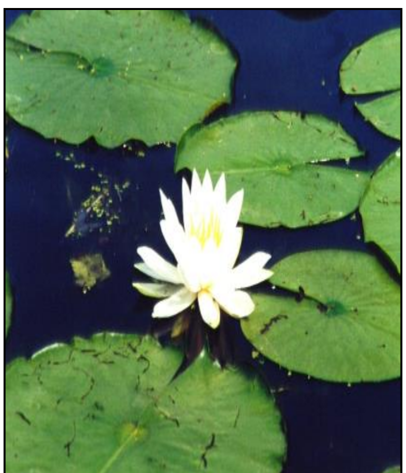


Figure 33. White Waterlily ©RLS

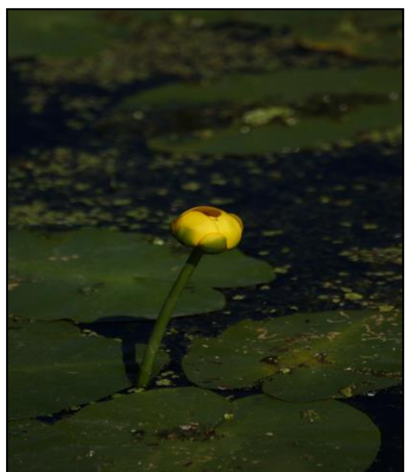


Figure 34. Yellow Waterlily ©RLS

Figure 35. Watershield ©RLS

Figure 36. Cattails ©RLS

Figure 37. Star Duckweed

Figure 38. Spikerush ©RLS

5.0 LAKE MITCHELL MANAGEMENT IMPROVEMENT METHODS

5.1 Lake Mitchell Aquatic Plant Management Methods

Improvement strategies, including the management of exotic aquatic plants, control of land and shoreline erosion, and further nutrient loading from external sources, are available for the various problematic issues facing Lake Mitchell. The lake management components involve both within-lake (basin) and around-lake (watershed) solutions to protect and restore complex aquatic ecosystems. The goals of a lake improvement program are to improve aquatic vegetation biodiversity, improve water quality and wildlife habitat, protect recreational use of a water resource and protect waterfront property values. Regardless of the management goals, all management decisions must be site-specific and should consider the socio-economic, scientific, and environmental components of the lake management plan (Madsen 1997).

The management of invasive submersed and emergent and some nuisance native aquatic plants is necessary in Lake Mitchell 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 some are capable of achieving strong results when used properly. Exotic aquatic plant species and nuisance-level native aquatic vegetation should be managed with solutions that will yield long-term results.

5.1.1 Aquatic Herbicides and Applications

The use of aquatic chemical herbicides is regulated by the MDEQ under Part 33 (Aquatic Nuisance) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, and requires a permit. The permit contains a list of approved herbicides for a particular body of water, as well as dosage rates, treatment areas, and water use restrictions. Contact and systemic aquatic herbicides are the two primary categories used in aquatic systems.

Contact herbicides such as diquat 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. There are often restrictions with usage of some systemic herbicides around shoreline areas that contain shallow drinking wells. In Lake Mitchell, the use of contact herbicides is recommended for the control of invasive Curly-leaf Pondweed in the Coves with the use of hydrothol (Aquathol-K®) at a dose of 2.0-3.0 gallons per acre. Additionally, Aquathol-K® may also be used in areas of dense pondweed growth where boating and swimming may be impaired. Flumioxazin (Clipper®) is effective on other nuisance growth such as excessive lily pad growth, Elodea, or Coontail may be used with chelated copper (Cutrine®) for nuisance filamentous algae which can occur in the Torenta Canal.

Systemic herbicides such as 2, 4-D and Triclopyr are the two primary systemic herbicides used to treat Hybrid watermilfoil that grows in less than 25% of a lake. 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. Fortunately, the patchy distribution of hybrid watermilfoil in Lake Mitchell has been effectively spot-treated with granular triclopyr nearshore and granular 2,4-D in offshore areas. Triclopyr must be used in near shore areas with shallow well (< 30 feet deep) restrictions.

5.1.2 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 39). 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 watermilfoil since the plant may fragment when cut and re-grow on the lake bottom. Mechanical harvesting does not require a permit from the Michigan Department of Environmental Quality (MDEQ); however, some counties require a launch site use permit from the Michigan Department of Natural Resources (MDNR) if a public access site is present.

Figure 39. A mechanical harvester. Photo courtesy of Dave Foley.

5.1.3 Diver Assisted Suction Harvesting (DASH)/Dredging

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 40) involves hand removal of individual plants by a SCUBA diver in selected areas of lake bottom with the use of a hand-operated suction hose. Samples are dewatered on land or removed via fabric bags to an offsite location. This method is generally recommended for small (less than 1 acre) spot removal of vegetation since it is costly on a large scale. It may be used in the future to remove small areas of growth in the Franke Coves or in the Torenta Canal. This process may remove either plant material or sediments and requires a joint MDEQ/USACE bottomlands permit. Furthermore, this activity may cause re-suspension of sediments (Nayar et *al*., 2007) which may lead to increased turbidity and reduced clarity of the water.

This method is a possible option for the removal of small areas of lily pads or sediment islands or areas where a mechanical harvester may not be able to access (such as some shallow parts of the Franke Coves and some parts of the Torenta Canal).

Figure 40. A DASH boat for hand-removal of watermilfoil or other nuisance vegetation. ©Restorative Lake Sciences, LLC

5.1.4 Biological Control

The use of the aquatic weevil, *Euhrychiopsis lecontei* (Figure 41) to control Hybrid watermilfoil has been implemented in a few lakes in Michigan. The use of the weevil for bio-control is both inundative and classical (Harley and Forno, 1992). The inundative approach refers to the application of weevils at a higher density than the existing population to damage watermilfoil. The classical approach refers to the use of a host-specific herbivore (weevil) to damage the target plant (watermilfoil). The weevil naturally exists in many of our lakes; however, the lack of adequate populations in many lakes requires that they be implanted or stocked for successful control of watermilfoil. The weevil feeds almost entirely on watermilfoil and will leave native aquatic species unharmed if adequate amounts of watermilfoil are present. The weevil burrows into the stems of watermilfoil and damages the vascular tissue, thereby reducing the plant's ability to store carbohydrates (Newman et *al*. 1996). Eventually, the stems lose buoyancy and the plant decomposes on the lake bottom.

Research has shown that the weevils require a substantial amount of aquatic plant biomass for successful control of watermilfoil. In addition, the weevils require adequate over-wintering habitat since they overwinter within shoreline vegetation. Lakes with sparse watermilfoil distribution are not ideal candidates for the watermilfoil weevil.

Previous peer-reviewed scientific research by Newman and Biesboer (2000) demonstrated that the requirements for weevil stocking density to obtain adequate control of watermilfoil may be as high as 150-300 weevils per square meter. It is important to note that this number refers to a "stocking density", which implies the number of weevils that should be stocked in a stocking area for ultimate population growth. It does not mean that each acre within the lake must have this density stocked to obtain the desired result.

This weevil was previously implemented in Big Cove on Lake Mitchell in 2010 and was monitored for a few years post-implementation. The results were not promising given the very high stocking density of over 10,000 weevil units per acre. Additionally, weevils were no longer available for inland lake stocking beginning in 2015.

The land beetle, *Galerucella sp.* (Figure 42) has been effective on the treatment of shoreline Purple Loosestrife in many locations throughout the Midwest and especially in Michigan. However, these beetles usually prefer a large stand of Purple Loosestrife to promote their population. In July of 2012, beetles that were cultured at the Kalamazoo Nature Center (Kalamazoo, Michigan) were released into areas around Lake Mitchell that had adequate stands of the plant. A total of 40 cultured pots have been released each July since into areas that contain significant stands of Purple Loosestrife plants and that were previously stocked (Figure 43). A damage index was developed that assesses the degree of damage observed on individual florescences (flowers) on individual Purple Loosestrife plants. Overall, many plants have sustained significant flower damage and future stocking is recommended in the same stocking density as in 2012-2015.

Figure 41. The watermilfoil weevil (*Euhrychiopsis lecontei*). Photo from R. Newman used with permission.

Figure 42. *Galerucella* sp. The “loosestrife” beetle

Figure 43. *Galerucella* sp. stocking locations around Lake Mitchell (2012-2015).

5.1.5 *Laminar Flow Aeration and Bioaugmentation*

Laminar flow aeration systems (Figure 44) are retrofitted to a particular site and account for variables such as water depth and volume, contours, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute dissolved oxygen throughout the lake sediments for efficient microbial utilization. A laminar flow aeration system utilizes diffusers which are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help to purge the lake sediment pore water of gases such as hydrogen sulfide (H_2S). In addition to the placement of the diffuser units, the concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment. Beutel (2006) found that lake oxygenation eliminates release of NH_3+ from sediments through oxygenation of the sediment-water interface. Allen (2009) demonstrated that NH_3+ oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry wt day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt day^{-1} in controls.

Although this is a relatively new area of research, recent case studies have shown promise on the positive impacts of laminar flow aeration systems on aquatic ecosystem management with respect to organic matter degradation and resultant increase in water depth, and rooted aquatic plant management in eutrophic ecosystems (Jermalowicz-Jones, 2010; 2011). Toetz (1981) found evidence of a decline in *Microcystis* algae (a toxin-producing blue-green algae) in Arbuckle Lake in Oklahoma. Other studies (Weiss and Breedlove, 1973; Malueg et *al.*, 1973) have also shown declines in overall algal biomass. The philosophy and science behind the laminar flow aeration system is to reduce the organic matter layer in the sediment so that a significant amount of nutrient is removed from the sediments and excessive sediments are reduced to yield a greater water depth.

Benefits and Limitations of Laminar Flow Aeration

The Laminar Flow Aeration system has some limitations including the inability to break down mineral sediments and the requirement of a constant Phase I electrical energy source to power the units.

Design of the Laminar Flow Aeration System

The design of a laminar flow system would be retrofitted to an area of interest. The system has several components which consists of in-water components such as micro-porous ceramic diffusers, self-sinking airline, and bacteria and enzyme treatments. Once the system has been installed, the MDEQ has instituted a required minimum sampling protocol to monitor the efficacy of the system for the intended purposes as determined by stakeholders.

Due to the high quantity of organic matter in Lake Mitchell, the reduction of organic muck is likely. However, it would be most practical for the Torenta Canal or the Coves due to the high cost of installation and operation in the main lake. The primary use of the technology would be for muck reduction in the Canal and for deepening the Coves in the future as a possible alternative to dredging. It would also reduce the presence of cyanobacteria and other filamentous algae in the Torenta Canal.

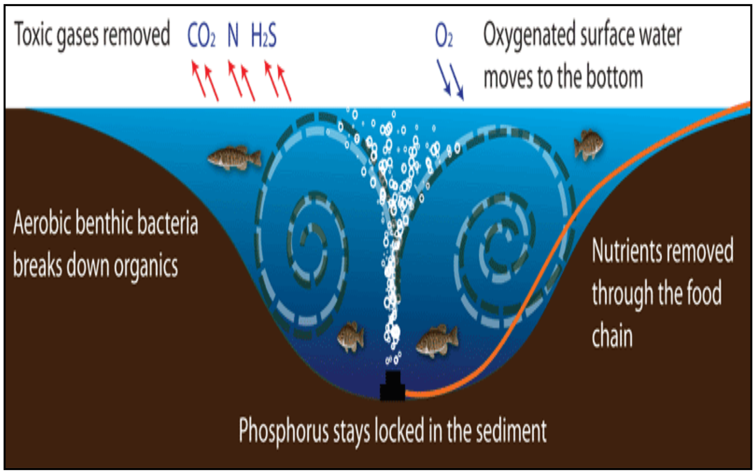


Figure 44. A diagram showing the laminar flow aeration mechanisms. ©Restorative Lake Sciences, LLC

5.2 Lake Mitchell Watershed Management Methods

In addition to the proposed treatment of Hybrid Watermilfoil in Lake Mitchell, it is recommended that Best Management Practices (BMP's) be implemented to improve the lake's water quality. The guidebook, Lakescaping for Wildlife and Water Quality (Henderson et *al*. 1998) provides the following guidelines:

1) Maintenance of brush cover on lands with steep slopes (those > 6%; see above soil table)
2) Development of a vegetation buffer zone 25-30 feet from the land-water interface with approximately 60-80% of the shoreline bordered with vegetation
3) Limiting boat traffic and boat size to reduce wave energy and thus erosion potential
4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion
5) Using only <u>native</u> genotype plants (those native to Lake Mitchell 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

The book may be ordered online at: http://web2.msue.msu.edu/bulletins/mainsearch.cfm.

5.2.1 Lake Mitchell Erosion and Sediment Control

The construction of impervious surfaces (i.e. paved roads and walkways, houses) should be minimized and kept at least 100 feet from the lakefront shoreline to reduce surface runoff potential. In addition, any wetland areas around Lake Mitchell should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat. Construction practices near the lakeshore should minimize the chances for erosion and sedimentation by keeping land areas adjacent to the water stabilized with rock, vegetation, or wood retaining walls. This is especially critical in areas that contain land slopes greater than 6%. Erosion of land 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, 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 Lake Mitchell. The emergent aquatic plant, *Scirpus* sp. (Bulrushes) present around Lake Mitchell offers satisfactory stabilization of shoreline sediments and assists in the minimization of sediment release into the lake.

5.2.2 Lake Mitchell Nutrient Source Control

Based on the high ratio of nitrogen to phosphorus (i.e. N: P > 15), any additional inputs of phosphorus to the lake are likely to create additional algal and aquatic plant growth. Accordingly, RLS recommends the following procedures to protect the water quality of Lake Mitchell:

1) Avoid the use of lawn fertilizers that contain phosphorus (P). P is the main nutrient required for aquatic plant and algae growth, and plants grow in excess when P is abundant. When possible, water lawns with lake water that usually contains adequate P for successful lawn growth. If you must fertilize your lawn, assure that the middle number on the bag of fertilizer reads “0” to denote the absence of P. If possible, also use low N in the fertilizer or use lake water.
2) Preserve riparian vegetation buffers around lake (such as those that consist of Cattails, Bulrushes, and Swamp Loosestrife), since they act as a filter to catch nutrients and pollutants that occur on land and may run off into the lake. As an additional bonus, Canada geese (*Branta canadensis*) usually do not prefer lakefront lawns with dense riparian vegetation because they are concerned about the potential of hidden predators within the vegetation.
3) Do not burn leaves near the lake shoreline since the ash is a high source of P. The ash is lightweight and may become airborne and land in the water eventually becoming dissolved and utilized by aquatic vegetation and algae.
4) Assure that all areas that drain into the lake from the surrounding land are vegetated and that no fertilizers are used in areas with saturated soils (see soil table above).

6.0 LAKE MITCHELL IMPROVEMENT CONCLUSIONS & RECOMMENDATIONS

The use of aquatic chemical herbicides are regulated by the MDEQ under Part 33 (Aquatic Nuisance) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, and require a permit. 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. Wherever possible, it is preferred to use a granular systemic aquatic herbicide for longer-lasting, localized aquatic plant control. The continued use of Sculpin G® and Renovate OTF LZR® is recommended for the spot-treatment of invasive hybrid watermilfoil throughout Lake Mitchell.

Doses of both should not be less than 240 pounds per acre for optimal efficacy (as has been proven in recent years).

The Coves should be managed for both navigability and aesthetics and thus strong contact herbicides that offer season-long control are recommended. Clipper® contains the active ingredient, flumioxazin, which works best for actively growing submersed vegetation of all types including Elodea, Pondweeds, Lily pads, and even some types of algae. RLS recommends treating all of the infested areas in early to mid-spring at a dose of 200-400 ppb. Aquathol-K may also be used to treat the dense pondweed growth at a dose of 2.0-3.0 gallons per acre with adjuvant. Mechanical harvesting may be pursued in late summer if removal of dead biomass is desired in the Coves and Torenta Canal. Additionally, biological treatments to reduce nuisance cyanobacteria may also be needed in the Torenta Canal and may require the need of unique enzyme blends and chelated copper products. Aeration and bioaugmentation is strongly encouraged for the long-term improvement of both of the Franke Coves and the Torenta Canal. Care must be taken wherever possible to protect the diversity of native aquatic vegetation in Lake Mitchell which is so pivotal to the fishery and overall lake health. RLS will also continue to conduct rigorous whole-lake scans and surveys to monitor the changes in the hybrid watermilfoil population as well as all of the native aquatic plant species. RLS limnologists will continue to monitor the Purple Loosestrife beetle efficacy in all of the previously stocked areas. Additional stocking will occur during the summer of 2016 and beetles will be applied to all previously stocked areas.

Water quality parameters as noted above will be monitored in the lake and tributaries during 2016.

A proposed lake improvement budget for 2016-2019 is provided below based on the aforementioned study recommendations:

6.1 Cost Estimates for Lake Mitchell Improvements

The proposed aquatic vegetation management program for the control of Hybrid watermilfoil and nuisance native aquatic plant growth in Lake Mitchell would begin during the 2016 season. The reduction in acres of watermilfoil would likely follow in 2016 and beyond and thus that portion of the annual budget may be spared and a surplus may continue in future years. The line items including the contact herbicides and permit fees will likely exist annually due to the temporary nature of contact herbicides on pondweeds and some groups of aquatic plants. A breakdown of estimated costs associated with the various necessary treatment in Lake Mitchell is presented in Table 8. 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).

Proposed Lake Mitchell Management Improvement Item	***Estimated 2016 Cost***	***Estimated 2017 Cost[4]***	***Estimated 2018-2019 Cost[5]***
Herbicides (2,4-D/Triclopyr) for Hybrid Watermilfoil[1] (plus MDEQ permit fee)	$98,000	$98,000	$98,000
Weed Pickup	$8,000	$8,000	$8,000
Professional Limnologist Services (limnologist surveys, contractor oversight, education)[2]	$16,000	$16,000	$16,000
Attorney Fees	$5,000	$5,000	$5,000
Assessment Appeals	$3,000	$3,000	$3,000
Purple Loosestrife Control	$2,000	$2,000	$2,000
Website Newsletter	$2,000	$2,000	$2,000
Newsletter Preparation	$800	$800	$800
Audit, Bond, Insurance	$1,400	$1,400	$1,400
Professional Membership	$100	$100	$100
Mailings, Publication	$800	$800	$800
Contingency (15%)[3]	$20,400	$20,400	$20,400
TOTAL ANNUAL ESTIMATED COST	$157,500	$157,500	$157,500
APPROX. ANNUAL COST PER UNIT OF BENEFIT	$225.00	$225.00	$225.00

Table 8. Lake Mitchell Improvement Program Proposed Budget (2016-2019).

[1] Herbicide treatment scope for the treatment of Hybrid watermilfoil is proposed to decline annually due to aggressive treatment with the use of systemic herbicides which attack the entire plant in the first year of treatment. As a result, it is hypothesized that 75% of year 1 (systemic herbicide) budget be allocated for year 2.

[2] Professional services includes annual GPS-guided, aquatic vegetation surveys, pre and post-treatment surveys for aquatic plant control methods, oversight and management of the aquatic plant control program, processing of all invoices from contractors and others billing for services related to the improvement program, education of local riparians, and attendance at all regularly scheduled Lake Mitchell Improvement Board meetings.

[3] Contingency is 15% of the total project cost, to assure that extra funds are available for unexpected expenses. Note: Contingency may be advised and/or needed for future treatment years.

[4] Cost estimates for 2017 based on 75% of the herbicide treatment costs for 2016. Note:
Herbicide unit costs given for 2017 may change in 2017 and beyond due to cost of living adjustments for the contractor services and/or products.
[5] Costs of the proposed program for years 2018-2019 are estimates only and may change
based on the distribution and/or abundance of hybrid watermilfoil or other invasives, and costs of products and contractor services.

7.0 LITERATURE CITED

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

Anderson, E. 1948. Hybridization of the habitat. *Evolution* 2:1-9.

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

Harley, K.L.S., and I.W. Forno. 1992. Biological control of weeds: a handbook for practitioners and students. 74 pp. Inkata Press.

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

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. Envrion. Manage 30 (3): 391-398.

Les, D.H., and C.T. Philbrick. 1993. Studies of hybridization and chromosome number variation in aquatic angiosperms: Evolutionary implications. *Aquatic Botany* 44: 181-228.

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.

Madsen, J.D., J.A. Bloomfield, J.W. Sutherland, L.W. Eichler, and C.W. Boylen. 1996. The aquatic plant community of Onondaga Lake: Field survey and plant growth bioassays of lake sediments, *Lake and Reservoir Management* 12:73-79.

Madsen, J.D. G.O. Dick, D. Honnell, J. Schearer, and R.M. Smart. 1994. Ecological assessment of Kirk Pond, Miscellaneous Paper A-94-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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

Moody, M.L., and D.H. Les. 2007. Geographic distribution and genotypic composition of invasive hybrid watermilfoil (*Myriophyllum spicatum* x *M. sibiricum*) populations in North America. *Biological Invasions* 9: 559-570.

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.

Newman, R.M., and D.D. Biesboer. 2000. A decline of Eurasian watermilfoil in Minnesota associated with the milfoil weevil *Euhrychiopsis lecontei*. *J. Aquatic Plant Management* 38:105-111.

Newman, R. M., K.L. Holmberg, D. D. Biesboer, and B.G. Penner. 1996. Effects of a potential biocontrol agent, *Euhrychiopsis lecontei*, on Eurasian milfoil in experimental tanks. *Aquat. Bot.* 53: 131-150.

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

Vilá, M., E. Weber, and C.M. D'Antonio. 2000. Conservation implications of invasion by plant hybridization. *Biological Invasions* 2:207-217.

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

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

I, Lon Michael Cooper, a licensed Professional Engineer in the state of Michigan (PE #44013) have reviewed this lake improvement feasibility study report prepared for the Lake Mitchell Improvement Board, pursuant to P.A. 451 of 1994, as amended

Signed Lon Michael Cooper

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