Barron Lake Management Plan Study
Cass County, Michigan

Provided for: Barron Lake Improvement Association

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1.0 EXECUTIVE SUMMARY

Barron Lake is a 216-acre lake located in Sections 20, 21, 28, and 29 of Howard Township (T7S, R16W), in Cass County, Michigan. The lake also has an augmentation well located at the northeast end of the lake which pumps cool groundwater into the lake. An outlet structure is located at the south end of the lake. The lake has approximately 2.75 miles of shoreline and a mean depth of approximately 15.4 feet and a maximum depth of 32.1 feet (Restorative Lake Sciences, 2017). The lake water volume was estimated at 3,043.5 acre-feet (Restorative Lake Sciences, 2017). These lake parameters were determined using a highly accurate benthic scanning instrument and utilizing satellite-dependent software. The immediate watershed (area draining directly into the lake) is approximately 1,620 acres and the watershed to lake ratio is 7.5 which denotes a moderate-sized watershed.

A whole-lake aquatic plant survey and scan of aquatic vegetation biovolume was conducted on August 14, 2017. The lake scan consisted of 11,236 GPS points and the aquatic vegetation sampling survey utilized nearly 429 points in the lake. Two invasive species were found in or around Barron Lake including Eurasian Watermilfoil and emergent Phragmites. At the time of the survey approximately 1.0 acre of Phragmites was found and 1.50 acres of milfoil were found. The milfoil acreage may be higher prior to treatments in the spring. Barron Lake has a fair biodiversity of native aquatic plants with 12 submersed, 1 floating-leaved, and 2 emergent aquatic plant species for a total of 15 native aquatic plant species.

Restorative Lake Sciences recommends an annual whole-lake GPS survey and scan to determine the relative abundance of all native and invasive aquatic plant species, their relative abundance, and the percent cover of the lake surface area. This data will be used each year to make management decisions about where to treat and what method(s) to use.

Restorative Lake Sciences also recommends that spot-treatments with highly selective granular systemic aquatic herbicides be used to treat the exotic hybrid watermilfoil within the lake and that the emergent Phragmites be treated with contact herbicides and/or hand-pulled. A reduction in the herbicide treatment areas is projected for ongoing years of the program if no other invasives enter the Barron Lake ecosystem. Methods for reducing the spread of invasives in Barron Lake are offered later in this study report.

Restorative Lake Sciences recommends installation of a whole-lake laminar flow aeration (LFA) system with bio augmentation (microbes). Aeration would increase the dissolved oxygen and improve the lake fishery, reduce muck and excess algae, and may even reduce milfoil if the sediment ammonia is also reduced. LFA will also reduce nutrients such as phosphorus which are highly elevated at the lake bottom. If implemented, RLS will evaluate the efficacy of the LFA system and determine the scientific impacts.

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 Barron Lake. The purpose of this study and report is to evaluate the current aquatic vegetation communities in the lake as they relate to water quality and to provide scientifically-sound and affordable management options to the Barron Lake community.

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. Barron Lake may be categorized as a seepage lake as it receives external water supplies from precipitation and groundwater via the augmentation well.

2.1.2 Lake Eutrophication

All inland lakes experience some degree of lake aging. This process occurs when nutrients such as phosphorus and nitrogen are introduced to a lake and cause accelerated aquatic vegetation and algae growth. Over time, the lake basin becomes shallower and organic material accumulates on the lake bottom. This organic material serves as a nutrient-rich substrate for further primary production in the form of vegetation and algae growth. Shallow, small lakes and canals are most vulnerable to this natural process due to less depth and probability of accumulation. Shallow waters also have warmer water temperatures and this creates an ideal environment for aquatic vegetation and algae growth. The largest threat to inland lakes is the accelerated lake ageing "eutrophication" from land use activities such as agriculture, urban runoff, and failing septic systems. Millions of dollars are spent annually in Michigan alone to counteract the effects of lake eutrophication in order to gain full property value benefits and improve recreation and lake fisheries. Figure 1 shows this gradual process of eutrophication.

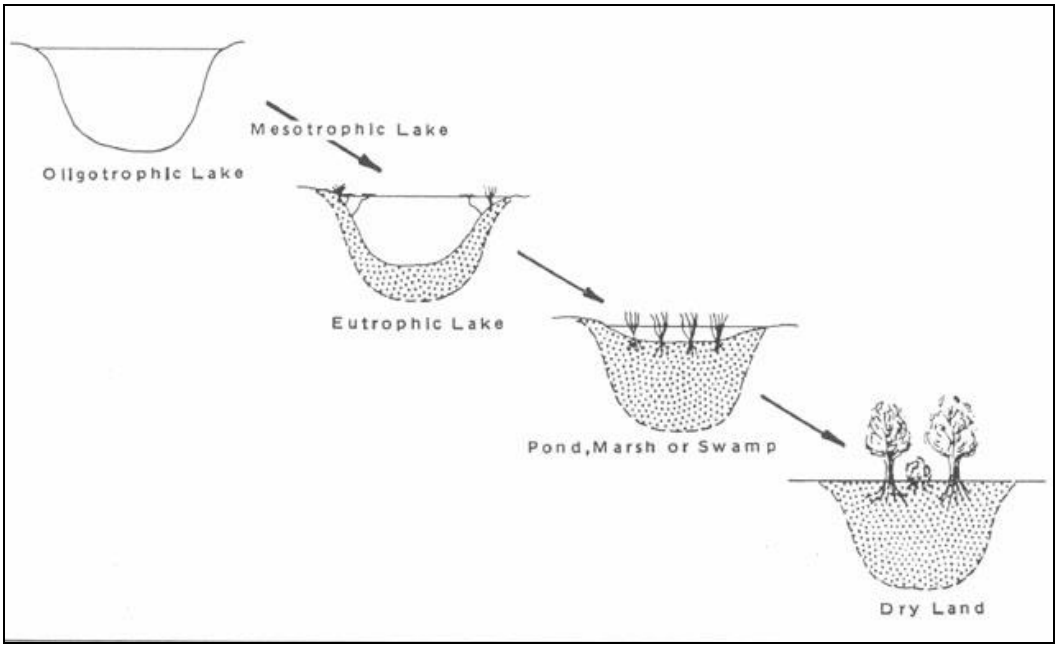


Figure 1. A diagram showing the lake aging (eutrophication) process.

2.1.3 Biodiversity and Habitat

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, zooplankton, phytoplankton, and may possess a plentiful yet beneficial benthic microbial community (Wetzel, 2001).

2.1.4 Watersheds and Land Use

A watershed is defined as an area of land that drains to a common point. It 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.

All land uses contribute to the water quality of the lake through the influx of pollutants from non-point and 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. Activities, such as residential land use, industrial land use, agricultural land use, water supply land use, wastewater treatment land use, and storm water management, influence the watershed of a particular lake. 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 BARRON LAKE PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Barron Lake Basin

Barron Lake is a 216-acre lake with an augmentation well (Figure 2) located in Sections 20, 21, 28, and 29 of Howard Township (T7SN R16W) in Cass County, Michigan. There is also an outlet structure (Figure 3) located at the south region of the lake. The lake has approximately 2.75 miles of shoreline and a mean depth of approximately 15.4 ft. (Restorative Lake Sciences, 2017). Barron Lake has a maximum depth of 32.1 feet (RLS, 2017). The whole lake was scanned during late summer of 2017 and this produced a modernized depth contour map (Figure 4). The lake is classified as a eutrophic (nutrient-enriched) aquatic ecosystem with a small to moderate-sized littoral (shallow) zone that is capable of supporting rigorous submersed rooted, aquatic plant growth. A whole-lake sediment bottom hardness scan (Figure 5) revealed that most of the areas which are currently colonized with submersed aquatic vegetation occur in areas where the sediment bottom hardness is soft and likely organic.

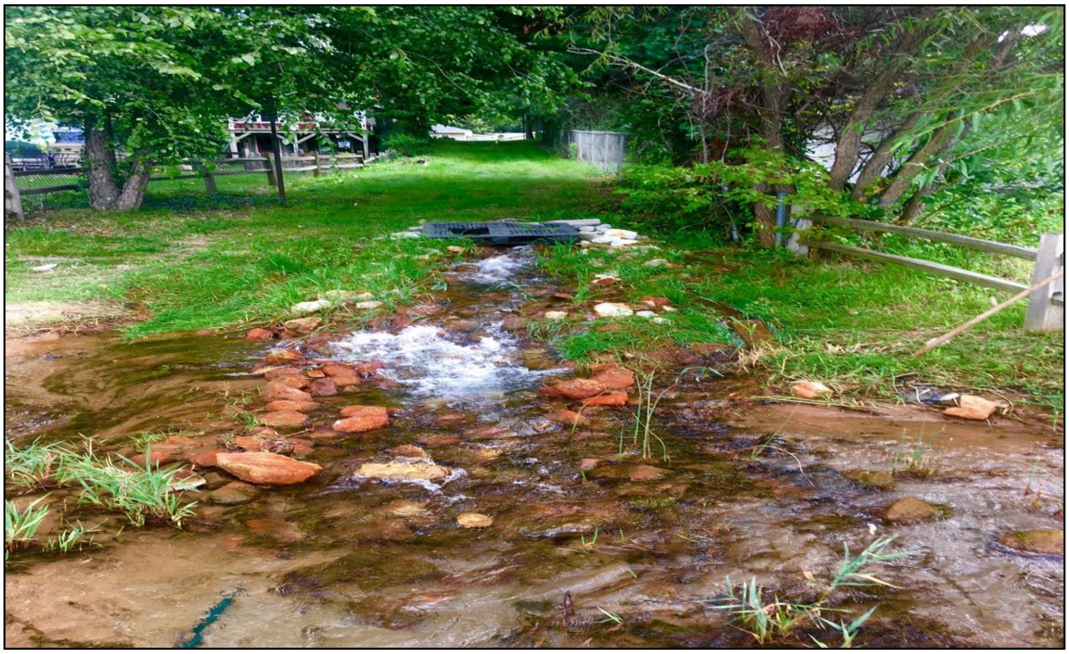


Figure 2. The augmentation well (inlet) that supplies groundwater to Barron Lake, Cass County, Michigan (RLS, 2017).

Figure 3. An outlet structure that receives water from Barron Lake, Cass County, Michigan (RLS, 2017).

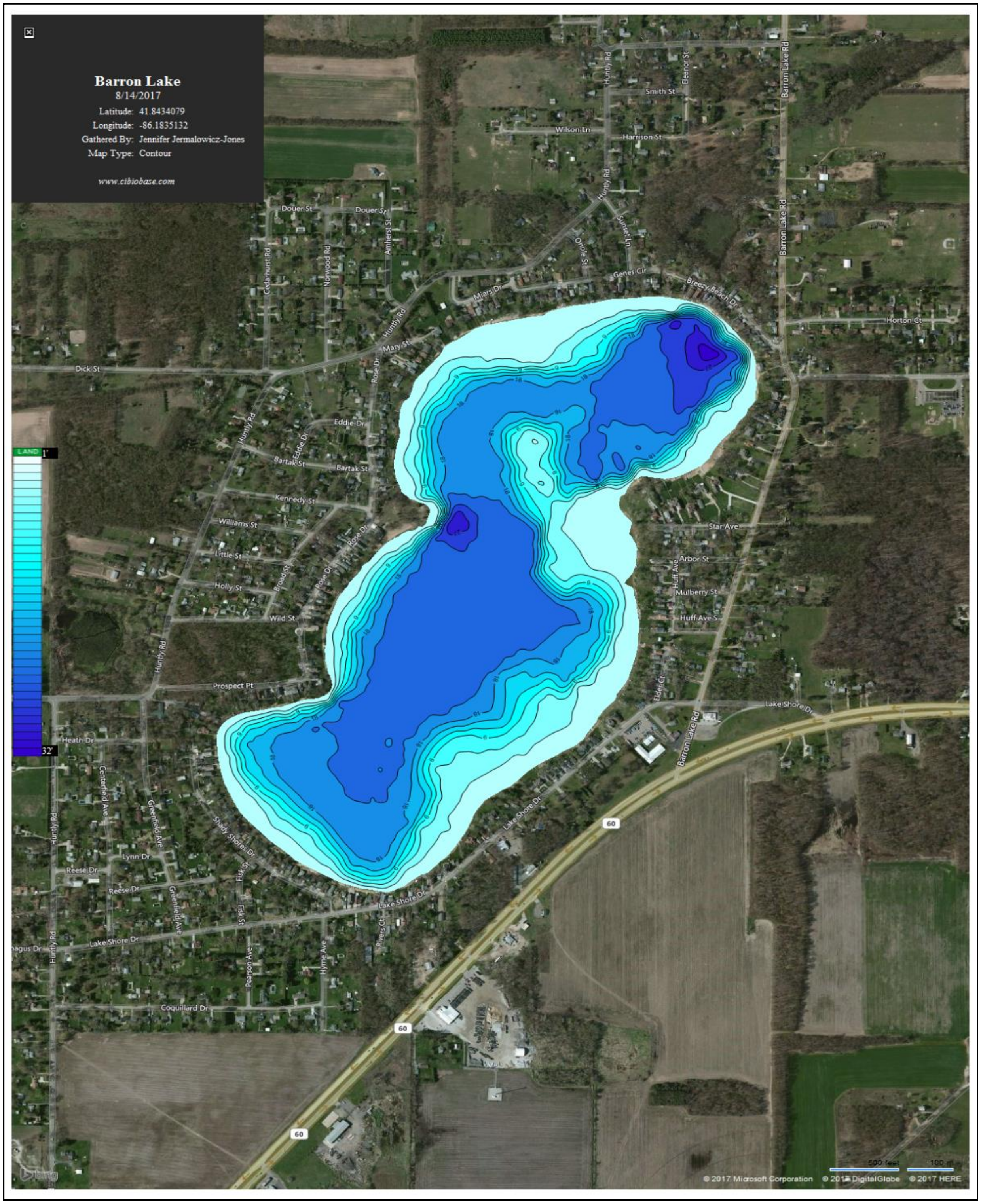


Figure 4. Barron Lake, Howard Township, Cass County, Michigan (RLS, 2017).

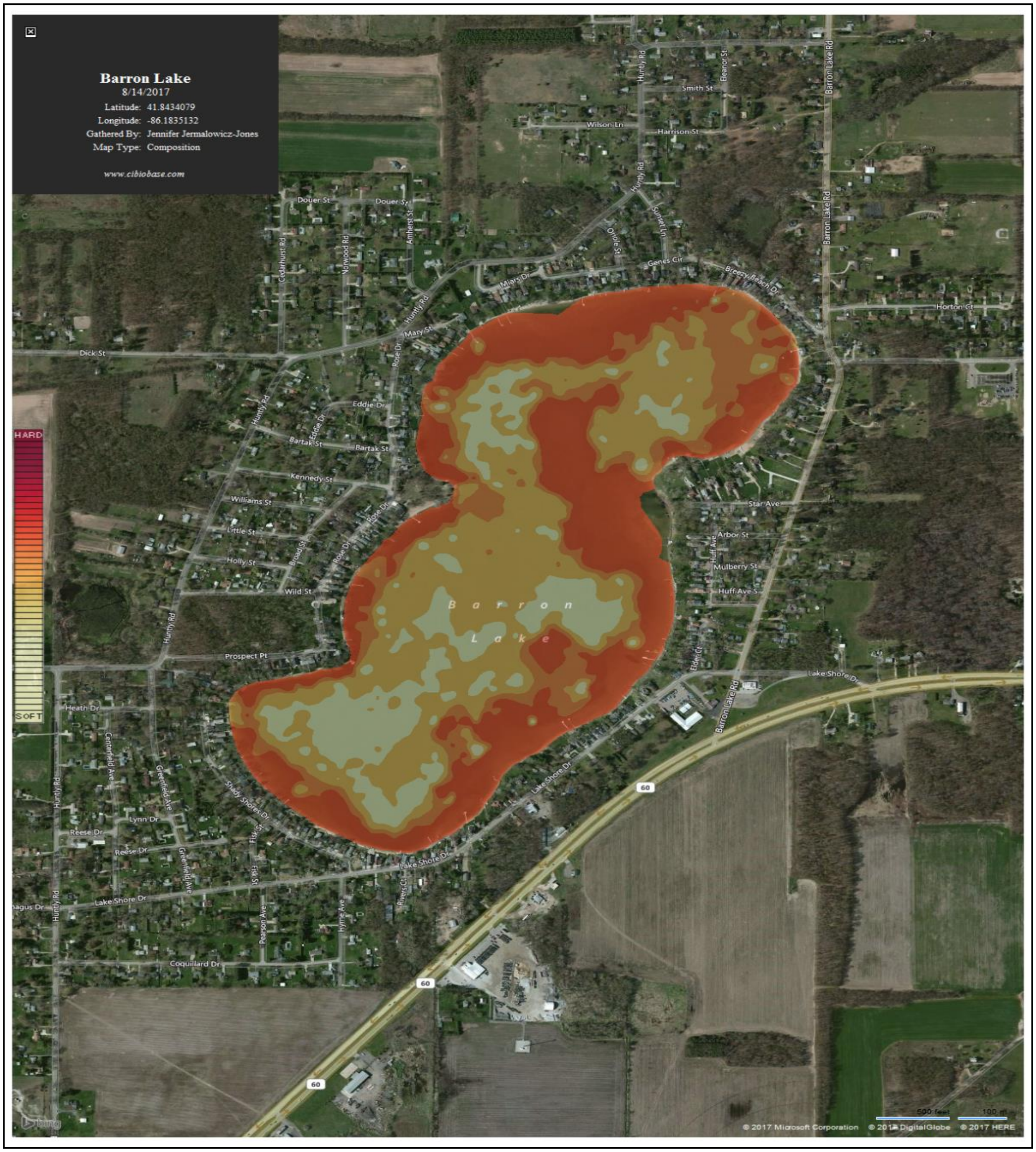


Figure 5. Barron Lake sediment bottom hardness scan map (RLS, 2017). Note: On this map of relative bottom hardness, areas with firmer more consolidated sediments appear as dark orange whereas areas with soft bottom appear as light beige in color. The majority of the aquatic vegetation grows in areas dominated by soft bottom.

3.2 Barron 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 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.

Barron Lake is located within the St. Joseph River extended watershed (Figure 6) which is approximately 2,998,400 acres (approximately 4,685 mi^2) in area and includes portions of 15 counties, including Berrien, Branch, Calhoun, Cass, Hillsdale, Kalamazoo, St. Joseph, and Van Buren in Michigan, and De Kalb, Elkhart, Kosciusko, Lagrange, Noble, St. Joseph, and Steuben in Indiana (Michigan Department of Environmental Quality, 2008). The extended watershed consists of primarily agricultural lands (> 50%), followed by 25-50% forested lands.

Nested within the St. Joseph River Extended Watershed is the Dowagiac River Watershed which is approximately 183,117 acres and spans three counties including Cass, Van Buren, and Berrien 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 Barron Lake immediate watershed include predominately agriculture, forests and wetlands, and developed (residential and commercial) land.

The immediate watershed area is the area that drains directly into Barron Lake and is approximately 1,620 acres in area (Restorative Lake Sciences, 2017; Figure 7). The immediate watershed is approximately 7.5 times larger than the size of Barron Lake, which indicates the presence of a moderate-sized immediate watershed. This immediate watershed allows for moderate watershed inputs to the lake compared to much smaller or larger sized watersheds.

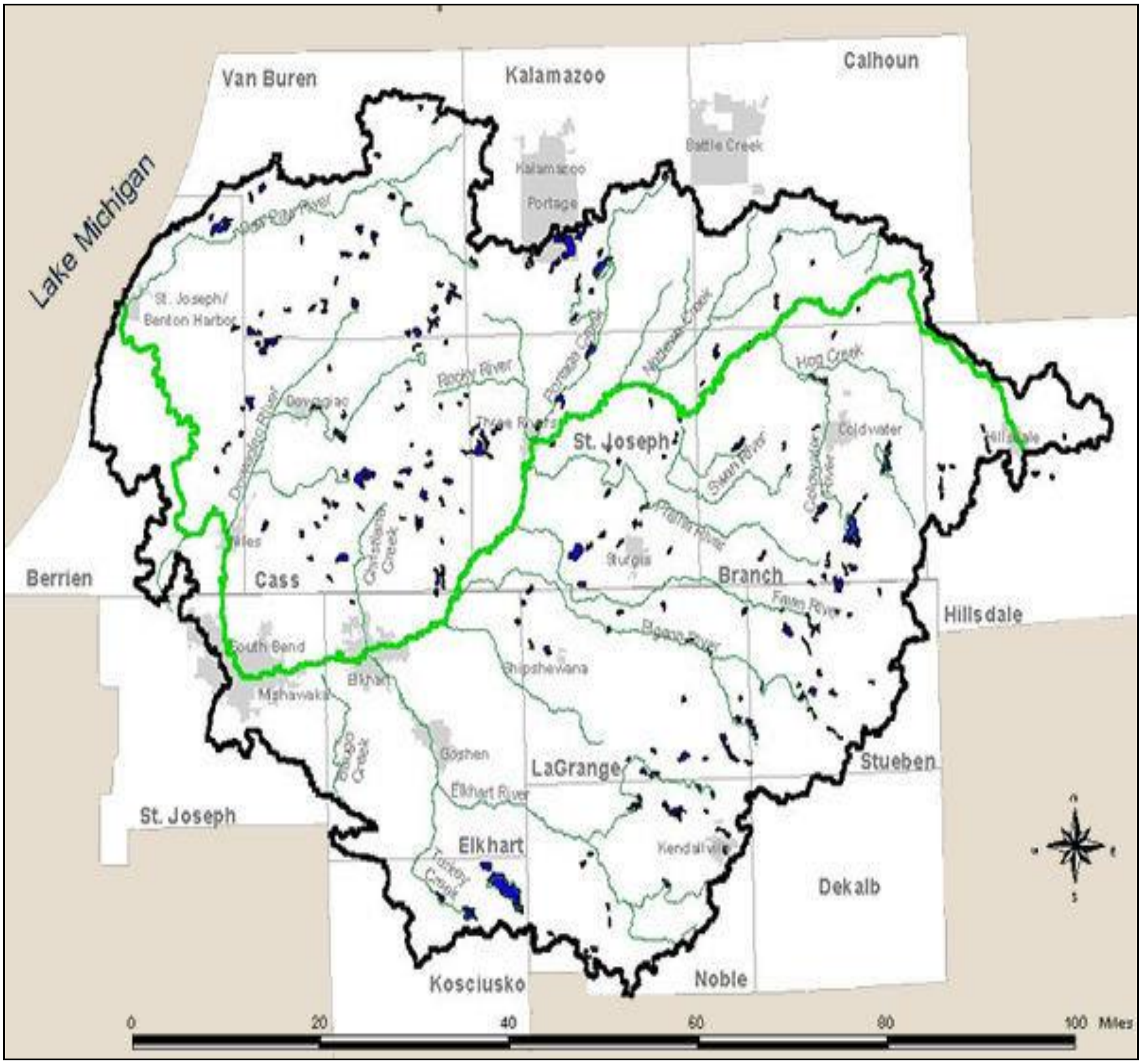
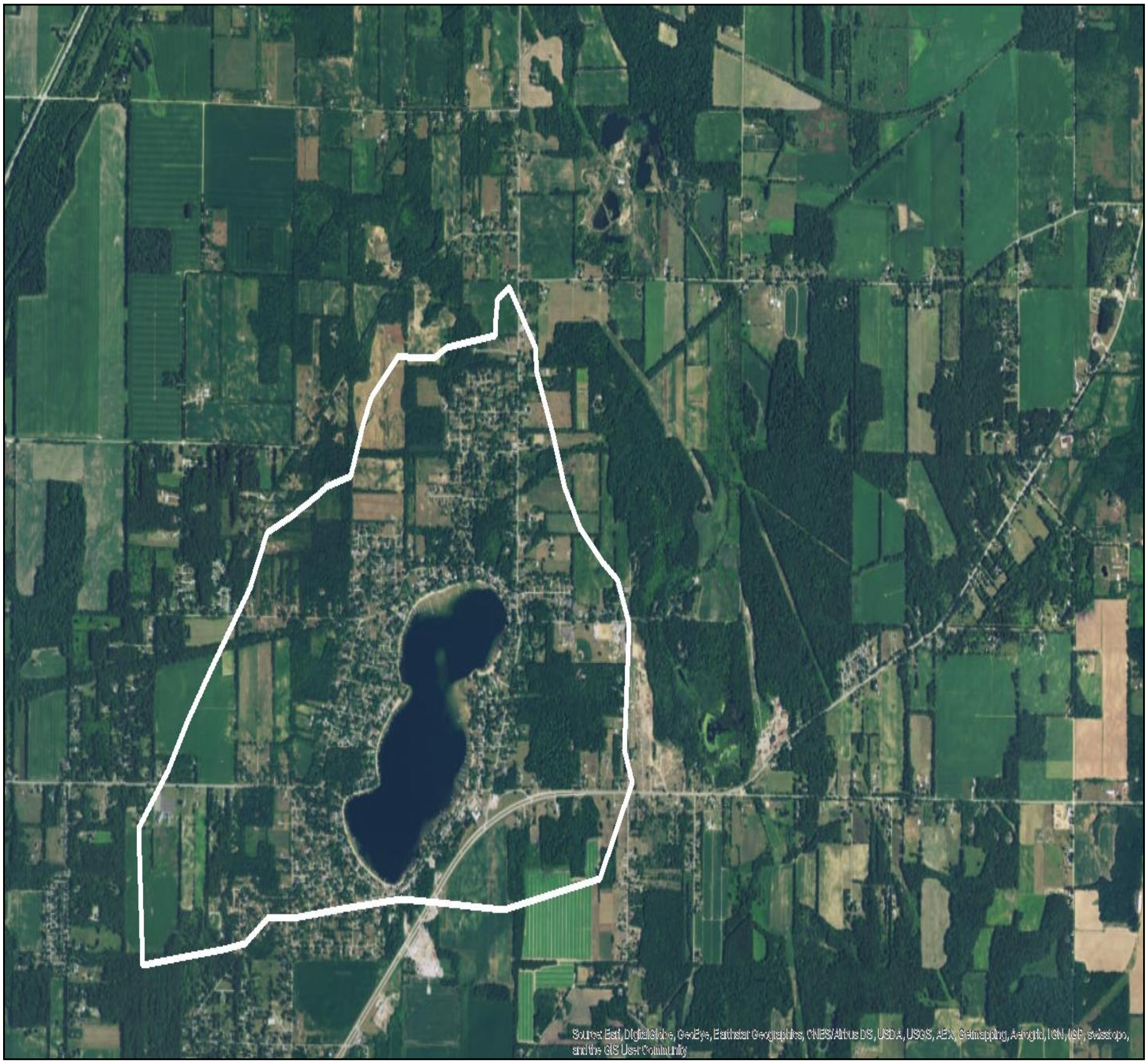


Figure 6. Extended St. Joseph River Watershed (www.stjoeriver.net, online resource).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 7. Immediate Watershed draining into Barron Lake, Cass County, Michigan (Restorative Lake Sciences, 2017).

3.3 Barron Lake Shoreline Soils

There are 3 major soil types immediately surrounding Barron Lake which may impact the water quality of the lake and may dictate the particular land use activities within the area. Figure 8 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service, 1999) demonstrates the precise soil types and locations around Barron Lake. Major characteristics of the dominant soil types directly surrounding the Barron Lake shoreline are discussed below. The major characteristics of each soil type are listed in Table 1 below.

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

USDA-NRCS Soil Series	***General Characteristics***
Urban Land-Spinks Complex, 0-6% slopes	Very deep, well drained, low runoff potential
Urban Land-Kalamazoo Complex, 0-6% slopes	Very deep, well drained, low runoff potential
Oshtemo Sandy Loam, 2-6% slopes	Very deep, well drained, low runoff potential

Figure 8. NRCS-USDA soils map for Barron Lake shoreline soils (1999 data).

The majority of the soils around Barron Lake are very deep and well drained soils with minimal ponding and reduced probability for runoff. 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. This is most often seen in soils that are mucks or peats compared to the loams and sands present around Barron Lake. 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.

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. The majority of the properties around the lake were on low slopes (<6%) that are not as susceptible to runoff or erosion as ones with steeper grades. There is also a small amount of different soil types directly around the lake which is favorable given that they are all well-drained soils and have a higher ability to filter water quickly and reduce overland flow of water into the lake. This is one reason why the water quality of the lake is still considered fair to good.

4.0 BARRON LAKE WATER QUALITY INDICATORS

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 geology, 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. Barron Lake is classified as eutrophic due to high nutrients and moderate chlorophyll-*a* and water clarity. Barron Lake harbors a healthy fishery and thus protection of its water quality is paramount. In fact, the lake has been stocked since 1993 with walleye and most recently black crappie by the Michigan Department of Natural Resources (MDNR).

Table 2. Lake Trophic Status Classification Table (MDNR)

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

4.1 Water Quality Indicators

Parameters such as, but not limited to, dissolved oxygen, water temperature, conductivity, turbidity, total dissolved and suspended solids, pH, total alkalinity, total phosphorus, total nitrogen and ammonia, chlorophyll-*a*, algal composition, and Secchi transparency, are critical indicators of water quality. On August 14, 2017, RLS collected water samples from within 2 deep basins in Barron Lake. Additionally on the same day, sediment samples were also collected in 30 locations throughout the lake to evaluate sediment nutrients such as phosphorus and organic matter. Algal community composition for the 2 deep basins is listed in Table 3. The water quality and sediment data are displayed below and are presented in Tables 4-6. A map showing the sampling locations for all water quality samples collected from the deep basins is shown below in Figure 9. A map showing the sampling locations for all sediment samples collected from the lake bottom are shown below in Figure 10.

All water samples and readings were collected on August 14, 2017 with the use of a Van Dorn horizontal water sampler and calibrated Eureka® multi-meter probe with parameter electrodes, respectively. Chlorophyll-*a* was measured *in situ* with a calibrated chlorophyll-*a* meter from Turner Designs®. Algal community composition analysis was conducted using a phase-contrast light compound microscope with Sedgewick Rafter counting cells to determine relative abundance. All other water quality samples were analyzed at NELAC-certified Trace Analytical Laboratories in Muskegon, Michigan.

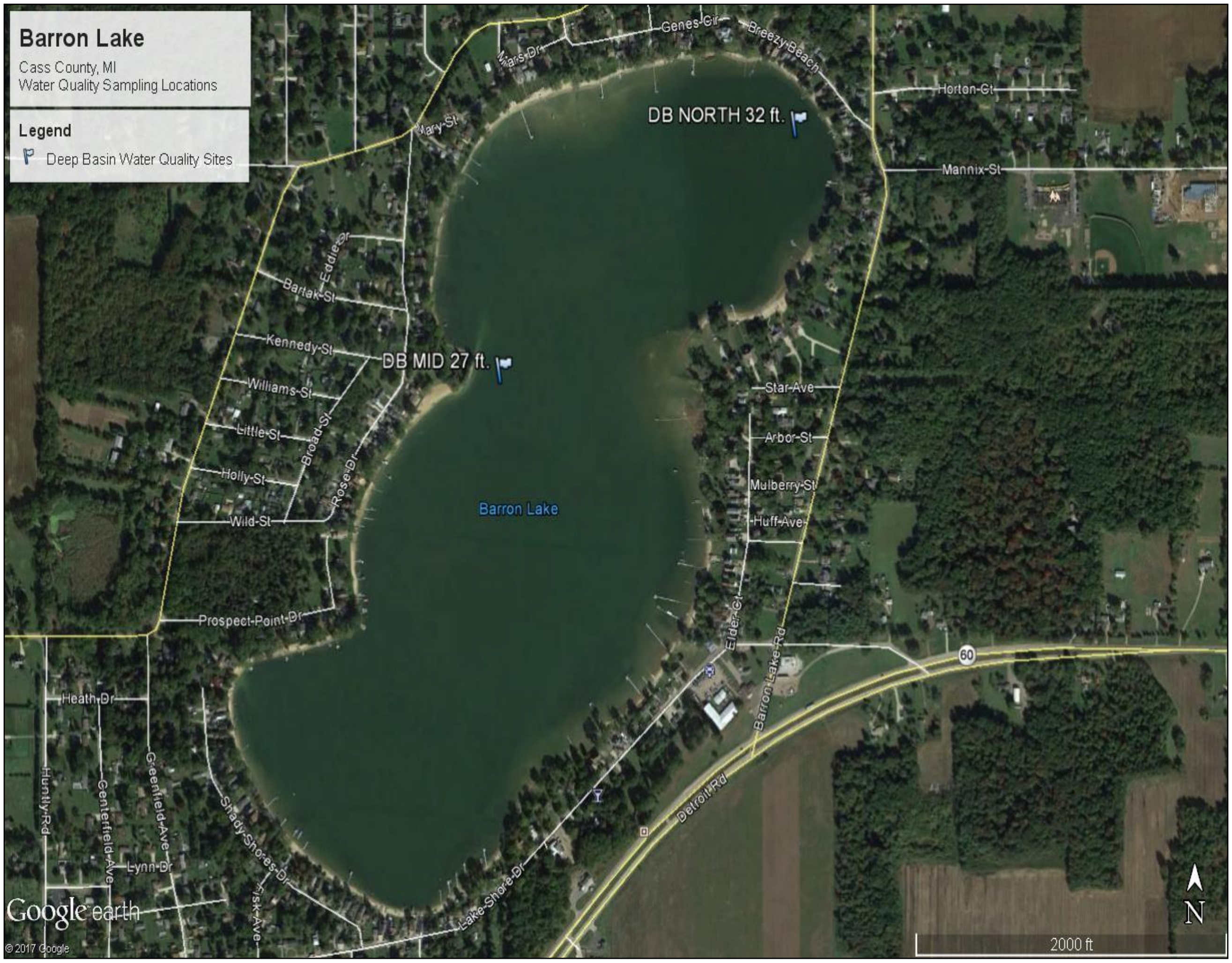


Figure 9. Location for water quality sampling of the deep basin in Barron Lake (August 14, 2017).

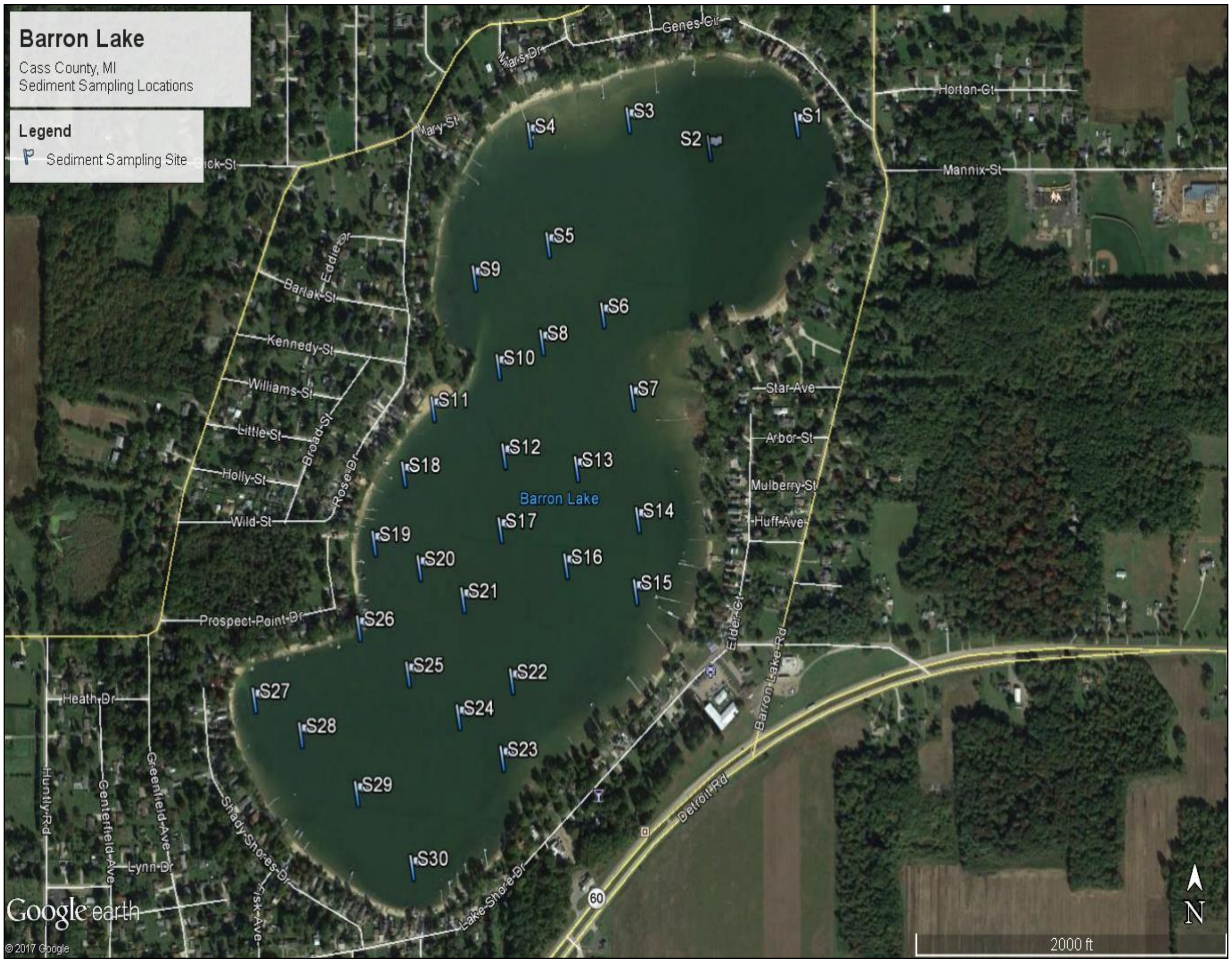


Figure 10. Location for sediment nutrient sampling in Barron Lake (August 14, 2017).

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 YSI® dissolved oxygen meter. 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. Dissolved oxygen concentrations during the August 14, 2017 sampling event ranged from 10.6-0.24 mg L^{-1}, with concentrations of dissolved oxygen higher near the surface and much lower at the bottom. The dissolved oxygen concentration of the augmentation well water was low at around 4.0 mg L^{-1}. This is not uncommon for groundwater to have lower dissolved oxygen as the water is not in contact with the atmosphere for long until it enters the lake.

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 (Figure 11). 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 August 14, 2017 water temperatures of Barron Lake demonstrated a measurable thermocline in both basins and ranged from a low of 66.7°F at the bottom to a high of 78.8°F at the surface. The water temperature at the augmentation well was 54.1°F which is considerably lower than the lake water temperature but completely normal for fresh groundwater.

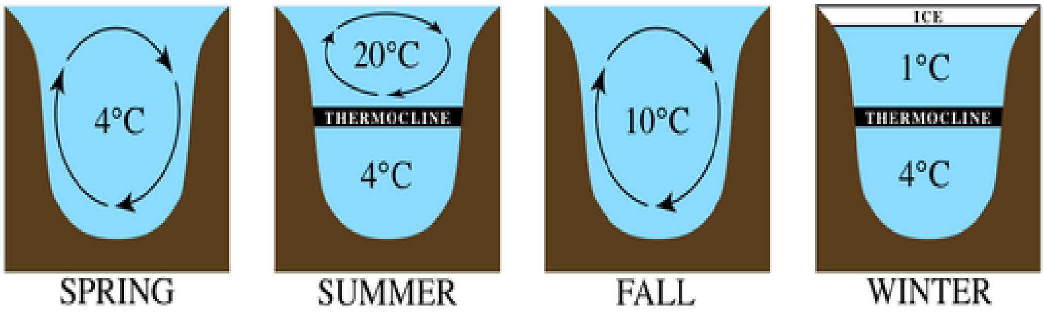


Figure 11. Diagram showing the process of stratification and turnover in lakes. Note: Barron Lake likely has multiple turn-over events in a given season due to the shallow depths and wind that induces constant mixing of the lake water.

4.1.3 Specific Conductivity

Specific conductivity is a measure of the amount of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. It increases under anoxic (low dissolved oxygen) conditions. Conductivity generally increases with the amount of dissolved minerals and salts in a lake. Specific conductivity was measured in micro Siemens per centimeter ($\mu S\ cm^{-1}$) with the use of a calibrated conductivity probe meter. The specific conductivity in the Barron Lake deep basins ranged from 283.6-391.2 $mS\ cm^{-1}$ during the August 14, 2017 sampling event. The specific conductivity for the Barron Lake augmentation well water was 409 $mS\ cm^{-1}$ during the August 14, 2017 sampling event. These values are moderate for an inland lake and mean that the lake water contains some dissolved ions in the salt form. Additionally, it is normal for the augmentation well to have a higher specific conductivity since it is a groundwater source. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Barron 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.

4.1.4 Turbidity, Total Dissolved Solids, and Total Suspended 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 is measured in Nephelometric Turbidity Units (NTU's) with the use of a turbimeter. 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 Barron Lake was quite low and ranged from 0.9-4.9 NTU's during the sampling event. The lake bottom has both organic and mineral factions which are moderate in bulk density and may remain suspended in the water column for only short periods, which reduces turbidity and enhances water clarity. Spring values would likely be higher due to increased watershed inputs from spring runoff and/or from increased algal blooms in the water column from resultant runoff contributions.

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 Barron Lake ranged from 80-92 mg L^{-1} for the deep basins on August 14, 2017, which is moderate for an inland lake. The TDS of the augmentation well was 110 mg L^{-1}. The preferred range for TDS in surface waters is between 0-1,000 mg L^{-1}.

Total Suspended Solids

Total suspended solids (TSS) refers to the quantity of solid particles detected in the water column that reduce light penetration and create turbidity in the water column. The TSS samples measured in the Barron Lake deep basins ranged from <10-140 mg L^{-1}. The TSS of the augmentation well was <10 mg L^{-1}. The ideal concentration for TSS in inland lakes is ≤ 20 mg L^{-1}.

4.1.5 pH

pH is the measure of acidity or alkalinity 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). pH changes on a daily basis due to changes in aquatic plant photosynthesis which actively grow during the daytime and respire at night. Generally speaking, the pH is usually lower in the hypolimnion (bottom depths) of a lake. The pH of Barron Lake water ranged from 8.1-8.5 S.U. with the lowest values at the bottom. The pH of the augmentation well water was 8.0=1 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 Barron Lake is considered "moderate" (< 100 mg L^{-1} of $CaCO_3$), and indicates that the water is neither hard nor soft. Total alkalinity in the deep basins ranged from 120-140 mg L^{-1} of $CaCO_3$ during the August 14, 2017 sampling event. The total alkalinity of the augmentation well water was around 190 mg L^{-1} of $CaCO_3$ which indicates that the well water is slightly more alkaline than the lake water. 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 Nitrogen and Ammonia Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. 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 ground or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen ($N: P > 15$), phosphorus may be the limiting nutrient for phytoplankton and aquatic macrophyte growth. Alternatively, in lakes with low nitrogen concentrations (and relatively high phosphorus), the blue-green algae populations may increase due to the ability to fix nitrogen gas from atmospheric inputs. Lakes with a mean TKN value of 0.66 mg L^{-1} may be classified as oligotrophic, those with a mean TKN value of 0.75 mg L^{-1} may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg L^{-1} may be classified as eutrophic. The mean TKN concentration in Barron Lake during the August 14, 2017 sampling event averaged 1.8 mg L^{-1}, which is moderate for an inland lake. The TKN was highest at the lake bottom at the deepest basin. Also, about 13% of the TKN was present in the ammonia form as the mean ammonia concentration in the lake was 0.24 mg L^{-1}. This is the form that can be most readily used by algae and rooted aquatic plants such as Eurasian Watermilfoil.

4.1.8 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 20 µg 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 was measured in micrograms per liter (µg L^{-1}) with the use of a chemical auto analyzer. The mean TP concentration in the deep basins of Barron Lake was 64 µg L^{-1} on August 14, 2017. The highest concentrations were present at the bottoms of the deep basins with deep basin north having a TP concentration of 230 µg L^{-1} which indicates the presence of internal loading. This condition along with the very low DO concentrations at the lake bottom allow for the release of phosphorus during stratified periods which then circulates around the lake and serves as nutrients for algae and aquatic vegetation.

4.1.9 Chlorophyll-a and Algae

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, typically in the form of planktonic algae. High chlorophyll-*a* concentrations are indicative of nutrient-enriched lakes.

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 or with the use of an in situ meter.

The chlorophyll-*a* concentrations in Barron Lake were determined by collecting composite samples of the algae throughout the water column at each of the 2 deep basin sites from just above the lake bottom to the lake surface. The mean chlorophyll-*a* concentration in the deep basins was 3.0 µg L^{-1} on August 14, 2017. These values indicate that planktonic algae are prominent in the water column which may be due to warmer water temperatures. 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).

Algal genera from a composite water sample collected over the deep basins of Barron Lake were analyzed under a compound brightfield microscope. Genera are listed here in the order of most abundant to least abundant. The genera and relative abundance of key taxa in the deep basins are listed in Table 3 below. The dominant algal genera found in the deep basins consisted of single-celled, multi-celled, and filamentous algae as well as silicaceous diatoms.

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 waters of Barron Lake 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.

Table 3. Dominant algal taxa found in the Barron Lake deep basins (August 14, 2017).

Algae Sample Location	**Dominant Algal Genera**
DB North	*Chlorella* sp., *Scenedesmus* sp., *Oscillatoria* sp., *Synedra* sp., *Navicula* sp., *Mougeotia* sp., *Hydrodictyon* sp., *Cymbella* sp. *Stephanodiscus* sp., *Gleocapsa* sp.
DB Middle	*Chlorella* sp., *Scenedesmus* sp., *Spirogyra* sp., *Closterium* sp., *Synedra* sp., *Pediastrum* sp., *Mougeotia* sp., *Cymbella* sp., *Oscillatoria* sp., *Gelocystis* sp.

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 (Figure 12). Secchi disk transparency is measured 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 are usually correlated with increased 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. Further, elevated phytoplankton and turbidity, also are associated with decreased Secchi transparency. The Secchi transparency of Barron Lake averaged 8.2 feet over the deep basins of Barron Lake during the August 14, 2017 sampling event. 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.

Figure 12. A Secchi disk.

4.1.11 Sediment Organic Matter and Phosphorus

Sediment Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the lake sediment. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. The TP concentrations in lake sediments are often up to several times higher than those in the water column since phosphorus tends to adsorb onto sediment particles and sediments thus act as a “sink” or reservoir of nutrients. TP concentrations are usually higher at increased depths due to higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Sediment TP is measured in milligrams per kilogram (mg kg^{-1}) with EPA method 6010B. Sediment TP values ranged from 9.3-360 mg kg^{-1}, with the highest values collected throughout all areas of the lake. These values were substantially higher than ones previously reported for White Lake (Muskegon County, Michigan) in 2005 with a mean of 60.4 ± 18.6 mg kg^{-1} (Jermalowicz-Jones, MS thesis, *unpublished data*), and indicate that Barron Lake sediments are rich in sediment nutrients. A study by Krogerus and Ekholm (2003) measured the release rates of P from sediment in shallow, open, agriculturally-impacted lakes and found that the mean daily rate of gross sedimentation was 0.04-0.18 g m^{-2} day^{-1} of phosphorus.

Organic matter (OM) contains a high amount of carbon that 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 allochthonus in nature where it originates from within the system or external to the system, respectively. Sediment OM is measured with the ASTM D2974 method and is usually expressed in a percentage (%) of total bulk volume. Barron Lake sediment samples were collected at the 30 sampling locations with the use of an Ekman hand dredge. The upper horizons of the sediment were kept intact for accurate evaluation of organic matter content in the upper layers. Samples were placed on ice and taken to a laboratory for analysis of sediment total phosphorus and percentage of organic matter. Percentage of OM ranged from 0.5-68% with the lowest and highest values measured in the south region of the lake. In contrast, sediments collected from similar depths in White Lake (Muskegon County, Michigan) had mean organic matter values of < 0.8% (Jermalowicz-Jones, MS thesis, *unpublished data*). Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present. There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then ferment to alcohol, CO_2, or CH_4. Second, proteins may be proteolyzed to amino acids, deaminated to NH_3+, nitrified to NO_2- or NO_3-, and denitrified to N_2 gas. Much of the organic matter present in Barron Lake originates from the surrounding immediate or from decomposition of submersed aquatic vegetation.

4.1.12 Oxidative Reduction Potential

The oxidation-reduction potential (E_h) of lake water describes the effectiveness of certain atoms to serve as potential oxidizers and indicates the degree of reductants present within the water. In general, the Eh level (measured in millivolts) decreases in anoxic (low oxygen) waters. Low E_h values are therefore indicative of reducing environments where sulfates (if present in the lake water) may be reduced to hydrogen sulfide (H_2S). Decomposition by microorganisms in the hypolimnion may also cause the E_h value to decline with depth during periods of thermal stratification. ORP values ranged from a low of 5.3 mV which was observed at the bottom of the lake and a high of 221.5 mV which was observed at the lake surface.

Table 4. Barron Lake water quality parameter data collected over Deep Basin North on August 14, 2017.

Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*TSS mg L^{-1}*	*TKN mg L^{-1}*	*Talk mg L^{-1} $CaCO_3$*	*Chl-a µg L^{-1}*	*Secchi ft.*
0	78.8	9.3	8.5	285	85	0.017	<10	0.6	120	3.0	8.3
3.0	78.7	10.0	8.4	285	85	--	--	--	--	--	--
6.0	78.5	10.2	8.4	285	78	--	--	--	--	--	--
9.0	77.7	10.3	8.3	285	88	--	--	--	--	--	--
12.0	76.7	10.3	8.3	287	87	--	--	--	--	--	--
15.0	76.2	9.8	8.3	293	82	0.047	<10	1.0	120	--	--
18.0	75.2	7.7	8.2	299	85	--	--	--	--	--	--
21.0	74.7	5.8	8.1	299	92	--	--	--	--	--	--
24.0	72.5	1.2	8.1	321	88	--	--	--	--	--	--
27.0	66.7	0.4	8.1	391	88	--	--	--	--	--	--
30.0	66.7	0.4	8.1	391	85	0.230	530	6.8	140	--	--

Table 5. Barron Lake water quality parameter data collected over Deep Basin Middle on August 14, 2017.

Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*TSS mg L^{-1}*	*TKN mg L^{-1}*	*Talk mg L^{-1} $CaCO_3$*	*Chl-a µg L^{-1}*	*Secchi ft.*
0	78.5	9.9	8.3	284	82	0.014	<10	0.7	130	3.0	8.1
3.0	78.5	10.2	8.3	284	80	--	--	--	--	--	--
6.0	78.0	10.5	8.3	284	79	--	--	--	--	--	--
9.0	77.5	10.6	8.3	284	84	--	--	--	--	--	--
12.0	76.6	9.9	8.3	286	84	0.021	<10	0.7	120	--	--
15.0	76.0	8.7	8.2	292	84	--	--	--	--	--	--
18.0	75.6	5.6	8.1	294	83	--	--	--	--	--	--
21.0	75.0	3.8	8.1	306	85	--	--	--	--	--	--
24.0	74.4	0.7	8.1	313	85	--	--	--	--	--	--
27.0	73.3	0.2	8.1	331	85	0.056	14	1.0	130	--	--

Table 6. Sediment TP and Organic Matter in Barron Lake, Cass County, Michigan sediment samples (August 14, 2017).

Sediment Site	*Total Phosphorus mg L^{-1}*	*% Organic Matter*
1	220	33
2	9.3	33
3	67	1.8
4	46	0.8
5	100	0.8
6	58	1.0
7	28	0.7
8	72	37
9	290	36
10	150	38
11	65	5.8
12	66	38
13	220	40
14	360	40
15	140	1.0
16	150	41
17	92	38
18	21	31
19	260	37
20	330	39
21	230	39
22	220	68
23	71	1.0
24	58	0.5
25	78	38
26	220	29
27	110	36
28	160	34
29	67	36
30	67	34

4.1.13 Macroinvertebrates and Zooplankton

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 processing of energy. Others are important predators, graze alga on rocks and logs, and are important food sources (biomass) for fish. The removal of macroinvertebrates has been shown to impact fish populations and total species richness of an entire lake or stream food web (Lenat and Barbour 1994). In the food webs of lakes, benthic macroinvertebrates have an intermediate position between primary producers and higher trophic levels (as fish) on the other side. Hence, they play an essential role in key ecosystem processes (food chain dynamics, productivity, nutrient cycling and decomposition). These may also include many rare species.

Several characteristics of benthic macroinvertebrates make them useful bio indicators of lake water quality including that many are sensitive to changes in physical, chemical, and biological conditions of a lake. Also, many complete their life cycle in a single year and their life cycles and ecological requirements are generally well known. They are sessile organisms and cannot readily escape pollution or other negative aspects and they are easily collected. Their ubiquitous nature and varied ecological role in lakes make them very useful as indicators of water quality. As benthic macroinvertebrates respond sensitively not only to pollution, but also to a number of other human impacts (hydro-logical, climatological, morphological, navigational, recreational, and others), they could potentially be used for a holistic indication system for lake ecosystem health (Solimini et *al.* 2006).

Some of the common lake macroinvertebrates include the Diptera (true flies), Coleoptera (beetles), Odonata (damselflies and dragonflies), Ephemeroptera (mayflies), Hemiptera (true bugs), Megaloptera (hellgrammites), Trichoptera (caddisflies), Plecoptera (stoneflies), Crustacea (freshwater shrimp, crayfish, isopods), Gastropoda (snails), Bivalvia (clams and mussels), Oligochaeta (earthworms), Hirudinea (leeches), Turbellaria (planarians). While the majority of these are native species, numerous invasive species have been impacting lakes in the Great Lakes Region.

Restorative Lake Sciences, LLC, collected sediment macroinvertebrates from four separate locations (north, west, east, and south regions) within Barron Lake, on May 2, 2017 (Table 7). The sampling found mayflies (*Hexagenia limbata*, Ephemeridae), midges (Chironomindae), wheel snails (Planorbidae), fingernail clams (Sphaeriidae), water mites (Hydrachnidae), freshwater shrimp (Gammaridae), segmented worms (Oligochaeata), pond snails (Physidae), and caddisfly larvae (Limnephilidae). While 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). The mayfly, *Hexagenia limbata*, found within this lake, has been shown to be linked with good water quality.

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 community 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.

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 noted these land-use practices are important to 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.

A zooplankton tow was conducted on Barron Lake on August 14, 2017 and samples were analyzed under a microscope. Four major taxa of zooplankton were present and included *Daphnia* sp., *Bosmina* sp., and the rotifers *Keratella* sp., and protest *Euglena* sp.

Table 7. Macroinvertebrates found in Barron Lake, Cass County, MI (May 2, 2017).

Sample 1	**Sample type – Sediment Grab**				
		Arachnida	Hydrachnidae	2	Water mites
		Amphipoda	Gammaridae	7	Freshwater shrimp
		Annelida	Oligochaeata	13	Segmented worms
		Ephemeroptera	Ephemerillidae	3	Mayfly larvae
		Gastropoda	Physidae	2	Pond snails
		Trichoptera	Limnephilidae	1	Caddis larvae
		Diptera	Chironomidae	14	Midge larvae
		Gastropoda	Planorbidae	1	Wheel snails
			Total	**43**	
Sample 2	**Sample type – Sediment Grab**				
		Gastropoda	Physidae	2	Pond snails
		Bivalvia	Sphaeridae	1	Fingernail clams
		Amphipoda	Gammaridae	4	Freshwater shrimp
		Diptera	Chironomidae	38	Midge larvae
		Arachnida	Hydrachnidae	9	Water mites
		Ephemeroptera	Ephemerillidae	1	Mayfly larvae
		Annelida	Oligochaeata	8	Segmented worms
			Total	**63**	

Sample 3	**Sample type –Sediment Grab**				
		Bivalvia	Sphaeridae	1	Fingernail clams
		Gastropoda	Physidae	3	Pond snails
		Annelida	Oligochaeata	4	Segmented worms
		Arachnida	Hydrachnidae	2	Water mites
		Diptera	Chironomidae	11	Midge larvae
		Amphipoda	Gammaridae	5	Freshwater shrimp
		Ephemeroptera	Ephemerillidae	2	Mayfly larvae
			Total	**28**	
Sample 4	**Sample type –Sediment Grab**				
		Bivalvia	Sphaeridae	1	Fingernail clams
		Arachnida	Hydrachnidae	14	Water mites
		Ephemeroptera	Ephemerillidae	3	Mayfly larvae
		Annelida	Oligochaeata	8	Segmented worms
		Diptera	Chironomidae	7	Midge larvae
		Trichoptera	Limnephilidae	1	Caddis larvae
			Total	**34**	

5.0 BARRON LAKE AQUATIC VEGETATION COMMUNITIES

5.1 Overview of Aquatic Vegetation and the Role for Lake Health

The overall health of Barron Lake is strongly connected to the type and density of aquatic vegetation present in the lake. 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. 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. Similarly, an overabundance of exotic aquatic plant species can also negatively impact native aquatic plant communities and create an unbalanced aquatic ecosystem.

5.2 Aquatic Vegetation Sampling Methods

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 and great mean depth of Barron Lake, a whole-lake GPS Point-Intercept grid matrix survey (Figure 13) was conducted on August 14, 2017 to assess all aquatic plants, including submersed, floating-leaved, and emergent species. The lake scan consisted of 11,236 GPS points and the aquatic vegetation sampling survey utilized over 429 points throughout the lake. This survey allowed for an unbiased sampling map that utilized closely-spaced sampling points to yield an accurate map along with the use of a side-scan sonar GPS device to scan the aquatic plant biovolume, bathymetric contours, and sediment bottom hardness of the lake. These scans were conducted using a Lowrance® HDS 8 GPS unit with BioBase® software. Figure 14 below shows the aquatic vegetation biovolume in Barron Lake. As noted earlier, these areas of growth correspond to areas with soft bottom substrate which most aquatic plants prefer for a growth medium.

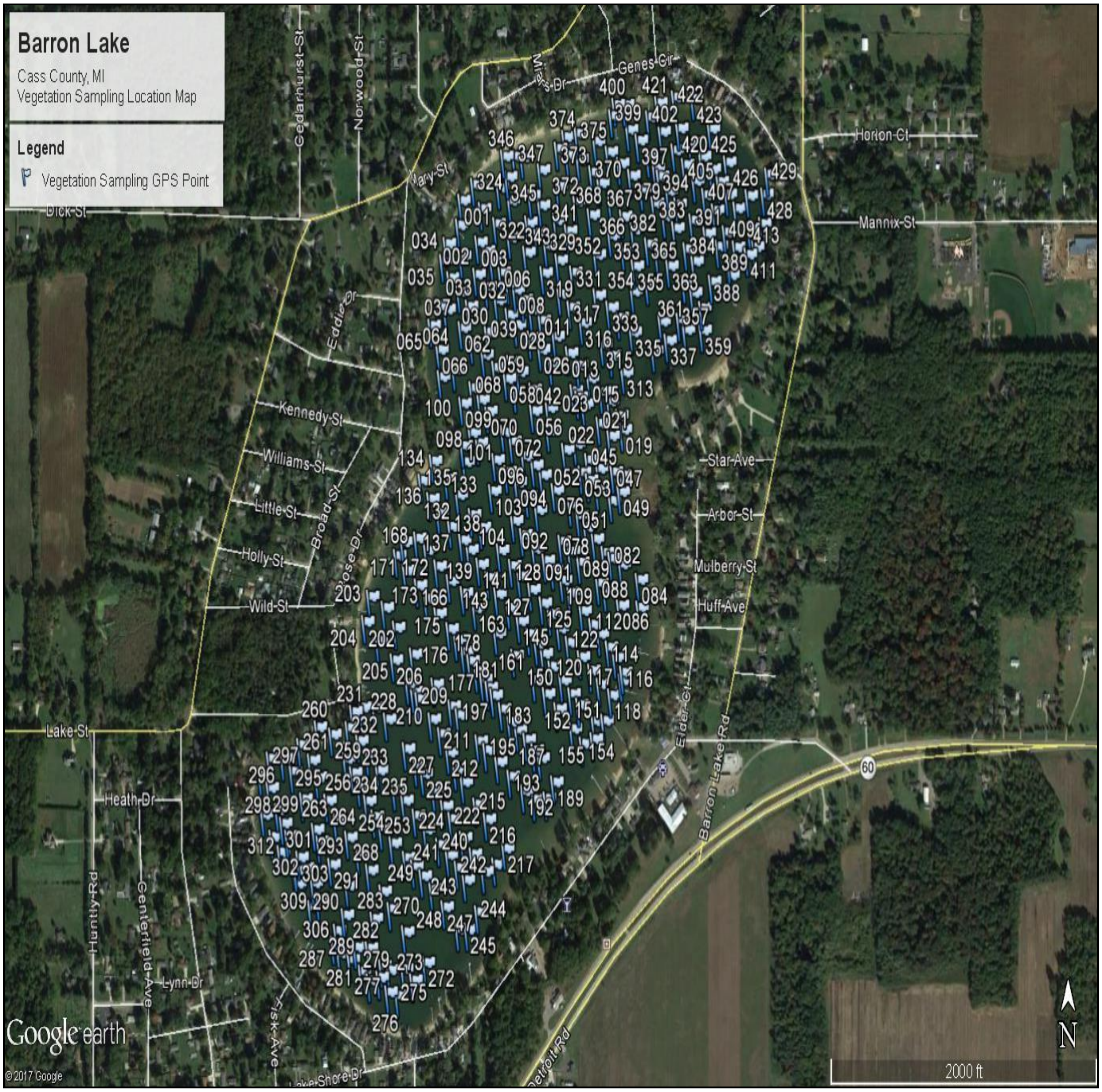


Figure 13. Aquatic vegetation sampling location GPS points in Barron Lake (RLS, August 14, 2017).

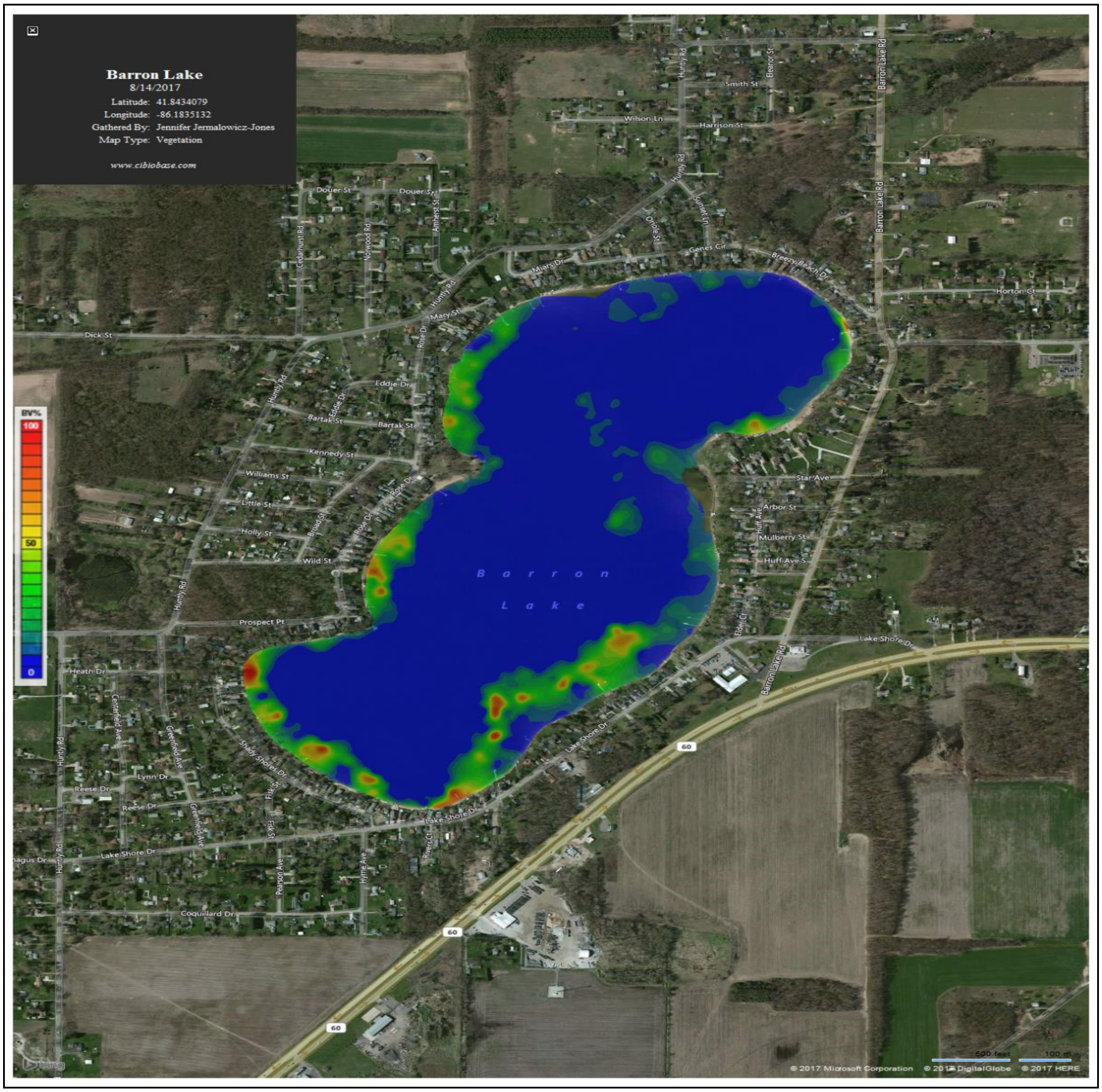


Figure 14. Aquatic vegetation biovolume scan map of Barron Lake (August 14, 2017). Note: The Barron color represents areas that are not covered with aquatic vegetation. The green color represents low-growing aquatic vegetation and the red colors represent high-growing aquatic vegetation. This scan does not differentiate between invasive and native aquatic vegetation biovolume which is why the GPS-point intercept survey is also executed in concert with the whole-lake scan.

5.3 Barron Lake Exotic Aquatic Plant Species

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

Eurasian Watermilfoil (*Myriophyllum spicatum*; Figure 15) is an exotic aquatic macrophyte that is a serious problem in Michigan inland lakes and has been found in Barron Lake. 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). Approximately 1.50 acres of dense milfoil was found in Barron Lake during the summer 2017 survey but this number is likely much higher prior to lake herbicide treatments. Previous accounts from the lake confirm that it is most likely hybrid watermilfoil.

The Giant Common Reed (*Phragmites australis*; Figure 16) was also found in a few locations along the shoreline of Barron Lake (approximate total of around 1 acre) and should be promptly removed before mitigation efforts become too costly due to rapid spread of the plant. *Phragmites* is an imminent threat to the surface area and shallows of the lake since it may grow submersed in water depths of ≥ 2 meters (Herrick and Wolf, 2005), thereby drying up wetland habitat and reducing lake surface area. In addition, large, dense stands of *Phragmites* accumulate sediments, reduce habitat variability, and impede natural water flow (Wang et *al*., 2006).

A distribution map showing the locations and sizes of weed beds for the milfoil and Phragmites in Barron Lake can be found as Figure 17. This map refers to the milfoil relative abundance with “a” level meaning found; “b” level meaning sparse; “c” level meaning common. Fortunately, there were no “d” levels or dense areas of milfoil found.

Figure 15. Eurasian Watermilfoil (branches, seed head, and leaves).

Figure 16. Invasive Emergent Phragmites.

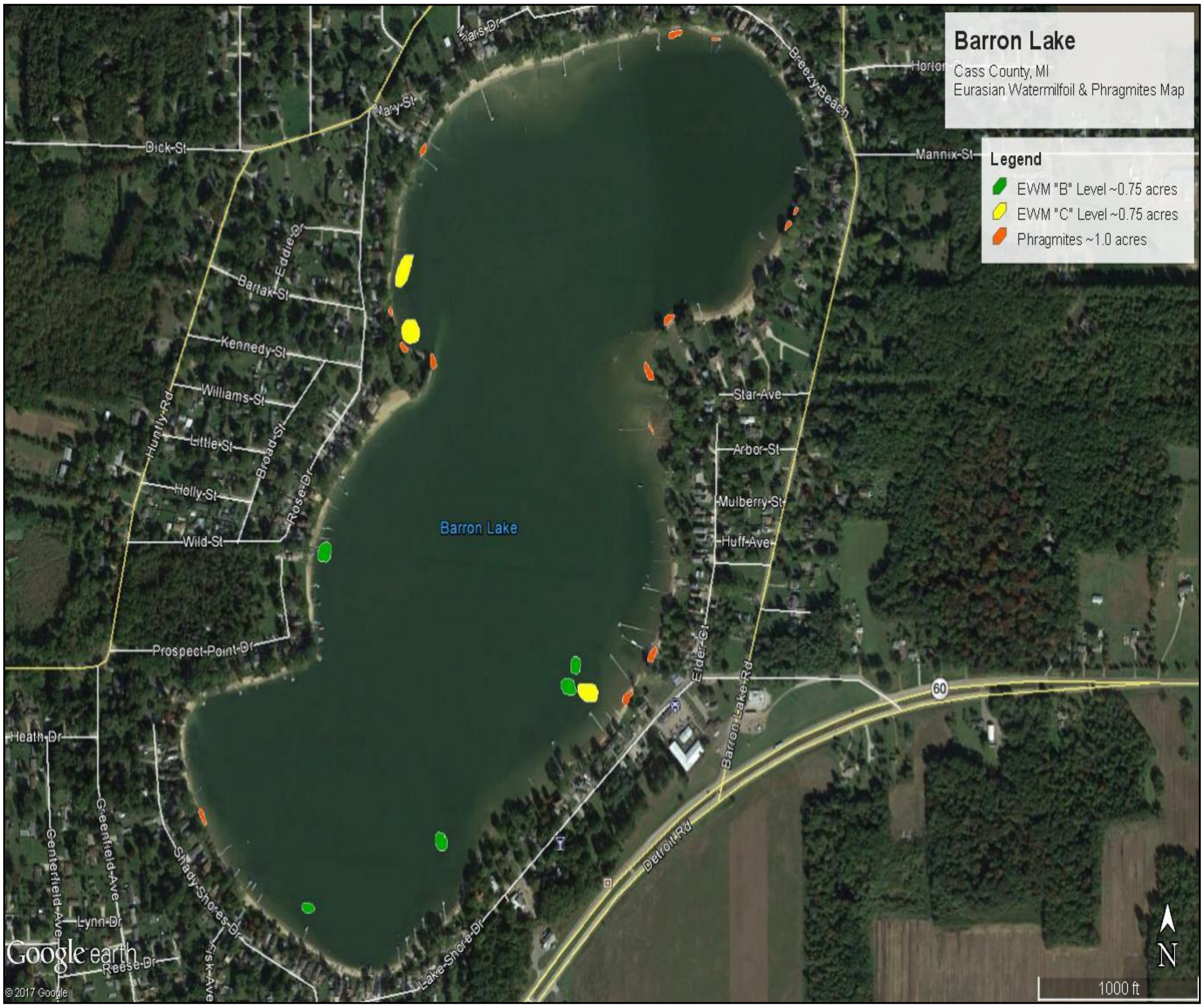


Figure 17. Invasive aquatic plants found in and around Barron Lake, Cass County, Michigan (August 14, 2017).

5.4 Barron Lake Native Aquatic Plant Species

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.

Barron Lake contained 12 native submersed, 1 floating-leaved, and 2 emergent aquatic plant species, for a total of 15 native aquatic macrophyte species (Table 8). Photos of all native aquatic plants are shown below in Figures 18-32. 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. 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 most dominant aquatic plant in the main part of the lake included the macro alga, *Chara* which is also called “skunkweed” due to its strong odor. This algae is only anchored to the bottom sediments by tiny rhizoids and serves as excellent fish spawning habitat. The second most common aquatic plant was Large-leaf Pondweed which resembles underwater cabbage and can grow tall into the water column. This plant is also excellent fish forage habitat. The plant has long, brown leaves that are wide and may harbor many colonies of aquatic insects. All of the pondweeds grow tall in the water column and serve as excellent fish cover. Due to the fact that only approximately 15-20% of the lake is vegetated (largely due to the great mean depth), protection of these native aquatic plants is important.

There was one floating-leaved macrophyte species, *Nymphaea odorata* (White-Waterlily), which is critical for housing macroinvertebrates and should be protected and preserved in all areas to serve as food sources for the fishery and wildlife around the lake. 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 invasive emergent Phragmites around the Barron Lake shoreline are currently low in abundance but could become a threat to the native emergent macrophyte populations if not controlled.

Table 8. Barron Lake native aquatic plant species (August 14, 2017).

Native Aquatic Plant Species Name	***Aquatic Plant Common Name***	***% Cover***	***Aquatic Plant Growth Habit***
Chara vulgaris	Muskgrass	6.9	Submersed, Rooted
Potamogeton pectinatus	Thin-leaf Pondweed	1.3	Submersed, Rooted
Potamogeton amplifolius	Large-leaf Pondweed	6.2	Submersed, Rooted
Potamogeton zosteriformis	Flat-stem Pondweed	0.1	Submersed, Rooted
Potamogeton robbinsii	Fern-leaf Pondweed	3.5	Submersed, Rooted
Potamogeton natans	Floating-leaf Pondweed	0.3	Submersed, Rooted
Potamogeton praelongus	White-stem Pondweed	0.1	Submersed, Rooted
Potamogeton illinoensis	Illinois Pondweed	0.1	Submersed, Rooted
Vallisneria americana	Wild Celery	3.6	Submersed, Rooted
Elodea canadensis	Common Waterweed	0.1	Submersed, Rooted
Najas guadalupensis	Southern Naiad	3.3	Submersed, Rooted
Nitella sp.	Macroalga	0.1	Submersed, Rooted
Nymphaea odorata	White Waterlily	0.1	Floating-Leaved, Rooted
Typha latifolia	Cattails	0.2	Emergent
Scirpus acutus	Bulrushes	1.1	Emergent

Figure 18. Chara (Muskgrass) ©RLS

Figure 19. Thin-leaf Pondweed

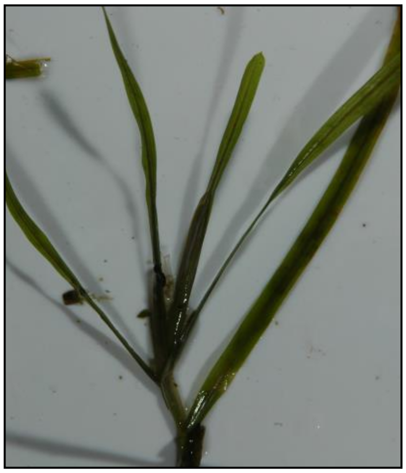


Figure 20. Flat-stem Pondweed ©RLS

Figure 21. Robbins Pondweed ©RLS

Figure 22. White-stem Pondweed ©RLS

Figure 23. Illinois Pondweed ©RLS

Figure 24. Large-leaf Pondweed
©RLS

Figure 25. Floating-leaf Pondweed

Figure 26. Wild Celery
©RLS

Figure 27. Elodea ©RLS

Figure 28. Southern Naiad
©RLS

Figure 29. Nitella sp. ©RLS

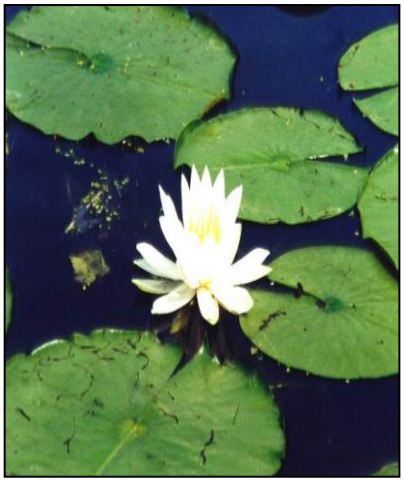


Figure 30. White Waterlily ©RLS

Figure 31. Cattails ©RLS

Figure 32. Bulrushes ©RLS

6.0 BARRON LAKE MANAGEMENT IMPROVEMENT METHODS

6.1 Barron Lake Aquatic Plant Management Methods

The management of exotic aquatic plants and further nutrient loading from external sources are important to the balance of Barron Lake. 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.

The management of invasive submersed and emergent invasive aquatic plants is necessary in Barron 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 some are capable of achieving strong results when used properly. Exotic aquatic plant species should be managed with solutions that will yield long-term results. The sections below discuss the individual lake management methods (tools) and then ultimately lead to a section with specific recommendations using those methods. Since there were only a few locations with the invasive emergent Phragmites, removal of these invasives by hand-pulling is recommended over other methods but this may also be conducted after topical application of contact herbicides.

Care should be taken to remove all of the roots and stolons from the plants and the plants should be discarded in wrapped plastic bags and taken to a landfill.

6.1.1 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. Aquatic herbicides are usually applied with a skiff boat or an airboat (Figure 33).

Contact herbicides such as diquat, hydrothol, and flumioxazin 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 Barron Lake, the use of contact herbicides for the invasive watermilfoil is not recommended since use of these herbicides results in temporary reductions of the plant.

Systemic herbicides such as 2, 4-D and triclopyr are the two primary systemic herbicides used to treat invasive watermilfoil by the root for a more sustained and effective treatment. 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 Barron Lake can be effectively spot-treated with granular triclopyr nearshore and granular 2,4-D or triclopyr in offshore areas. Triclopyr must be used in near shore areas with shallow well (< 30 feet deep) restrictions.

Figure 33. An herbicide treatment airboat and crew preparing for a lake treatment.

6.1.2 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 34). 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 34. A mechanical harvester. Photo courtesy of Dave Foley.

6.1.3 Diver Assisted Suction Harvesting (DASH)/Dredging

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 35) 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. The advantage it has is that it can be selective in what species it removes since a diver is guiding the suction hose to targeted plants. 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. There are not any areas currently in Barron Lake where this method is recommended.

Figure 35. A DASH boat for hand-removal of watermilfoil or other nuisance vegetation. ©Restorative Lake Sciences, LLC

6.1.4 Laminar Flow Aeration and Bio augmentation

Laminar flow aeration systems (Figure 36) 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) which gives lake sediments a “rotten egg” odor. 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 Barron-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.

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. Regular equipment maintenance is also required. Additionally, a year of data may be required from the MDEQ as a part of the permit application. This data may be collected in spring, summer, and fall of the year prior to aeration and then again in the first two years and the fifth year in anticipation of another permit.

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 moderate to high quantity of organic matter and algae in Barron Lake, the use of aeration with bio augmentation (addition of microbes) is highly recommended. This aeration system would also increase DO throughout the lake water column which would be beneficial for the lake fishery.

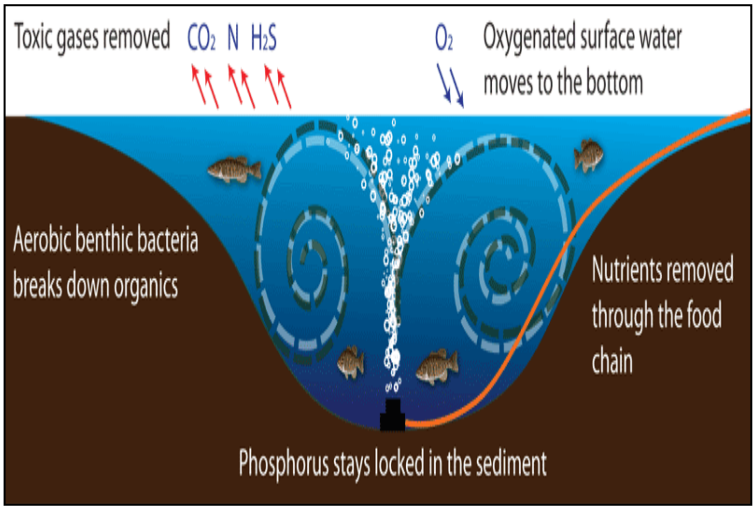


Figure 36. A diagram showing the laminar flow aeration mechanisms. ©Restorative Lake Sciences, LLC

6.1.5 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 37) or Weed Rollers (Figure 38) 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 implementation of a benthic barrier mat requires a minor permit from the MDEQ which can cost around $50-$100. 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 Barron Lake and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth. These technologies could be used in beach areas on the main lake or in the canals if the bottom substrate is consolidated (firm).

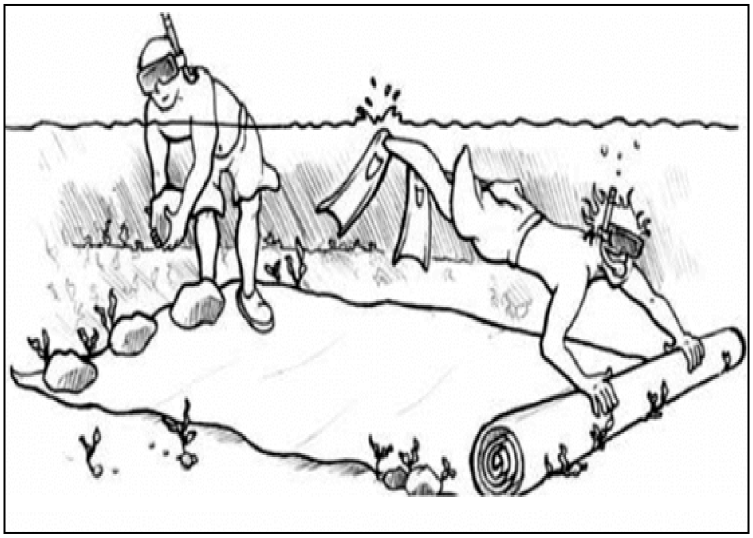


Figure 37. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.

Figure 38. A Weed Roller.

6.2 Barron Lake Watershed Management Methods

In addition to the proposed treatment of invasive watermilfoil and Phragmites in Barron Lake, 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% grade)
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 (Note: this may be tough for Barron Lake but could be enforced in canals and nearshore areas)
4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion
5) Using only native genotype plants (those native to Barron 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

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

6.2.1 Barron Lake 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 Barron Lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat. Construction practices near the lakeshore should minimize the chances for erosion and sedimentation by keeping land areas adjacent to the water stabilized with rock, vegetation, or wood retaining walls. This is especially critical in areas that contain land slopes greater than 6%. 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 Barron Lake. The emergent aquatic plant, *Scirpus* sp. (Bulrushes) present around Barron Lake offers some stabilization of shoreline sediments and assists in the minimization of sediment release into the lake but more of this vegetation is desired for shoreline stabilization.

6.2.2 Barron Lake Nutrient Source Control

Based on the high ratio of nitrogen to phosphorus (i.e. N: P = 28), 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 Barron Lake:

1) Avoid the use of lawn fertilizers that contain phosphorus (P). P is the main nutrient required for aquatic plant and algae growth, and plants grow in excess when P is abundant. When possible, water lawns with lake water that usually contains adequate P for successful lawn growth. If you must fertilize your lawn, assure that the middle number on the bag of fertilizer reads “0” to denote the absence of P. If possible, also use low N in the fertilizer or use lake water. Fortunately, there exists a county ordinance where P fertilizers are not allowed. Individual riparians should never use P in fertilizers since it will create more algae and weed growth in the lake over time.
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).
5) If septic tank systems are in use, then annual pumping and cleaning is recommended since drainfield water eventually enters the groundwater and enters the lake. This can also lead to accelerated aquatic weed growth. If sewers are present, then regular inspections and maintenance of the sewer lines are necessary for reducing nutrient seepage into the surrounding lake soils.

6.2.3 Zebra Mussels and Other Invasives

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 Barron Lake is awareness and education. The majority of the exotic species of concern have been listed in this report. Other exotic species on the move could be introduced to the riparians around Barron Lake through the use of a professionally developed educational newsletter.

Zebra Mussels

Zebra mussels (*Dreissena polymorpha*) were first discovered in Lake St. Clair in 1988 (Herbert et *al*. 1989) and likely arrived in ballast water or on shipping vessels from Europe (McMahon 1996). They are easily transferred to other lakes because they inherit a larval (nearly microscopic) stage where they can easily avoid detection. The mussels then grow into the adult (shelled) form and attach to substrates (i.e. boats, rafts, docks, pipes, aquatic plants, and lake bottom sediments) with the use of byssal threads. The fecundity (reproductive rate) of female zebra mussels is high, with as many as 40,000 eggs laid per reproductive cycle and up to 1,000,000 in a single spawning season (Mackie and Schlosser 1996). Although the mussels only live 2-3 years, they are capable of great harm to aquatic environments. In particular, they have shown selective grazing capabilities by feeding on the preferred zooplankton food source (green algae) and expulsion of the non-preferred blue green algae (cyanobacteria). Additionally, they may decrease the abundance of beneficial diatoms in aquatic ecosystems (Holland 1993). Such declines in favorable algae, can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations. Zebra mussels are viewed by some as beneficial to lakes due to their filtration capabilities and subsequent contributions to increased water clarity. However, such water clarity may allow other photosynthetic aquatic plants to grow to nuisance levels (Skubinna et *al*. 1995).

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

Invasive Aquatic Plants

In addition to Eurasian watermilfoil (*M. spicatum*), many other invasive aquatic plant species are being 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. 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* and *Trapa natans* (Water Chestnut). *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. *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. However, use of the Grass Carp in Michigan is currently not permitted by the MDNR.

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 lake. Methods of control involve the use of mechanical removal and chemical herbicides. Biological controls are not yet available for the control of this aquatic plant.

7.0 BARRON LAKE IMPROVEMENT CONCLUSIONS & RECOMMENDATIONS

The information given above for the long-term management of Barron Lake should be considered for effective management and ultimate protection of the lake native aquatic plants and fisheries. The overall goal of this proposed management program is to conduct whole-lake surveys and scan the lake each year to determine changes in aquatic vegetation communities with time and use that detailed data to make annual management recommendations to effectively control invasive aquatic plant species and preserve native aquatic plant species and the lake fishery.

Additionally, implementation of whole-lake aeration (laminar flow) is recommended to increase dissolved oxygen throughout the water column, reduce nutrients that feed weeds and algae, and reduce organic muck on the lake bottom. Table 9 below describes the primary and secondary goals and locations for the proposed improvement methods.

The following recommendations can be made for the proposed lake improvement program:

1) 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 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. Wherever possible, it is preferred to use a granular systemic aquatic herbicide for longer-lasting, localized aquatic plant control. The use of Sculpin G® (2,4-D) or Renovate OTF LZR® (triclopyr) is recommended for the spot-treatment of invasive hybrid watermilfoil throughout Barron Lake.

2) A whole-lake survey and scan should be executed each year along with additional surveys to accurately compare the changes in weed bed size and invasive species polygons in the lake over time. These survey results will produce lake scans of aquatic vegetation biovolume, sediment hardness, and maps showing the locations of all invasive species and their relative abundance. This will allow for season to season determination of efficacy of both herbicide treatments and aeration on aquatic vegetation control and muck reduction.

3) Water quality monitoring which will consist of parameters similar to the ones used in this study. This will be an MDEQ requirement and will also help determine what impacts the aeration system is may be having on the water quality and trophic status of Barron Lake.

Table 9. Proposed lake improvement methods for Barron Lake's improvement plan.

Lake Management Activity	Primary Goal	Secondary Goal	Best Locations to Use
Aquatic herbicide treatment of milfoil	To reduce areas where the milfoil is dense	To prevent dense areas from spreading in the lake	Throughout lake
Manual removal of Phragmites	To reduce areas where it is dense	To prevent plant from colonizing more of the shoreline	Shoreline of lake
Laminar flow aeration/bio augmentation	To reduce odorous muck and reduce nutrients and increase DO in water column	To holistically manage the muck, weeds, and algae in the lake	Throughout lake
Lake vegetation surveys/scans	To determine % cover by invasives and use as data tool	To compare year to year reductions in nuisance vegetation areas	Throughout lake each spring/summer
Water quality/sediment monitoring	To troubleshoot areas that have poor water quality	To compare trend in water quality parameters with time	Deep Basins for water quality and 30 sediment sites

7.1 Cost Estimates for Barron Lake Improvements

The proposed lake improvement program for the improvements of Barron Lake would begin during the 2018 season and continue through 2022. The reduction in acres of watermilfoil and Phragmites would likely follow in 2018-2019 and beyond and thus that portion of the annual budget may be spared and a surplus may continue in future years. A breakdown of estimated costs associated with the various necessary treatment in Barron Lake is presented in Table 10. 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).

Table 10. Proposed lake improvement costs for a five year program.

Proposed Barron Lake Management Improvement Item	***Estimated 2018 Cost***	***Estimated 2019 Cost***	***Estimated 2020-2022 Cost***
Herbicides for Watermilfoil Phragmites, Permit Fees[1]	$10,000	$10,000	$8,000
Professional Limnologist Services (limnologist surveys, sampling, contractor oversight, education)[2]	$12,000	$12,000	$12,000
LFA aeration system install, lease, and maintenance, bioaugmentation	$70,000	$60,000	$60,000
Contingency (10%)[3]	$9,200	$8,200	$8,200
TOTAL ANNUAL ESTIMATED COST	$101,200	$90,200	$90,200
APPROX. ANNUAL COST PER UNIT OF BENEFIT[4]	$518.97	$462.56	$462.56

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[1] Herbicide treatment scope for the treatment of watermilfoil and Phragmites is proposed to decline annually due to aggressive treatment with the use spot-treatment herbicides and manual pulling after treatment.

[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, review of all invoices from contractors and others billing for services related to the improvement program, education of local riparians, and attendance at regularly scheduled Barron Lake Association Board meetings. The service also provides for the annual MDEQ sampling requirements that will be a condition of the MDEQ LFA permit application. The annual lake consulting contract should be reviewed annually, based on performance and meeting of deliverables. There should also be a termination clause for either party if needed.

[3] Contingency is 10% of the total project cost, to assure that extra funds are available for unexpected expenses. Note: Contingency may be advised and/or needed for future treatment years.

[4] Current study estimates based on 195 units of benefit. This value is subject to change as the SAD is refined or changed by the Barron Lake Association Board. This would mean that a lakefront lot would pay the amount shown and back lots would pay half of that amount. Commercial lots would pay 2.0 times the amount shown.

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