Annual Report

Houghton Lake
2014 Annual Report

Prepared for:

Houghton Lake Improvement Board
P.O. Box 843
Houghton Lake, MI 48629

Prepared by:

Progressive AE
1811 4 Mile Road, NE
Grand Rapids, MI 49525-2442
616/361-2664

March 2015

Project No: 55520101

progressive | ae

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Introduction

Houghton Lake is Michigan's largest inland lake at 20,044 acres, but it is also shallow with an average depth of less than 10 feet (Figure 1). Aquatic plants have been abundant and diverse in Houghton Lake for many years. However, by the late 1990s, the nuisance exotic plant, Eurasian milfoil (Myriophyllum spicatum, Figure 2), had spread to approximately 11,000 acres of the lake and was crowding out beneficial native plant species.

To address this problem, the Houghton Lake Improvement Board was established in accordance with Michigan's Natural Resources and Environmental Protection Act and commissioned a management feasibility study of Houghton Lake (Smith et al. 2002). To control the spread of milfoil in Houghton Lake, a whole-lake treatment with the aquatic herbicide fluridone (trade name Sonar®) was conducted in the spring of 2002 as part of a five-year management plan. Public hearings were held in 2006 and 2011 pursuant to statute, and the project was continued through 2016. Key components of the management plan include aquatic plant control, water quality and vegetation monitoring, information and education, and watershed management. This report provides a summary of project activities through 2014.

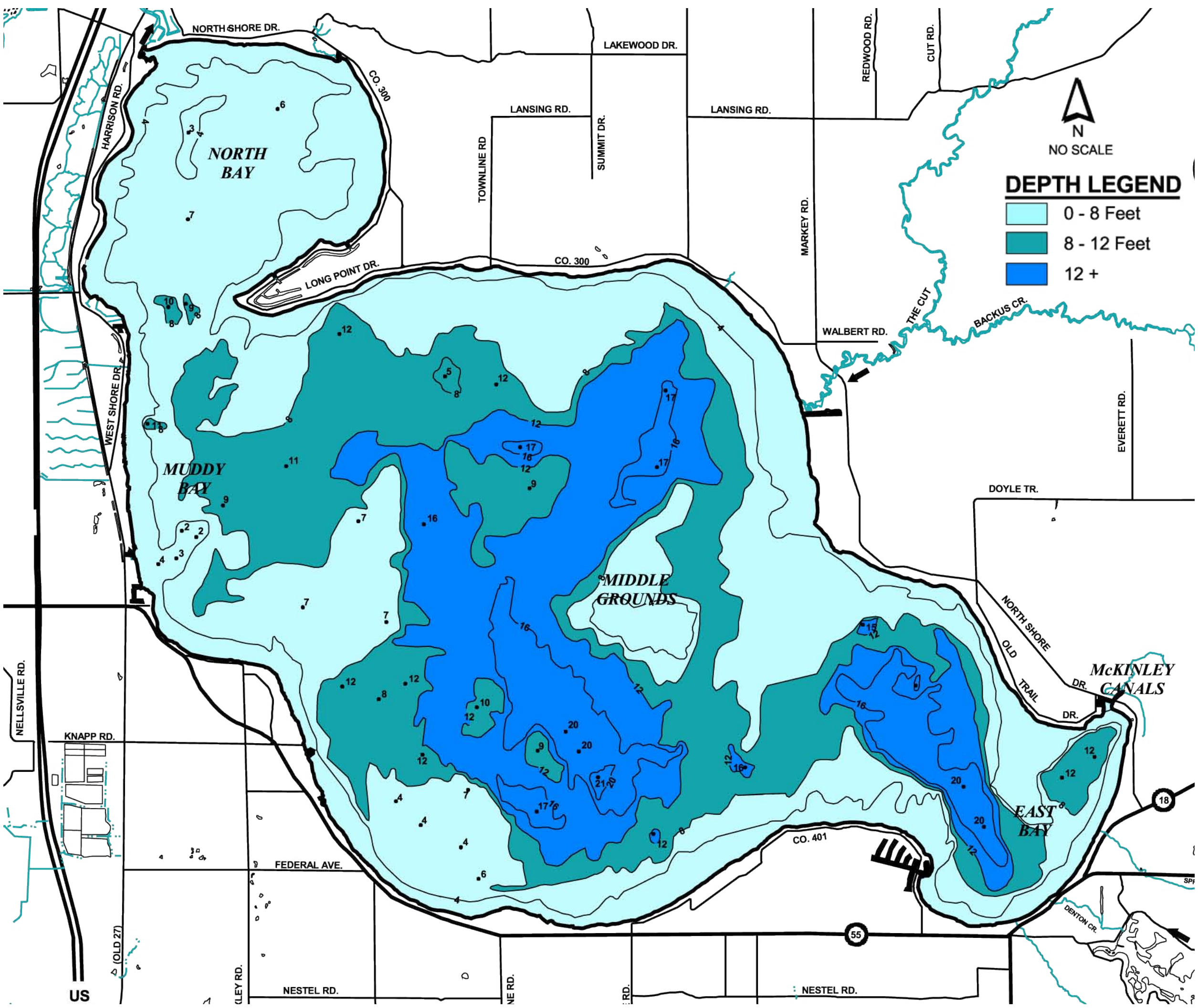

Figure 1. Houghton Lake depth contour map.

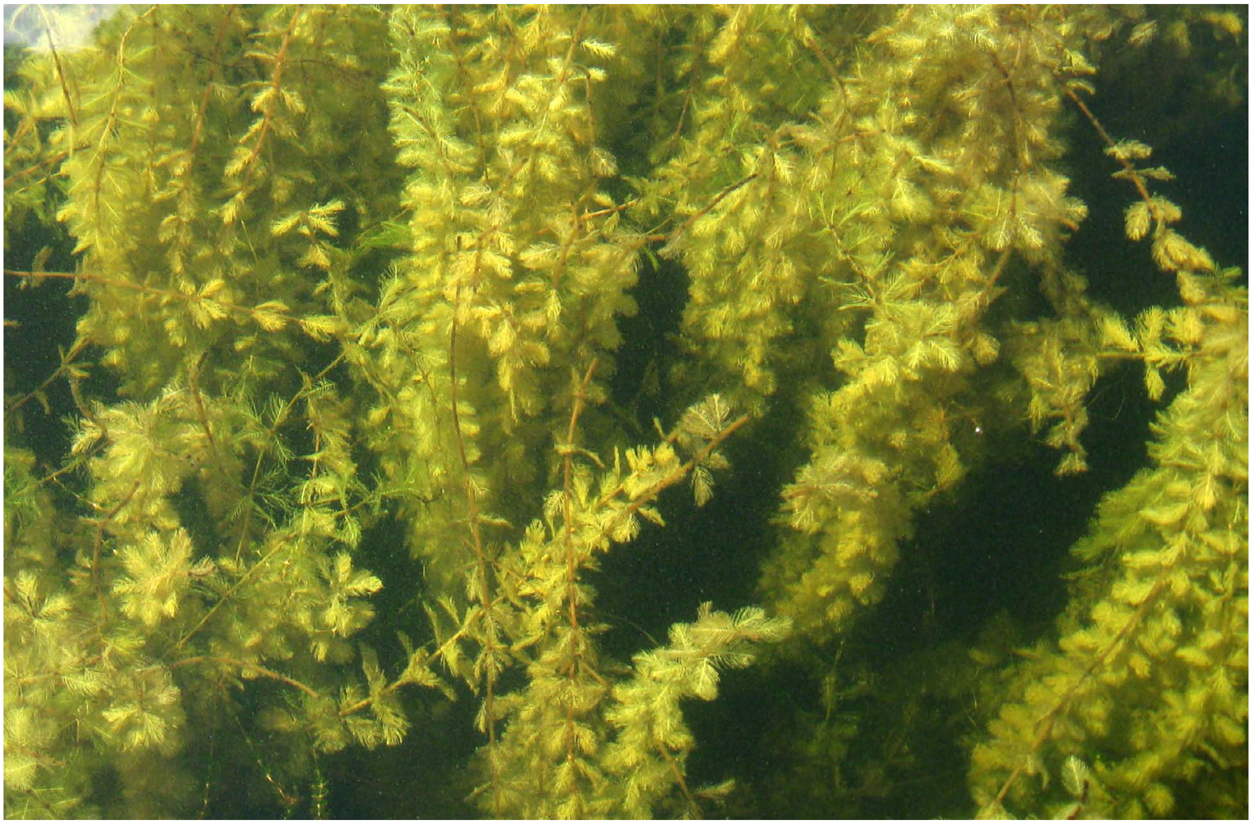

Figure 2. Eurasian milfoil (*Myriophyllum spicatum*).

Aquatic Plants

PLANT CONTROL IN HOUGHTON LAKE 2002 – 2014

Plant control in Houghton Lake focuses exclusively on the control of exotic plant species, primarily non-native milfoil. Plant control activities conducted in Houghton Lake since 2002 are summarized in Table 1. Since the whole-lake Sonar® treatment in 2002, milfoil beds in the lake have been spot-treated, primarily with systemic herbicides. In 2014, less than 6 percent of the lake was treated (Figure 3). The extremely harsh winter and prolonged ice cover of the winter of 2013-2014 may have contributed to the reduced treatment area in 2014.

TABLE 1
HOUGHTON LAKE PLANT CONTROL HISTORY

	Herbicides (acres treated)			Acres	Milfoil Weevils
	Sonar®	Contacts	Systemic	Harvested	(# 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		

To minimize potential impacts to wild rice in Houghton Lake, the permit issued by the Michigan Department of Environmental Quality for the 2014 treatment required that low doses of the systemic herbicide triclopyr be used for Eurasian milfoil control in areas known or suspected to contain wild rice, i.e., the Middle Grounds and North Bay. The low-dose protocol was used throughout the Middle Grounds treatment area. As in the previous three years, no treatments were conducted in in North Bay in order to address concerns raised by the Houghton Lake, Lake Association regarding potential treatment impacts to wild rice.

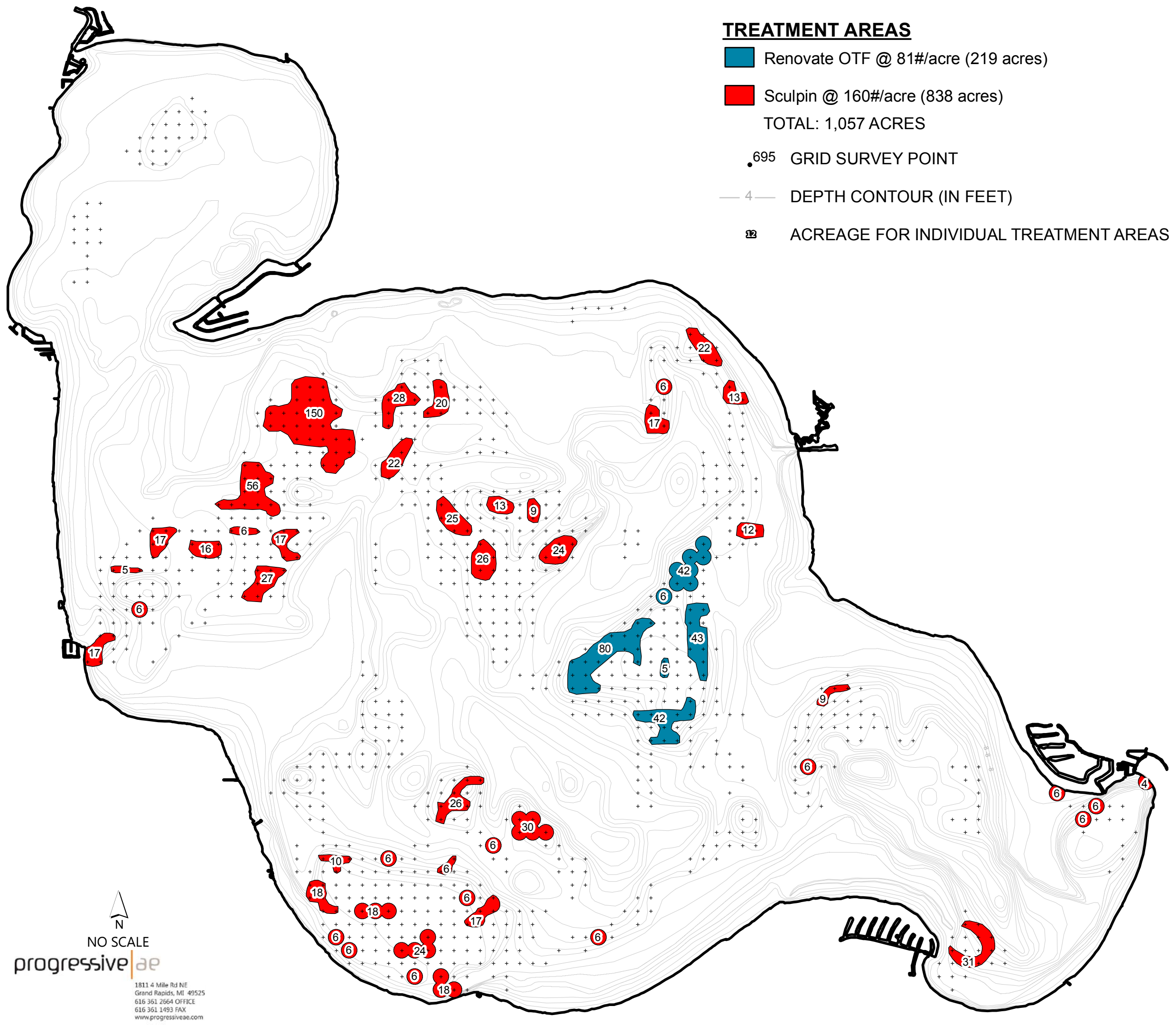

Figure 3. Houghton Lake 2014 treatment map. In addition to herbicide treatments in the main body of the lake, several of the canal areas were treated in 2014 to control Eurasian milfoil.

2014 SURVEY METHODS AND RESULTS

Aquatic plant surveys of Houghton Lake are conducted by the Houghton Lake Improvement Board's environmental consultant, Progressive AE. In 2014, biologists from Progressive conducted plant surveys on June 16-17 and September 3-4 using the point-intercept method (Madsen 1999). Sampling locations were established with a global positioning system (GPS) at grid points spaced every 500-feet in locations where nuisance Eurasian milfoil growth had occurred historically in Houghton Lake (Figure 4). At each sampling location, a double-sided thatch rake attached to a line was dragged for approximately 15 feet in two rake tosses, one on each side of the boat. At each grid point where milfoil was found, the relative abundance of milfoil was noted. In addition to the point-intercept surveys conducted in the lake proper, each of the canal systems around the lake was surveyed to identify milfoil locations. Areas of the lake and canals where nuisance milfoil growth was observed during the June surveys were targeted for treatment. Pre-treatment and post-treatment milfoil distribution maps are shown in Figures 5 and 6.

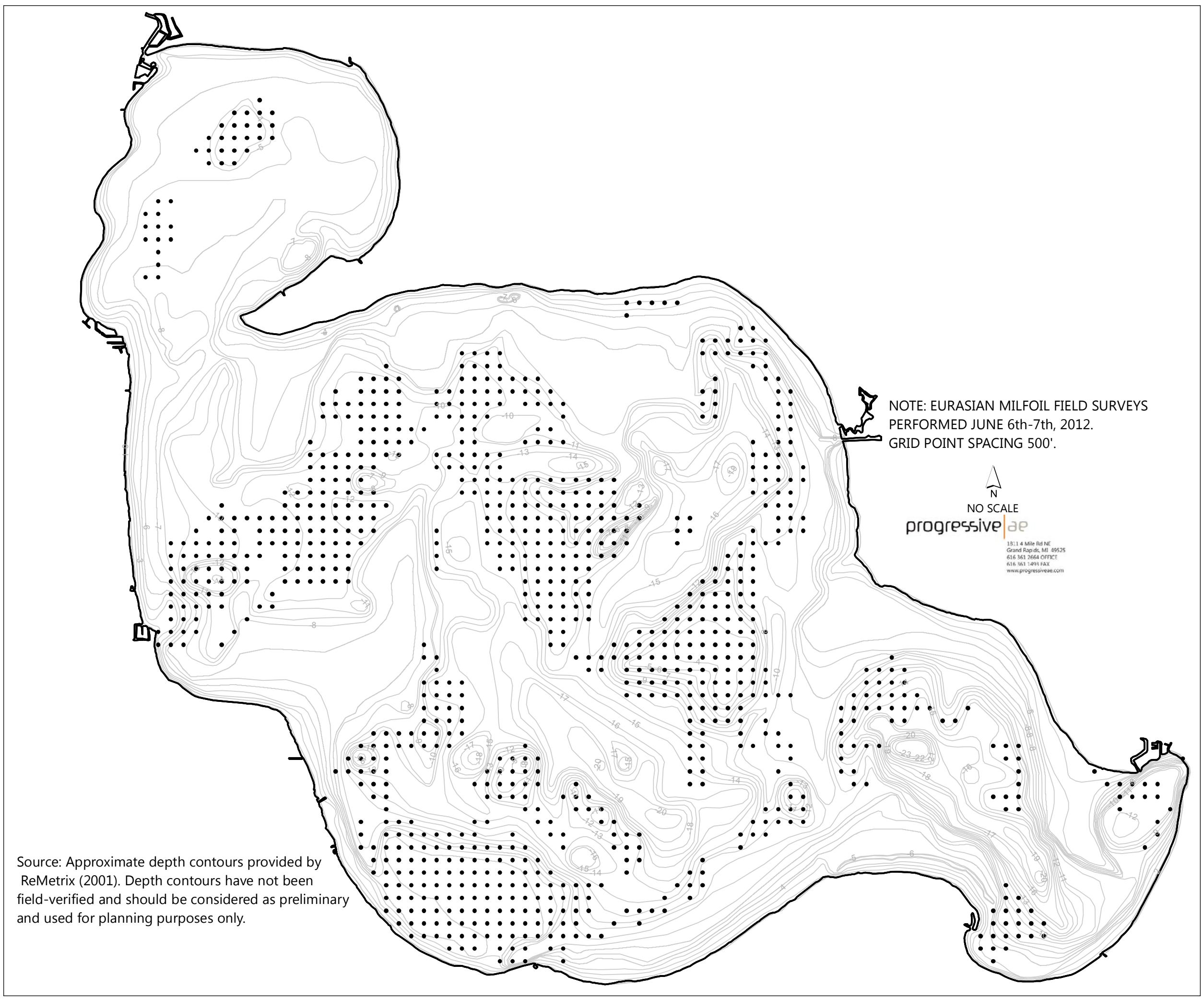

Figure 4. Houghton Lake 2014 aquatic plant survey sampling location map.

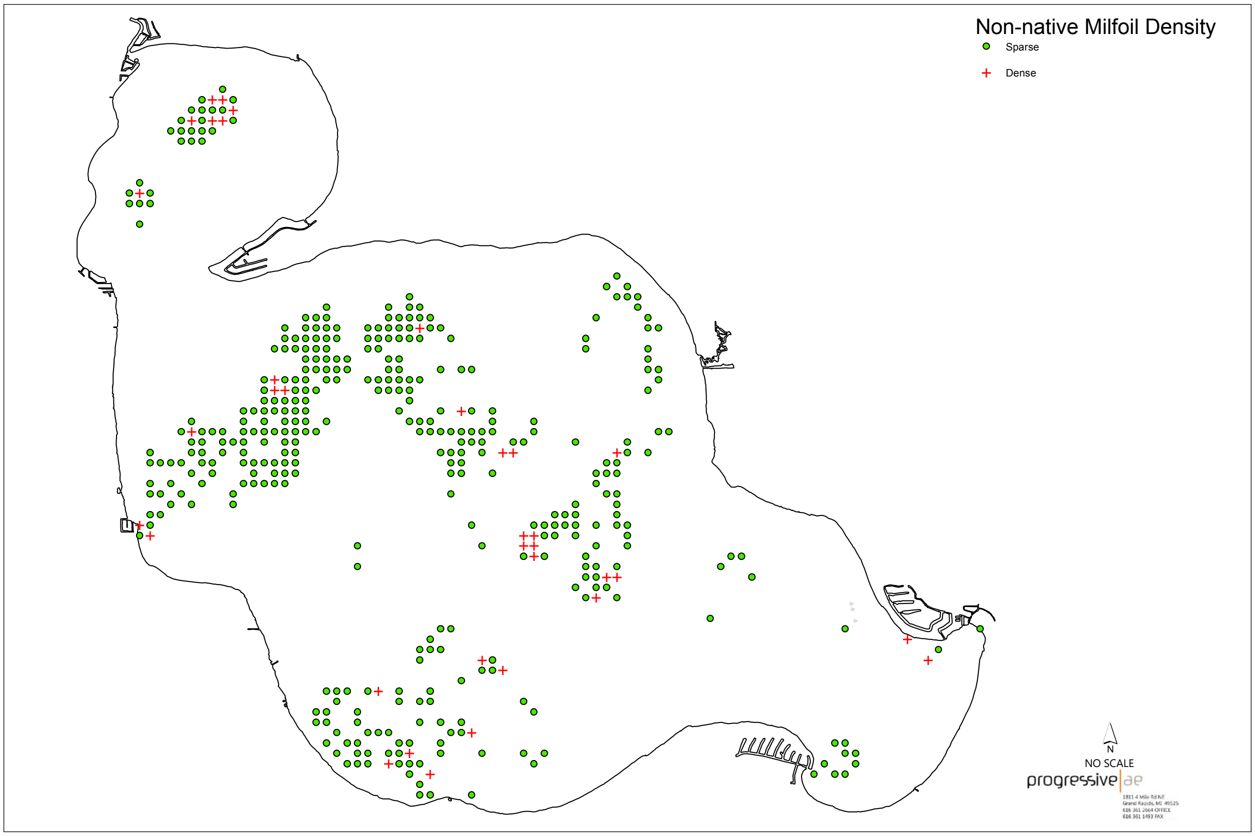

Figure 5. Houghton Lake pre-treatment non-native milfoil distribution, June 16-17, 2014.

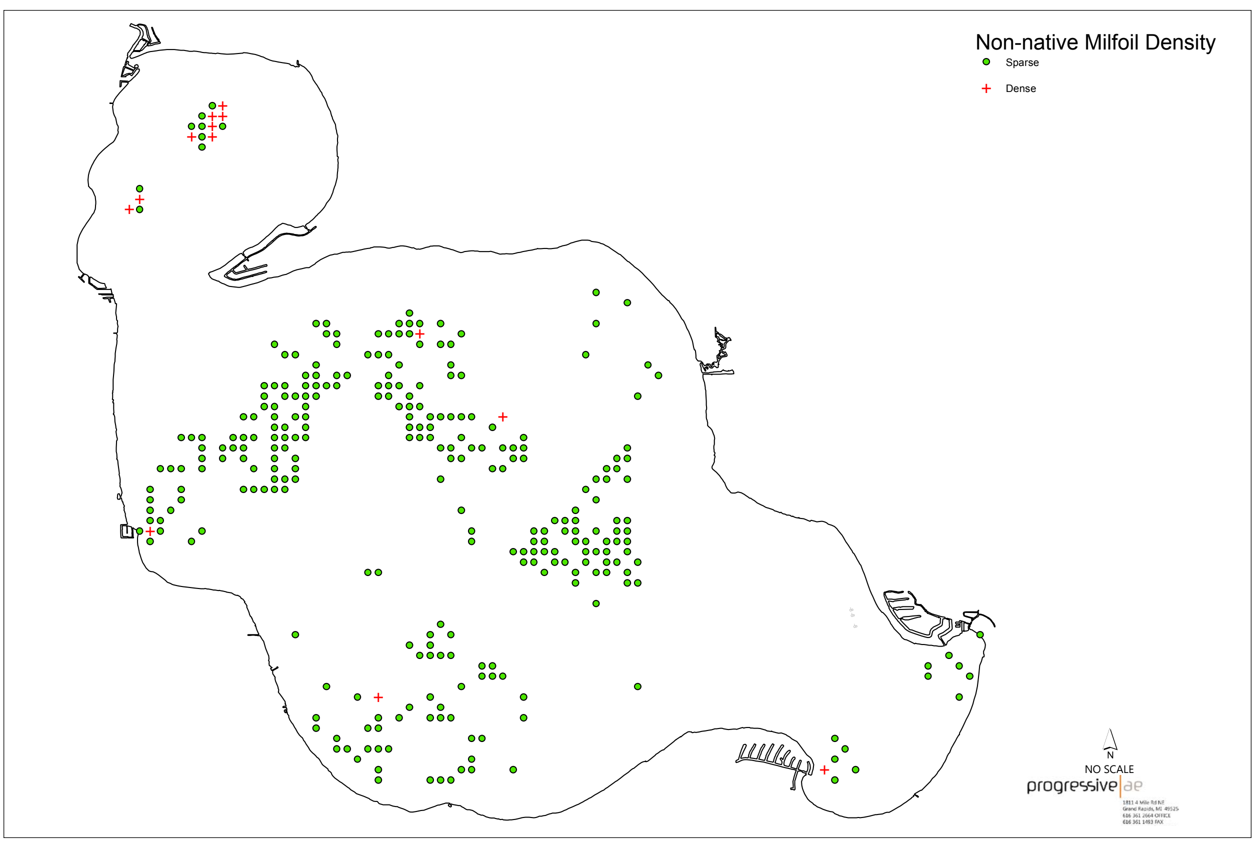

Figure 6. Houghton Lake post-treatment non-native milfoil distribution, September 3-4, 2014.

Recent genetic testing indicates that hybrid milfoil is present in Houghton Lake (Progressive AE 2013). Hybrid milfoil is a cross between the invasive, exotic species Eurasian milfoil (*Myriophyllum spicatum*) and the native northern milfoil (*Myriophyllum sibiricum*). Because the hybrid milfoil combines traits of the native and exotic milfoils, there is concern in the scientific community that the hybrid milfoil will be more aggressive growing than the Eurasian milfoil (Appendix A). Some hybrid milfoil variants also appear to be tolerant to certain herbicides. Genetic screening can provide a valuable tool to inform management decisions regard the control of hybrid milfoil (Appendix B).

To better discern potential management implications of hybrid milfoil in Houghton Lake, scientists from Grand Valley State University's (GVSU) Annis Water Resources Institute were retained in 2014 to evaluate the extent of hybrid milfoil in the lake. During the 2014 plant surveys, GVSU scientists accompanied Progressive's biologists and, at each site where milfoil was found, a sample was collected for genetic identification at GVSU's Annis Water Resources Institute in Muskegon. Pre-and post-treatment genetic screening results are summarized in Table 2 and in Figures 7 and 8.

TABLE 2
HOUGHTON LAKE 2014 GENETIC TESTING RESULTS

	Pre-treatment	Post-treatment
Hybrid watermilfoil	499	299
Eurasian watermilfoil	51	10
Northern watermilfoil	2	0
Unindentified	4	

During the initial pre-treatment survey conducted in June, milfoil was found at 556 of the 996 survey sites. Of the sites where milfoil was found, hybrid milfoil was present at 499 or 90% of the sites. In the follow-up, post-treatment survey conducted in September, milfoil was found at 309 of the 996 survey sites. Of the sites where milfoil was found, hybrid milfoil was present at 299 or 97% of the sites. These data indicate that hybrid milfoil is currently the dominant type of milfoil found in Houghton Lake.

While the 2014 treatments reduced common to dense milfoil growth overall in Houghton Lake (Figures 5 and 6), the treatments were only marginally successful in controlling hybrid milfoil. In about one-half of the treatment areas, milfoil was detected during the post-treatment survey. These data suggest that the hybrid milfoil in Houghton Lake is showing herbicide resistance.

In addition to the genetic testing conducted in 2014, plants were collected at multiple locations in the lake during the September 2014 survey and were cultured overwinter in the laboratory for herbicide susceptibility testing. Herbicide susceptibility testing is a tool that has been developed to evaluate plant response to various herbicides. This work was conducted at the SePro Research and Technology Campus laboratory in North Carolina. Screening involved exposing the plants to operational dose rates of commonly used auxin herbicides (e.g., triclopyr and 2,4-D amine) and measuring plant response. Plant response was then referenced against a pure Eurasian milfoil biotype and a hybrid biotype. Herbicide screening allows an assessment to be made of diminished responses to commonly used herbicides and to evaluate if there is a differential response between Eurasian and the hybrid milfoil biotypes. Herbicide susceptibility results are pending that will help evaluate herbicide dose rates needed to optimize treatment effectiveness in Houghton Lake in 2015.

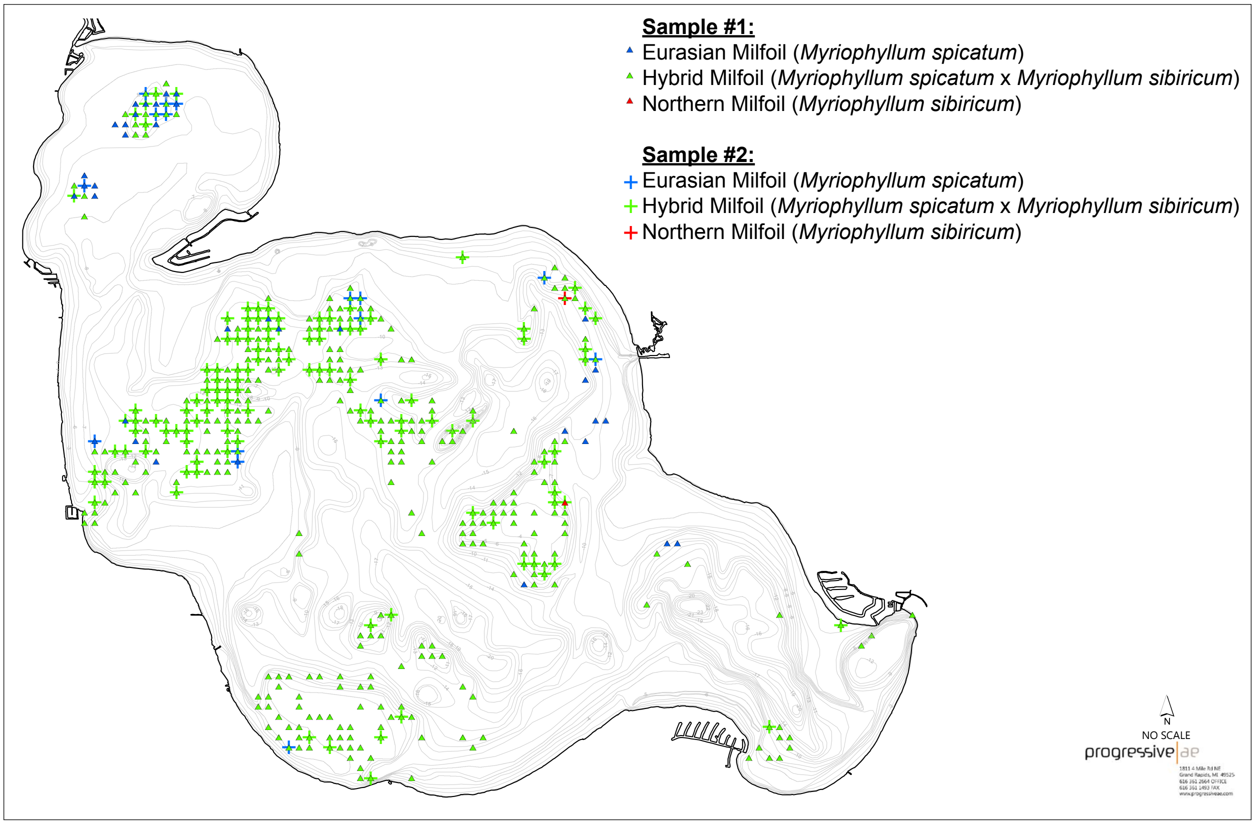

Figure 7. Houghton Lake pre-treatment genetic screening results, June 16-17, 2014.

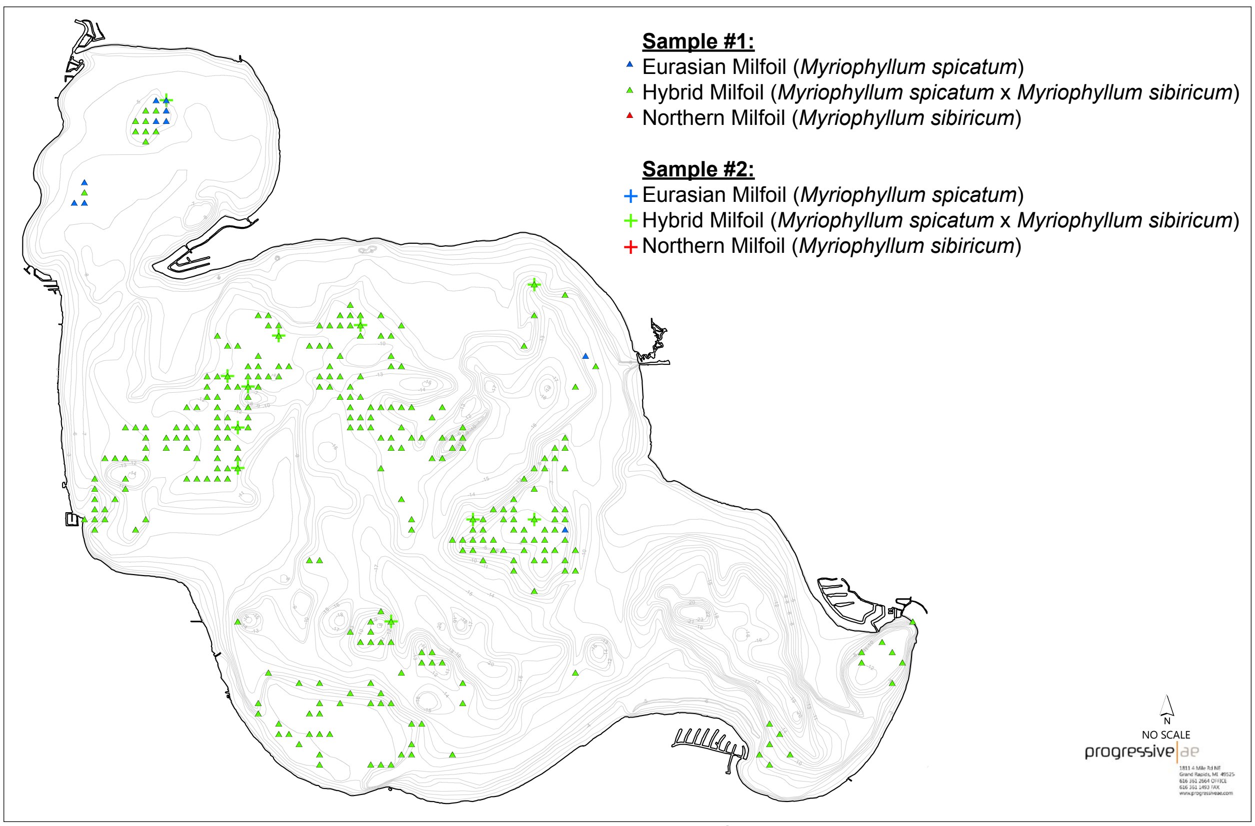

Figure 8. Houghton Lake post-treatment genetic screening results, September 3-4, 2014.

Lake Water Quality

Lake water quality is determined by a unique combination of processes that occur both within and outside of the lake. In order to make sound management decisions, it is necessary to have an understanding of the current physical, chemical, and biological condition of the lake, and the potential impact of drainage from the surrounding watershed.

Lakes are commonly classified as oligotrophic, mesotrophic, or eutrophic (Figure 9). Oligotrophic lakes are generally deep and clear with little aquatic plant growth. These lakes maintain sufficient dissolved oxygen in the cool, deep bottom waters during late summer to support cold water fish such as trout and whitefish. By contrast, eutrophic lakes are generally shallow, turbid, and support abundant aquatic plant growth. In deep eutrophic lakes, the cool bottom waters usually contain little or no dissolved oxygen. Therefore, these lakes can only support warm water fish such as bass and pike. Lakes that fall between these two extremes are called mesotrophic lakes.

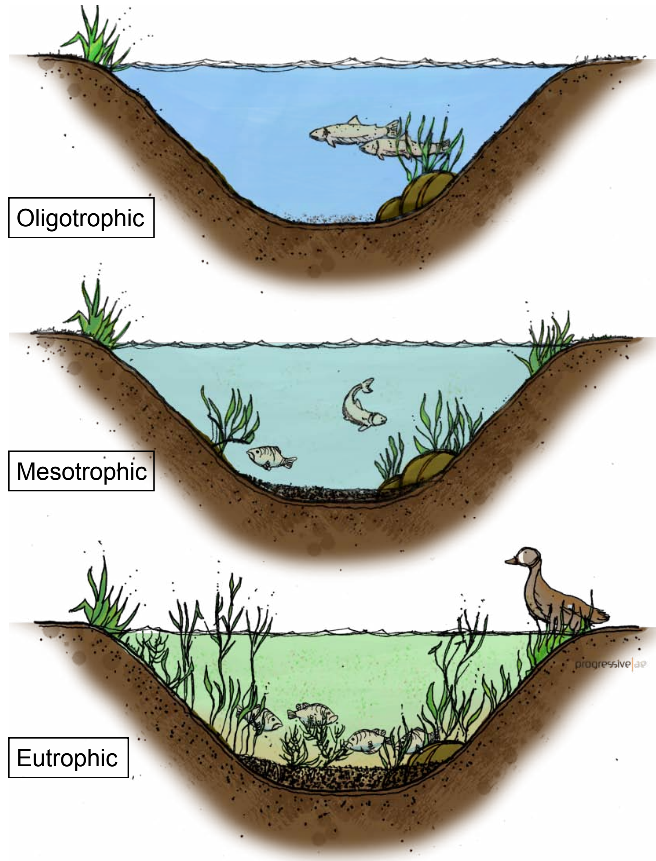

Figure 9. Lake classification.

Under natural conditions, most lakes will ultimately evolve to a eutrophic state as they gradually fill with sediment and organic matter transported to the lake from the surrounding watershed. As the lake becomes shallower, the process accelerates. When aquatic plants become abundant, the lake slowly begins to fill in as sediment and decaying plant matter accumulate on the lake bottom. Eventually, terrestrial plants become established and the lake is transformed to a marshland. The aging process in lakes is called "eutrophication" and may take anywhere from a few hundred to several thousand years, generally depending on the size of the lake and its watershed. The natural lake aging process can be greatly accelerated if excessive amounts of sediment and nutrients (which stimulate aquatic plant growth) enter the lake from the surrounding watershed. Because these added inputs are usually associated with human activity, this accelerated lake aging process is often referred to as "cultural eutrophication." The problem of cultural eutrophication can be managed by identifying sources of sediment and nutrient loading (i.e., inputs) to the lake and developing strategies to halt or slow the inputs. Thus, in developing a management plan, it is necessary to determine the limnological (i.e., the physical, chemical, and biological) condition of the lake and the physical characteristics of the watershed as well.

Key parameters used to evaluate the limnological condition of a lake include temperature, dissolved oxygen, total phosphorus, chlorophyll-*a*, and Secchi transparency. A brief description of these water quality measurements is provided as an introduction for the reader. Particular attention should be given to the interrelationship of these water quality measurements.

TEMPERATURE

Temperature is important in determining the type of organisms that may live in a lake. For example, trout prefer temperatures below 68°F. Temperature also determines how water mixes in a lake. As the ice cover breaks up on a lake in the spring, the water temperature becomes uniform from the surface to the bottom. This period is referred to as "spring turnover" because water mixes throughout the entire water column. As the surface waters warm, they are underlain by a colder, more dense strata of water. This process is called thermal stratification. Once thermal stratification occurs, there is little mixing of the warm surface waters with the cooler bottom waters. The transition layer that separates these layers is referred to as the "thermocline." The thermocline is characterized as the zone where temperature drops rapidly with depth. As fall approaches, the warm surface waters begin to cool and become more dense. Eventually, the surface temperature drops to a point that allows the lake to undergo complete mixing. This period is referred to as "fall turnover." As the season progresses and ice begins to form on the lake, the lake may stratify again. However, during winter stratification, the surface waters (at or near 32°F) are underlain by slightly warmer water (about 39°F). This is sometimes referred to as "inverse stratification" and occurs because water is most dense at a temperature of about 39°F. As the lake ice melts in the spring, these stratification cycles are repeated (Figure 10). Shallow lakes do not stratify. Lakes that are 15 to 30 feet deep may stratify and destratify with storm events several times during the year.

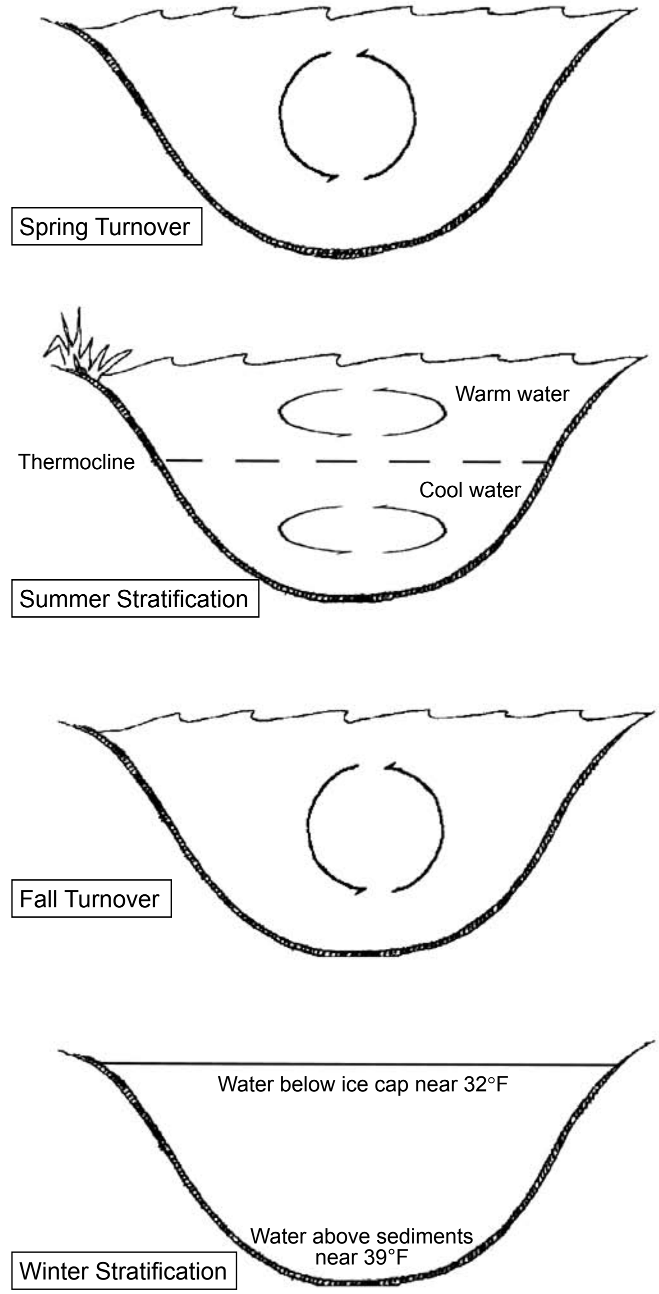

Figure 10. Lake stratification and turnover.

DISSOLVED OXYGEN

An important factor influencing lake water quality is the quantity of dissolved oxygen in the water column. The major inputs of dissolved oxygen to lakes are the atmosphere and photosynthetic activity by aquatic plants. An oxygen level of about 5 mg/L (milligrams per liter, or parts per million) is required to support warm water fish. In lakes deep enough to exhibit thermal stratification, oxygen levels are often reduced or depleted below the thermocline once the lake has stratified. This is because deep water is cut off from plant photosynthesis and the atmosphere, and oxygen is consumed by bacteria that use oxygen as they decompose organic matter (plant and animal remains) at the bottom of the lake. Bottom-water oxygen depletion is a common occurrence in eutrophic and some mesotrophic lakes. Thus, eutrophic and most mesotrophic lakes cannot support cold water fish because the cool, deep water (that the fish require to live) does not contain sufficient oxygen.

PHOSPHORUS

The quantity of phosphorus present in the water column is especially important since phosphorus is the nutrient that most often controls aquatic plant growth and the rate at which a lake ages and becomes more eutrophic. In the presence of oxygen, lake sediments act as a phosphorus trap, retaining phosphorus and, thus, making it unavailable for aquatic plant growth. However, if bottom-water oxygen is depleted, phosphorus will be released from the sediments and may be available to promote aquatic plant growth. In some lakes, the internal release of phosphorus from the bottom sediments is the primary source of phosphorus loading (or input).

By reducing the amount of phosphorus in a lake, it may be possible to control the amount of aquatic plant growth. In general, lakes with a phosphorus concentration greater than 20 µg/L (micrograms per liter, or parts per billion) are able to support abundant plant growth and are classified as nutrient-enriched or eutrophic.

CHLOROPHYLL-*a*

Chlorophyll-*a* is a pigment that imparts the green color to plants and algae. A rough estimate of the quantity of algae present in lake water can be made by measuring the amount of chlorophyll-*a* in the water column. A chlorophyll-*a* concentration greater than 6 µg/L is considered characteristic of a eutrophic condition.

SECCHI TRANSPARENCY

A Secchi disk is often used to estimate water clarity. The measurement is made by fastening a round, black and white, 8-inch disk to a calibrated line (Figure 11). The disk is lowered over the deepest point of the lake until it is no longer visible, and the depth is noted. The disk is then raised until it reappears. The average between these two depths is the Secchi transparency. Generally, it has been found that aquatic plants can grow at a depth of approximately twice the Secchi transparency measurement. In eutrophic lakes, water clarity is often reduced by algae growth in the water column, and Secchi disk readings of 7.5 feet or less are common.

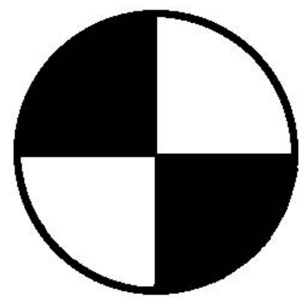

Figure 11. Secchi disk.

Ordinarily, as phosphorus inputs (both internal and external) to a lake increase, the amount of algae the lake can support will also increase. Thus, the lake will exhibit increased chlorophyll-*a* levels and decreased transparency. A summary of lake classification criteria developed by the Michigan Department of Environmental Quality is shown in Table 3.

TABLE 3
LAKE CLASSIFICATION CRITERIA

Lake Classification	Total Phosphorus (µg/L)[1]	Chlorophyll-*a* (µg/L)	Secchi Transparency (feet)
Oligotrophic	Less than 10	Less than 2.2	Greater than 15.0
Mesotrophic	10 to 20	2.2 to 6.0	7.5 to 15.0
Eutrophic	Greater than 20	Greater than 6.0	Less than 7.5

[1] µg/L = micrograms per liter = parts per billion.

pH and TOTAL ALKALINITY

pH is a measure of the amount of acid or base in the water. The pH scale ranges from 0 (acidic) to 14 (alkaline or basic) with neutrality at 7. The pH of most lakes in the Upper Midwest ranges from 6.5 to 9.0 (MDEQ 2012; Table 4). In addition, according to MDEQ (2013):

> While there are natural variations in pH, many pH variations are due to human influences. Fossil fuel combustion products, especially automobile and coal-fired power plant emissions, contain nitrogen oxides and sulfur dioxide, which are converted to nitric acid and sulfuric acid in the atmosphere. When these acids combine with moisture in the atmosphere, they fall to earth as acid rain or acid snow. In some parts of the United States, especially the Northeast, acid rain has resulted in lakes and streams becoming acidic, resulting in conditions which are harmful to aquatic life. The problems associated with acid rain are lessened if limestone is present, since it is alkaline and neutralizes the acidity of the water.
>
> Most aquatic plants and animals are adapted to a specific pH range, and natural populations may be harmed by water that is too acidic or alkaline. Immature stages of aquatic insects and young fish are extremely sensitive to pH values below 5. Even microorganisms which live in the bottom sediment and decompose organic debris cannot live in conditions which are too acidic. In very acidic waters, metals which are normally bound to organic matter and sediment are released into the water. Many of these metals can be toxic to fish and humans. Below a pH of about 4.5, all fish die.

The Michigan Water Quality Standard (Part 4 of Act 451) states that pH shall be maintained within the range of 6.5 to 9.0 in all waters of the state.

Alkalinity, also known as acid-neutralizing capacity or ANC, is the measure of the pH-buffering capacity of water in that it is the quantitative capacity of water to neutralize an acid. pH and alkalinity are closely linked and are greatly impacted by the geology and soil types that underlie a lake and its watershed. According to MDEQ (2012):

> Michigan's dominant limestone geology in the Lower Peninsula and the eastern Upper Peninsula contributes to the vast majority of Michigan lakes being carbonate-bicarbonate dominant [which increases alkalinity and moderates pH] and lakes in the western Upper Peninsula having lower alkalinity and thus lesser buffering capacity.

The alkalinity of most lakes in the Upper Midwest is within the range of 23 to 148 milligrams per liter, or parts per million, as calcium carbonate (MDEQ 2012; Table 4).

TABLE 4
pH AND ALKALINITY OF UPPER MIDWEST LAKES

Measurement	Low	Moderate	High
pH (in standard units)	Less than 6.5	6.5 to 9.0	Greater than 9.0
Total Alkalinity or ANC (in mg/L as $CaCO_3$)[1]	Less than 23	23 to 148	Greater than 148

1 mg/L $CaCO_3$ = milligrams per liter as calcium carbonate.

SAMPLING METHODS

Water quality samples were collected in the spring and summer of 2014 from five locations within Houghton Lake (Figure 12). Temperature was measured using a ClineFinder probe. Samples were collected at the surface and just above the lake bottom with a Kemmerer bottle to be analyzed for dissolved oxygen, pH, total alkalinity, and total phosphorus. Dissolved oxygen samples were fixed in the field and were analyzed at Progressive AE using the modified Winkler method (Standard Methods Procedure 4500-O C). pH was measured in the field using a Oakton EcoTestr 2. Total alkalinity and total phosphorus samples were placed on ice and transported to Progressive AE and to Prein and Newhof[1], respectively, for analysis. Total alkalinity was titrated at Progressive AE using Standard Methods Procedure 2320.B, and total phosphorus was analyzed at Prein and Newhof using Standard Methods Procedure 4500P-E. Also at each of the five sampling locations, Secchi transparency was measured and composite chlorophyll-*a* samples were collected from the surface to a depth equal to twice the Secchi transparency. Chlorophyll-*a* samples were analyzed by Prein and Newhof using Standard Methods Procedure 10200H.

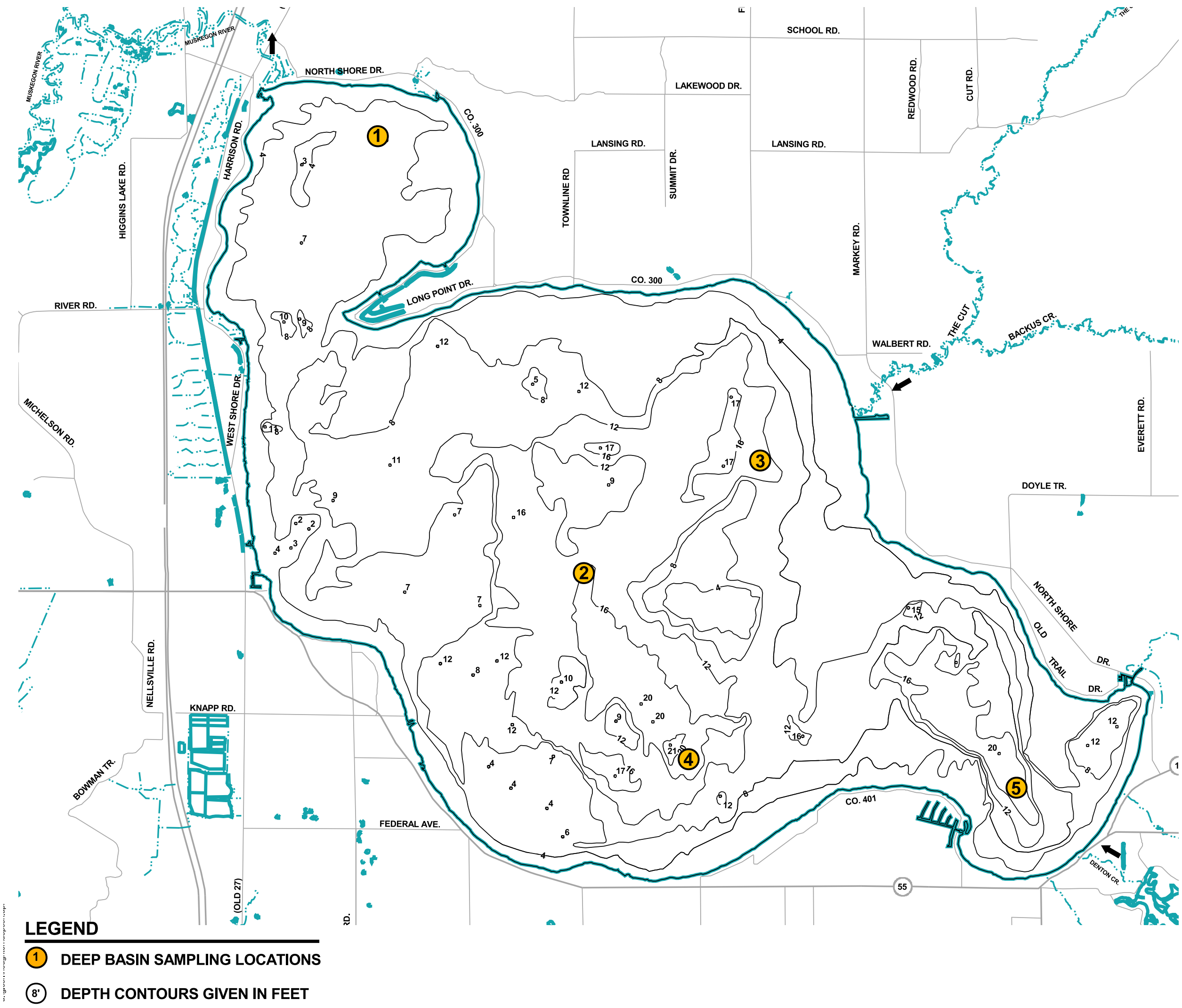

Figure 12. Houghton Lake sampling location map.

1 Prein and Newhof, 3260 Evergreen Drive, NE, Grand Rapids, MI 49525.

SAMPLING RESULTS AND DISCUSSION

Lake water quality data is provided in Tables 5 and 6. In-lake summary statistics are included in Table 7.

TABLE 5
HOUGHTON LAKE
2014 DEPTH PROFILE WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temp-erature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
8-May-14	1	1	50	11.5	<5	8.5	77
8-May-14	1	6	50	11.7	<5	8.4	79
8-May-14	2	1	50	10.9	<5	8.1	76
8-May-14	2	14	49	11.2	5	8.1	77
8-May-14	3	1	49	11.0	<5	8.3	81
8-May-14	3	16	49	11.5	5	8.4	80
8-May-14	4	1	50	12.1	5	8.2	84
8-May-14	4	19	49	10.7	<5	8.4	83
8-May-14	5	1	50	11.8	<5	8.5	80
8-May-14	5	20	49	11.2	<5	8.4	79
4-Sep-14	2	1	72	9.5	41	8.9	84
4-Sep-14	2	12	72	9.1	9	8.9	83
4-Sep-14	4	1	72	8.8	7	8.9	
4-Sep-14	4	16	72	8.9	12	8.9	82
4-Sep-14	5	1	73	9.8	13	8.9	85
4-Sep-14	5	16	72	9.9	8	8.9	85

[1] mg/L = micrograms per liter = parts per billion.
[2] µg/L = micrograms per liter = parts per billion.
[3] S.U. = standard units.
[4] mg/L as $CaCO_3$ = milligrams per liter as calcium carbonate.

TABLE 6
HOUGHTON LAKE
2014 SURFACE WATER QUALITY DATA

Date	Station	Secchi Transparency (feet)	Chlorophyll-*a* (μg/L)[1]
8-May-14	1	7.0	0
8-May-14	2	8.0	0
8-May-14	3	8.0	1
8-May-14	4	8.5	1
8-May-14	5	9.5	1
4-Sep-14	2	6.0	0
4-Sep-14	4	5.0	0
4-Sep-14	5	5.0	

TABLE 7
HOUGHTON LAKE IN-LAKE SUMMARY STATISTICS
2003-2014

	Total Phosphorus (μg/L)[1]	Secchi Transparency (feet)	Chlorophyll-*a* (μg/L)[1]
Average	27	5.5	1.1
Standard deviation	28	1.4	1.3
Median	19	5.5	0.9
Minimum	<5	2.5	0.0
Maximum	256	9.5	8.2
Number of samples	293	145	144

1 μg/L = micrograms per liter = parts per billion.

The shallow depths in Houghton Lake cause the lake to mix constantly from spring to fall and as such, water temperature and chemistry are fairly uniform from top to bottom. Temperatures were cool in spring and warm in summer. The water was well oxygenated from the surface to bottom during both the spring and summer sampling periods in 2014, and were well above the concentration needed to sustain a warmwater fishery. Although dissolved oxygen concentrations are adequate, water temperatures in Houghton Lake are too warm to sustain a coldwater fishery.

In 2014, total phosphorus concentrations were generally low in spring and summer. Phosphorus data collected in recent years indicates that phosphorus levels in Houghton Lake can vary considerably both season-to-season and year-to-year (Table 5; Figure 13). This variability in phosphorus levels may be related to wind action that periodically stirs unconsolidated bottom sediments into the water column. The median phosphorus concentration of all in-lake phosphorus data collected since 2003 is 19 ppb, a level that is just below the eutrophic threshold.

Algal growth was low in 2014, as indicated by the chlorophyll-*a* concentrations that were 1 ppb or less. The low chlorophyll-*a* levels suggest that most of the phosphorus in Houghton Lake is used by rooted plants rather than algae. Secchi transparency measurements were low to moderate in 2014. Given the low chlorophyll-*a* concentrations, it is unlikely the poor clarity is related to algae growth. Instead, turbidity in the water column caused by wind-mixing of bottom sediments probably reduces water clarity. Similar Secchi transparency measurements were reported by Pecor et al. (1973); therefore, reduced clarity is not a new phenomenon in Houghton Lake.

During 2014, the pH and total alkalinity in Houghton Lake were moderate in comparison to other upper midwestern lakes.

Based on the data collected and presented herein, Houghton Lake is meso-eutrophic in that the lake exhibits moderately elevated phosphorus levels, low chlorophyll-*a*, and low transparency (Figures 13 through 15).

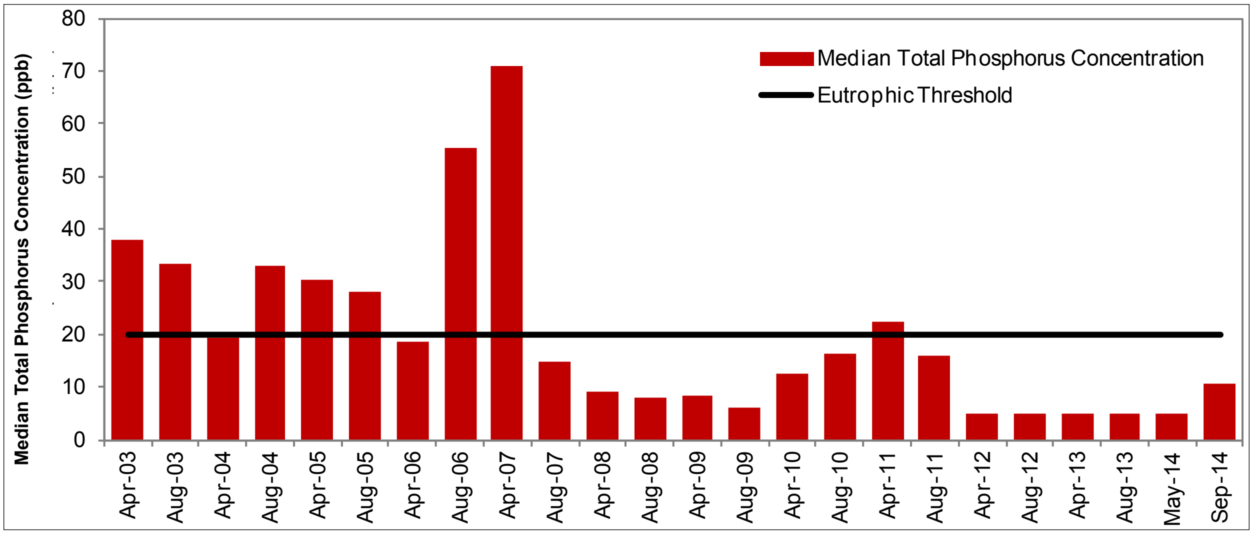

Figure 13. Houghton Lake median total phosphorus concentrations, 2003 - 2014.

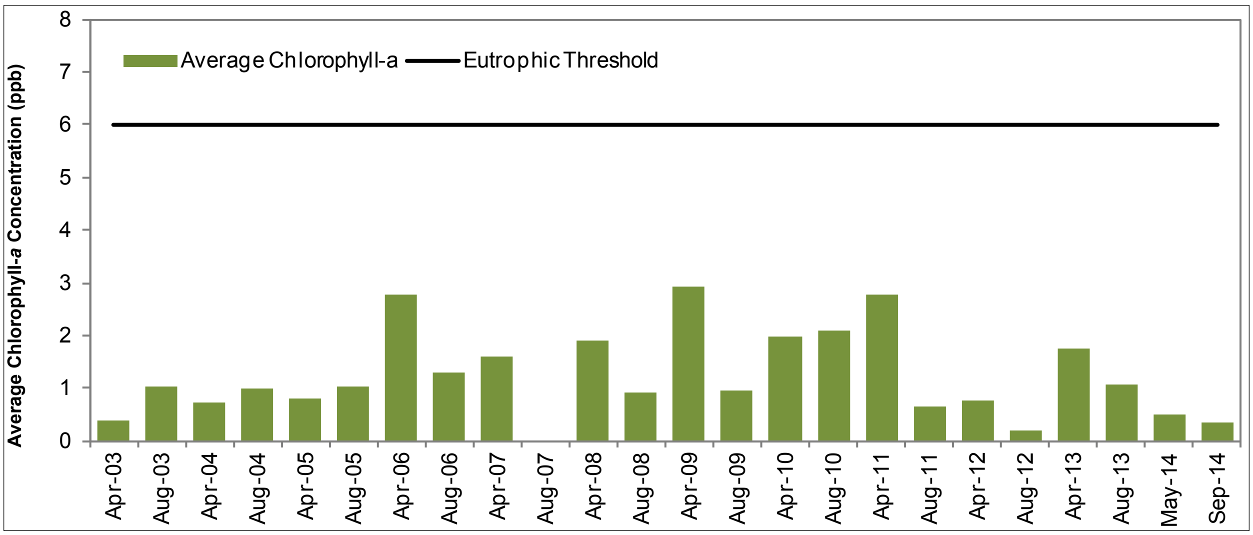

Figure 14. Houghton Lake average chlorophyll-*a* concentrations, 2003 - 2014.

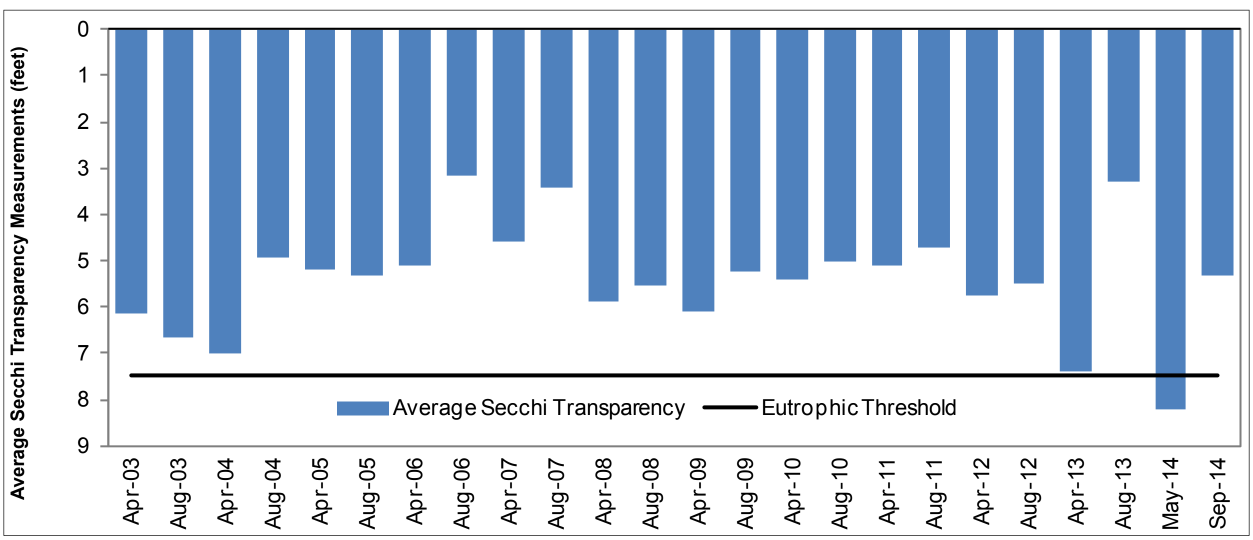

Figure 15. Houghton Lake average Secchi transparency measurements, 2003 - 2014.

Information and Education

Information regarding project activities and lake board meeting dates are posted on the Houghton Lake Improvement Board web site. The site is typically updated annually with new information as it becomes available. In 2014, the web address was published multiple times in the Houghton Resorter and all property owners around the lake were mailed a post card with the web site address and information about the lake treatment program.

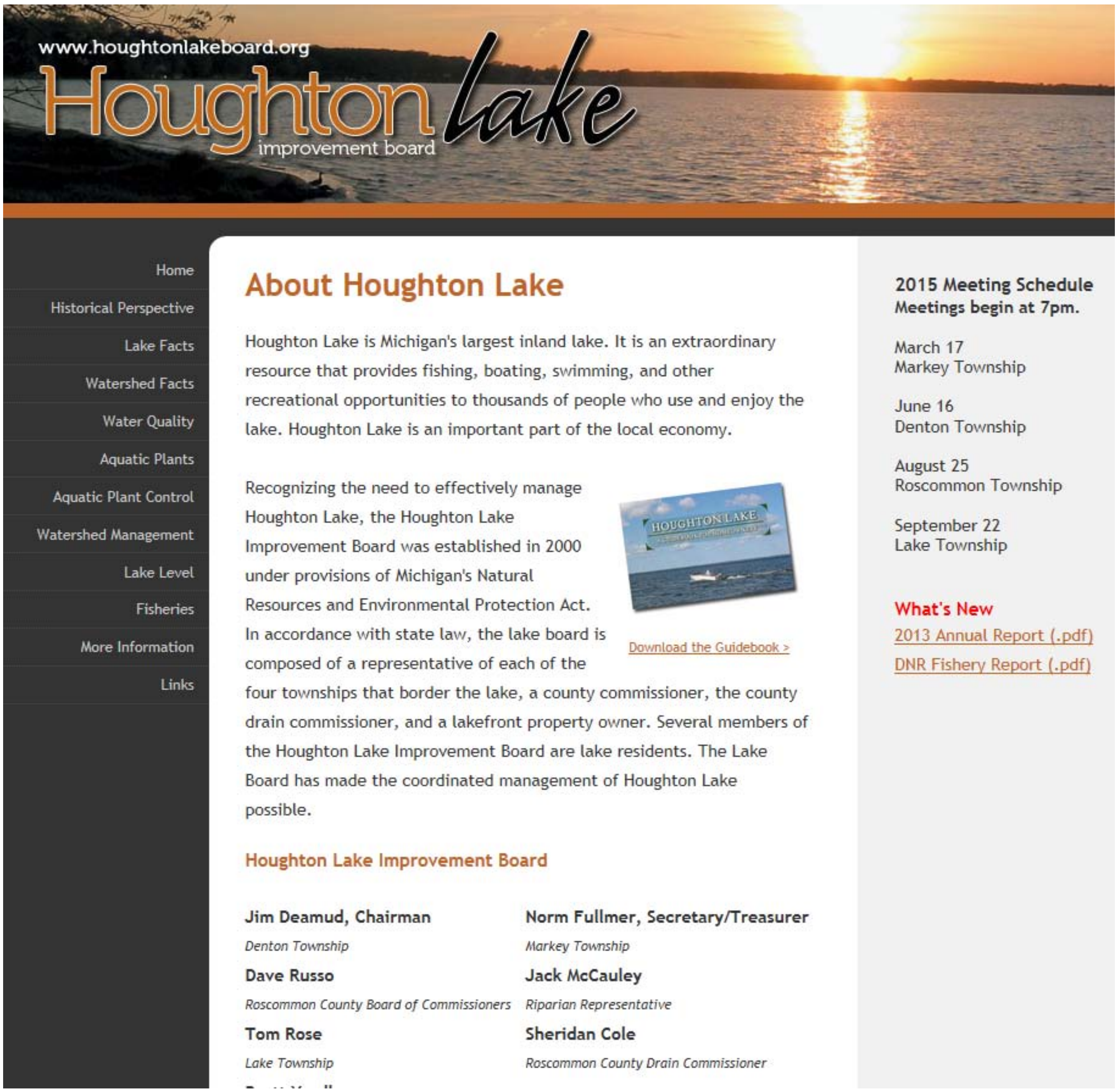

Figure 16. Houghton Lake Improvement Board website.

Watershed Management

In 2014, the Muskegon River Watershed Assembly completed a watershed management plan for the Upper Muskegon River Watershed that includes Houghton Lake. Key partners in the project included Grand Valley State University's Annis Water Resources Institute and the Central Michigan District Health Department. Invasive aquatic plants and periodic elevated *E. coli* bacteria were cited in the watershed management plan as a potential concern. Key components of the plan included long term monitoring of water quality and aquatic invasive species, both of which are currently being conducted by the Houghton Lake Improvement Board.

Figure 17. Houghton Lake watershed map.

Appendix A
Hybrid Milfoil: Management Implications and Challenges

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Background

Millions of dollars are spent annually on programs to combat invasive aquatic plants in Michigan. A primary focus of many of these programs is the control of Eurasian milfoil (*Myriophyllum spicatum*), an aggressive-growing exotic plant introduced into the United States from Europe and Asia.

Eurasian milfoil is not the only type of milfoil found in Michigan. There are several native milfoil species, such as northern milfoil (*Myriophyllum sibiricum*). Some native species closely resemble Eurasian milfoil and are commonly mistaken for it. However, the native milfoils rarely form dense, impenetrable plant beds like Eurasian milfoil often does. In some lakes, hybridization between exotic Eurasian milfoil (*M. spicatum*) and native northern milfoil (*M. sibiricum*) is occurring. Genetic testing has found milfoil hybrids to be widely dispersed across the northern portion of the United States and hybrid milfoil appears to be widespread in Michigan. The documentation of the presence of hybrid milfoil is important because hybridity in plants is often linked to invasive traits. In fact, hybrid milfoil may be more invasive than Eurasian milfoil. There is concern in the scientific community that hybrids could have a competitive advantage over, and ultimately displace both northern milfoil and Eurasian milfoil.

In terms of physical appearance, hybrid milfoil is difficult to distinguish from Eurasian milfoil. For positive identification, genetic testing is required. Further, not all hybrid milfoils are the same. There is considerable genetic variability within hybrids.

Herbicide Treatments

Herbicide applications are the most commonly-used method to control Eurasian milfoil. However, in some lakes, herbicide treatments have become less effective. Dose rates that historically provided good control of milfoil are sometimes only partially effective, and plant die-back is incomplete and/or regrowth occurs more rapidly.

Recent research indicates that hybrid milfoils may exhibit increased tolerance to some herbicides. On average, hybrid milfoil is less susceptible to control with the commonly-used aquatic herbicide 2,4-D in comparison with Eurasian milfoil. The decreased sensitivity to 2,4-D appears to be common across different hybrid lineages. Lakes that have been treated historically with 2,4-D have a higher incidence of hybrid milfoil than non-treated lakes. This research suggests that use of certain herbicides may inadvertently allow tolerant hybrid milfoil to gain dominance.

With the aquatic herbicide fluridone (Sonar®), hybrid tolerance appears to be limited to fewer hybrid lineages. While hybrid resistance to fluridone has been observed in a small percentage of lakes, hybridity does not necessarily infer fluridone tolerance.

Management Implications

Management of hybrid milfoil presents new challenges. Fortunately, there are some new tools available to document the presence of hybrid milfoil and to evaluate the potential for herbicide resistance.

Eurasian milfoil (Myriophyllum spicatum)

Hybrid milfoil (Myriophyllum spicatum x Myriophyllum sibiricum)

Genetic Testing: As discussed in an article in the Summer 2014 issue of the Michigan Riparian, genetic testing is now commercially available and can be used to determine the presence and distribution of Eurasian versus northern versus hybrid milfoil in a given lake. This data can, in turn, be used to inform management decisions.

Herbicide Susceptibility Screening: Another approach that is being used is herbicide susceptibility screening in which milfoil samples are collected from various locations in a lake and exposed to typical herbicide dose rates to evaluate plant response. If plant response is diminished, it may indicate the presence of hybrid milfoil and the need for reevaluation of a treatment approach, before substantial resources are committed to a treatment protocol that may not be very effective.

As with most invasive species, early detection and rapid response is key to effective control. Annual monitoring of the type and abundance of aquatic plants is an essential first step in this endeavor. In areas of the lake where milfoil is found, plant samples can be collected for further analysis.

In general, the use of herbicides with different modes of action, rather than using the same type of herbicide year after year, may help stem the spread of hybrids that are showing resistance to a particular herbicide or class of herbicides.

Given the potential management implications, genetic testing and herbicide susceptibility screening may soon become standard practices for lake managers. Additional research is ongoing to better evaluate the distribution of hybrid milfoil, its biological characteristics, herbicide treatment impacts, and its susceptibility to control measures.

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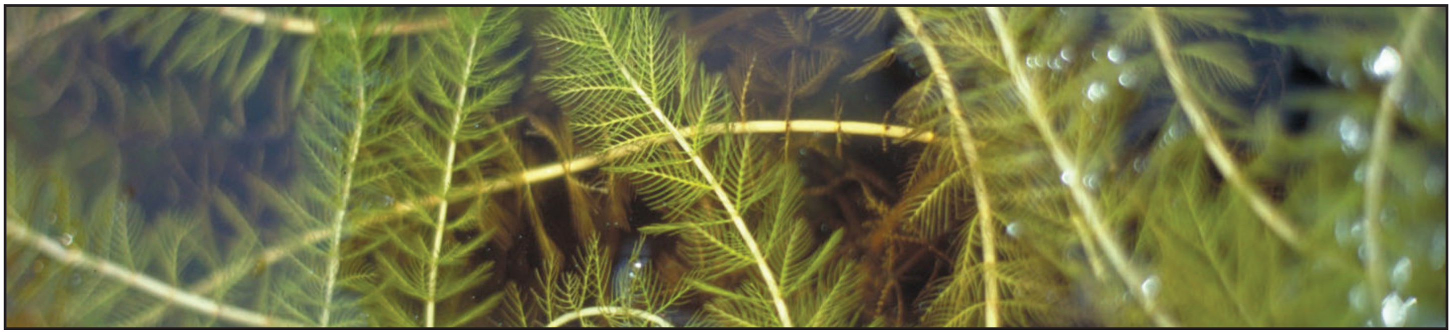
Appendix B

Incorporating Genetic Identifications of Watermilfoils into Aquatic Vegetation Mapping to Inform Management Decisions



Incorporating genetic identifications of watermilfoils into aquatic vegetation mapping to inform management decisions

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Aquatic vegetation mapping has long been an important component of developing and implementing aquatic plant management plans. Vegetation maps provide important information on the distribution and abundance of plants over time, which helps to identify important changes that help stakeholders identify when and where management should occur, as well as to determine the efficacy of management actions. Aquatic vegetation mapping therefore plays an important role in adaptive management of lakes, where the overall goal is to reduce uncertainty in management responses over time by careful monitoring to evaluate management actions.

Aquatic vegetation surveys have historically been conducted using visual identifications of species. However, some aquatic plant taxa can be very difficult to distinguish from others using visual identification methods alone. For these taxa, new technologies such as genetic methods of identification can provide an objective alternative to visual identifications.

For example, Eurasian watermilfoil *(Myriophyllum spicatum)* is an invasive aquatic plant that is extensively managed with herbicides to mitigate its large economic and ecological impacts in many lakes. Eurasian watermilfoil hybridizes with the ecologically benign and native northern watermilfoil *(Myriophyllum sibiricum)*. These hybrids can differ significantly from Eurasian watermilfoil in patterns of nuisance growth and response to management. However, due to their morphological variability, many hybrids are difficult to distinguish from Eurasian and northern watermilfoil, even for those with aquatic plant identification training. In contrast, molecular genetic methods of identification have proven more reliable. Here, we stress the importance of careful identification of distinct watermilfoils using molecular genetic methods, and suggest incorporating genetic monitoring of watermilfoils into existing aquatic vegetation mapping to assist in the prescription and evaluation of management actions.

More than Meets the Eye

Watermilfoils are notoriously difficult to identify to species. Eurasian watermilfoil is most commonly confused with its native sister species, northern watermilfoil, and hybrids between these two. Eurasian watermilfoil and northern watermilfoil can be distinguished visually by counting the number of pairs of leaflets (about 9-11 for northern watermilfoil and about 12-20 for Eurasian watermilfoil). Nevertheless, the two species can be mistaken for one another. More importantly, since hybrids are a cross between Eurasian watermilfoil and northern watermilfoil, distinguishing hybrids is even more challenging. For example, leaflet counts of hybrids can resemble either Eurasian watermilfoil or northern watermilfoil. Moreover, not all hybrids look the same (Fig. 1). Finally, it is important to recognize that there are several other native species of watermilfoils, and it is important to accurately distinguish these native species from Eurasian watermilfoil or hybrids that are targeted for management.

Figure 1. Leaves from different genotypes of northern watermilfoil (top row), hybrid watermilfoil (middle row), and Eurasian watermilfoil (bottom row). Leaf characteristics can differ among different genotypes within taxa, and hybrids can exhibit characteristics of both Eurasian and northern watermilfoils. Genetic analyses are therefore more reliable for distinguishing Eurasian, northern, and hybrid watermilfoils.

Problems with Mistaken Identity

Accurate identifications of watermilfoils are critical for informing aquatic plant management programs. We highlight three general situations spanning the range of intensity of in-lake aquatic vegetation management in which accurate distinction of Eurasian, northern, and hybrid watermilfoils can inform management decisions.

- **Early Detection and Rapid Response –** Early detection and rapid response provides the greatest likelihood of preventing the establishment and spread of introduced species. To be effective, introduced species must be rapidly and accurately identified and verified (see Table 1). For example, misidentifying native northern watermilfoil as non-native Eurasian or hybrid watermilfoil would lead to unnecessary management actions. In the best case, this unnecessary management would incur superfluous management costs to stakeholders; in the worst case, unnecessary removal of northern watermilfoil could open up habitat for invasion by non-native Eurasian or hybrid watermilfoil. On the flip side, misidentification of Eurasian or hybrid watermilfoil as native northern watermilfoil could result in the rapid development of a nuisance population that ultimately requires more intensive and costly management actions, and that spread to nearby water bodies.

Visual ID (What you think it is)	Genetic ID (What it actually is)	Outcome
Eurasian or Hybrid	Northern	Natives identified as invasive can lead to inadvertently treating native plants. Removing native plants may lead to future invasion.
Northern	Eurasian or Hybrid	Plants may not be treated and may become a problem locally and/or spread to nearby lakes.
Hybrid	Eurasian	May use more potent treatment than necessary.
Eurasian	Hybrid	Hybrids may have muted response to treatments normally effective on Eurasian.

Table 1. A summary of the ways to misidentify watermilfoils visually, and their potential consequences for management of non-native watermilfoil.

- **Developing Precise Management Prescriptions in Lakes with Co-occurring Watermilfoil Types –** It is important to recognize that different types of watermilfoil can co-occur within a lake, either in the same or different locations (Fig. 2). Genetic surveys where multiple plants and locations were sampled have revealed that co-occurrence of distinct watermilfoils is common in lakes (Sturtevant et al. 2009; Thum, unpublished data). We posit that managers should take care to accurately identify and map watermilfoils throughout a lake to determine the distribution and abundance of any different types. For example, it may be desirable to avoid management activities, such as herbicide application, in northern watermilfoil patches to preserve this native species. Recent research demonstrates that hybrids, on the other hand, are more likely to exhibit nuisance growth conditions in lakes and ponds compared to either parent species. In addition, hybrid watermilfoils can demonstrate a muted response to some herbicides. Thus, hybrids may warrant increased vigilance in terms of prescribing and monitoring management activities (Fig 2.).

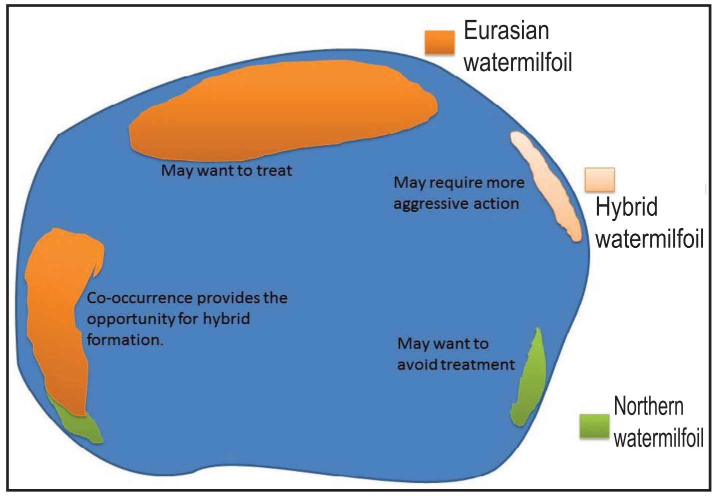

Figure 2. Eurasian, northern, and hybrid watermilfoil have been observed to co-occur in the same lake. The abundance of these different types of watermilfoil in each patch may impact treatment prescriptions and the amount of monitoring effort post-treatment.

- **Long-term Aquatic Vegetation Management Projects –** Many lakes with established infestations of non-native watermilfoils require periodic treatments with herbicides or other management techniques because plants frequently re-establish, even after a treatment successfully reduces non-native watermilfoil distribution and abundance. However, there is considerable variation in how widespread and dense the regrowth is, and how soon after treatment it occurs (see Fig. 3). For example, some lakes may have several seasons of 'relief' from non-native watermilfoil following management while others may only get one season of relief; still others may experience rapid regrowth within the same season of treatment. Furthermore, anecdotal reports from some lakes indicate that the extent of regrowth can increase across successive treatments. Given the considerable economic costs associated with management activities, understanding the variation in the magnitude and timing of resurgence is essential in order to minimize the economic costs and ecological effects of management.

While there are a large number of factors that can influence the efficacy of any given management activity on a specific lake, we posit that significant changes in the composition of watermilfoil types in a lake is one possible cause for variation in the extent and speed of regrowth in lakes. Recall that hybrid watermilfoils have been shown to exhibit faster growth and reduced sensitivity to some herbicides. It stands to reason that the extent and speed of regrowth may change if the watermilfoil shifted from Eurasian watermilfoil to hybrid watermilfoil over time in a lake (Fig. 3). We therefore argue that frequent monitoring of watermilfoil in lakes with long-term aquatic vegetation management projects can be used to adapt management techniques. For example, in the absence of accurate monitoring data of watermilfoil types, it is impossible to determine whether any observed changes in watermilfoil regrowth or management efficacy is related to changes in the composition or distribution of different watermilfoil types (e.g., Eurasian versus hybrid) versus other factors.

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Incorporating genetic identifications of watermilfoils

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Integration of Genetic Identifications with Aquatic Vegetation Mapping –

Integrating genetic identifications into existing aquatic vegetation mapping services begs the question of how best to do it. How much sampling is required within a lake? How frequently should genetic surveys be conducted?

Ideally, genetic identifications would be integrated into standardized aquatic vegetation survey methods designed to quantify the distribution and abundance of aquatic plants, such as Point-Intercept methods. Since these surveys rely on species-specific identifications, and since Eurasian, northern, and hybrid watermilfoils can easily be misidentified, we recommend that at least one plant from each survey point with watermilfoil be genetically identified in order to accurately map their distribution and abundance. However, we recognize that this level of detailed sampling may not be economically feasible at the present time for all lakes. We predict this will become the standard, especially as the per sample costs for genetic identifications decrease with increased technology and infrastructure to support genetic identifications.

For more limited budgets, we recommend sampling plants from each area of the lake where watermilfoil is present. Because native and non-native watermilfoils can occur in the same water body, and because native and non-native watermilfoils can be difficult to distinguish, it is important to sample plants from all areas of the lake instead of sampling only plants that are thought to be non-native. For example, in early-detection-and-rapid-response scenarios, it is important to sample both the putative invasive and native plants to ensure that management actions are based on accurate identifications (see Table 1). Similarly, for lakes undergoing management, it is important to sample treated areas both before and after treatment in order to detect any important changes in biotype distribution before and after management.

The overall goal of adaptive management is to make effective decisions in the face of uncertainty. As with management of any natural resource, lake management is inherently uncertain. A critical part of adaptive management is detailed monitoring of the system in order to evaluate and modify management approaches. Aquatic vegetation mapping plays a critical role in the development and evaluation of aquatic vegetation management actions. However, in the case of watermilfoil management, limited ability to distinguish Eurasian, northern, and hybrid watermilfoils may have historically limited the ability to develop, implement, and evaluate management actions that target the selective removal of

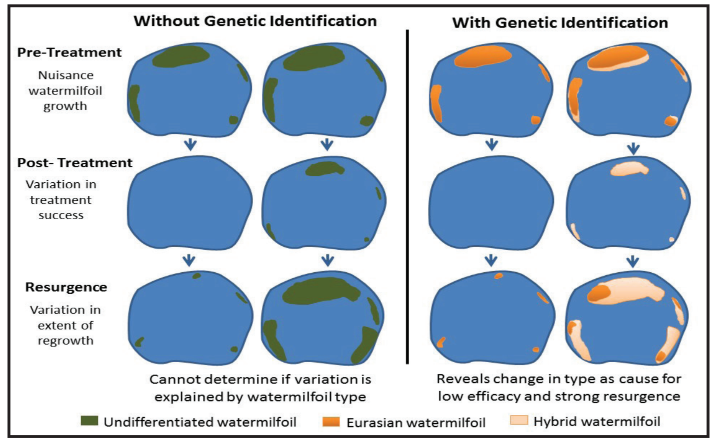

Figure 3. Genetic identifications provide information on whether variation in treatment efficacy and resurgence is related to changes in dominance of different watermilfoil types.

non-native watermilfoils. Genetic identifications can improve vegetation mapping by providing more accurate distribution and abundance estimates of Eurasian, hybrid, northern and other native watermilfoils. As genetic monitoring becomes routine, we believe our understanding of watermilfoil distribution and abundance over time in managed lakes will become more apparent. This, along with continued results from active research on the genetics of invasiveness, promises to provide additional tools for lake evaluation and maximizing treatment efficacy in the future. With this increased understanding will come more cost-effective and environmentally responsible aquatic vegetation management.

For more information and guidelines on genetic identifications, go to: http://www.gvsu.edu/geneticidentification/.

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