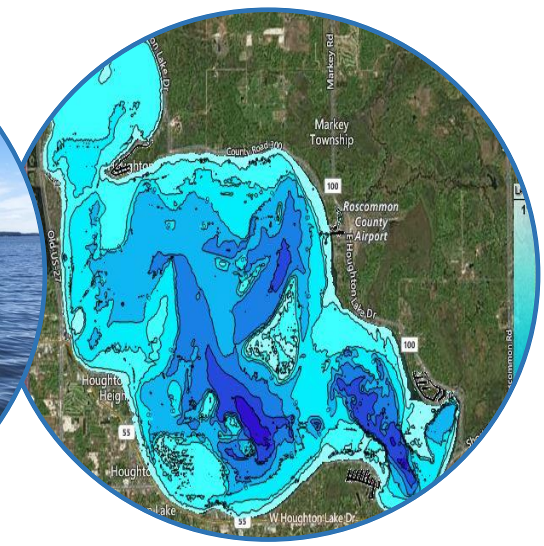
Houghton Lake Improvement Feasibility Study and Five Year Aquatic Vegetation Management Plan Roscommon County, Michigan



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

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

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1.0 EXECUTIVE SUMMARY

Houghton Lake is a 22,044-acre natural, glacial lake located in Sections 2-11,14,15,17-18 of Denton Township (T22N R3W), Sections 10-16, 21-28, 35, and 36 of Lake Township (T23N R4W), Sections 1-3, 11-13 of Roscommon Township (T22N R4W), and Sections 19-21, 28-34 of Markey Township (T23N R3W). The lake also has several major tributaries including Sucker Creek at the north, Backus Creek and the Cut at the east region of the lake, Knappen Creek, Denton Creek, and Spring Brook Creek at the South region along with outflow at the Flats. There is also an outlet to the Muskegon River at the north region of the lake. The lake has approximately 30.5 miles of shoreline and a mean depth of approximately 8.5 ft (Restorative Lake Sciences, 2016). The lake water volume was estimated at 170,187.02 acre-feet (Restorative Lake Sciences, 2016).

A whole-lake aquatic plant survey and scan of aquatic vegetation biovolume was conducted from June 23-July 7, 2016. The lake scan consisted of 321,196 GPS points and the aquatic vegetation sampling survey utilized nearly 15,000 points in the lake and canals combined. Based on this data, Houghton Lake lacks aquatic vegetation in 69.54% of the lake (Restorative Lake Sciences, 2016). This makes it critical to selectively manage only exotic invasive species such as the approximately 500 acres of invasive hybrid watermilfoil (*Myriophyllum spicatum* var. *sibiricum*) and 450 acres of Starry Stonewort that were found in high density prior to the lake treatment in September of 2016. These particular invasive plants threaten the biodiversity of the submersed native aquatic plant (macrophyte) communities, threaten navigation and recreational activities, and also may harbor bacteria and other nuisance algae that are not beneficial to the lake's ecosystem. Furthermore, the invasive plants may reduce waterfront property values. RLS recommends that the Houghton Lake Improvement Board (HLIB) create a set of goals relative to the acreage of each invasive species. The range of acceptable coverage varies among professionals and regulatory agencies and thus these goals should be a community-based decision in conjunction with direction from RLS and other informative sources. The native aquatic plant diversity in Houghton Lake is very high with 32 native aquatic plant species present. All measures should be taken to preserve this biodiversity and allow for the re-establishment of Wild Rice (*Zizania aquatica*).

The overall water quality of Houghton Lake was measured as 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 neutral pH and low to moderate conductivity. The nutrients entering the lake from two tributaries (Sucker Creek and Spring Brook) are higher than the ambient concentrations in the lake and indicate that they are sources of significant nutrient loading to Houghton Lake. Restorative Lake Sciences recommends installation of nutrient and solid filtration barriers for both of the aforementioned tributaries. The immediate watershed draining to Houghton Lake is moderate in size and approximately 5.4 times the size of Houghton Lake. Restorative Lake Sciences will continue to monitor possible Critical Source Areas (CSA's) in the immediate watershed for the long-term protection of Houghton Lake.

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. Where aquatic herbicide treatment is not desired, the use of a DASH boat may be practical for small treatment areas of dense exotic vegetation.

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 strong contact herbicides be used to control the Starry Stonewort. Only dense growth of both species should be treated to allow for native aquatic plant species to re-colonize weed beds. A reduction in the herbicide treatment areas is projected for ongoing years of the program if no other invasives enter the Houghton Lake ecosystem. The HLIB and HLLA should work together to implement a boat washing station and provide education to residents and visitors on the proper washing of boats and trailers and on invasive species to reduce the transport of these invasives into Houghton Lake.

Restorative Lake Sciences recommends installation of aeration systems with bioaugmentation (microbes) in the Prudenville Canals and in McKinley Park Canal #5. These canals were found to have impaired water quality with high nutrient concentrations and solids. Aeration would reduce the blue-green algal blooms and muck in these canals and reduce nutrients over time. RLS will continue to monitor these and other canals for water quality, aquatic vegetation, and algae.

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. Additionally, RLS recommends that the HLIB develop a "mission statement" that assists the board with improvement direction. Finally, RLS recommends an annual review of the 5-year plan objectives to assist the HLIB in prioritization of goals. RLS also has developed a set of By-Laws for the HLIB to consider for adoption. These By-Laws will also assist the HLIB with any possible conflicts of interest so as to remain an unbiased, objective governing board.

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 Houghton 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 Houghton 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. Houghton Lake may be categorized as a drainage lake as it receives external water supplies from several tributaries (inlets) and has an outlet which empties into the Muskegon River at the north and eventually empties into Lake Michigan. The estimated hydrological retention time of water in Houghton Lake is approximately 1.71 years (Water Quality Investigators, 2009).

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.

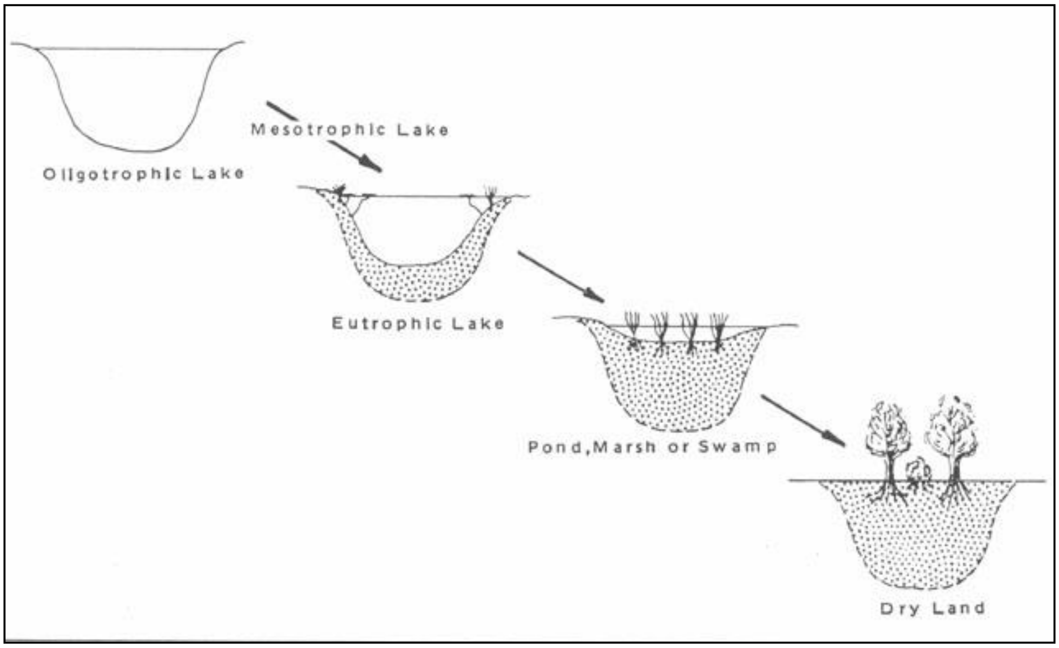

Figure 1. A diagram showing the lake aging (eutrophication) process.

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 HOUGHTON LAKE PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Houghton Lake Basin

Houghton Lake is a 22,044-acre natural, glacial lake located in Sections 2-11,14,15,17-18 of Denton Township (T22N R3W), Sections 10-16, 21-28, 35, and 36 of Lake Township (T23N R4W), Sections 1-3, 11-13 of Roscommon Township (T22N R4W), and Sections 19-21, 28-34 of Markey Township (T23N R3W). The lake also has many major tributaries including Sucker Creek at the north, Backus Creek and the Cut at the east region of the lake, Knappen Creek, Denton Creek, and Spring Brook Creek at the South region. There is also an outlet to the Muskegon River at the north region of the lake. The lake has approximately 30.5 miles of shoreline and a mean depth of approximately 8.5 ft (Restorative Lake Sciences, 2016). The lake lies at an elevation of 1,138 feet above sea level. The residence time of

Houghton Lake is approximately 1.71 years. Houghton Lake has a mean (average) depth of approximately 8.5 ft and a maximum depth of 21.0 feet (RLS, 2016). The whole lake was scanned during late summer of 2016 and this produced a modernized depth contour map (Figure 2). The fetch of the lake (longest distance across the lake) was calculated to be approximately 9.3 miles (Restorative Lake Sciences, 2016). The lake is classified as a meso-eutrophic (moderately nutrient-enriched) aquatic ecosystem with a large-sized littoral (shallow) zone that is capable of supporting rigorous submersed rooted, aquatic plant growth. A whole-lake sediment bottom hardness scan (Figure 3) 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.

Lake Levels:

The Roscommon County Circuit Court established a legal lake level of 1,138.1 feet above sea level for Houghton Lake in 1926. In 1938, a concrete dam was created to replace the existing dam that was a timber dam and was leading to extreme lake levels (too high and too low). In 1954, the Michigan Department of Conservation determined that outflow from the lake and outlet channel could be reduced by the dam and a dam enlargement and channel widening was recommended. Low-lying properties experienced flooding issues since the lake levels became problematic to those areas during ice-off. As a result of this, the Roscommon Board of Commissioners which led to a 1982 Circuit Court decision to maintain the 1926 court-ordered level of 1,138.1 feet above sea level as long as the lake is lowered to not less than 1,137.6 feet by November 1st of each year. The legal lake level of Houghton is regulated by the Roscommon County Board of Commissioners.

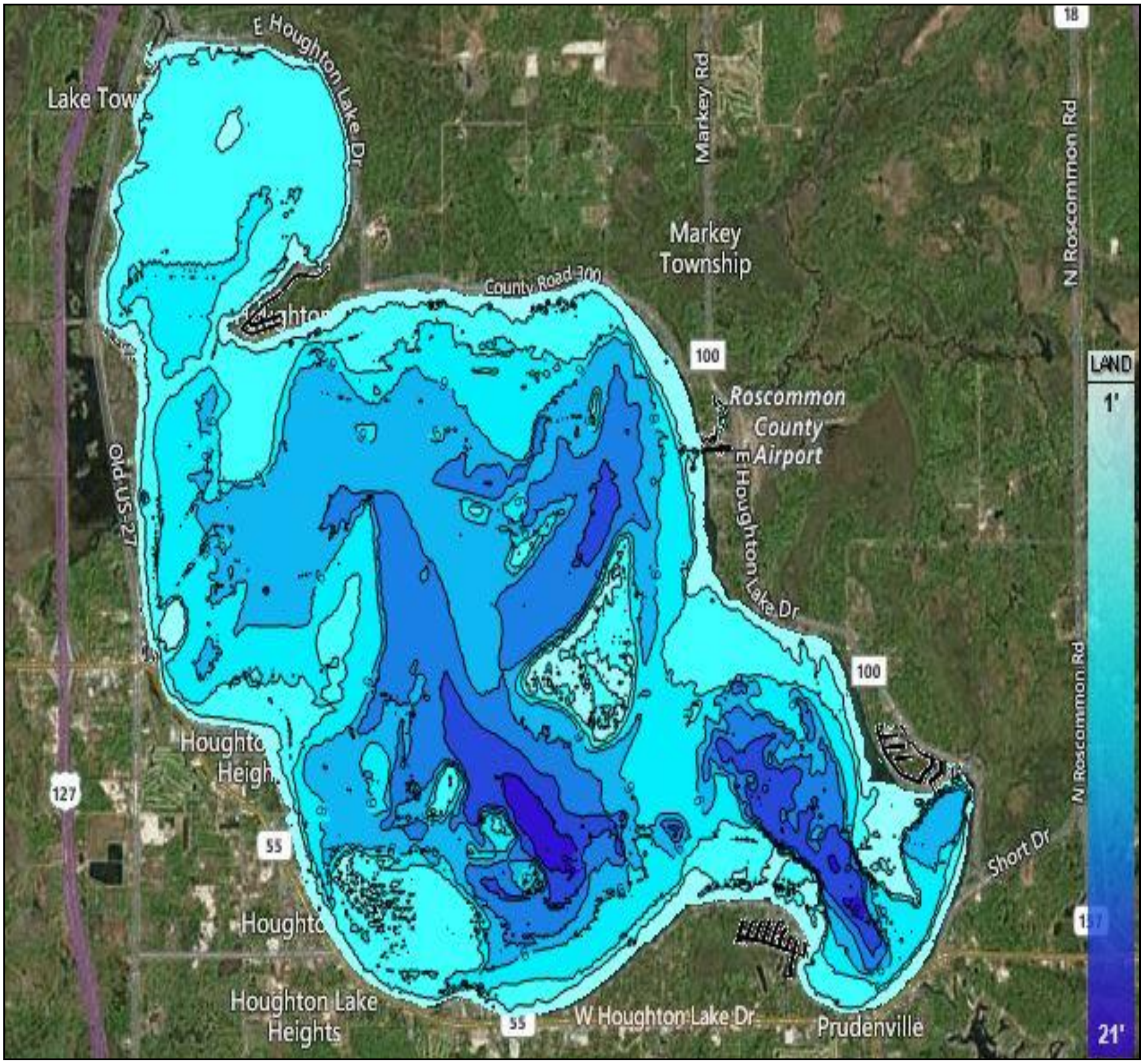

Figure 2. Houghton Lake, Roscommon County, Michigan (RLS, 2016).

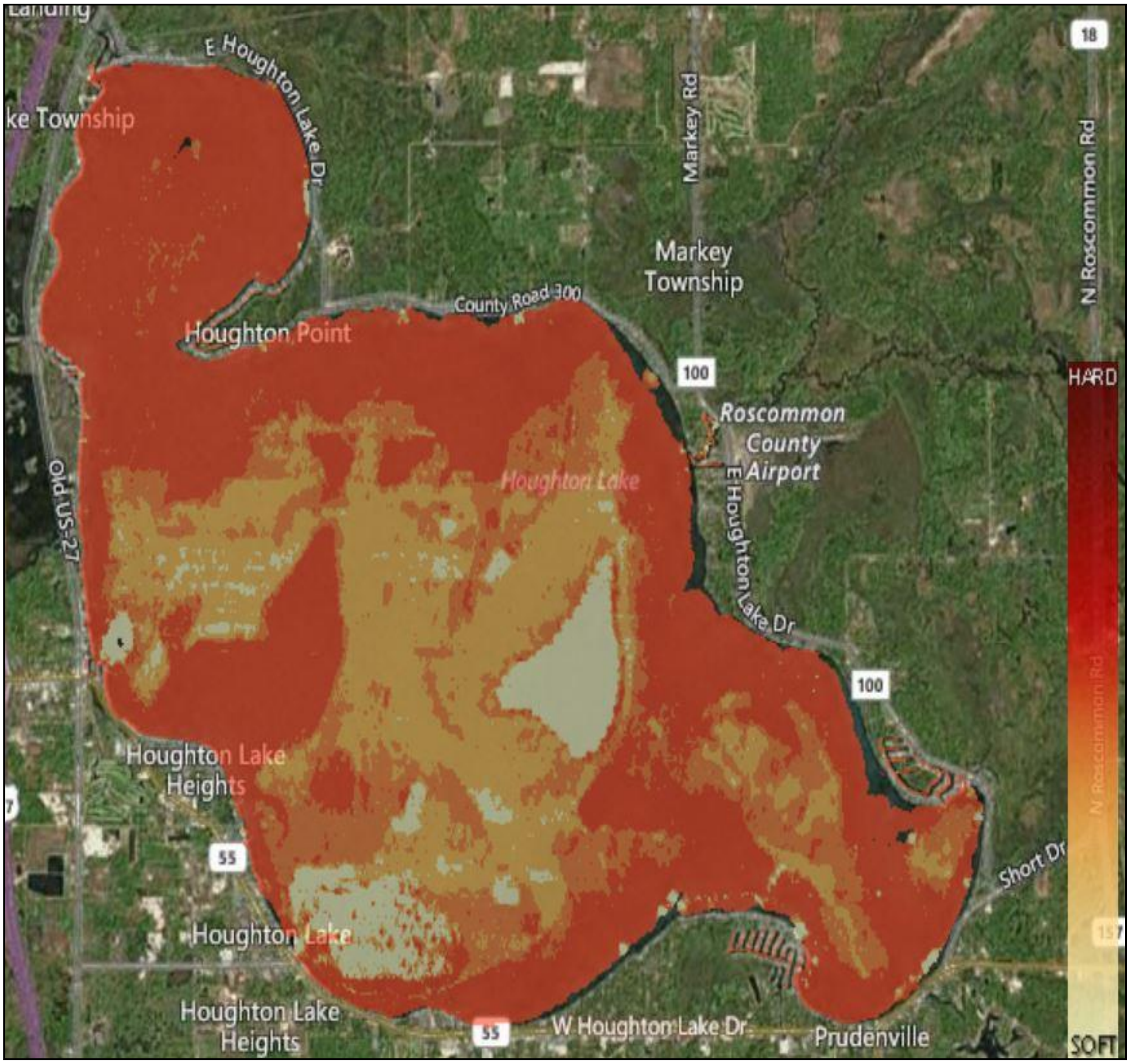

Figure 3. Houghton Lake sediment bottom hardness scan map (RLS, 2016). Note: On this map of relative bottom hardness, areas with firmer more consolidated sediments appear as dark orange whereas areas with soft bottom appear as light beige in color. The majority of the aquatic vegetation grows in areas dominated by soft bottom.

3.2 Houghton 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. The Houghton Lake extended watershed (Muskegon River; Figure 4) is approximately 2,350 mi^2 or 1,504,000 acres in area. The Muskegon River Watershed spans 8 counties including Roscommon, Missaukee, Clare, Osceola, Mecosta, Montcalm, Newaygo, and Muskegon Counties. Several watercourses and municipalities are included in this watershed such as Higgins Lake, Houghton Lake, the West Branch of the Muskegon River, Evart, the Hersey River, the Reedsburg Dam, the Clam River, the Middle Branch River, the City of Hersey, City of Big Rapids, the Rogers Dam, the Hardy Dam, the Croton Dam, the Little Muskegon River, the City of Newaygo, Bigelow Creek, Cedar Creek, Muskegon Lake, and the City of Muskegon. 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 Houghton Lake immediate watershed include forests and wetlands, agriculture, and developed (residential and commercial) land. There are also oil fields to the north and west of Houghton Lake which lie just outside of the immediate watershed.

The immediate watershed area is approximately 107,728.75 acres in area (Restorative Lake Sciences, 2016; Figure 5). 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 5.4 times larger than the size of Houghton Lake, which indicates the presence of a moderate-sized immediate watershed.

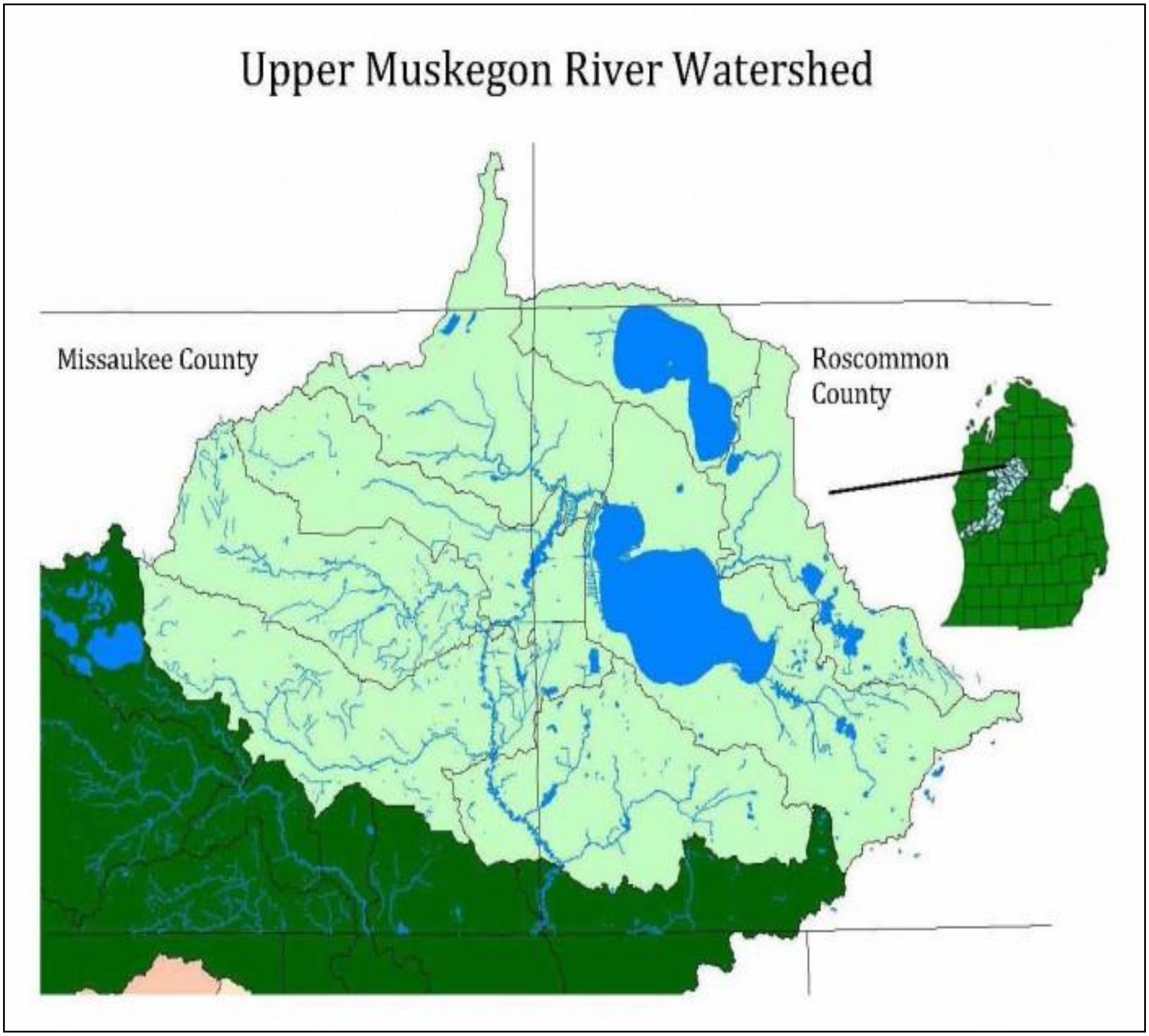

Figure 4. Extended Muskegon River Watershed (www.mwra.org, online resource).

Figure 5. Immediate Watershed draining into Houghton Lake, Roscommon County, Michigan (Restorative Lake Sciences, 2016).

3.3 Houghton Lake Shoreline Soils

There are 8 major soil types immediately surrounding Houghton Lake which may impact the water quality of the lake and may dictate the particular land use activities within the area. Figure 6 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service, 1999) demonstrates the precise soil types and locations around Houghton Lake. Major characteristics of the dominant soil types directly surrounding the Houghton Lake shoreline are discussed below. The major characteristics of each soil type are listed in Table 1 below.

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

USDA-NRCS Soil Series	***General Characteristics***
Tawas and Lupton Mucks 0-1% slopes	Organic, deep, very poorly drained, high runoff potential
Grayling sand 0-6% slopes	Deep, excessively drained, low runoff potential
Graycalm-Klacking Sands 0-6% slopes	Deep, somewhat excessively drained, low runoff potential
Graycalm Sand 0-6% slopes	Deep, somewhat excessively drained, low runoff potential
Histosols and Aquents, ponded	Organic (peat), poorly drained, high runoff potential
Wakeley Muck	Deep, poorly drained, high runoff potential
Croswell-Au Gres sands 0-3% slopes	Deep, moderately drained, moderate runoff potential
Au Gres-Kinross-Croswell complex, 0-6% slopes	Very deep, moderate to poorly drained, moderate to high runoff potential

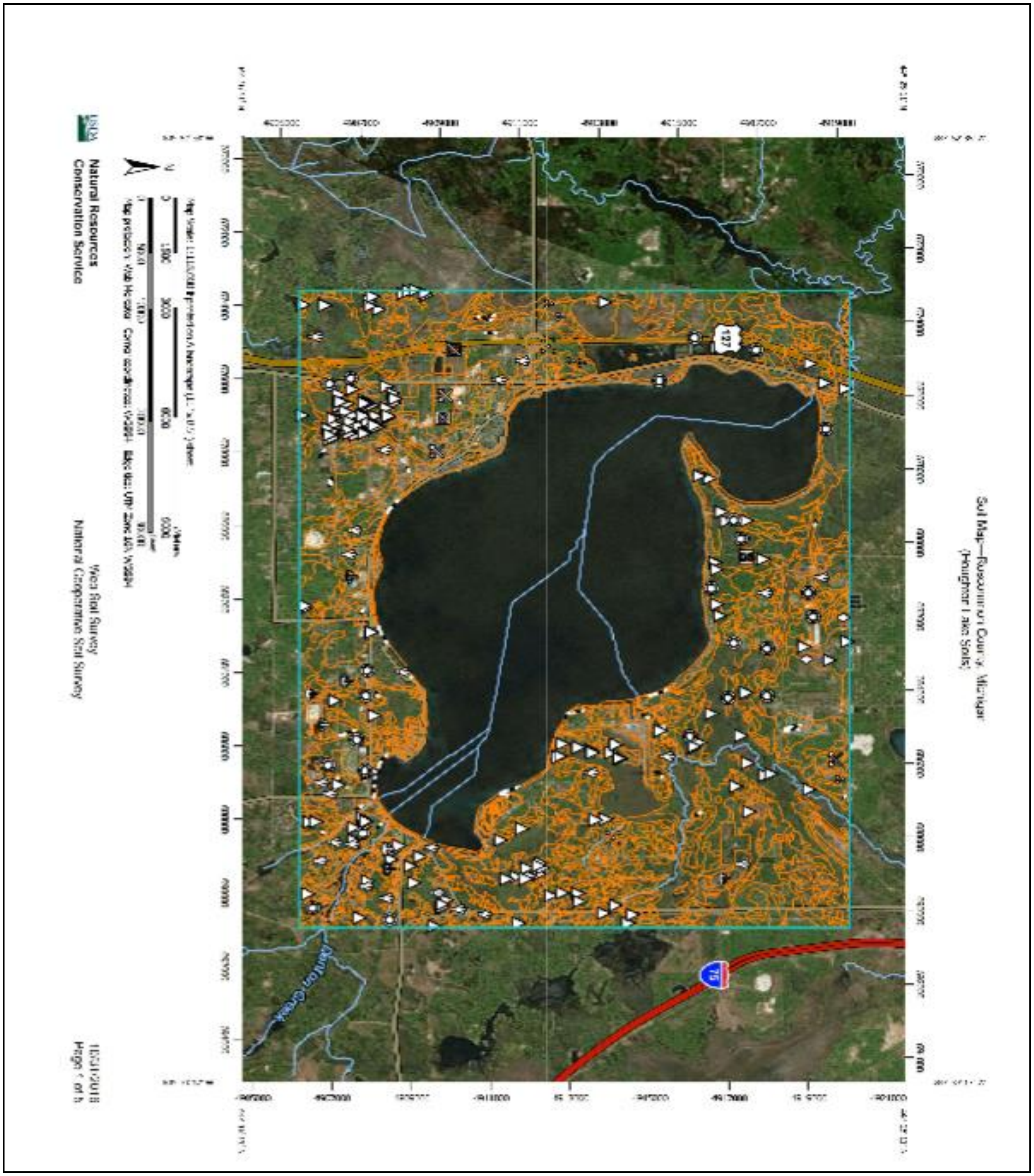

Figure 6. NRCS-USDA soils map for Houghton Lake shoreline soils (1999 data).

The majority of the soils around Houghton Lake are poorly drained soils with ponding and increased probability for runoff. These soils 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 HOUGHTON LAKE WATER QUALITY

Water quality is highly variable among Michigan's inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by 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. Houghton Lake is classified as meso-eutrophic. However, the canals may be classified as eutrophic since they contain higher nutrient concentrations. Houghton Lake harbors a healthy fishery and thus protection of its water quality is paramount.

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 Parameters

Parameters such as, but not limited to, dissolved oxygen, water temperature, conductivity, total dissolved and suspended solids, pH, total alkalinity, total phosphorus and ortho-phosphorus, total nitrogen, chlorophyll-*a*, algal composition, and Secchi transparency, are critical indicators of water quality. On August 11, 2016, RLS collected water samples from within 6 deep basins in Houghton Lake. Additionally, water samples were also collected in the 27 canals and in the 7 tributaries for the water quality parameters mentioned above. The results are discussed below and are presented in Tables 5-12. 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 collected from the deep basins is shown below in Figure 7. A map showing the sampling locations for all water quality samples collected from the tributaries is shown below in Figure 8. Maps showing the sampling locations for all water quality samples collected from the canals are shown below in Figures 9-9g. All water samples and readings were collected on August 11, 2016 with the use of a Van Dorn horizontal water sampler and calibrated YSI® multi-meter probe with parameter electrodes, respectively. Chlorophyll-a was measured *in situ* with a calibrated chlorophyll-a meter from Turner Designs®. Total Nitrogen was also measured *in situ* with Hach® Total Nitrogen Reagent Set. 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. RLS recommends that the HLIB co-develop testing policies in future years that could include testing of well water (if needed due to herbicide residues), lake water quality, and shoreline soil testing in areas susceptible to nutrient inputs or pollution.

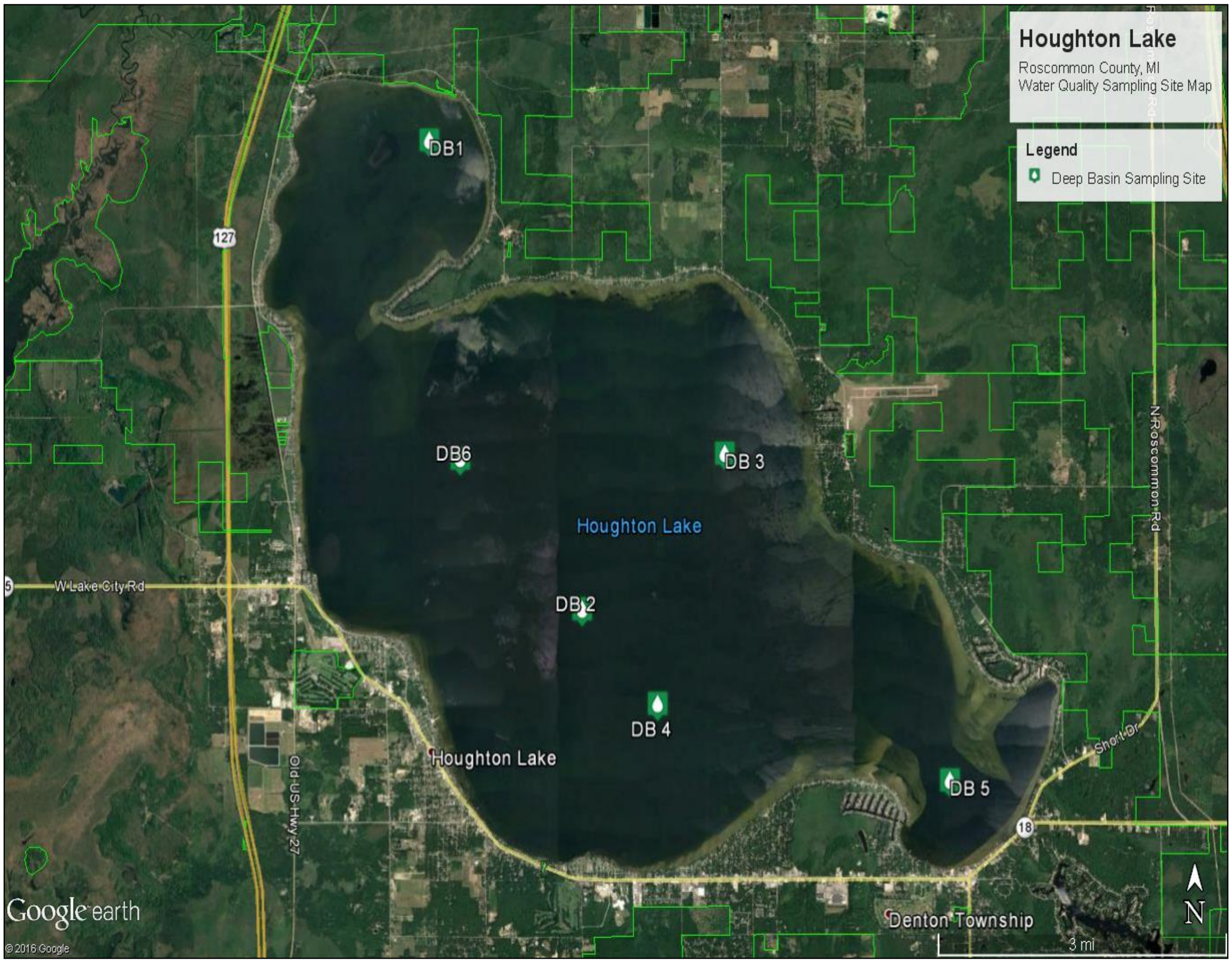

Figure 7. Locations for water quality sampling of the 6 basins in Houghton Lake (August 11, 2016).

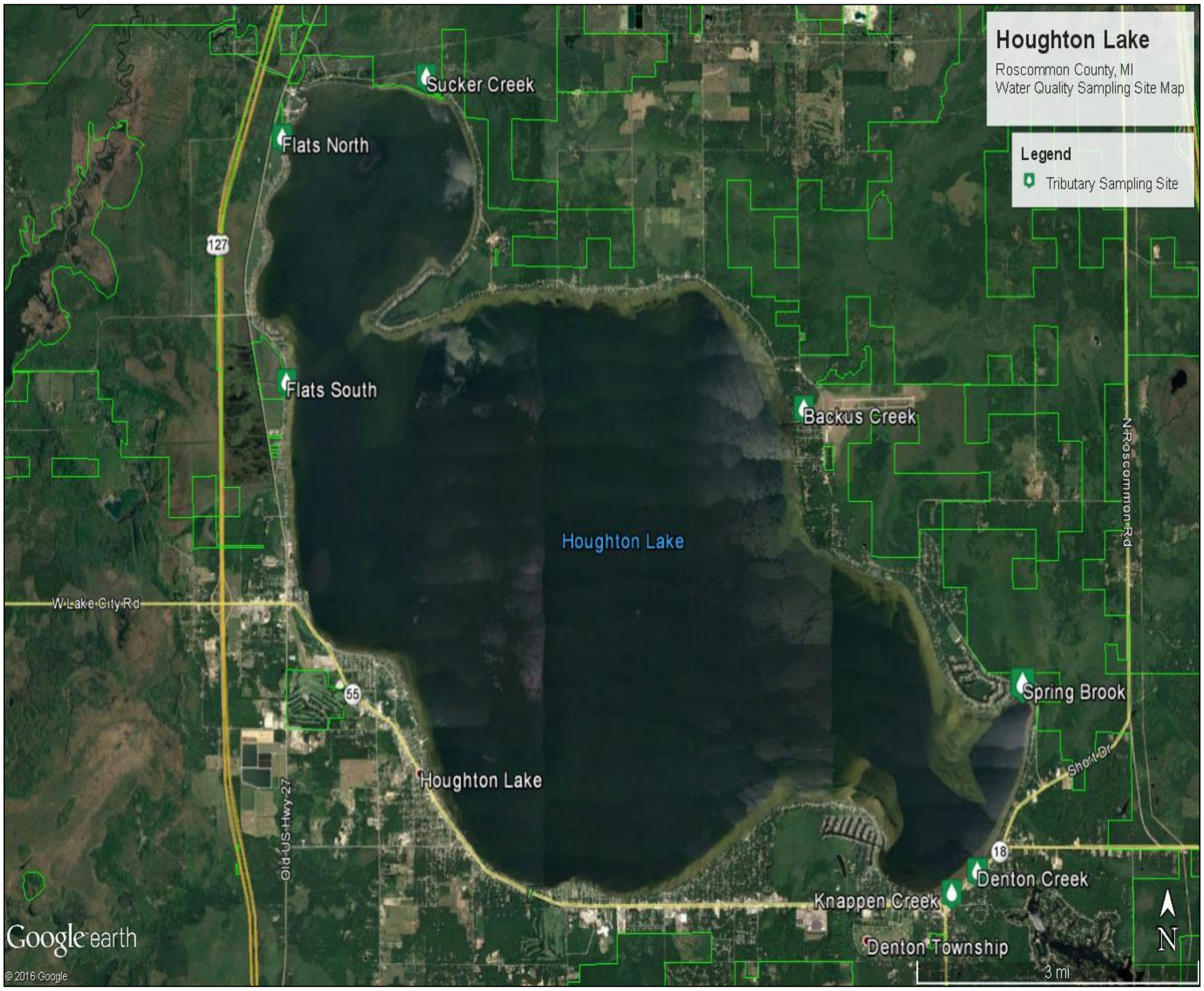

Figure 8. Locations for water quality sampling of the tributaries in Houghton Lake (August 11, 2016).

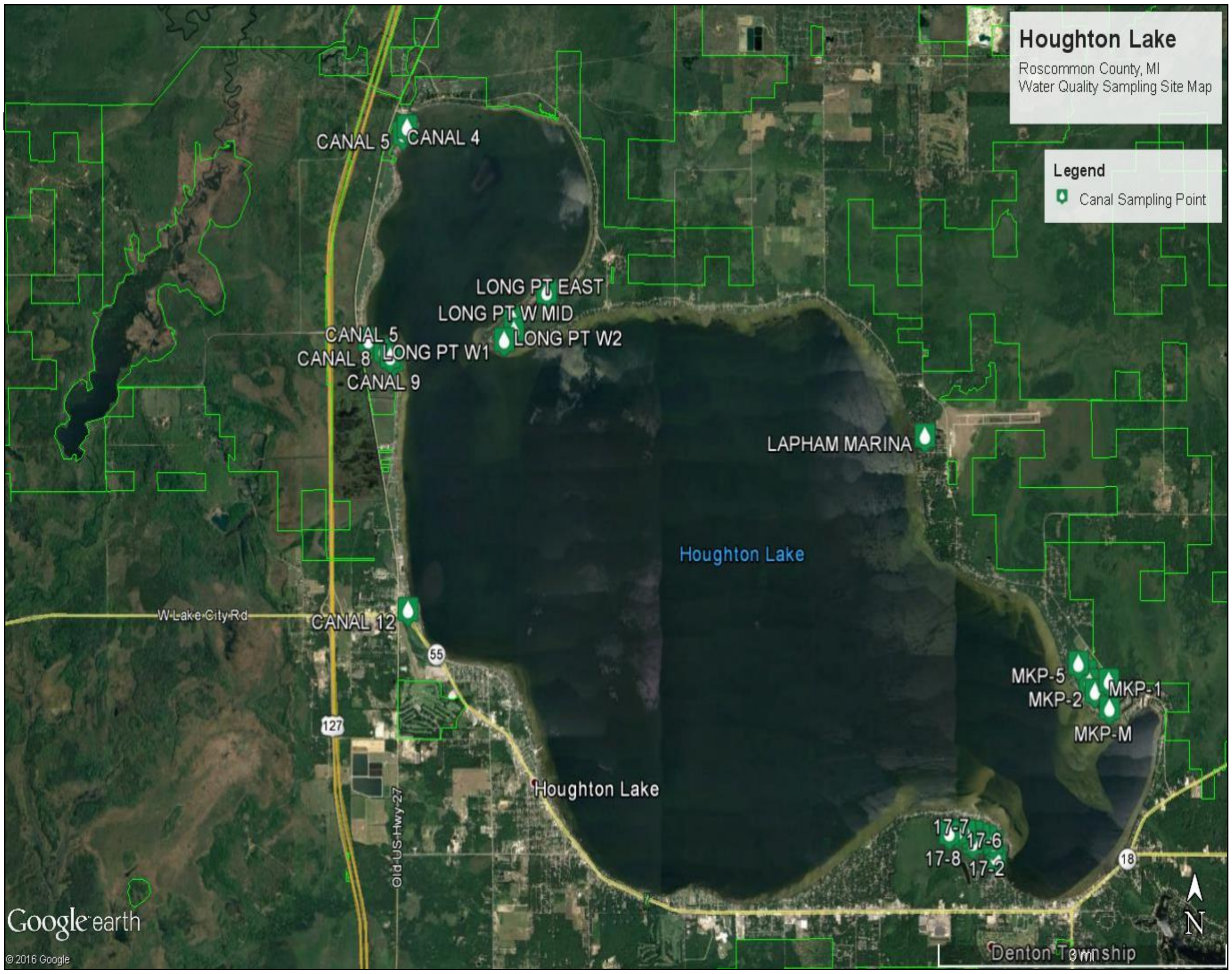

Figure 9. Locations for water quality sampling of the canals in Houghton Lake (August 11, 2016).

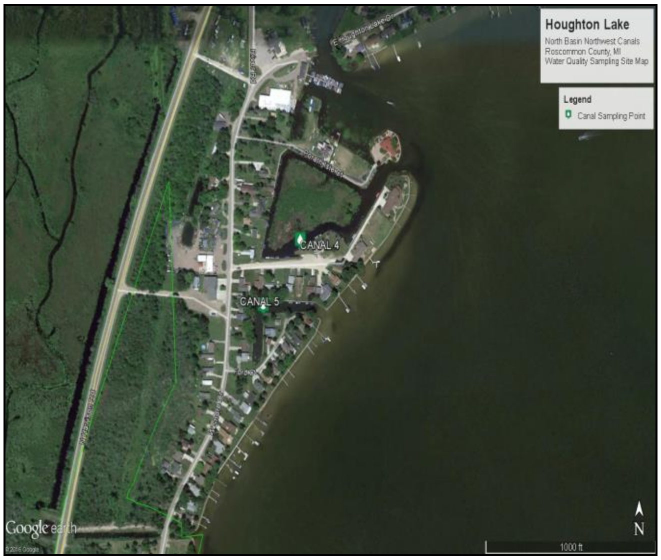

Figure 9a. Northwest canals

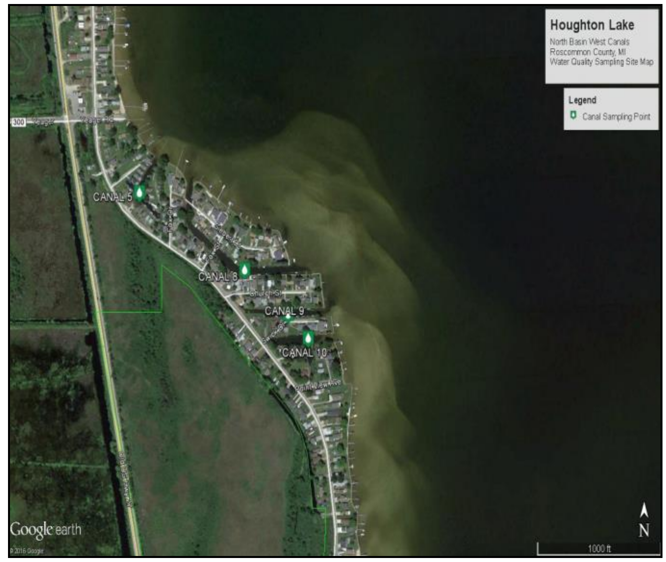

Figure 9b. Northwest canals

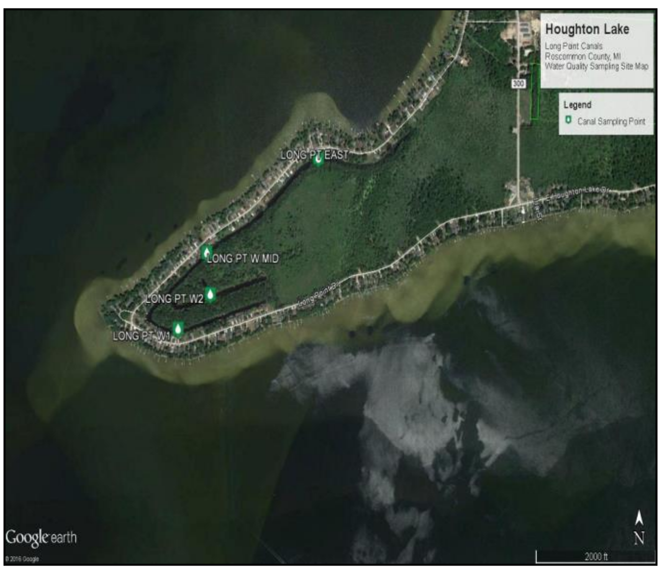

Figure 9c. Long Point canals

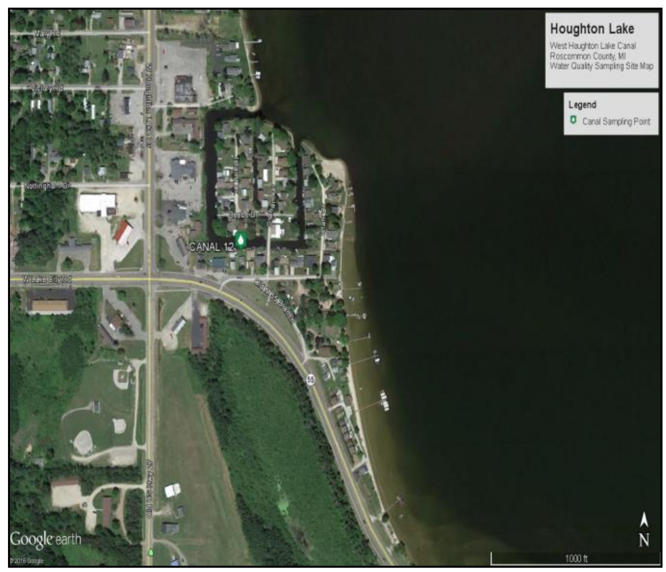

Figure 9d. West Canal

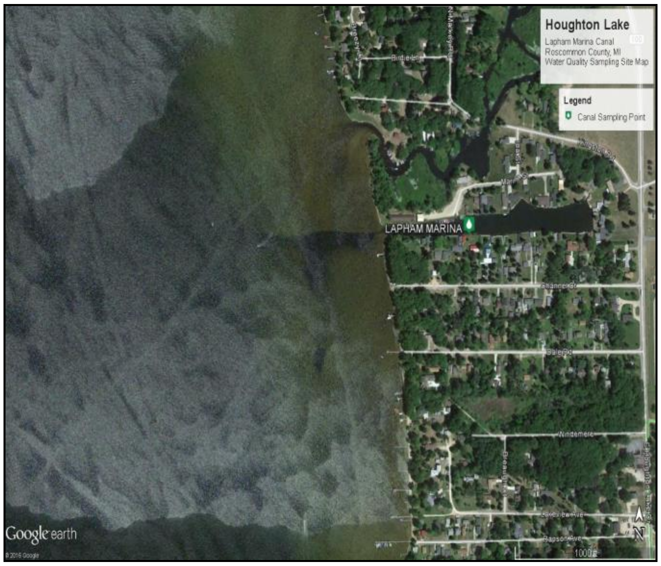

Figure 9e. Lapham Marina canal

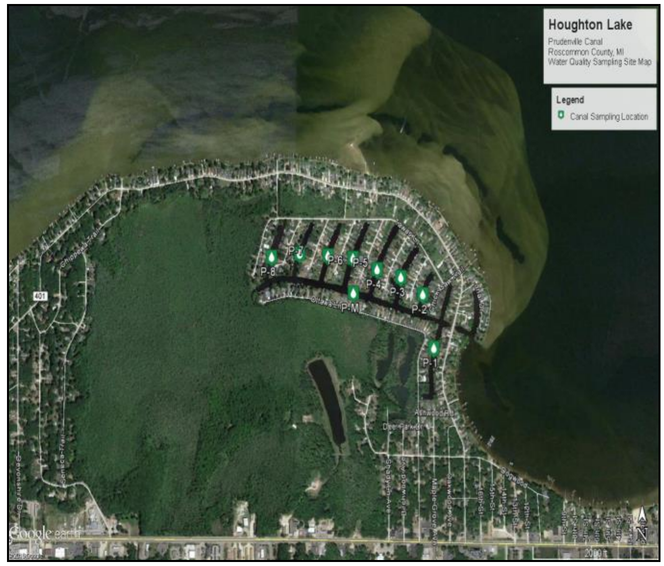

Figure 9f. Prudenville canals

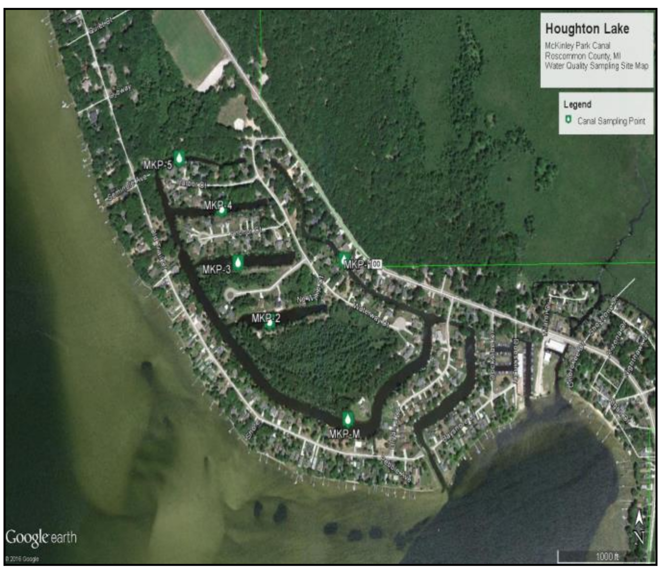

Figure 9g. McKinley Park canals

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 11, 2016 sampling event ranged from 5.4-7.3 mg L^{-1}, with concentrations of dissolved oxygen higher at the surface and slightly lower at the bottom. The dissolved oxygen concentrations of the tributaries ranged from 1.5-7.2 mg L^{-1} with the lowest value recorded at Sucker Creek. The dissolved oxygen concentrations in the canals ranged from 5.3-7.3 mg L^{-1}. All of these concentrations are likely higher (based on historical data) in the spring due to cooler water temperatures which hold more oxygen. Figure 10 below shows the changes in mean dissolved oxygen with time in Houghton Lake.

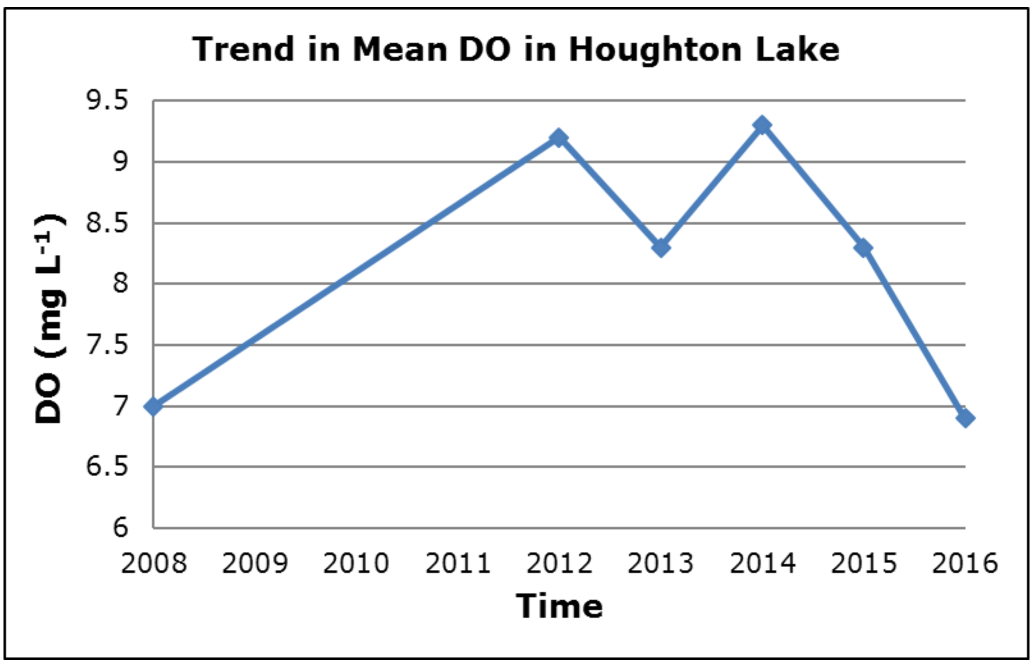

Figure 10. Trend in DO concentrations with time in Houghton Lake.

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 11, 2016 water temperatures of Houghton Lake demonstrated a weak thermocline in a few basins and ranged from a low of 72.1°F at the bottom to a high of 83.5°F at the surface. All of the water temperatures recorded in the canals and tributaries on August 11, 2016 were ≥80°F. These are considerably warm water temperatures since the mid-August temperatures recorded back in 2006 were around 73°F (MDEQ legacy data, 2006).

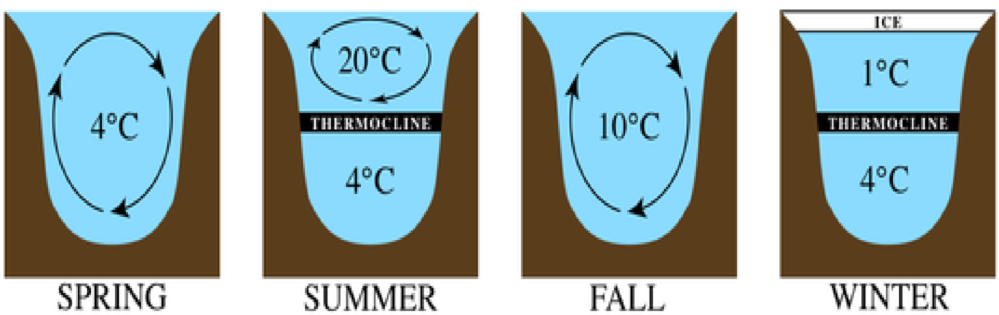

Figure 11. Diagram showing the process of stratification and turnover in lakes. Note: Houghton Lake likely has multiple turn-over events in a given season due to the shallow depths and wind that induces constant mixing of the lake water.

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 (µS cm^{-1}) with the use of a calibrated conductivity probe meter. The mean specific conductivity for Houghton Lake deep basins was 214 mS cm^{-1} during the August 11, 2016 sampling event. The mean specific conductivity for the Houghton Lake canals was 316 mS cm^{-1} during the August 11, 2016 sampling event and the mean specific conductivity for the tributaries was 290 mS cm^{-1}. These values are moderate for an inland lake and mean that the lake water contains some dissolved metals. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Houghton 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 Total Dissolved Solids and Total Suspended 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 mean TDS in Houghton Lake was 104 mg L^{-1} for the deep basins on August 11, 2016, which is moderate for an inland lake. The TDS of the tributaries averaged 130 mg L^{-1} and the TDS of the canals averaged 175 mg L^{-1}. It is not uncommon for shallow waters to have higher values due to concentration of dissolved solids in less water volume. 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 Houghton Lake tributaries ranged from <10-140 mg L^{-1}. All of the tributaries except Sucker Creek had TSS concentrations < 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 Houghton Lake water has been stable over time and ranged from 8.1 – 8.7 S.U. During the August 11, 2016 sampling event, the mean pH was around 8.1 S.U. The mean pH of the tributaries on August 11, 2016 was 8.0 S.U. and the mean pH of the canals was 8.1 S.U. on August 11, 2016. Figure 12 below shows the changes in mean pH with time in Houghton Lake.

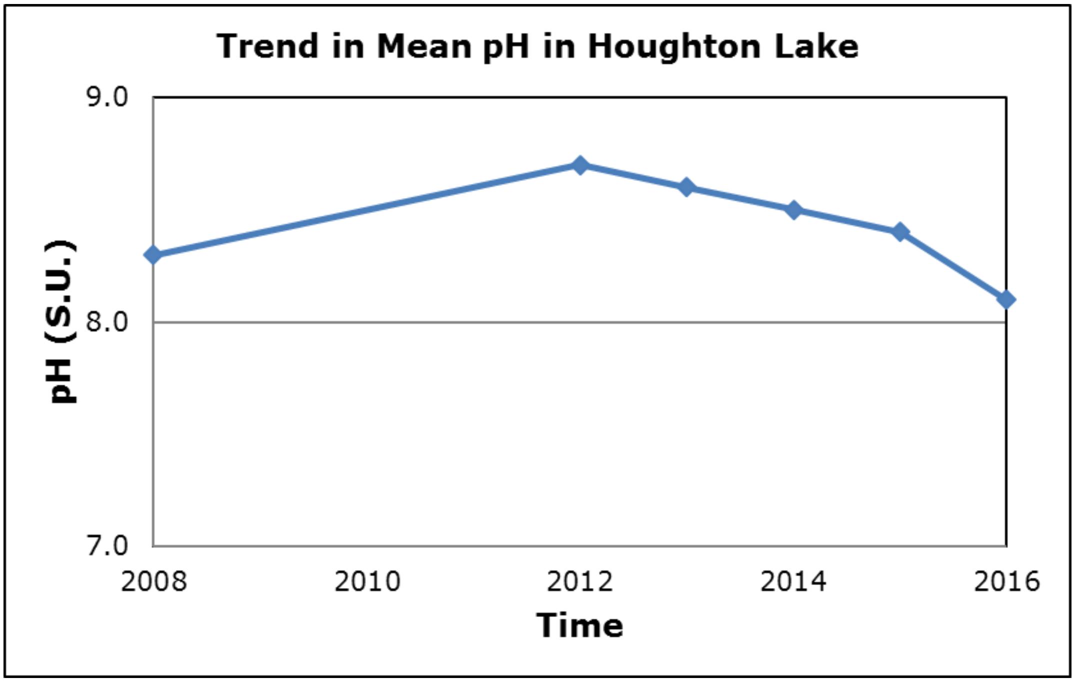

Figure 12. Trend in pH with time in Houghton Lake.

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 Houghton 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 averaged 85 mg L^{-1} of $CaCO_3$ during the August 11, 2016 sampling event and have historically ranged from 76-98 mg L^{-1} of $CaCO_3$. 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

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 Houghton Lake during the August 11, 2016 sampling event averaged 0.6 mg L^{-1}, which is moderately low for an inland lake.

4.1.8 Total Phosphorus and Ortho-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 Houghton Lake was 12.3 µg L^{-1} on August 11, 2016. The mean TP concentration in the tributaries was 28.4 µg L^{-1} on August 11, 2016. The mean TP concentration in the canals was 24.0 µg L^{-1} on August 11, 2016. Historical mean concentrations ranged from 4.0-43.0 µg L^{-1}. Houghton Lake is thus moderate in TP but the canals and especially the tributaries are significant sources of TP to the lake. Figure 13 below shows the changes in mean TP with time in Houghton Lake.

Ortho-phosphorus refers to the concentration of phosphorus that is soluble and thus bioavailable to aquatic life. The ideal concentration of ortho-phosphorus is < 10 µg L^{-1}. All of the ortho-phosphorus concentrations in Houghton Lake were < 10 µg L^{-1}. However, Sucker Creek and Spring Brook had concentrations in August, 2016 of 110 µg L^{-1} and 32 µg L^{-1}, respectively.

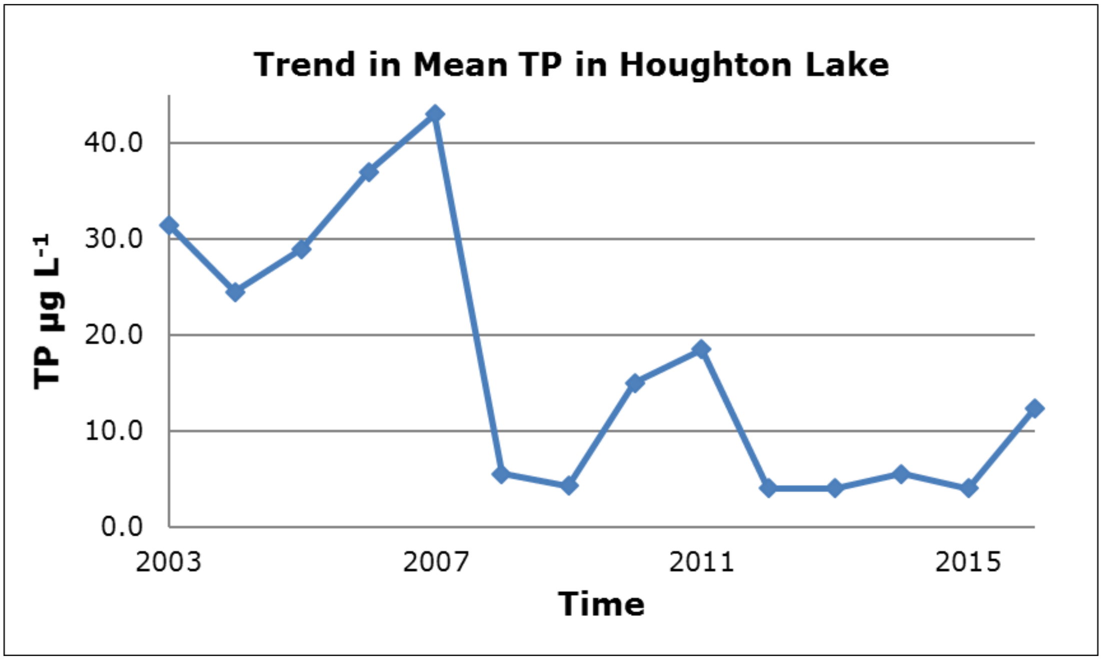

Figure 13. Trend in mean TP with time in Houghton Lake.

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.

The chlorophyll-*a* concentrations in Houghton Lake were determined by collecting composite samples of the algae throughout the water column at each of the 6 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 11, 2016. Additionally, the mean chlorophyll-*a* concentration in the canals was 7.4 µg L^{-1} and in the tributaries was 5.0 µg L^{-1} on August 11, 2016. These values indicate that planktonic algae are prominent in the water column and were likely higher in 2016 due to significantly 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). 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. Note: Zebra Mussels are an invasive species and further introduction into

Houghton Lake should be reduced. Figure 14 below shows the trend in mean chlorophyll-*a* with time in Houghton Lake.

Algal genera from a composite water sample collected over the deep basins and canals of Houghton 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 and canals are listed in Tables 3 and 4 below, respectively. The dominant algal genera found in the deep basins consisted of single-celled, multi-celled, and filamentous algae. The dominant filamentous algae, Spirogyra resembles silky horse hair and was found in high densities at the bottom of the lake in various areas. Blue-green algae was found in the canals and in moderation.

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 Houghton 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.

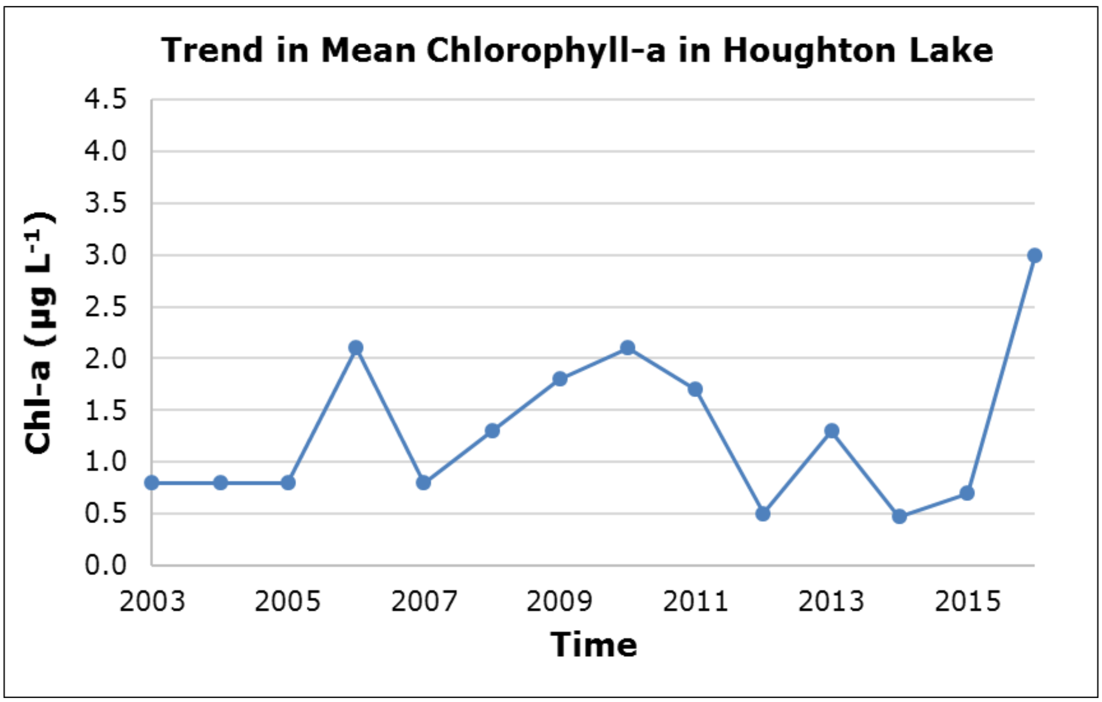

Figure 14. Trend in mean chlorophyll-a with time in Houghton Lake.

Table 3. Dominant algal taxa found in the Houghton Lake deep basins (August 11, 2016).

Algae Sample Location	Dominant Algal Genera
DB #1	*Chlorella* sp., *Scenedesmus* sp., *Spirogyra* sp., *Mougeotia* sp.
DB #2	*Chlorella* sp., *Scenedesmus* sp., *Spirogyra* sp., *Closterium* sp.
DB #3	*Chlorella* sp., *Pediastrum* sp., *Spirogyra* sp., *Mougeotia* sp.
DB #4	*Chlorella* sp., *Scenedesmus* sp., *Zygnema* sp., *Mougeotia* sp.
DB #5	*Chlorella* sp., *Pediastrum* sp., *Spirogyra* sp., *Mougeotia* sp.
DB #6	*Chlorella* sp., *Scenedesmus* sp., *Spirogyra* sp., *Closterium* sp.

Table 4. Dominant algal taxa found in the Houghton Lake canals (August 11, 2016).

Algae Sample Location	Dominant Algal Genera
Canal 4 (N)	*Chlorella* sp., *Haematococcus* sp., *Scenedesmus* sp, *Oscillatoria* sp.
Canal 5 (N)	*Chlorella* sp., *Microcystis* sp., *Scenedesmus* sp, *Oscillatoria* sp.
Canal 6 (NW)	*Chlorella* sp., *Haematococcus* sp., *Mougeotia* sp, *Oscillatoria* sp
Canal 8 (NW)	*Chlorella* sp., *Haematococcus* sp., *Scenedesmus* sp, *Oscillatoria* sp.
Canal 9 (NW)	*Chlorella* sp., *Mougeotia* sp., *Scenedesmus* sp, *Oscillatoria* sp.
Canal 10 (NW)	*Chlorella* sp., *Haematococcus* sp., *Spirogyra* sp, *Oscillatoria* sp.
Canal 12 (W)	*Chlorella* sp., *Haematococcus* sp., *Spirogyra* sp, *Oscillatoria* sp.
P1 (EB)	*Scenedesmus* sp., *Haematococcus* sp., *Spirogyra* sp, *Oscillatoria* sp.
P2 (EB)	*Chlorella* sp., *Haematococcus* sp., *Spirogyra* sp, *Oscillatoria* sp
P3 (EB)	*Chlorella* sp., *Oscillatoria* sp., *Mougeotia* sp, *Microcystis* sp
P4 (EB)	*Chlorella* sp., *Scenedesmus* sp., *Mougeotia* sp, *Oscillatoria* sp
P5 (EB)	*Chlorella* sp., *Closterium* sp., *Mougeotia* sp, *Oscillatoria* sp
P6 (EB)	*Chlorella* sp., *Scenedesmus* sp., *Mougeotia* sp, *Zygnema* sp
P7 (EB)	*Chlorella* sp., *Haematococcus* sp., *Mougeotia* sp, *Oscillatoria* sp
P8 (EB)	*Chlorella* sp., *Zygnema* sp., *Mougeotia* sp, *Oscillatoria* sp
PM (EB)	*Chlorella* sp., *Haematococcus* sp., *Mougeotia* sp, *Oscillatoria* sp
MKP-1 (EB)	*Chlorella* sp., *Haematococcus* sp., *Spirogyra* sp, *Oscillatoria* sp
MKP-2 (EB)	*Chlorella* sp., *Spirogyra* sp., *Mougeotia* sp, *Oscillatoria* sp
MKP-3 (EB)	*Scenedesmus* sp., *Haematococcus* sp., *Closterium* sp, *Oscillatoria* sp
MKP-4 (EB)	*Chlorella* sp., *Scenedesmus* sp., *Microcystis* sp, *Oscillatoria* sp
MKP-5 (EB)	*Chlorella* sp., *Scenedesmus* sp., *Spirogyra* sp, *Oscillatoria* sp
MKP-M (EB)	*Chlorella* sp., *Scenedesmus* sp., *Zygnema* sp, *Oscillatoria* sp
Lapham (E)	*Scenedesmus* sp., *Chlorella* sp., *Spirogyra* sp, *Oscillatoria* sp.
Long PT W MID	*Scenedesmus* sp., *Haematococcus* sp., *Spirogyra* sp, *Oscillatoria* sp.
Long PT W 1	*Chlorella* sp., *Haematococcus* sp., *Mougeotia* sp, *Oscillatoria* sp
Long PT W2	*Chlorella* sp., *Mougeotia* sp., *Scenedesmus* sp, *Oscillatoria* sp.
Long PT E	*Chlorella* sp., *Spirogyra* sp., *Scenedesmus* sp, *Oscillatoria* 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 15). 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 Houghton Lake averaged 7.0 feet over the deep basins of Houghton Lake during the August 11, 2016 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. 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. The water clarity of Houghton Lake may be increasing with time due to the activity of Zebra Mussels which are prevalent in the lake and filter phytoplankton out of the water column which increases water clarity. Figure 16 below shows the mean Secchi transparency with time in Houghton Lake. The mean Secchi transparency in the canals was slightly lower at 5.0 feet during the August 11, 2016 sampling event. This is likely due to more re-suspension of fine bottom sediments and elevated algal counts.

Figure 15. A Secchi disk

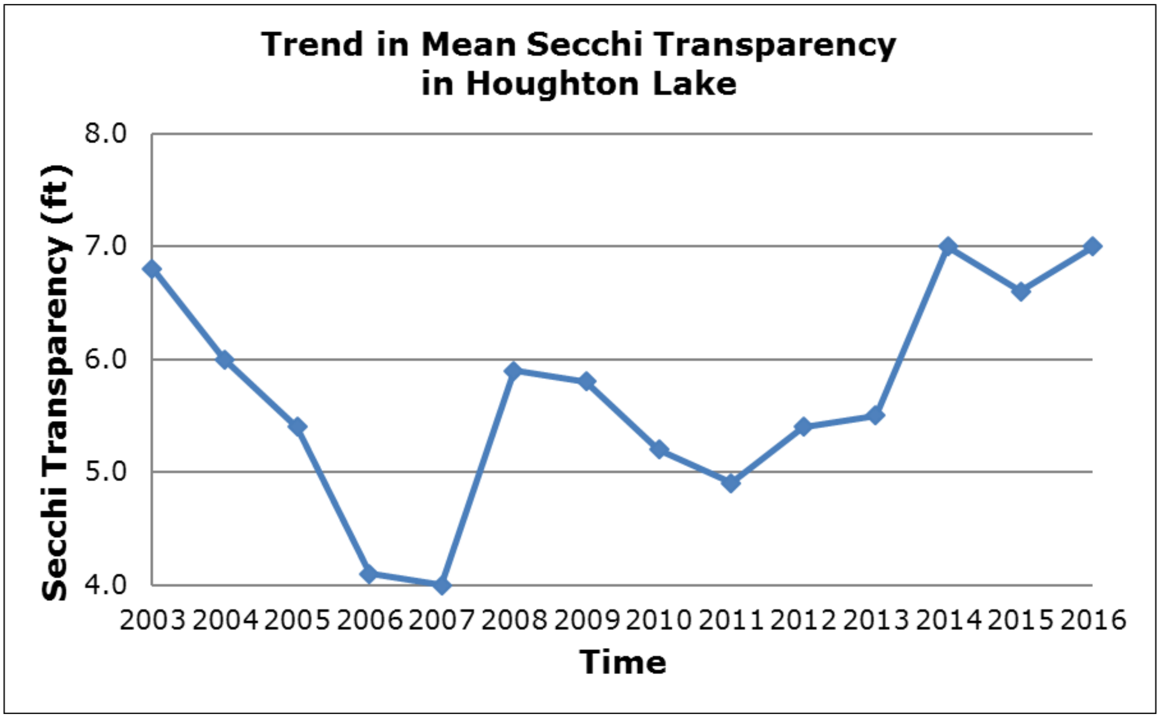

Figure 16. Mean Secchi transparency with time in Houghton Lake (2010-2016)

Houghton Lake Deep Basin Water Quality Data:

Table 5. Houghton Lake water quality parameter data collected over Deep Basin 1 on August 11, 2016.

Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*Ortho-P mg L^{-1}*	*TKN mg L^{-1}*	*Chl-a µg L^{-1}*	*Secchi ft.*
0	81.0	6.6	8.1	203	110	<0.010	<0.010	<0.5	2.0	6.0+
3.0	81.0	7.1	8.1	205	112	<0.010	<0.010	<0.5	--	--
6.0	81.1	7.1	8.1	205	110	<0.010	<0.010	<0.5	--	--

Table 6. Houghton Lake water quality parameter data collected over Deep Basin 2 on August 11, 2016.

Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*Ortho-P mg L^{-1}*	*TKN mg L^{-1}*	*Chl-a µg L^{-1}*	*Secchi ft.*
0	81.0	7.0	8.1	215	107	<0.010	<0.010	<0.5	4.0	7.5
7.5	80.4	6.9	8.1	218	108	<0.011	<0.010	<0.5	--	--
15.0	78.2	5.4	8.1	220	108	<0.011	<0.010	0.9	--	--

Table 7. Houghton Lake water quality parameter data collected over Deep Basin 3 on August 11, 2016.

Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*Ortho-P mg L^{-1}*	*TKN mg L^{-1}*	*Chl-a µg L^{-1}*	*Secchi ft.*
0	81.0	7.0	8.1	206	92	0.034	<0.010	<0.5	3.0	7.5
8.0	79.0	7.3	8.1	207	93	<0.010	<0.010	<0.5	--	--
16.0	73.8	6.5	8.1	205	94	0.010	<0.010	1.0	--	--

Table 8. Houghton Lake water quality parameter data collected over Deep Basin 4 on August 11, 2016.

Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*Ortho-P mg L^{-1}*	*TKN mg L^{-1}*	*Chl-a µg L^{-1}*	*Secchi ft.*
0	81.5	7.2	8.2	220	107	0.010	<0.010	<0.5	3.0	6.8
9.0	81.0	7.2	8.2	221	108	0.012	<0.010	<0.5	--	--
18.0	77.4	6.5	8.2	217	109	<0.010	<0.010	0.8	--	--

Table 9. Houghton Lake water quality parameter data collected over Deep Basin 5 on August 11, 2016.

Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*Ortho-P mg L^{-1}*	*TKN mg L^{-1}*	*Chl-a µg L^{-1}*	*Secchi ft.*
0	81.0	7.3	8.1	220	93	<0.010	<0.010	<0.5	3.0	7.5
9.5	79.0	7.1	8.1	217	97	<0.010	<0.010	<0.5	--	--
18.0	72.1	6.0	8.1	214	94	0.013	<0.010	1.0	--	--

Table 10. Houghton Lake water quality parameter data collected over Deep Basin 6 on August 11, 2016.

Depth ft.	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*Ortho-P mg L^{-1}*	*TKN mg L^{-1}*	*Chl-a µg L^{-1}*	*Secchi ft.*
0	83.5	6.8	8.0	209	131	<0.010	<0.010	<0.5	3.0	6.5
6.0	79.7	7.4	8.0	220	102	0.021	<0.010	<0.5	--	--
12.0	79.2	7.0	8.0	222	101	<0.010	<0.010	<0.5	--	--

Houghton Lake Canals and Tributary Water Quality Data:

Table 11. Houghton Lake water quality parameter data collected in the Houghton Lake Tributaries on August 11, 2016.

Trib Name	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*Ortho-P mg L^{-1}*	*TSS mg L^{-1}*	*Chl-a µg L^{-1}*
Flats-N	82.2	6.5	8.1	210	120	<0.010	0.013	<10	4.0
Flats-S	82.4	6.8	8.1	243	108	0.021	0.011	<10	4.0
Sucker Creek	81.5	1.5*	7.5	499*	152*	0.300*	0.110*	140*	11.0*
Denton Creek	81.5	7.0	8.0	238	125	0.013	<0.010	<10	4.0
Backus Creek	81.5	7.0	8.0	221	97	<0.010	<0.010	<10	3.0
Spring Brook	81.0	7.2	8.1	252	130	0.049*	0.032*	<10	5.0
Knappen Creek	80.0	6.9	8.0	366*	176*	0.015	0.013	<10	4.0

Table 12. Houghton Lake water quality parameter data collected in the Houghton Lake Canals on August 11, 2016.

Canal Name	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*TP mg L^{-1}*	*Chl-a µg L^{-1}*	*Secchi ft.*
Canal 4 (N)	81.5	6.6	8.1	248	124	<0.010	3.0	3.2+
Canal 5 (N)	81.3	7.2	8.1	220	125	0.018	4.0	4.2+
Canal 6 (NW)	81.0	7.0	8.1	381*	134	0.029	10.0*	2.8+
Canal 8 (NW)	80.4	7.3	8.1	210	114	0.013	5.0	4.9+
Canal 9 (NW)	81.5	7.0	8.0	221	97	<0.010	3.0	4.0+
Canal 10 (NW)	82.2	7.1	8.1	205	114	<0.010	4.0	4.0+
Canal 12 (W)	81.5	6.4	8.1	235	120	0.012	8.0*	4.0+
P1 (EB)	81.0	7.0	8.1	395*	245*	0.038*	4.0	5.6
P2 (EB)	81.9	6.9	8.1	394*	268*	0.025	6.0	4.8
P3 (EB)	81.7	6.9	8.1	397*	275*	0.065*	10.0*	5.5
P4 (EB)	81.0	6.9	8.1	400*	270*	0.049*	8.0*	5.7
P5 (EB)	82.0	7.0	8.1	412*	245*	0.032*	11.0*	5.8
P6 (EB)	82.5	6.9	8.1	378*	250*	0.043*	6.0	5.4
P7 (EB)	82.3	7.0	8.0	410*	278*	0.039*	12.0*	5.2
P8 (EB)	82.2	6.5	8.0	401*	275*	0.031*	12.0*	5.2
PM (EB)	82.0	7.0	8.1	403*	280*	0.034*	10.0*	5.4
MKP-1 (EB)	82.0	7.0	8.1	287	134	<0.010	8.0*	6.2
MKP-2 (EB)	84.7	5.5*	8.0	320*	141	<0.010	9.0*	4.5
MKP-3 (EB)	86.2	5.3*	8.0	316*	148	<0.010	8.0*	4.5
MKP-4 (EB)	83.5	6.4	8.0	341*	155	0.012	9.0*	4.2
MKP-5 (EB)	84.2	6.3	8.1	330*	161	0.044*	9.0*	4.0
MKP-M (EB)	83.3	5.7	8.0	306*	135	0.018	6.0	4.7
Lapham (E)	82.2	6.6	8.1	230	117	0.012	6.0	6.5
Long PT W MID	82.2	6.6	8.1	245	118	0.020	8.0*	4.7
Long PT W 1	81.0	7.2	8.1	301*	135	0.025	8.0*	5.5
Long PT W2	82.0	6.6	8.0	285	125	0.013	6.0	6.6
Long PT E	81.3	7.1	8.1	250	138	0.022	6.0	6.8

5.0 HOUGHTON LAKE FISHERY SUMMARY

Houghton Lake is the largest and most popular fishing lake in the state of Michigan. There are nearly 28 different species of fish according to the Michigan Department of Natural Resources (MDNR) which include: Black Crappie, Black Bullhead, Bluegill, Bluntnose Minnows, Bowfin, Brown Bullhead, Bullhead Catfishes, Carps and Minnows, Common Carp, Channel Catfish, White Sucker, Emerald Shiner, Fathead Minnow, Golden Shiner, Lake herring, Largemouth bass, Longnose Gar, Log perch, Lake whitefish, Northern pike, Pumpkinseed, Rainbow Trout, Rock Bass, Smallmouth Bass, Spottail shiner, Walleye, Yellow Perch, and Yellow Bullhead. However, up to 39 species have been reported in past study efforts (Clark et *al*., 2004). This list includes prized fish species such as Walleye and Lake Whitefish. Walleye were stocked in Houghton Lake between 1979-2011. Table 13 shows the number of Walleye stocked and the mean size of the stocked fish. Houghton Lake is known as “Tip Up Town USA” which is an annual event that recruits numerous fishing enthusiasts. Thus, it is a lake in which fishing occurs throughout the year. In fact, a 2004 fisheries study of Houghton Lake conducted by the MDNR Fisheries Division (Clark et *al*., 2004; Fisheries Special Report 30), determined that in one year anglers fished a total of 499,048 hours and made 199,056 trips to Houghton Lake. This included 56% of the fishing time occurring in the open-water period and 44% of the fishing time occurring during ice-cover.

Table 13. Fish Stocking Schedule on Houghton Lake.

Year	*# Walleye Stocked*	*Average Walleye Length (inches)*
1979	68,936	--
1980	106,717	--
1981	178,757	--
1982	26,699	--
1983	39,400	--
1984	24,739	3.5
1985	70,663	2.2
1986	62,450	2.5
1986	45,500	2.3
1987	17,000	3.6
1988	75,200	2.6
1989	67,150	3.4
1990	106,049	1.8
1990	19,420	4.4
1991	101,050	3.5
1993	158,282	1.6
1994	10,000	2.6
1995	7,150	4.4
1999	152,346	1.9
2001	319,494	1.5
2005	212,568	1.5
2011	75,063	1.4

6.0 HOUGHTON LAKE AQUATIC VEGETATION COMMUNITIES

6.1 Overview of Aquatic Vegetation and the Role for Lake Health

The overall health of Houghton 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.

6.2 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 shallow mean depth of Houghton Lake, an annual whole-lake GPS Point-Intercept grid matrix survey (Figure 17) was conducted from June 22-July 1, 2016 to assess all aquatic plants, including submersed, floating-leaved, and emergent species. The lake scan consisted of 321,196 GPS points and the aquatic vegetation sampling survey utilized over 15,000 points with the main lake and canals combined. Based on this data, Houghton Lake lacks aquatic vegetation in 69.54% of the lake (Restorative Lake Sciences, 2016). GPS point survey matrix was developed by the Michigan State University Geography Department to allow for an unbiased sampling map that utilized closely-spaced sampling points to yield an accurate map of all In July of 2016, the use of a side-scan sonar GPS device to scan the aquatic plant biovolume, bathymetric contours, and sediment bottom hardness of the lake was conducted using a Lowrance® HDS 8 unit with BioBase® software. Figure 18 below shows the aquatic vegetation biovolume in Houghton Lake. As noted earlier, these areas of growth correspond to areas with soft bottom substrate which most aquatic plants prefer for a growth medium. Comparison of this scan map to the original weed bed map of Houghton Lake (provided by Rich O'Neal of the Michigan DNR; Figure 19) shows that the majority of the weed beds are still present and thus protection of those beds is critical for the immediate and long-term health of the lake fishery.

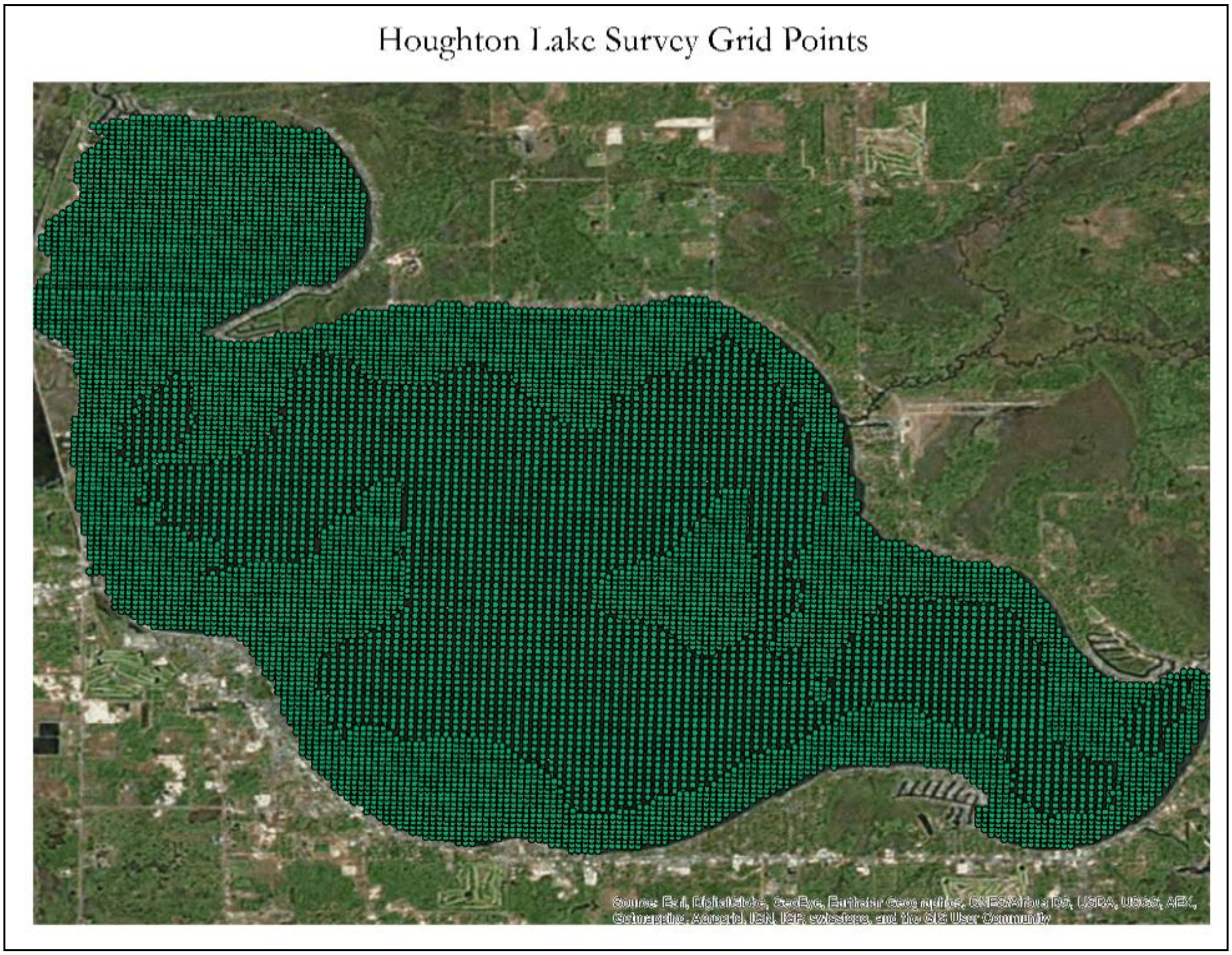

Figure 17. Aquatic vegetation sampling point locations in Houghton Lake (June 22-July 1, 2016). Note: The closely-spaced points represent shallow areas and the more distant-spaced points represent the deep water sampling locations.

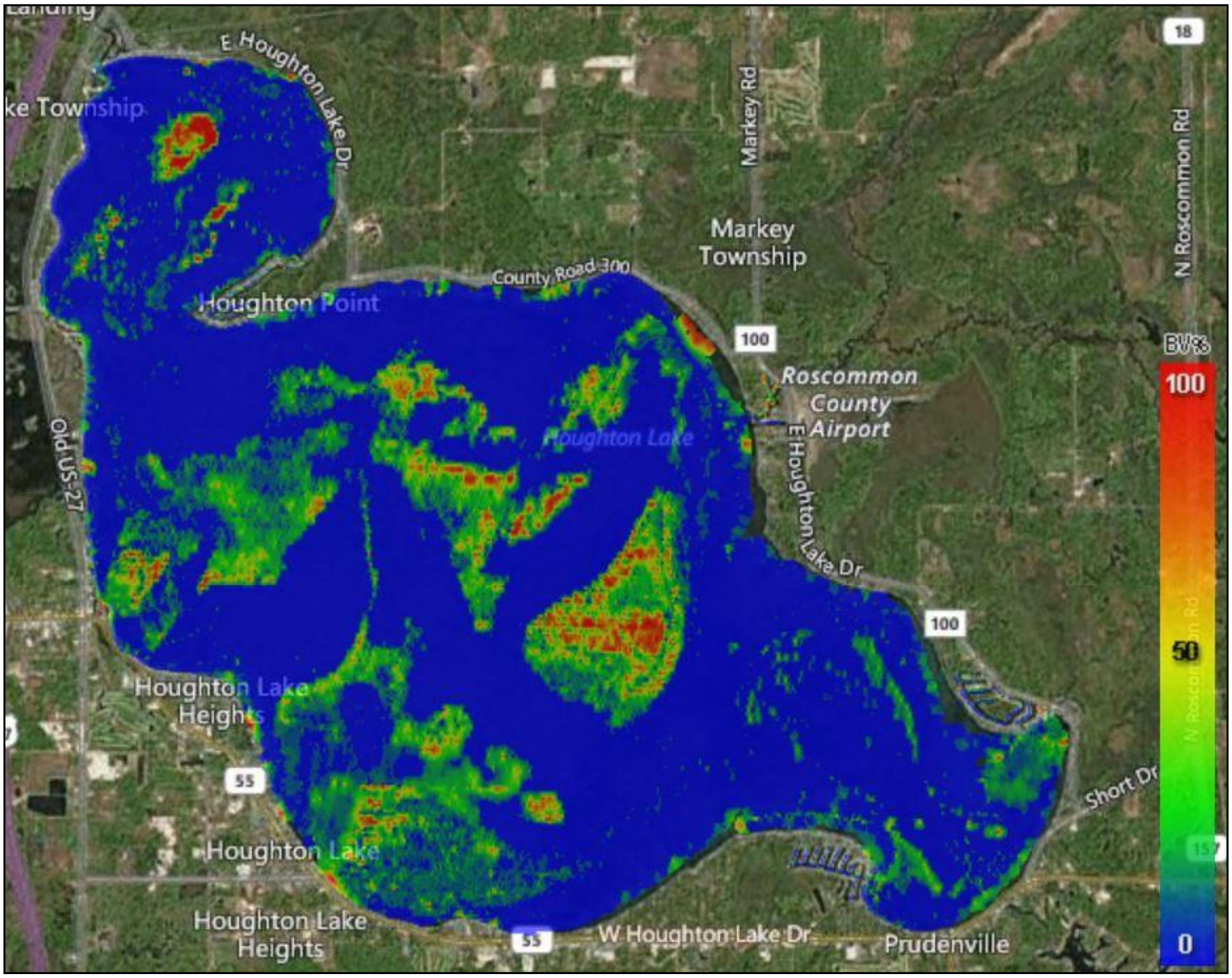

Figure 18. Aquatic vegetation biovolume scan map of Houghton Lake (June-July, 2016). Note: The blue color represents areas that are not covered with aquatic vegetation. The green color represents low-growing aquatic vegetation and the red colors represent high-growing aquatic vegetation. This scan does 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.

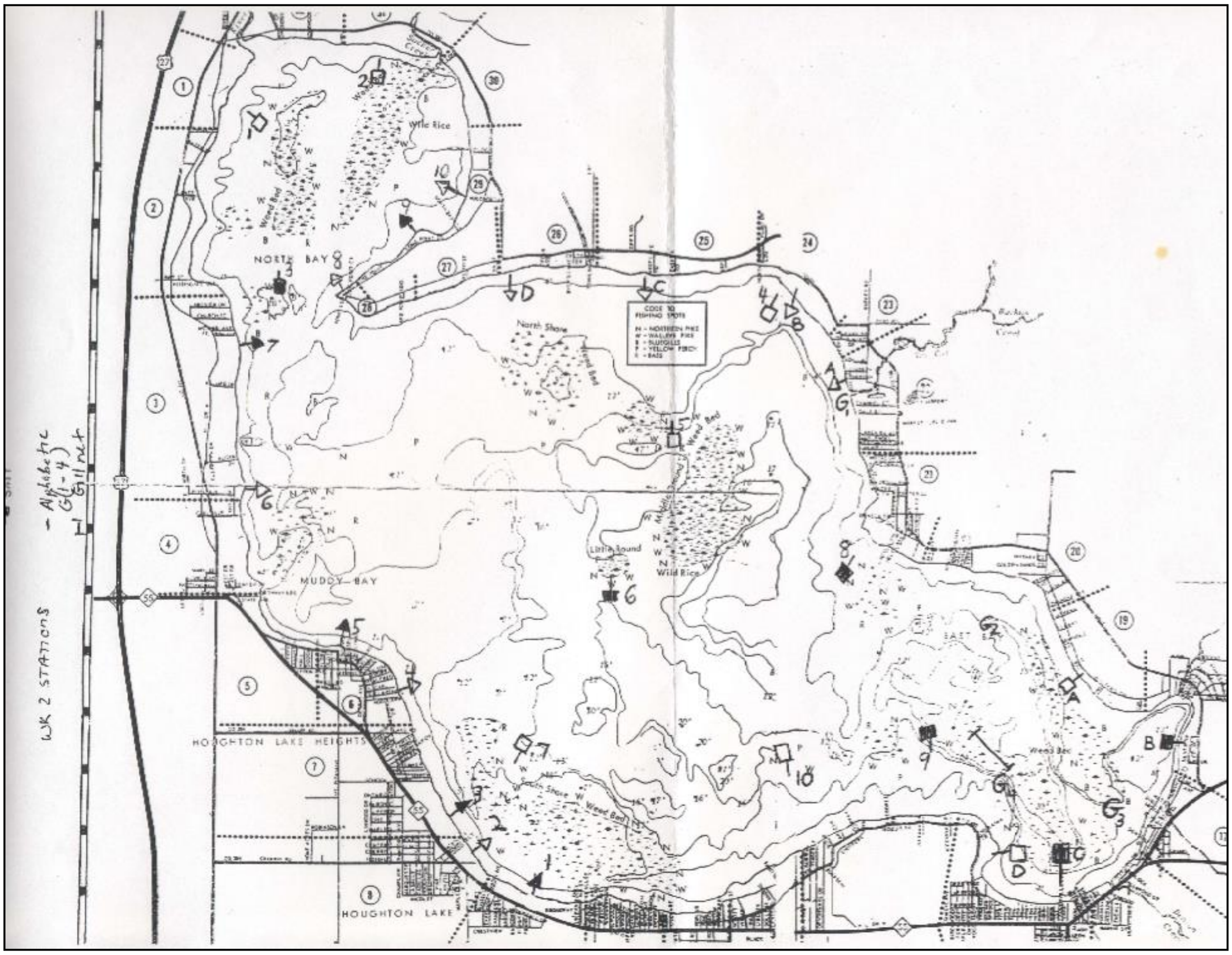

Figure 19. Original weed bed locations in Houghton (MDNR).

6.3 Houghton Lake Exotic Aquatic Macrophytes

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

Hybrid watermilfoil (*Myriophyllum spicatum var. sibiricum*; Figure 20) is an exotic aquatic macrophyte that is a serious problem in Michigan inland lakes and has been genetically determined in Houghton 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 500 acres of dense milfoil was found in Houghton Lake during the summer 2016 survey.

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 as this usually varies among sites.

Starry stonewort (*Nitellopsis obtusa*; Figure 21) is an invasive macro alga that has invaded many inland lakes of Michigan and was originally discovered in the St. Lawrence River. Approximately 450 acres of this dense invasive alga was found in Houghton Lake during the summer 2016 survey. The “leaves” appear as long, smooth, angular branches of differing lengths. The alga has been observed in dense beds at depths beyond several meters and can grow to heights in excess of a few meters. It prefers clear alkaline waters and has been shown to cause significant declines in water quality and fishery spawning habitat. Management options for the plant are provided in the management recommendations section of the report.

Curly-leaf Pondweed (*Potamogeton crispus*; Figure 22) 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 lake which includes the canals. It is not considered a threat to the Houghton Lake ecosystem at the present time.

Purple loosestrife (*Lythrum salicaria*; Figure 23) 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 Houghton Lake. 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 in one area around the lake shoreline.

Lastly, the Giant Common Reed (*Phragmites australis*; Figure 24) was also found in a location along the shoreline of Houghton Lake 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 list of all invasive species found in and around Houghton Lake in 2016 is shown below in Table 14. The distribution and relative abundance of hybrid watermilfoil in 2016 is shown in Figures 25-28 and the proposed treatment areas are shown in Figure 29. The distribution and relative abundance of Starry Stonewort in 2016 is shown below in Figures 30-33 and the proposed treatment areas are shown in Figure 34. The distribution of invasive emergent such as Purple Loosestrife and Phragmites is shown in Figure 35 below.

Table 14. Exotic invasive aquatic plant species found in Houghton Lake in 2016. * Includes dense treatment areas. In other areas shown on the relative abundance maps, single plants or small clusters were noted to be sparse.

Exotic Aquatic Plant Species Name	***Exotic Aquatic Plant Common Name***	***Exotic Aquatic Plant Growth Habit***	***Abundance in or around Houghton Lake (acres)****
Myriophyllum spicatum	Eurasian Watermilfoil	Submersed; Rooted	500
Nitellopsis obtusa	Starry Stonewort	Submersed; Rooted	450
Potamogeton crispus	Curly-leaf Pondweed	Submersed; Rooted	< 0.5
Lythrum salicaria	Purple Loosestrife	Emergent	< 0.25
Phragmites australis	Giant Common Reed	Emergent	< 0.25

Figure 20. Eurasian Watermilfoil

Figure 21. Starry Stonewort

Figure 22. Curly-leaf Pondweed

Figure 23. Purple Loosestrife

Figure 24. Phragmites

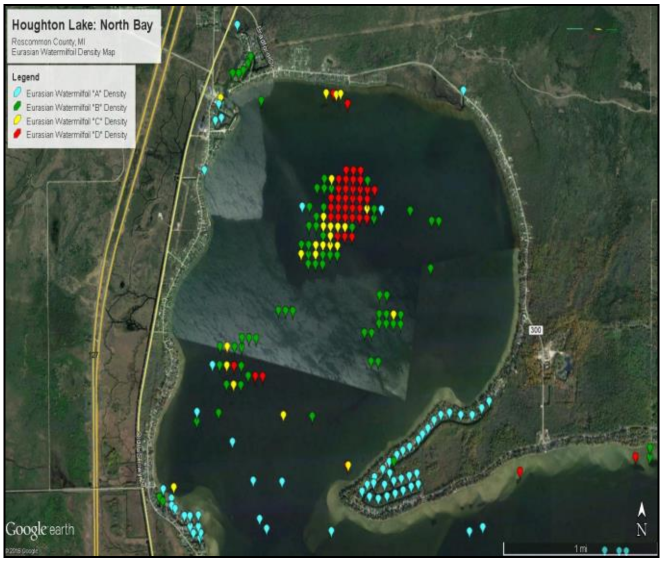

Figure 25. EWM relative abundance in the North Bay of Houghton Lake (June-July, 2016).

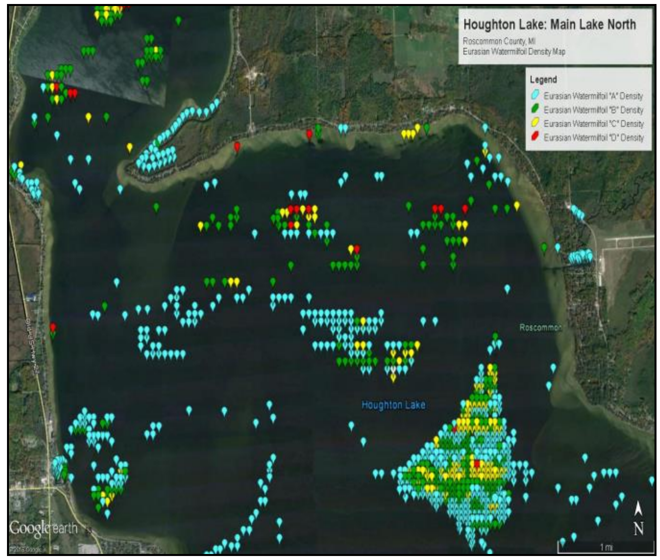

Figure 26. EWM relative abundance in the Main Lake North in Houghton Lake (June-July, 2016).

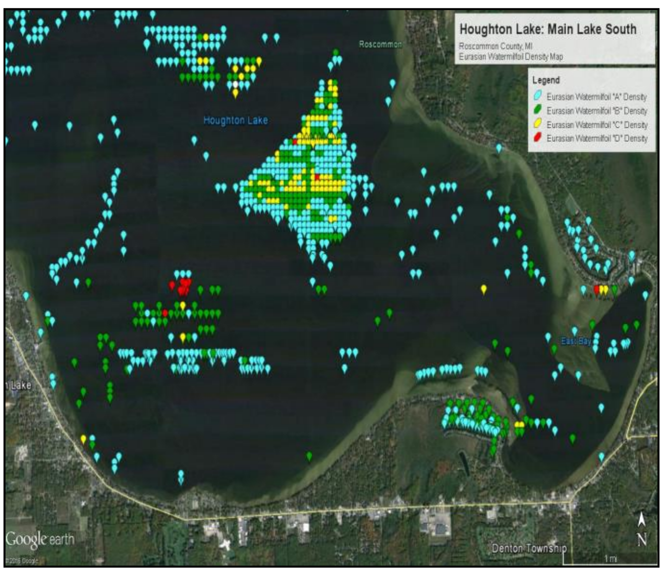

Figure 27. EWM relative abundance in the Main Lake South in Houghton Lake (June-July, 2016).

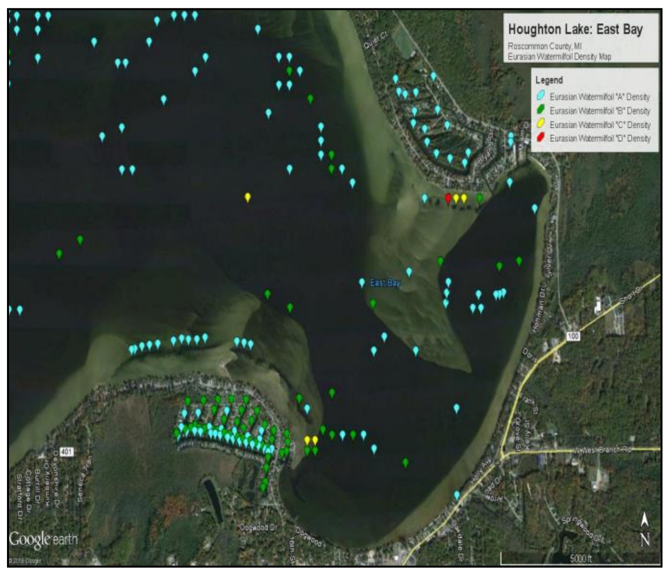

Figure 28. EWM relative abundance in the East Bay of Houghton Lake (June-July, 2016).

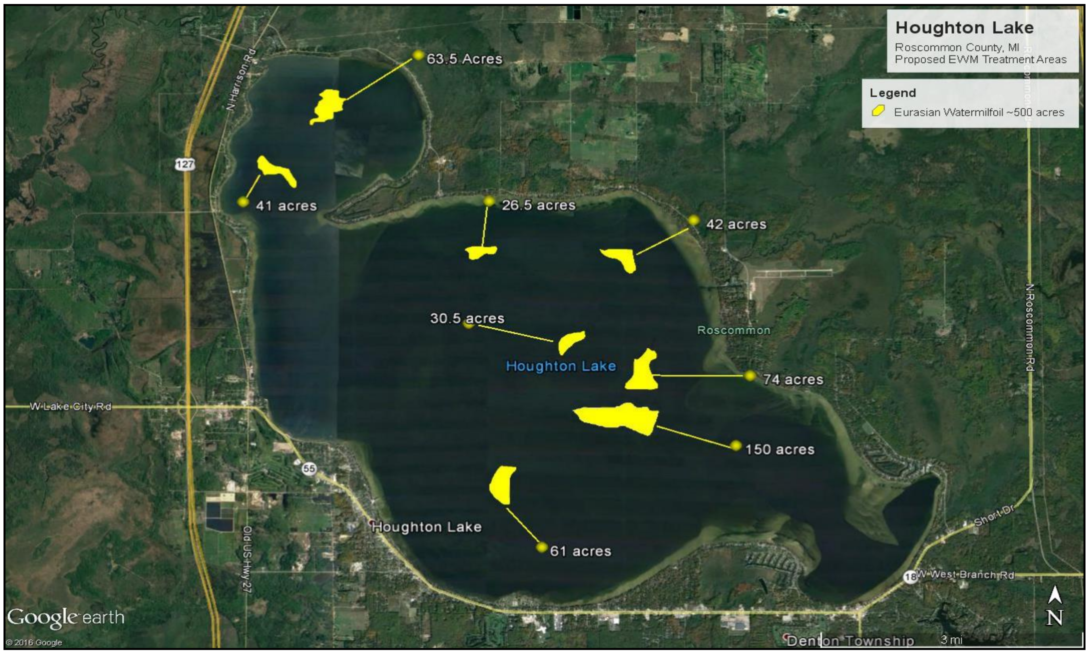

Figure 29. Invasive watermilfoil areas recommended for treatment in 2016.

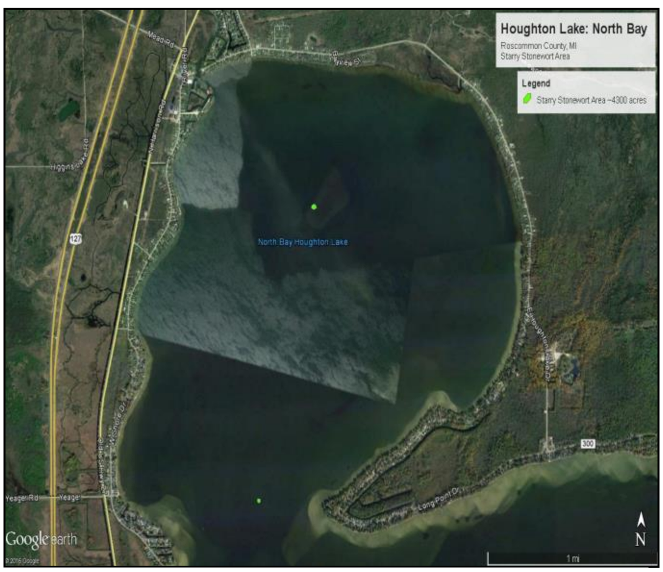

Figure 30. Starry Stonewort relative abundance in the North Bay (June-July, 2016).

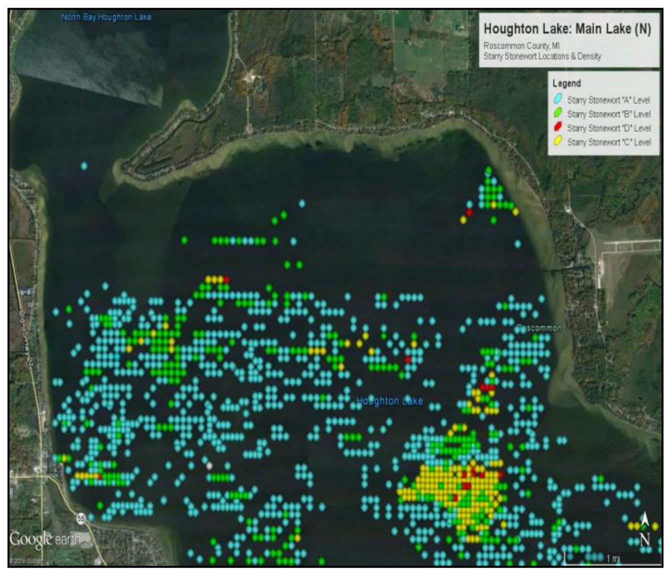

Figure 31. Starry Stonewort relative abundance in the Main Lake North (June-July, 2016).

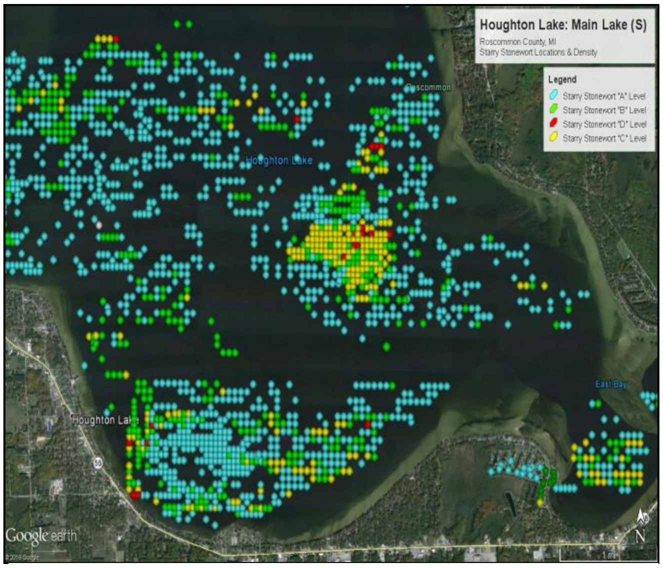

Figure 32. Starry Stonewort relative abundance in the Main Lake South (June-July, 2016).

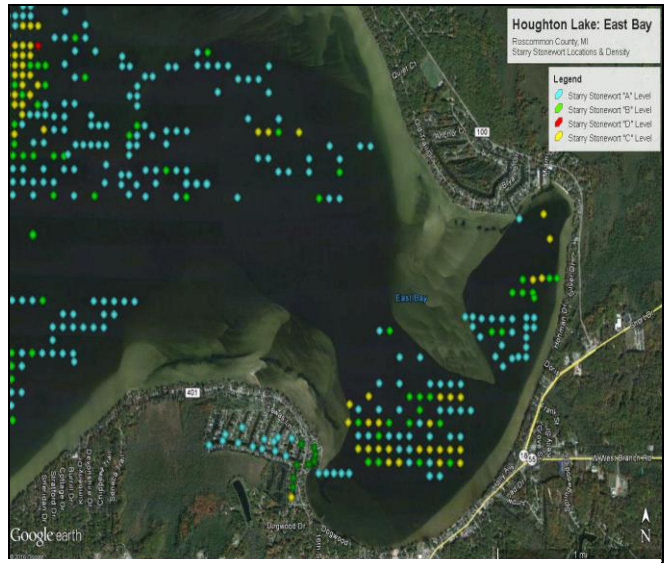

Figure 33. Starry Stonewort relative abundance in the East Bay (June-July, 2016).

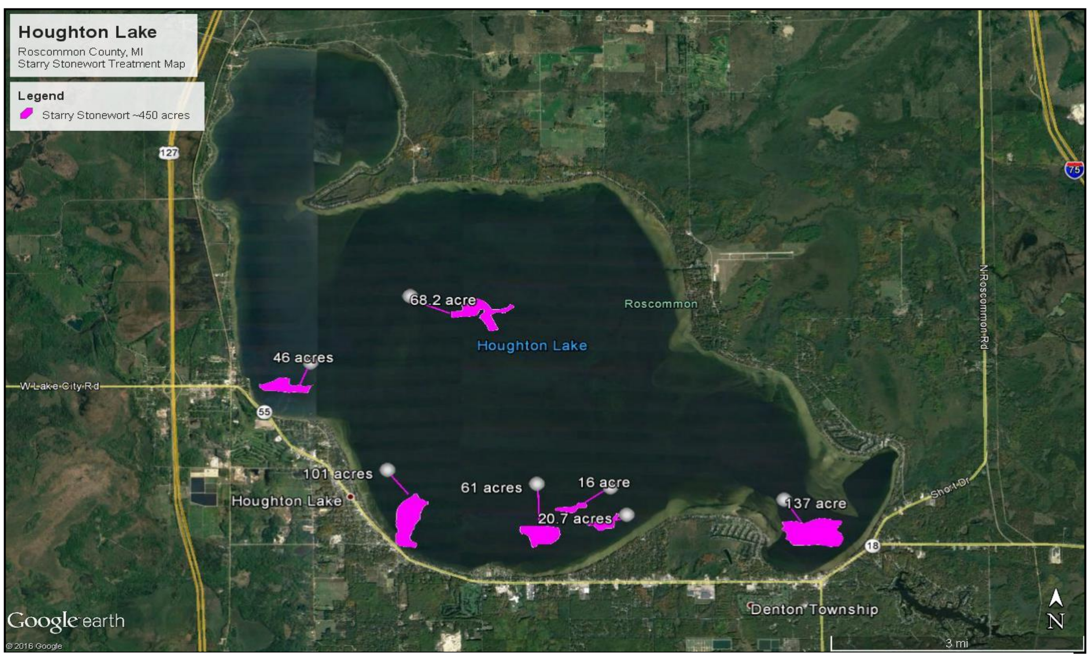

Figure 34. Starry Stonewort areas recommended for treatment in 2016.

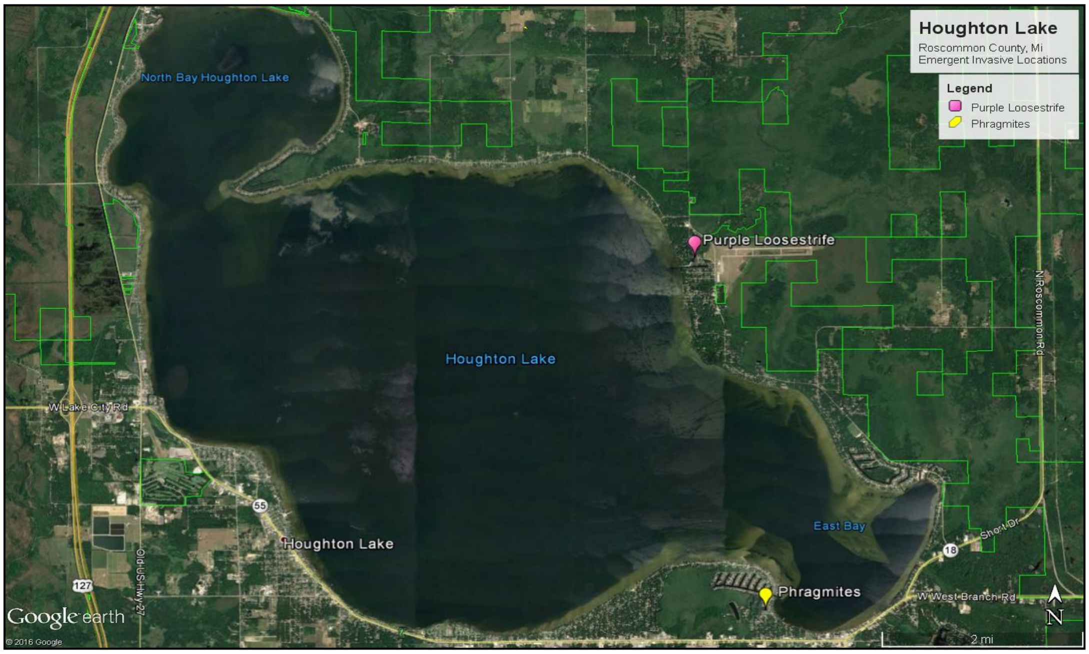

Figure 35. Distribution of invasive emergents around Houghton Lake in 2016.

6.4 Houghton Lake Native Aquatic Macrophytes

There are hundreds of native aquatic plant species in the waters of the United States. The most diverse native genera include the Potamogetonaceae (Pondweeds) and the Haloragaceae (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.

Houghton Lake contained 23 native submersed, 3 floating-leaved, and 6 emergent aquatic plant species, for a total of 32 native aquatic macrophyte species (Table 15). Photos of all native aquatic plants are shown below in Figures 36-67. 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 canals. 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 the tall White-stem Pondweed which can reach the surface and often forms prominent shite seed heads. This plant is also excellent fish forage habitat. The plant has long, green leaves and often bears a white-ish stem that is firmly rooted in the lake bottom. All of the Pondweeds grow tall in the water column and serve as excellent fish cover. Due to the fact that only approximately 1/3 of the lake is vegetated, protection of these native aquatic plants is important.

There were also two 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. 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 such as Purple Loosestrife and Phragmites around the Houghton Lake shoreline are currently low in abundance but could become a threat to the native emergent macrophyte populations if not controlled.

Although only present in a few select areas of the lake, Backus Creek and Middle Grounds contained Wild Rice (*Zizania aquatica*), and re-colonization efforts of the plant are recommended due to the value that it has for waterfowl, wildlife, and human consumption. Pip and Stephaniuk (1988) reported that Wild Rice is highly sensitive to changing water levels and that the plant desires consistent low to moderate water levels. There has also been significant genetic variability in seemingly isolated stands of Wild Rice and this may be a reason that specific plants respond to some environmental conditions differently than others (Tucker et *al*., 2011).

In 2015, a blue-green algae bloom of the genus *Microcystis* sp. was found in several canals. This algae favors warm waters that are high in nutrients and is a normal component of algae in most lakes. It can however, be exacerbated by excessive aquatic herbicide and algaecide treatments since the alga responds with an increase in population growth when threatened. Figures 68 and 69 below show the *Microcystis* sp. bloom in a canal in 2015 as well as a microscopic photo of the alga itself.

Table 15. Houghton Lake native aquatic plant species (June 22-Jul 1, 2016).

Native Aquatic Plant Species Name	*Aquatic Plant Common Name*	*% Cover*	*Aquatic Plant Growth Habit*
Chara vulgaris	Muskgrass	32.4	Submersed, Rooted
Potamogeton pectinatus	Thin-leaf Pondweed	1.3	Submersed, Rooted
Potamogeton amplifolius	Large-leaf Pondweed	1.0	Submersed, Rooted
Potamogeton zosteriformis	Flat-stem Pondweed	2.8	Submersed, Rooted
Potamogeton gramineus	Variable-leaf Pondweed	0.8	Submersed, Rooted
Potamogeton robbinsii	Fern-leaf Pondweed	0.5	Submersed, Rooted
Potamogeton natans	Floating-leaf Pondweed	0.2	Submersed, Rooted
Potamogeton praelongus	White-stem Pondweed	20.5	Submersed, Rooted
Potamogeton richardsonii	Clasping-leaf Pondweed	1.5	Submersed, Rooted
Ranunculus sp.	Buttercup	0.1	Submersed, Rooted
Megalodonta sp.	Water Marigold	0.1	Submersed, Rooted
Potamogeton pusillus	Small-leaf Pondweed	0.01	Submersed, Rooted
Potamogeton illinoensis	Illinois Pondweed	3.1	Submersed, Rooted
Myriophyllum sibiricum	Northern Watermilfoil	0.03	Submersed, Rooted
Myriophyllum verticillatum	Whorled Watermilfoil	0.01	Submersed, Rooted
Zosterella dubia	Water star grass	0.03	Submersed, Rooted
Drepanocladus revolvens	Water scorpion moss	0.02	Submersed, Non-Rooted
Vallisneria americana	Wild Celery	2.5	Submersed, Rooted
Elodea canadensis	Common Waterweed	1.3	Submersed, Rooted
Ceratophyllum demersum	Coontail	0.4	Submersed, Non-Rooted
Utricularia vulgaris	Bladderwort	1.4	Submersed, Non-Rooted
Najas guadalupensis	Southern Naiad	12.4	Submersed, Rooted
Najas flexilis	Slender Naiad	4.9	Submersed, Rooted
Nymphaea odorata	White Waterlily	0.8	Floating-Leaved, Rooted
Nuphar variegata	Yellow Waterlily	1.1	Floating-Leaved, Rooted
Lemna minor	Duckweed	0.02	Floating-leaved, Non-Rooted
Typha latifolia	Cattails	0.13	Emergent
Scirpus acutus	Bulrushes	0.21	Emergent
Iris sp.	Iris	0.04	Emergent
Decodon verticillatus	Swamp Loosestrife	0.10	Emergent
Sagittaria sp.	Arrowhead	0.05	Emergent
Pontedaria cordata	Pickerelweed	0.03	Emergent
Zizania aquatica	Wild Rice	0.6	Emergent

Figure 36. Chara (Muskgrass) ©RLS

Figure 37. Thin-leaf Pondweed ©RLS

Figure 38. Large-leaf Pondweed ©RLS

Figure 39. Variable-leaf Pondweed ©RLS

Figure 40. Fern-leaf Pondweed ©RLS

Figure 41. White-stem Pondweed ©RLS

Figure 42. Slender Naiad ©RLS

Figure 43. Clasping-leaf Pondweed ©RLS

Figure 44. Bladderwort ©RLS

Figure 45. Buttercup ©RLS

Figure 46. Illinois Pondweed ©RLS

Figure 47. Small-leaf Pondweed ©RLS

Figure 48. Northern Watermilfoil ©RLS

Figure 49. Elodea ©RLS

Figure 50. Water Marigold ©RLS

Figure 51. Coontail ©RLS

Figure 52. Water Stargrass ©RLS

Figure 53. Whorled Watermilfoil ©RLS

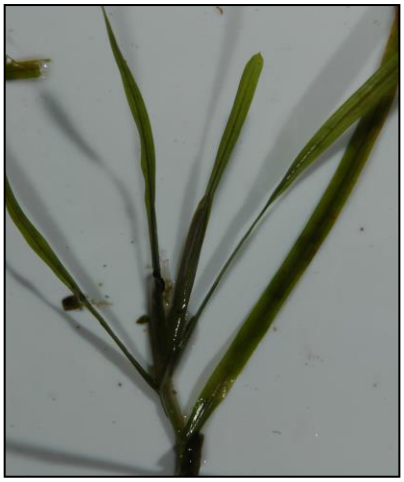

Figure 54. Flat-stem Pondweed ©RLS

Figure 55. Floating-leaf Pondweed

Figure 56. Wild Celery ©RLS

Figure 57. Southern Naiad ©RLS

Figure 58. Bulrushes ©RLS

Figure 59. Pickerelweed ©RLS

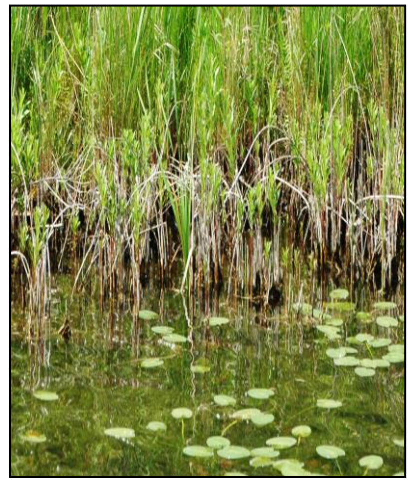

Figure 60. Swamp Loosestrife ©RLS

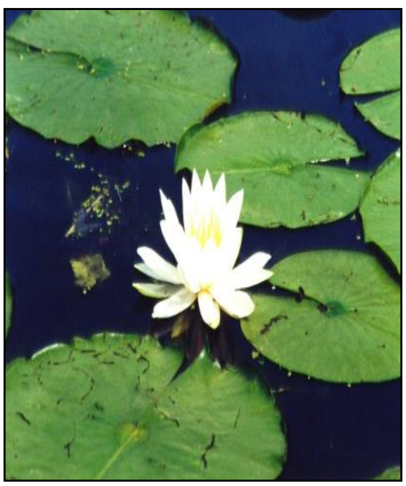

Figure 61. White Waterlily ©RLS

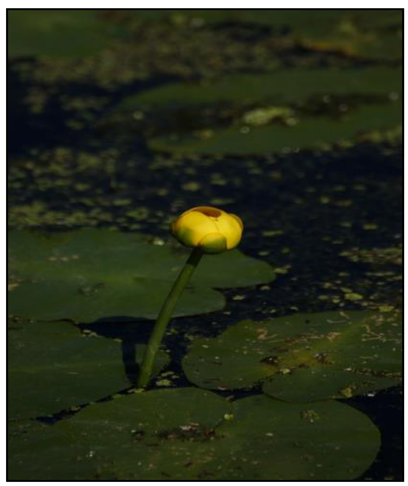

Figure 62. Yellow Waterlily ©RLS

Figure 63. Sagittaria ©RLS

Figure 64. Cattails ©RLS

Figure 65. Iris sp. ©RLS

Figure 66. Water Smartweed

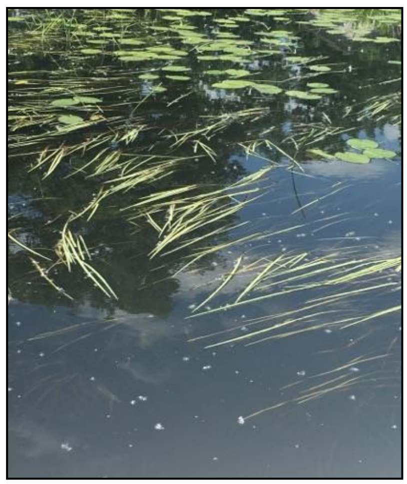

Figure 67. Wild Rice ©RLS

Figure 68. *Microcystis* algal bloom in a Houghton Lake canal in 2015.

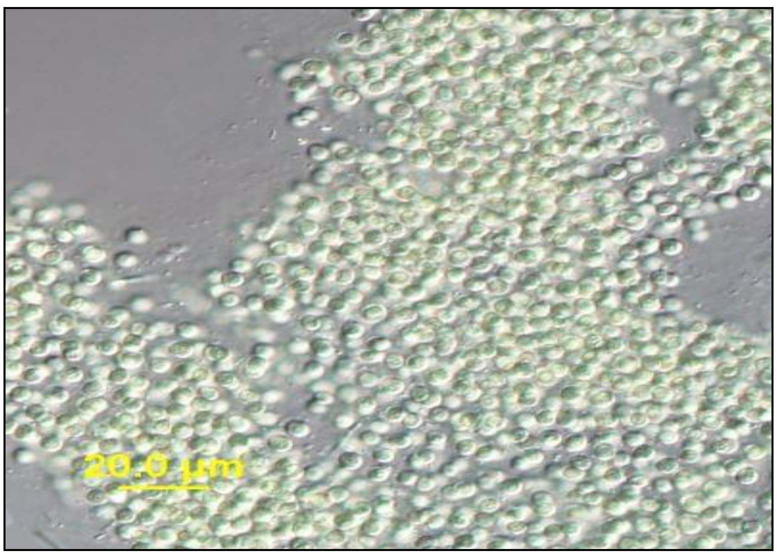

Figure 69. Microscopic image of *Microcystis* sp. Photo courtesy of Barry H. Rosen, USGS.

7.0 HOUGHTON LAKE MANAGEMENT IMPROVEMENT METHODS

7.1 Houghton Lake 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 Houghton 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 Houghton 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. There are two major goals that the Houghton Lake Improvement Board (HLIB) should pursue relative to vegetation management: 1) reduction of submersed invasive aquatic plant species such as hybrid watermilfoil and Starry Stonewort, 2) protection of the native aquatic plant species found throughout the lake, and 3) cultivation of Wild Rice through careful management planning. These three objectives are critical for the health and balance of Houghton Lake and will take special management recommendations to accomplish both. It must be stated that they are not mutually exclusive since the protection of the native species must be compatible with treatment of the invasives. 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 Purple Loosestrife and Phragmites, removal of these invasives by hand-pulling is recommended over other methods. 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.

7.1.1 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 70).

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 Houghton Lake, the use of contact herbicides such as flumioxazin (Clipper®) is recommended for the control of invasive Starry Stonewort since there are no systemic herbicides available for the macro algae and copper bio accumulates in the lake sediment.

Systemic herbicides such as 2, 4-D and triclopyr are the two primary systemic herbicides used to treat Hybrid watermilfoil. 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 Houghton Lake can be 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. Additionally, care must be taken while using these herbicides in areas with sensitive aquatic plant species such as Wild Rice. A study on the effects of various herbicides on Wild Rice was conducted by Nelson et *al*., at the U.S. Army Engineer Research and Development Center in 2003 and determined that: 1) young plants were more susceptible to herbicide damage than plants further along in their development, 2) all products (such as diquat, endothall, fluridone, and 2,4-D) did not have an impact on the Wild Rice plants when applied during the late tillering and flowering stages of maturity, and 3) the herbicide 2,4-D had the greatest negative effect on Wild Rice. Given these findings, the treatment of invasive species such as EWM and Starry Stonewort should only occur in areas where Wild Rice has fully matured.

It is also recommended that the HLIB seek input prior to any lake treatments from both the MDNR and MDEQ. Both parties have historical perspectives on the lake and should offer such information to the HLIB to assist in annual management decision-making.

Figure 70. An herbicide treatment airboat and crew preparing for a lake treatment.

Table 16. Aquatic vegetation management activities in Houghton Lake from 2002-2016.

Year	Acres Sonar	Acres Contacts	Acres Systemic	Acres Harvested	# Milfoil Weevils Stocked
2002	20,044	17	--	--	--
2003	--	--	32	--	--
2004	--	--	44	81	5,000
2005	--	50	395	84	28,000
2006	--	59	444	105	--
2007	--	106	660	--	30,000
2008	--	20	1,310	35	--
2009	--	40	1,751	--	--
2010	--	39	558	--	--
2011	--	42	1,747	--	--
2012	--	84	1,237	--	--
2013	--	49	1,902	--	--
2014	--	51	1,054	--	--
2015	--	65	600	--	--
2016	--	450	499	--	--

7.1.2 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 71). 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. This technology would have the most efficacy on very large weed beds where milfoil is sparse or not present. It may also be useful in areas such as public boat launches or canals to reduce nuisance aquatic vegetation biomass. It would be quite costly to have the very slow-moving harvester make repeated trips out in the open waters of Houghton Lake.

Figure 71. A mechanical harvester. Photo courtesy of Dave Foley.

7.1.3 Diver Assisted Suction Harvesting (DASH)/Dredging

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 72) 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 nuisance invasives in the Middle Grounds area or in the North Bay if a non-chemical approach is desired in those areas. 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. It may also have application for the canals in reducing areas of dense aquatic vegetation without the use of chemicals.

Figure 72. A DASH boat for hand-removal of watermilfoil or other nuisance vegetation. ©Restorative Lake Sciences, LLC

7.1.4 Biological Control

In the past, the use of the aquatic weevil, *Euhrychiopsis lecontei* (Figure 73) to control Hybrid watermilfoil was implemented to reduce milfoil infestations. Weevils were previously stocked in Houghton Lake until 2008. They are no longer commercially available but there may still be active colonies present in Houghton Lake and may help to keep some milfoil populations low in areas where their colonies are abundant. RLS will assess milfoil stems for any weevil damage in 2017.

The land beetle, *Galerucella sp.* (Figure 74) 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. Fortunately, only a small area around Houghton Lake contained this plant and hand-pulling is recommended at this time over biological control due to the overall low abundance and biomass.

Figure 73. The watermilfoil weevil (*Euhrychiopsis lecontei*). Photo from R. Newman used with permission.

Figure 74. *Galerucella* sp. The "loosestrife" beetle

7.1.5 Laminar Flow Aeration and Bioaugmentation

Laminar flow aeration systems (Figure 75) 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 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.

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.

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 and algae in many of the canals in Houghton Lake, the use of aeration with bioaugmentation (addition of microbes) is recommended. This is especially recommended in the Prudenville Canals and McKinley Park Canal #5 which have the highest nutrient concentrations. Sediment organic matter samples are recommended to be collected from these canals in 2017 to evaluate the possible efficacy of an aeration system on reducing muck in those canals. If desired by the canal residents, individual aeration systems can be installed in specific canals but each would be priced based on size and depth and other physical characteristics.

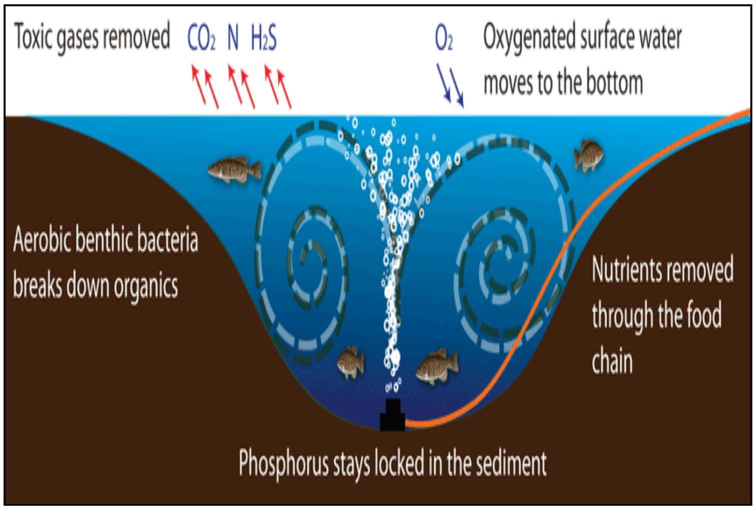

Figure 75. A diagram showing the laminar flow aeration mechanisms. ©Restorative Lake Sciences, LLC

7.1.6 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 76) or Weed Rollers (Figure 77) 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 Houghton 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).

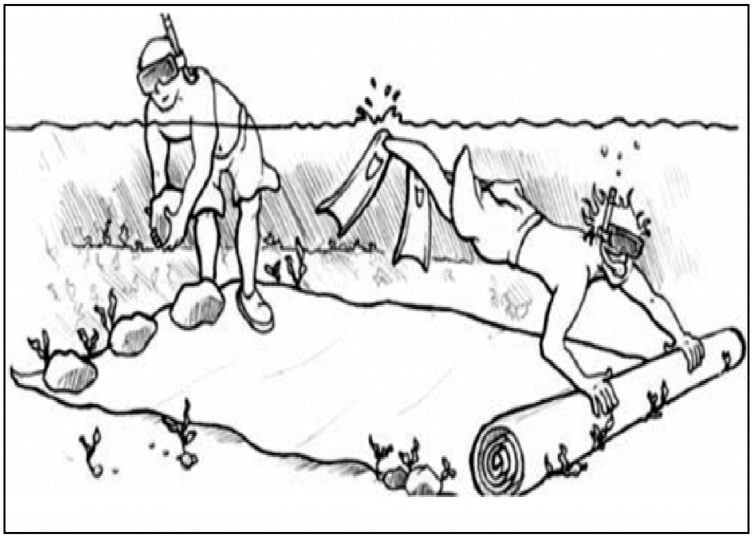

Figure 76. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.

Figure 77. A Weed Roller.

7.1.7 Boat Launch Washing Station

The Houghton Lake-Lake Association (HLLA) and the Houghton Lake Improvement Board (HLIB) have been working on plans with the MDNR for a boat washing station at the East Bay region of the lake. With over 13 million registered boaters in the U.S. alone, the need for reducing transfer of aquatic invasive species (AIS) has never been greater. The Minnesota Sea Grant program identifies five major boat wash scenarios which include: 1) permanent washing stations at launch sites, 2) Portable drive-thru or transient systems, 3) Commercial car washes, 4) Home washing, and 5) Mandatory vs. volunteer washing. The HLIB and HLLA are considering construction of a permanent boat washing station that is voluntary for incoming and exiting boaters. Boat washing stations promote the Clean Waters Clean Boats volunteer education program by educating boaters to wash boating equipment (including trailers and bait buckets) before entry into every lake. Critical elements of this education include: 1) how to approach boaters, 2) demonstration of effective boat and trailer inspections and cleaning techniques, 3) the recording of important information, 4) identification of high-priority invasive species, and 5) sharing findings with others. Once a boat washing station is in place on Houghton Lake, the HLLA and the HLIB should work together to educate the public and lake users on proper cleaning techniques and other invasive species information. A “Landing Blitz” can be held once the station is in place and the public can be invited to a field demonstration of how to use the washing station.

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

1) MLSA: www.mymlsa.org/aquatic-invasive-species
2) MDEQ: www.mi.gov/aquaticinvasives
3) MDNR: www.mi.gov/invasivespecies
4) MISIN: www.misin.msu.edu
5) Stop Aquatic Hitchhikers!: www.protectyourwaters.net

7.2 Houghton Lake Watershed Management Methods

In addition to the proposed treatment of Hybrid Watermilfoil and Starry Stonewort in Houghton 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 Houghton 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 Houghton 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.

7.2.1 Houghton 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 Houghton 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 Houghton Lake. The emergent aquatic plant, *Scirpus* sp. (Bulrushes) present around Houghton Lake offers satisfactory stabilization of shoreline sediments and assists in the minimization of sediment release into the lake.

7.2.2 Houghton Lake 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 Houghton 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.

7.3 Houghton Lake Tributary Management Methods

The tributaries that contribute water to Houghton Lake are vital resources for maintaining the quantity of water in Houghton Lake. The tributaries are also a source of nutrients and solids to the lake and thus are critical factors in protecting the water quality of Houghton Lake. In August of 2016, scientists from RLS collected multiple water quality parameters from the tributaries to evaluate the health of the tributaries. Both Sucker Creek and Spring Brook contained elevated phosphorus concentrations that can contribute significant nutrient loads to Houghton Lake during moderate to high water flow. These tributaries would benefit from a biological charcoal filter that can help adsorb phosphorus and reduce sediments and other nutrients from entering Houghton Lake. The filters are placed along the width of the tributaries and may last up to five years before replacement is needed. Figure 78 demonstrates what the filters look like.

Figure 78. A tributary filter strip (photo courtesy of Lake Savers, LLC).

8.0 HOUGHTON LAKE IMPROVEMENT CONCLUSIONS & RECOMMENDATIONS

The information given above for the long-term management of Houghton 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. Table 17 below describes the primary and secondary goals and locations for the proposed improvement methods. The following recommendations can be made for the proposed 5 year 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® or Renovate OTF LZR® is recommended for the spot-treatment of invasive hybrid watermilfoil throughout Houghton Lake. Care must be taken to avoid the use of any 2, 4-D near Wild Rice beds. As required by the MDEQ treatment permit, there are dose limitations for products used in the Middle Grounds and North Bay area. Only dense milfoil in these areas should be treated with the goal in mind to facilitate future growth of Wild Rice and other native aquatic plants in those areas. Only dense areas of Starry Stonewort should also be treated and the 2017 post-treatment survey will determine the efficacy of flumioxazin (Clipper) on the Starry Stonewort. An overall goal

should be to have as many of the original weed beds restored on the lake as possible since the lake only contains 33% cover. In areas where herbicides are not desired, the use of a DASH boat could be executed. This is costly though and generally ranges from $1,000-$3,000 per acre.

2) To determine whether the aquatic herbicide treatments are having a negative effect on sediment macroinvertebrates (the base of the lake food chain to support the fishery), RLS will sample proposed treatment areas before and after treatment to evaluate any changes in sediment macroinvertebrate biodiversity and relative abundance. After the 2017 whole-lake survey and polygon mapping, RLS will propose the macroinvertebrate sampling locations.
3) Baseline data for sediment copper concentrations was collected in previous years but more data is desired. RLS will create a sampling map of several areas throughout the lake that may be compared to baseline concentrations. This can also be correlated to sediment macroinvertebrate biodiversity if desired.
4) Due to the fact that the weed beds present in the lake now overlap strongly with the soft sediment type, RLS recommends having the lake sampled for sediment nutrients such as phosphorus and organic matter. This will allow for the determination of why certain vegetation is growing in certain areas.
5) The Sucker Creek and Spring Brook tributaries have sigfnicantly high concentrations of phosphorus and contribute loads to the lake which could increase nuisance weed and algae growth. RLS recommends installation of nutrient trap barriers across these two tributaries in 2017. RLS will monitor the water quality parameters again in 2017 to evaluate their efficacy in reducing nutrients to the lake.
6) The Prudenville Canals and McKinley Canal #5 would both benefit from aeration and bioaugmentation (addition of microbes) since they are very high in nutrients and solids. If muck reduction is desired by the Associations on these canals, then sediment organic matter tests will determine if muck would be reduced in those areas.
7) Per discussion with the MDNR (Rich O'Neal) and RLS (November, 2016), it was recommended that lit buoys be placed in the Middle Grounds and North Bay areas. The purpose of the buoys would be to reduce the need for treatment of milfoil and Starry Stonewort since the buoys would allow boats to stay clear of the area or reduce speed and the threat of milfoil fragmentation. If this was pursued, the HLLA and HLIB would have to assume full liability. The buoys would have to be quite large and always lighted. This would require solar panels since electrical connection from shore would be impractical due to the distance from shore.
8) If the boat washing station is implemented, then an educational program executed by both the HLLA and the HLIB is recommended. This program would include the elements described above that support the Clean Waters Clean Boats program.
9) Water quality parameters as noted above will be monitored in the lake and tributaries during 2017 to continue to measure trends in the water quality and determine if any tributaries require filter strips or other corrective measures.
10) A whole-lake survey and scan will be executed each year to accurately compare the changes in weed bed size and invasive species polygons in the lake over time. This survey will results in lake scans of aquatic vegetation biovolume, sediment hardness, and maps showing the locations of all invasive species and their relative abundance.

Table 17. Proposed lake improvement methods for Houghton Lake's 5-year plan.

Lake Management Activity	Primary Goal	Secondary Goal	Best Locations to Use
Aquatic herbicide treatment of hybrid milfoil	To reduce areas where the milfoil is dense	To prevent dense areas from spreading in the lake	Main Lake (only dense areas of growth)
Aquatic Herbicide treatment of Starry Stonewort	To reduce areas where it is dense	To prevent plant from carpeting lake bottom	Main Lake; Canals if needed for dense growth
Suction Harvesting	To remove selective areas of dense invasive plants in Middle Grounds/North Bay/Canals	To reduce dependency on chemical herbicides	Main Lake (small invasive polygons in Middle Grounds), Canals
Benthic Barriers/Weed Rollers	To prevent germination of nuisance weeds in beach areas or canals	To reduce dependency on chemicals in nearshore areas	Beach areas, Canals
Wild Rice Cultivation	To allow for new growth of Wild Rice	To increase habitat for Waterfowl	Middle Grounds, North Bay
Laminar Flow Aeration/Bioaugmentation	To reduce odorous muck in canals and aerate sediments	To holistically manage the muck and weeds in the canals	Canals (especially P1-PM canals and MKP-5 canal)
Tributary Nutrient Barriers	To reduce nutrients and solids entering Houghton Lake	To reduce weed growth associated with incoming nutrients	Tributaries (especially Sucker Creek and Spring Brook)
Lake Vegetation Surveys/Scans	To determine % cover by invasives and use as data tool	To compare year to year reductions in nuisance vegetation areas	Main Lake, Canals
Boat Washing Station	To clean boats of invasives before entering the lake	To educate boaters on the proper cleaning of boats and on invasives	South Bay; more if affordable in future and if pilot successful
Water Quality/Sediment Monitoring	To troubleshoot areas that have poor water quality	To compare trend in water quality parameters with time	Main Lake, Canals, Tributaries
Macroinvertebrate Sampling	To determine baseline populations	To determine if herbicides have an impact on populations	Areas proposed to be treated in Main Lake

8.1 Cost Estimates for Houghton Lake Improvements

The proposed aquatic vegetation management program for the improvements of Houghton Lake would begin during the 2017 season and continue through 2021. The reduction in acres of watermilfoil and Starry Stonewort would likely follow in 2017 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 Houghton Lake is presented in Table 18. 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 18. Proposed lake improvement costs for the five year program.

Proposed Houghton Lake Management Improvement Item	*Estimated 2017 Cost*	*Estimated 2018 Cost*	*Estimated 2019-2021 Cost*
Herbicides for Hybrid Watermilfoil and Starry Stonewort and/or DASH Boat removal of invasives, Permit Fees[1]	$400,000	$350,000	$250,000
Professional Limnologist Services (limnologist surveys, sampling, contractor oversight, education)[2]	$65,000	$65,000	$65,000
Attorney Fees	$5,000	$5,000	$5,000
Assessment Appeals	$3,000	$3,000	$3,000
Canal Aeration Systems	$70,000	$50,000	$50,000
Tributary Filter Buffers	$10,000	$0	$0
Boat Washing Station	$140,000	$20,000	$20,000
Audit, Bond, Insurance	$1,400	$1,400	$1,400
Professional Memberships	$100	$100	$100
Mailings, Publication	$2,000	$0	$2,000
Contingency (15%)[3]	$104,475	$74,175	$59,475
TOTAL ANNUAL ESTIMATED COST	$800,975	$568,675	$455,975
APPROX. ANNUAL COST PER UNIT OF BENEFIT[4]	$175.00	$125.00	$100.00

[1] Herbicide treatment scope for the treatment of Hybrid watermilfoil and Starry Stonewort is proposed to decline annually due to aggressive treatment with the use spot-treatment herbicides.
[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 all regularly scheduled Houghton Lake Improvement Board meetings. 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 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] Current study estimates based on 4,568 units of benefit. This value is subject to change as the SAD is refined or changed by the Houghton Lake Improvement 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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