



Higgins Lake 2022 Limnological Evaluation & Revised Lake Management Plan Roscommon County, Michigan



Provided for: Higgins Lake Property Owners Association (HLPOA) Board

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

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TABLE OF CONTENTS

SECTION	PAGE
LIST OF FIGURES	4
LIST OF TABLES	7
1.0 EXECUTIVE SUMMARY	9
2.0 LAKE ECOLOGY BACKGROUND INFORMATION	14
2.1 Introductory Concepts	14
2.1.1 Lake Hydrology	14
2.1.2 Biodiversity and Habitat Health	15
2.1.3 Watersheds and Land Use	15
3.0 HIGGINS LAKE PHYSICAL & WATERSHED CHARACTERISTICS	17
3.1 The Higgins Lake Basin	17
3.2 Higgins Lake Extended and Immediate Watershed and Land Use	20
3.3 Higgins Lake Shoreline Soils	22
4.0 HIGGINS LAKE WATER QUALITY	24
4.1 Water Quality Parameters	25
4.1.1 Dissolved Oxygen	26
4.1.2 Water Temperature	27
4.1.3 Specific Conductivity	28
4.1.4 Turbidity, Total Dissolved Solids, and Total Suspended Solids	29
4.1.5 pH	30
4.1.6 Total Alkalinity	31
4.1.7 Total Phosphorus and Ortho-Phosphorus	31
4.1.8 Total Kjeldahl Nitrogen and Total Inorganic Nitrogen	33
4.1.9 Chlorophyll- <i>a</i> and Algae	33
4.1.10 Secchi Transparency	35
4.1.11 <i>E. coli</i> Bacteria	37
4.2 Higgins Lake Aquatic Vegetation Communities	42
4.2.1 Higgins Lake Native Aquatic Macrophytes	46
4.2.2 Higgins Lake Exotic Aquatic Macrophytes	53
4.3 Higgins Lake Food Chain: Zooplankton and Macroinvertebrates	58
4.4 Higgins Lake Fishery	66

5.0	HIGGINS LAKE MANAGEMENT METHODS.....	68
5.1	Higgins Lake Aquatic Plant Management.....	68
	5.1.1 Aquatic Invasive Species Prevention & Boat Washing Stations	68
	5.1.2 Aquatic Herbicides and Applications	78
	5.1.3 Mechanical Harvesting.....	79
	5.1.4 Benthic Barriers and Nearshore Management Methods.....	80
	5.1.5 Diver Assisted Suction Harvesting.....	81
5.2	Higgins Lake Early Detection Rapid Response Protocol	82
5.3	Higgins Lake Water Quality Improvement	85
	5.3.1 Reducing Nutrients and Pollutants into Higgins Lake.....	85
	5.3.2 Reduction of Shoreline Erosion and Sediment Deposition	90
6.0	HIGGINS LAKE MANAGEMENT PLAN CONCLUSIONS AND RECOMMENDATIONS.....	94
6.1	2023 Cost Estimates for Higgins Lake Improvements.....	99
7.0	SCIENTIFIC REFERENCES.....	100
	APPENDIX A	103

LIST OF FIGURES

FIGURE	PAGE
1. Aerial Photo of Higgins Lake (RLS, 2019)	18
2. Higgins Lake Depth Contour Map (RLS, 2022).....	19
3. Higgins Lake Sediment Hardness Map (RLS, 2022)	20
4. Higgins Lake Immediate Watershed Map (RLS, 2019)	21
5. Higgins Lake Soils Map (NRCS-USDA data)	23
6. Higgins Lake Deep Basin Sampling Location Map (August 12, 2022).....	26
7. Lake Thermal Stratification Process	28
8. Trends in Mean TP in Higgins Lake (1975-2022)	32
9. Trends in Mean Chl-a in Higgins Lake (1975-2022)	35
10. Secchi Disk Measurement Process	36
11. Trends in Mean Secchi Transparency in Higgins Lake (1975-2022)	37
12. Higgins Lake Aquatic Vegetation Biovolume Map (July, 2022)	44
13. Higgins Lake Aquatic Vegetation Sampling Location Map (July 15-20, 2022).....	45
14. Change in Major Higgins Lake Aquatic Plant Taxa (2019 and 2022)	49
15. Photo of Chara.....	50
16. Photo of Tolypella.....	50
17. Photo of Sago Pondweed	50
18. Photo of Flat-stem Pondweed.....	50
19. Photo of Illinois Pondweed.....	50
20. Photo of Claspig-leaf Pondweed	50

21.	Photo of Large-leaf Pondweed	51
22.	Photo of Variable-leaf Pondweed	51
23.	Photo of Slender Pondweed.....	51
24.	Photo of Leafy Pondweed.....	51
25.	Photo of White-Stem Pondweed.....	51
26.	Photo of Water thread Pondweed	51
27.	Photo of Northern Watermilfoil	52
28.	Photo of Common Waterweed.....	52
29.	Photo of Wild Celery.....	52
30.	Photo of Southern Naiad	52
31.	Photo of Cattails	52
32.	Photo of Spikerush.....	52
33.	Photo of American Pondweed.....	53
34.	Photo of EWM	54
35.	Distribution of EWM in Higgins Lake (July 15-20, 2022)	55
36.	A Photo of Starry Stonewort.....	56
37.	Distribution of Starry Stonewort in Higgins Lake (July 15-20, 2022).....	57
38.	Photo of a Zooplankton Collection Net	59
39.	Higgins Lake Macroinvertebrate Sampling Location Map (August 12, 2022)	62
40.	Photo of an Ekman Sediment Dredge	63
41.	Spongilla Freshwater Sponges in Higgins Lake (August 2019)	65
42.	Photo of an AIS Prevention Sign	70
43.	Photo of an Aquatic Hitchhiker	70

44.	Photo of a Boat Washing Station on South Higgins Lake (2019)	71
45.	Photo of Boat Cleaning at South State Park Launch Site (2019)	71
46.	Higgins Lake Boat Launch Access Sites	72
47.	Zebra and Quagga Mussels.....	74
48.	Asian Clam	74
49.	Photo of Hydrilla.....	77
50.	Photo of Water Chestnut.....	77
51.	Photo of Fanwort.....	77
52.	Photo of European Frog bit	77
53.	Photo of Water Pennywort.....	77
54.	Photo of European Water Clover	77
55.	Photo of an Aquatic Herbicide Application Boat.....	79
56.	Photo of a Mechanical Harvester	80
57.	Diagram of a Benthic Barrier	81
58.	Photo of a Weed Roller.....	81
59.	Photo of a DASH Boat	82
60.	Photo of Shoreline Erosion on Higgins Lake (2019)	92
61.	Photo of Shoreline Erosion on Higgins Lake (2019)	92
62.	Photo of Shoreline Erosion on Higgins Lake (2019)	93

LIST OF TABLES

TABLE	PAGE
1. Higgins Lake Relative Bottom Hardness (August 2022)	18
2. Higgins Lake Shoreline Soils (NRCS USDA data)	22
3. Lake Trophic Status Classification.....	24
4. Higgins Lake Deep Basin #1 Physical Water Quality Data (August 12, 2022).....	38
5. Higgins Lake Deep Basin #1 Chemical Water Quality Data (August 12, 2022).....	38
6. Higgins Lake Deep Basin #2 Physical Water Quality Data (August 12, 2022).....	38
7. Higgins Lake Deep Basin #2 Chemical Water Quality Data (August 12, 2022).....	39
8. Higgins Lake Deep Basin #3 Physical Water Quality Data (August 12, 2022).....	39
9. Higgins Lake Deep Basin #3 Chemical Water Quality Data (August 12, 2022).....	39
10. Higgins Lake Deep Basin #4 Physical Water Quality Data (August 12, 2022).....	40
11. Higgins Lake Deep Basin #4 Chemical Water Quality Data (August 12, 2022).....	40
12. Higgins Lake Deep Basin Physical Water Quality Data (August 12, 2022).....	40
13. Higgins Lake Deep Basin #5 Chemical Water Quality Data (August 12, 2022).....	41
14. Higgins Lake Aquatic Vegetation Biovolume Data (July 15-20, 2022).....	45
15. Higgins Lake Native Aquatic Plant Species Frequency (July 15-20, 2022).....	47
16. Higgins Lake Native Aquatic Plant Species Relative Abundance (July 15-20, 2022)	48
17. Higgins Lake Exotic Aquatic Plant Species (July 15-20, 2022)	56
18. Higgins Lake Deep Basin #1 Zooplankton (August 12, 2022)	59
19. Higgins Lake Deep Basin #2 Zooplankton (August 12, 2022)	59

20. Higgins Lake Deep Basin #3 Zooplankton (August 12, 2022) 60

21. Higgins Lake Deep Basin #4 Zooplankton (August 12, 2022) 60

22. Higgins Lake Deep Basin #5 Zooplankton (August 12, 2022) 60

23. Higgins Lake Macroinvertebrates (August 12, 2022) 64

24. Higgins Lake Fish Stocking History (MDNR, 1979-2022) 66

25. Higgins Lake Proposed Annual Lake Improvement Methods and Objectives..... 96

26. Higgins Lake Proposed 2023 Annual Management Plan Costs 99

Higgins Lake 2022 Limnological Evaluation & Revised Lake Management Plan Roscommon County, Michigan

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1.0 EXECUTIVE SUMMARY

Higgins Lake is located in Sections 5-10; 17,18,20,21,27,29,32-34 in Gerrish Township (T. 24N, R.3W), and Sections 1-3;10-15 in Lyons Township (T.24N, R. 4E) in Roscommon County, Michigan (T.20N, R.3E) and is a natural glacial lake. The lake is comprised of 10,201 acres (RLS, 2019). The lake has a dam located at the southeast region which drains into the Cut River. A legal lake level was established in 1982 at 1,154.11 feet above sea level. There are three significant areas of water influx to the lake which includes the North Creek, East Creek, and Big Creek. The average mean depth of the lake is approximately 30.4 feet, and the maximum depth is approximately 135 feet (RLS, 2019 bathymetric scan data). The lake also has a fetch (longest distance across the lake) of around 6.5 miles (RLS, 2019) and a shoreline length of 20.9 miles without the island and 22.2 miles including the island.

Higgins Lake has an approximate water volume of 524,509.7 acre-feet (RLS, 2019 bathymetric data) and contains some springs. The outlet of the lake drains into the Cut River at an average velocity of around 44.2 cfs (Minnerick) and hourly water elevations are recorded via an automated telemetered recorder placed in the lake on November 6, 1998. This outflow is regulated by the Roscommon County Board of Commissioners. Higgins Lake is identified as a high groundwater-recharge lake since groundwater contributes the majority of the water to the lake via springs and springs within the tributaries entering the lake. Higgins Lake lies within the Muskegon River watershed which drains to Lake Michigan. The immediate watershed which is the area directly draining into the lake is approximately 28,783 acres which is about 3 times the size of the lake and is considered to be a small immediate watershed.

The 2022 evaluation determined the presence of two invasive aquatic plant species including approximately 4.0 acres of Eurasian Watermilfoil (*Myriophyllum spicatum*) and approximately 2.2 acres of invasive Starry Stonewort (*Nitellopsis obtusa*). This represents a significant reduction in Eurasian Watermilfoil and a small reduction in Starry Stonewort since 2019.

Late season additional growth was noted, and the south state park lagoon was being actively managed for both invasives and this area was included in the totals. During the RLS survey of littoral zone aquatic vegetation, RLS noted that DASH removal of invasives was occurring in both the south Lagoon and the main lake basin. There were milfoil fragments floating on the lake surface that may not have been adequately contained by the turbidity curtain. These fragments may root in any area of the lake if they settle to the bottom and produce roots. Thus, it is possible that new growth may have occurred after the RLS survey was completed. In addition, any discovery of invasives along the steep lake drop-offs with SCUBA is a different methodology from the GPS Point-Intercept survey method used by RLS. Although both methods are complimentary, they may determine the presence of invasives in different regions, with SCUBA locating invasives in deeper waters that may not respond to rake sampling during the littoral zone intercept survey method.

The appearance of more native aquatic plant species may occur since invasives are being removed and an open niche is present for natives to colonize. The overall cover of these native aquatic plants is low throughout the lake and thus preservation of them is critical for lake health. In 2022, Higgins Lake contained 19 native submersed and 2 emergent aquatic plant species, for a total of 21 native aquatic macrophyte species. In 2022, there was a new native aquatic plant species present (American Pondweed, *Potamogeton nodosus*) which is encouraging for an increase in biodiversity. A total of 4 native aquatic plant species increased in frequency in 2022 from 2019 and included Flat-stem Pondweed, Claspingleaf Pondweed, Wild Celery, and Spikerush. These species occupy more space in certain areas and may allow for those areas to look “weedier” than in 2019, but many other areas declined. This finding also supports the measured aquatic vegetation biovolume with increased cover in the 0-5% and 20-40% categories that would correspond to increases in the native species just mentioned in terms of position in the water column. Some areas of Wild Celery may represent low biovolume (0-5%) due to the presence of marl deposits that weigh the leaf blades down. Changes in all aquatic vegetation communities occur each year on inland lakes with each year demonstrating different plant frequencies and distributions. Any aquatic plant species, including Starry Stonewort may die and decay under winter ice and during mild winters may increase. Many variables influence annual variability in aquatic vegetation and include climatic factors and seed bank ecology. There have been cases of lakes that have experienced unexplained die-offs of certain aquatic plants including invasives and thus each year may yield significant differences that may be due to circumstances beyond management.

Management of both invasive species would be best achieved with the DASH method in place of herbicides or harvesting. This is due to the highly scattered distribution of both invasives throughout the lake that would render spot-treatments with granular herbicides difficult with the possibility of the plants returning the following season. Individual GPS points can be given to the DASH operator and the plant beds can be removed by the roots while preserving the nearby native aquatic plants.

RLS highly recommends that the MDNR and other parties involved in the active removal of invasives coordinate with RLS, HLPOA, and HLF as a team to better understand the quantity and locations of invasives removed each year and combine efforts of SCUBA implemented from the HLF and the GPS Point-Intercept survey from RLS working for the HLPOA. RLS may be able to provide these parties with additional data on other areas found during the surveys. Appendix A demonstrates the areas where DASH removed invasives in 2022. As previously stated, annual variations in environmental factors such as seedbank ecology are likely to alter the quantity and distribution of invasives over time. In some years, a hard winter or reduced seedbank productivity may lead to reduced overall growth. Thus, it is difficult to discern whether DASH or natural environmental factors have resulted in declines over time. The importance lies with the ability to reduce invasives over time using as many methods as possible for surveys. The Point-Intercept survey is recommended from the shore to the drop-off (littoral zone) and SCUBA may be best used on the drop-offs. It should be noted that milfoil or Starry Stonewort fragments may escape with offshore DASH activity in the lake basin since it is nearly impossible for turbidity curtains to contain these plants at such depths as the curtains do not have adequate length. The curtains are most effective in shallow areas such as the Lagoon.

Systemic herbicides such as 2,4-D and ProcettaCOR[®] were used in the South State Park Lagoon in the past few years and this would be another option for controlling milfoil in that area; however, Starry Stonewort is best removed with DASH due to its low long-term response to any herbicides or algaecides. SCUBA as mentioned above, can also be a complimentary sampling method.

In 2022, RLS initiated the development of a detailed, Early Detection- Rapid Response (EDRR) protocol for future invasives that may enter the lake and introduced many new invasive species that have been moving into waters of the Midwest. This EDRR protocol is adaptive and should be revised prior to the arrival of any new additional invasive species as each species will likely require a different management approach. RLS can expand on this EDRR in 2023 which is recommended.

Furthermore, a professional limnologist/aquatic botanist should perform regular GPS-guided whole-lake surveys each summer/early fall to monitor the growth and distribution of all invasives prior to and after DASH treatments to determine treatment efficacy. Continuous monitoring of the lake for potential influxes of other exotic aquatic plant genera (i.e., *Hydrilla*) that could also significantly disrupt the ecological stability of Higgins Lake is critical. The lake manager should oversee all management activities and would be responsible for the creation of aquatic plant management survey maps, direction of the DASH operator to target-specific areas of aquatic vegetation for removal, implementation of watershed best management practices, administrative duties such as the processing of contractor invoices, and lake management education. Currently, Higgins Lake has a low quantity of native aquatic vegetation and so management efforts must include preservation of native aquatic plant species.

The signage at the boat washing stations present at three of the access sites has been effective at educating visitors to clean their boats and trailers and at reducing the spread of invasive aquatic plant species. However, there have been some reports of equipment damage or improper/lack of usage of these stations and thus more education and possible future oversight is recommended. More stations and AIS signs are recommended at other access sites identified earlier in this evaluation.

Swimmer's itch continues to be effectively managed with reductions in resident merganser populations and through verification of parasite reductions from the *Stagnicola* snails. Continued efforts to reduce these parasites and also reduce the goose population are recommended. The use of copper sulfate should never again be considered for Higgins Lake since it bioaccumulates in the lake sediments and may harm lake benthos and macroinvertebrates.

The lake has a healthy population of prized fishes (such as Rainbow, Brown, and Lake Trout) that are stocked regularly by the MDNR. In 2022, the MDNR stocked 142,100 Lake Trout, 11,260 Rainbow Trout, and 25,000 Brown Trout. In addition, there is an abundance of healthy zooplankton and macroinvertebrates such as stone fly larvae, crayfish, and freshwater sponges, among numerous others. All of these organisms are indicative of very healthy waters.

Higgins Lake has overall low nutrient concentrations in the deep basins but nearshore increases in nitrogen and phosphorus have been previously studied and are likely due to septic inputs. Additionally, an evaluation of the Higgins Lake surface waters in 2022 revealed pharmaceuticals such as antibiotics and other substances above detectable levels. These substances are a direct product of human urine which would most likely originate from septic leachate. There is a possibility that these products may be transported to the lake via runoff or tributaries, but the probability is much higher from septic leachate given the concentrations and substances detected. In 2022, the dissolved oxygen was abundant at all depths and locations and the conductivity and chlorophyll-a were low.

A lake-wide sewer is recommended to reduce these inputs and nutrients to the lake if the lake is to remain oligotrophic. The tributaries possess higher nutrient concentrations than the lake and are thus nutrient sources to the lake. Maintenance of tributary areas is important to allow for nutrient reductions over time. This may include removal of leaves and debris and upstream land use improvements (such as erosion stabilization). The water clarity of the lake continues to increase due to the ability of both Zebra and Quagga Mussels to filter phytoplankton out of the water column. Not much can be done to eradicate these invasives at this time which is why prevention is so important to reduce future populations.

A few areas around the lake (aside from road ends) were found to have shoreline erosion during the 2019 evaluation and these areas should be stabilized with rip-rap or soft shoreline emergent vegetation as soon as possible.

Lastly, a riparian education program is recommended through the development of this management plan and through holding future educational workshops. Such workshops may include dispersal of relevant lake information and also identification of local lake biota so that residents know to be vigilant of certain invasives. RLS provides information on these new invasives later in this report. They should be integrated into the EDRR.

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 Higgins Lake.

2.1.1 Lake Hydrology

Aquatic ecosystems include rivers, streams, ponds, lakes, and the Laurentian Great Lakes. There are thousands of lakes in the state of Michigan, and each possesses unique ecological functions and socio-economic contributions. In general, lakes are divided into four categories:

- Seepage Lakes,
- Drainage Lakes,
- Spring-Fed Lakes, and
- Drained Lakes.

Some lakes (seepage lakes) contain closed basins and lack inlets and outlets, relying solely on precipitation or groundwater for a water source. Seepage lakes generally have small watersheds with long hydraulic retention times which render them sensitive to pollutants. Drainage lakes receive significant water quantities from tributaries and rivers. Drainage lakes contain at least one inlet and an outlet and generally are confined within larger watersheds with shorter hydraulic retention times. As a result, they are less susceptible to pollution. Spring-fed lakes rarely contain an inlet but always have an outlet with considerable flow. The majority of water in this lake type originates from groundwater and is associated with a short hydraulic retention time. Drained lakes are similar to seepage lakes, yet rarely contain an inlet and have a low-flow outlet. The groundwater and seepage from surrounding wetlands supply the majority of water to this lake type and the hydraulic retention times are rather high, making these lakes relatively more vulnerable to pollutants. The water quality of a lake may thus be influenced by the quality of both groundwater and precipitation, along with other internal and external physical, chemical, and biological processes.

Higgins Lake may be categorized as a spring-fed lake with some drainage and an outlet since it has three significant drainage areas as well as an outlet at the southeast shore of the lake which enters the Cut River and eventually enters the Muskegon River before exiting to Lake Michigan.

2.1.2 Biodiversity and Habitat Health

A healthy aquatic ecosystem possesses a variety and abundance of niches (environmental habitats) available for all of its inhabitants. The distribution and abundance of preferable habitat depends on limiting man's influence from man and development, while preserving sensitive or rare habitats. As a result of this, undisturbed or protected areas generally contain a greater number of biological species and are considered more diverse. A highly diverse aquatic ecosystem is preferred over one with less diversity because it allows a particular ecosystem to possess a greater number of functions and contribute to both the intrinsic and socio-economic values of the lake. Healthy lakes have a greater biodiversity of aquatic macroinvertebrates, aquatic macrophytes (plants), fishes, phytoplankton, and may possess a plentiful yet beneficial benthic microbial community (Wetzel, 2001).

2.1.3 Watersheds and Land Use

A watershed is defined as an area of land that drains to a common point and is influenced by both surface water and groundwater resources that are often impacted by land use activities. In general, larger watersheds possess more opportunities for pollutants to enter the ecosystem, altering the water quality and ecological communities. In addition, watersheds that contain abundant development and industrial sites are more vulnerable to water quality degradation from pollution which may negatively affect both surface and ground water. Since many inland lakes in Michigan are relatively small in size (i.e., less than 300 acres), they are inherently vulnerable to nutrient and pollutant inputs, due to the reduced water volumes and small surface areas. As a result, the living (biotic) components of the smaller lakes (i.e., fishery, aquatic plants, macro-invertebrates, benthic organisms, etc.) are highly sensitive to changes in water quality from watershed influences. Land use activities have a dramatic impact on the quality of surface waters and groundwater.

In addition, the topography of the land surrounding a lake may make it vulnerable to nutrient inputs and consequential loading over time. Topography and the morphometry of a lake dictate the ultimate fate and transport of pollutants and nutrients entering the lake. Surface runoff from the steep slopes surrounding a lake will enter a lake more readily than runoff from land surfaces at or near the same grade as the lake. In addition, lakes with steep drop-offs may act as collection basins for the substances that are transported to the lake from the land.

Land use activities, such as residential land use, industrial land use, agricultural land use, water supply land use, wastewater treatment land use, and storm water management, can influence the watershed of a particular lake. All land uses contribute to the water quality of the lake through the influx of pollutants from non-point sources or from point sources.

Non-point sources are often diffuse and arise when climatic events carry pollutants from the land into the lake. Point-source pollutants are discharged from a pipe or input device and empty directly into a lake or watercourse.

Residential land use activities involve the use of lawn fertilizers on lakefront lawns, the utilization of septic tank systems for treatment of residential sewage, the construction of impervious (impermeable, hard-surfaced) surfaces on lands within the watershed, the burning of leaves near the lakeshore, the dumping of leaves or other pollutants into storm drains, and removal of vegetation from the land and near the water. In addition to residential land use activities, agricultural practices by vegetable crop and cattle farmers may contribute nutrient loads to lakes and streams. Industrial land use activities may include possible contamination of groundwater through discharges of chemical pollutants.

3.0 HIGGINS LAKE PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Higgins Lake Basin

Higgins Lake is located in Sections 5-10; 17,18,20,21,27,29,32-34 in Gerrish Township (T. 24N, R.3W), and Sections 1-3;10-15 in Lyons Township (T.24N, R.4E) in Roscommon County, Michigan (T.20N, R.3E) and is a natural glacial lake (Figure 1). The lake is comprised of 10,201 acres (RLS, 2019). The lake has a dam located at the southeast region which drains into the Cut River. A legal lake level was established in 1982 at 1,154.11 feet above sea level. There are 3 areas of water influx to the lake which includes the North Creek, East Creek, Big Creek. The average mean depth of the lake is approximately 30.4 feet, and the maximum depth is approximately 135 feet (RLS, 2019 bathymetric scan data; Figure 2). The lake also has a fetch (longest distance across the lake) of around 6.5 miles (RLS, 2019) and a shoreline length of 20.9 miles without the island and 22.2 miles including the island. There is a prominent shelf around most of the lake which comprises the littoral zone and prevents much of the nearshore waters from mixing with the lake open waters.

Higgins Lake has an approximate water volume of 524,509.7 acre-feet (RLS, 2019 bathymetric data) and contains some springs. Higgins Lake lies within the Muskegon River watershed which drains to Lake Michigan. The immediate watershed which is the area directly draining into the lake is approximately 28,783 acres which is about 3 times the size of the lake, which is considered to be a small immediate watershed.

A bottom sediment hardness scan was conducted of the entire lake bottom on July 15-20, and August 2-5, 2022. The bottom hardness map shows (Figure 3) that most of the lake bottom consists of fairly soft and sandy sediments throughout the lake with larger areas of marl in the deeper waters. A detailed analysis of the geology of Higgins Lake is offered in Section 3.4. Table 1 below shows the categories of relative bottom hardness with 0.0-0.1 referring to the softest and least consolidated bottom and >0.4 referring to the hardest, most consolidated bottom. This scale does not mean that any of the lake contains a truly “hard” bottom but rather a bottom that is more cohesive and not flocculent with most of the lake falling into the ≥ 0.2 category.

One unique observation relative to lake sediments was that many nearshore areas contained black-colored sediments under the exposed bottom which were likely anaerobic given the sulfur odor. This may be attributed to anaerobic septic leachate present in the groundwater which enters the lake sediments.

A previous study by Water Quality Investigators (1998) determined that the sediments in Higgins Lake are predominately mineral (mean = 83% mineral) and are comprised of mostly marl and sand.

Table 1. Higgins Lake 2019 and 2022 relative hardness of the lake bottom by category or hardness and percent cover of each category (relative cover).

Lake Bottom Relative Hardness Category	% Relative Cover of Bottom by Category 2019	% Relative Cover of Bottom by Category 2022
0.0-0.1	0.02	0.00
0.1-0.2	0.05	0.15
0.2-0.3	52.2	71.5
0.3-0.4	16.6	15.4
>0.4	31.2	12.9

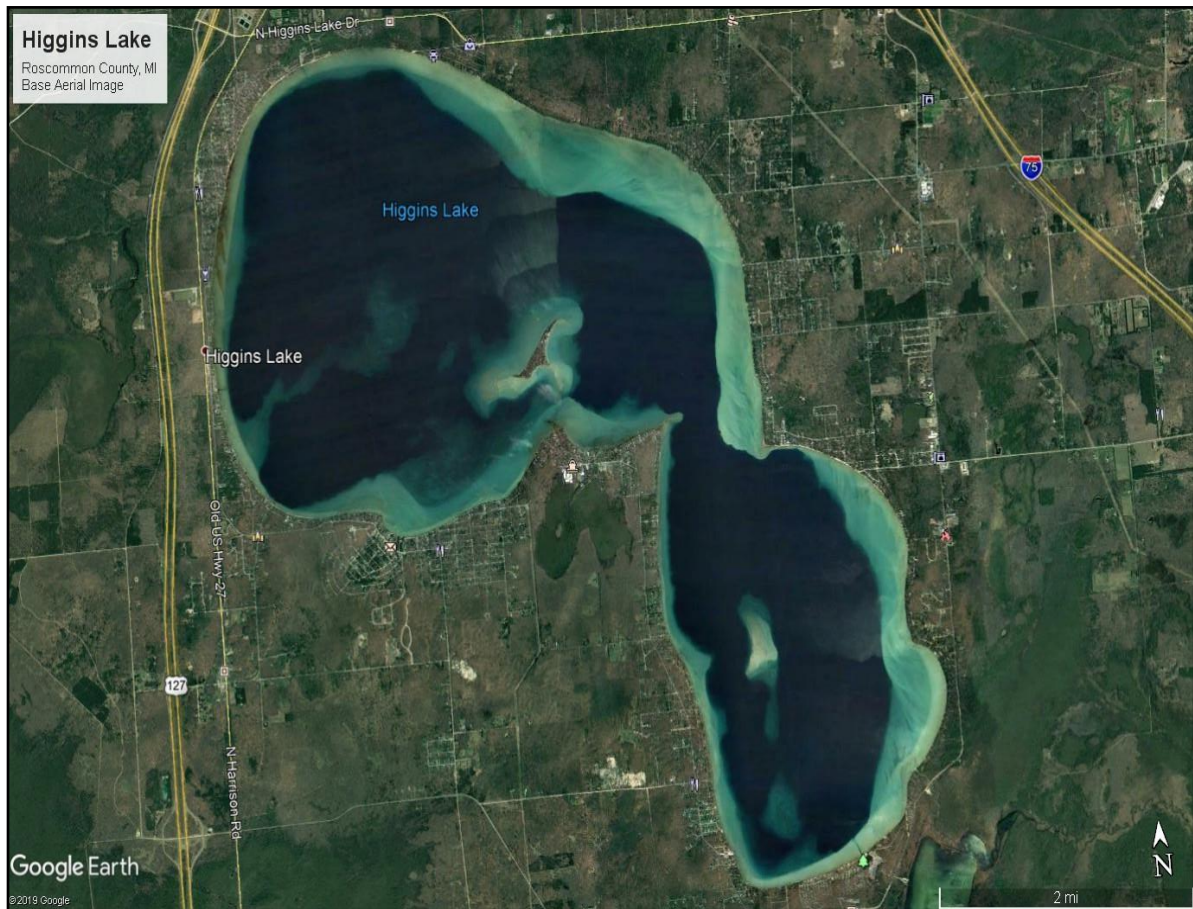


Figure 1. Higgins Lake Aerial Photo, Roscommon County, Michigan.

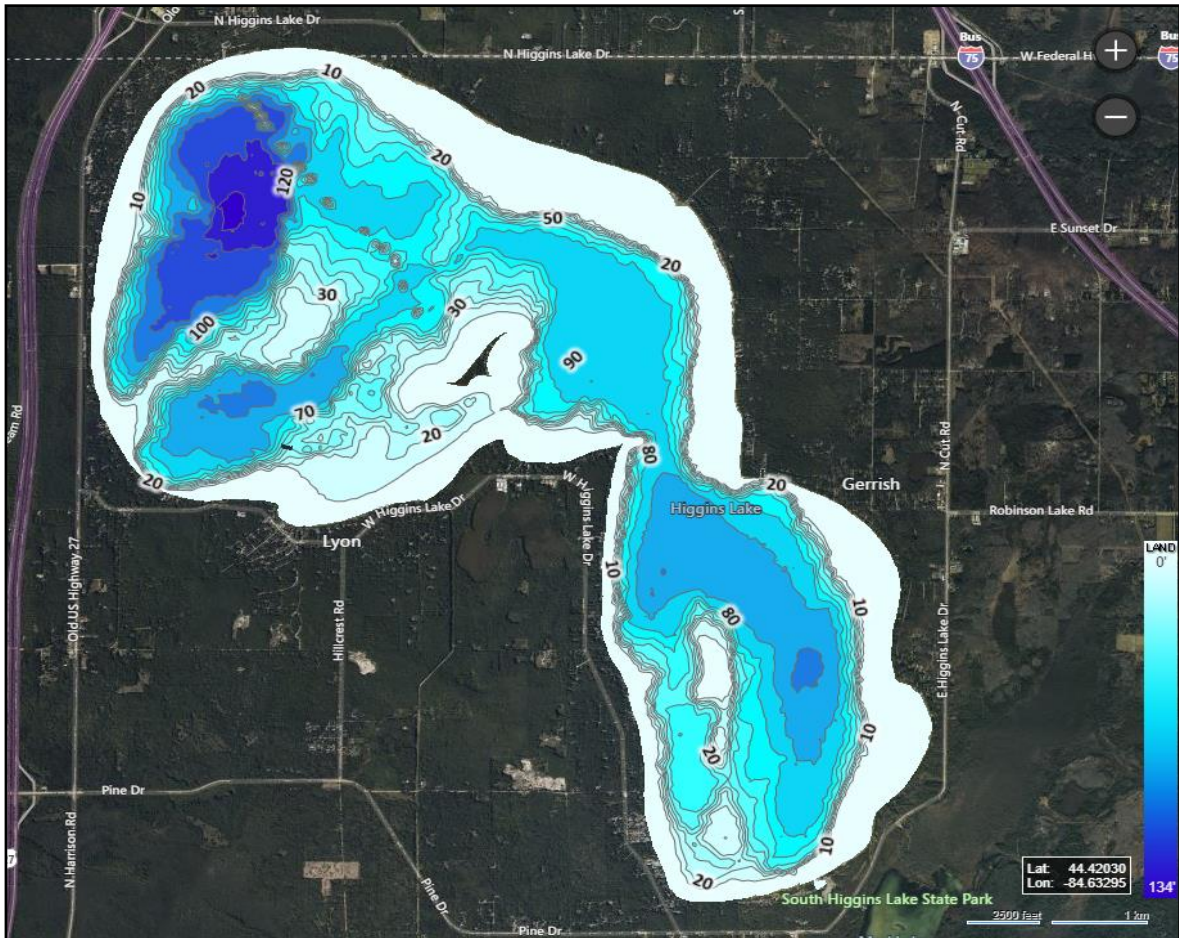


Figure 2. Higgins Lake 2022 Depth Contour Map, Roscommon County, Michigan.

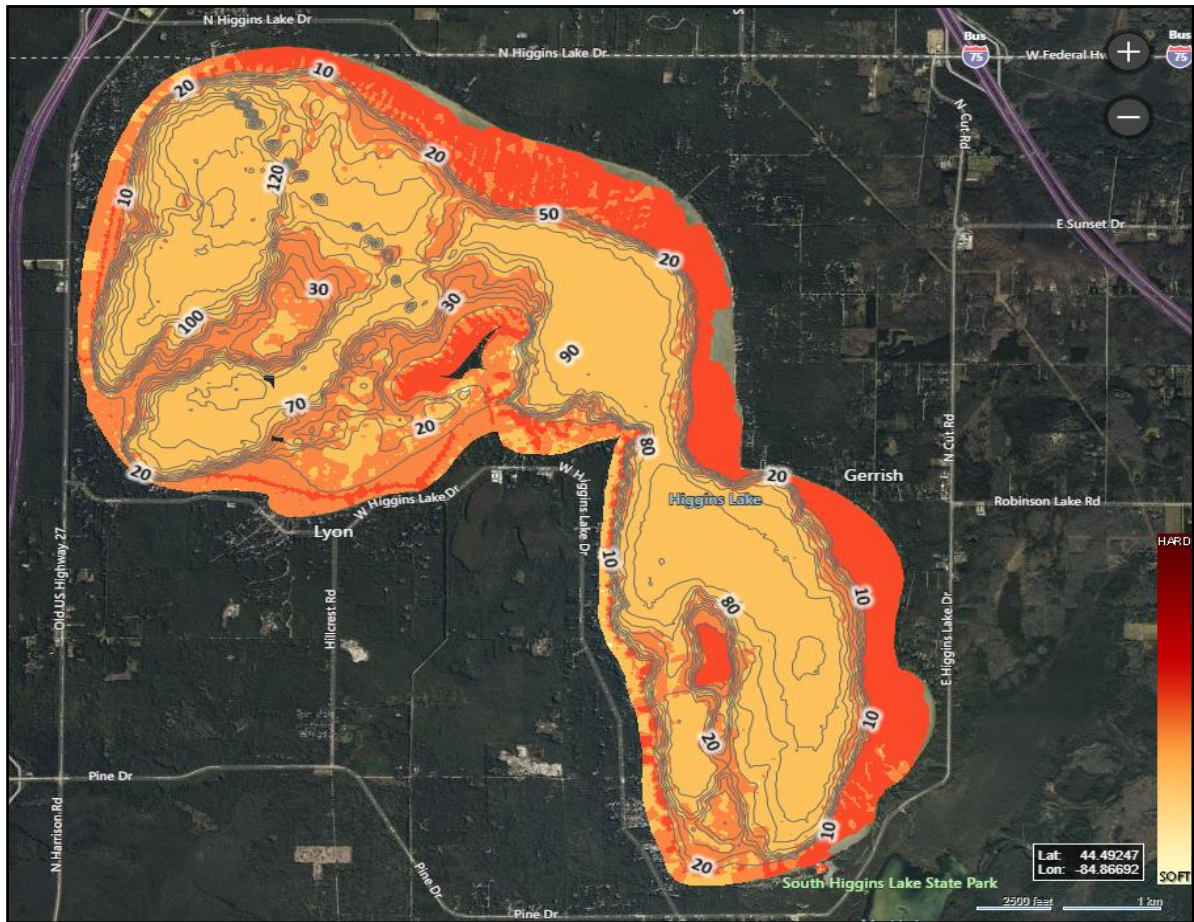


Figure 3. Higgins Lake 2022 Sediment Hardness Map, Roscommon County, Michigan.

3.2 Higgins Lake Extended and Immediate Watershed and Land Use Summary

A watershed is defined as a region surrounding a lake that contributes water and nutrients to a waterbody through drainage sources. Watershed size differs greatly among lakes and also significantly impacts lake water quality. Large watersheds with much development, numerous impervious or paved surfaces, abundant storm water drain inputs, and surrounding agricultural lands, have the potential to contribute significant nutrient and pollution loads to aquatic ecosystems.

Higgins Lake is located within the Muskegon River extended watershed (HUC 04060102) which covers an area of approximately 2,700 mi² in nine counties which include Wexford, Roscommon, Missaukee, Clare, Osceola, Mecosta, Montcalm, Newaygo, and Muskegon. Higgins and Houghton Lakes are at the headwaters of this watershed where the Muskegon River eventually drains into Muskegon Lake and then out into Lake Michigan. The watershed is characterized predominately by forest and agriculture.

This information is valuable on a regional scale; however, it is at the immediate watershed scale that significant improvements can be made by the local Higgins Lake community.

The immediate watershed of Higgins Lake consists of the area around the lake that directly drains to the lake and measures approximately 28,783 acres in size (Figure 4; RLS, 2019). The immediate watershed is about 3 times the size of the lake, which is considered a small immediate watershed. The lakefront itself has a diverse application of land uses such as beachfront for swimming, wetlands, and forested lands. Thus, management options should also consider all of these land uses and preserve their unique functions. Erosion and drain influxes of soils and nutrients are the second largest threat to the water quality of Higgins Lake next to septic systems. Some of the areas around the lake are also of high slope or unstable shorelines and are prone to erosion. Best Management Practices (BMP's) for water quality protection are offered in the watershed improvement section of this report.

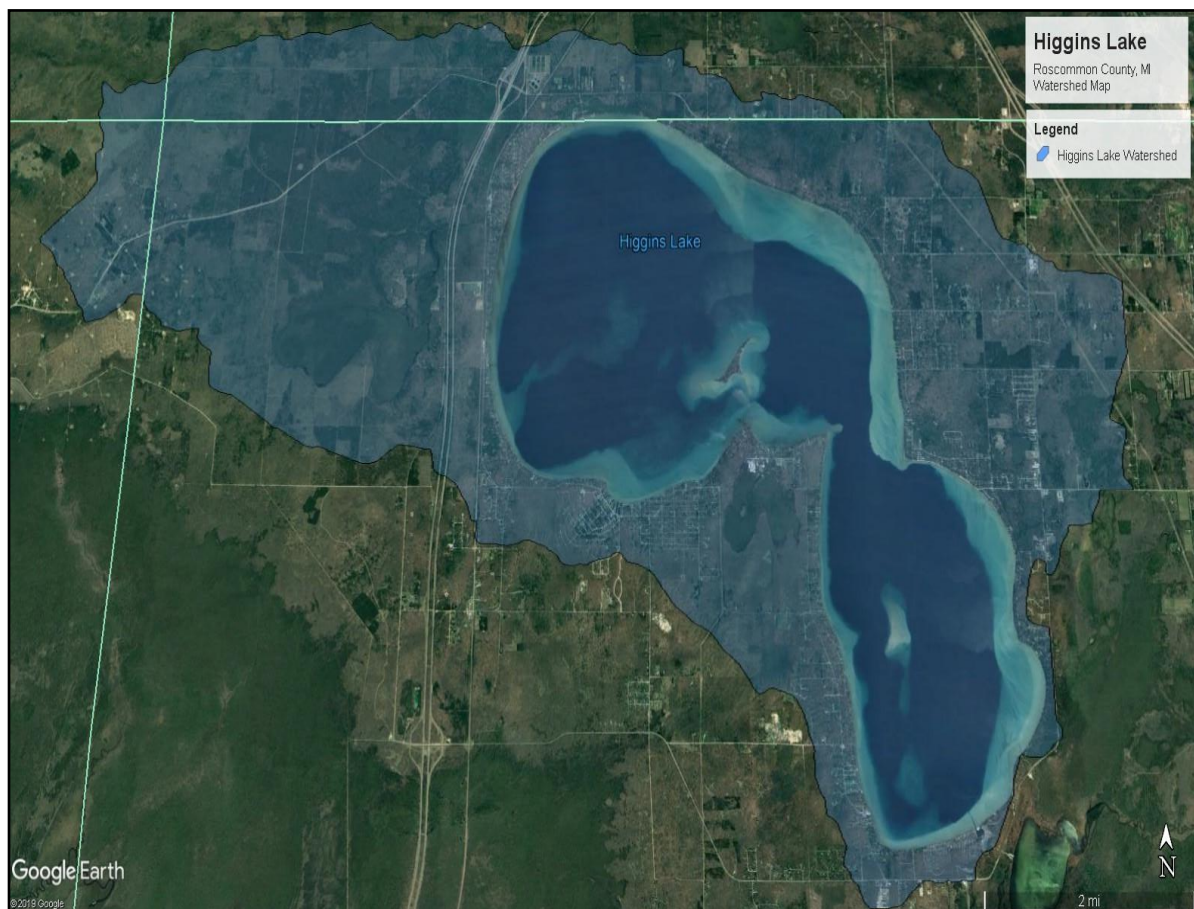


Figure 4. Immediate Watershed draining into Higgins Lake, Roscommon County, Michigan (Restorative Lake Sciences, 2019).

3.3 Higgins Lake Shoreline Soils

There are 12 major soil types (defined as occupying greater than 200 acres in the area of interest) immediately surrounding Higgins Lake which may impact the water quality of the lake and may dictate the particular land use activities within the area (Table 2). This denotes a lake with fairly complex geology; Figure 5 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service) demonstrates the precise soil types and locations around Higgins Lake. Major characteristics of the dominant soil types directly surrounding the Higgins Lake shoreline are discussed below.

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

<i>USDA-NRCS Soil Series</i>	<i># Acres in Higgins Lake (Area of Interest on Map)</i>
Graycalm sand; 0-6% slopes	5,929.5
Graycalm sand; 6-18% slopes	4,932.3
Graycalm-Klacking sands; 0-6% slopes	2,343.1
Tawas and Lupton mucks	1,878.9
Klacking sand; 0-6 slopes	965.3
Croswell sand; 0-6 slopes	840.4
Graycalm-Klacking sands; 6-18% slopes	426.4
Dawson-Loxley peats	324.0
Deford muck	308.2
Au Gres-Kinross Complex; 0-6% slopes	297.3
Chinwhisker sand; 0-4% slopes	224.3
Gerrish sand; 6-18% slopes	202.8

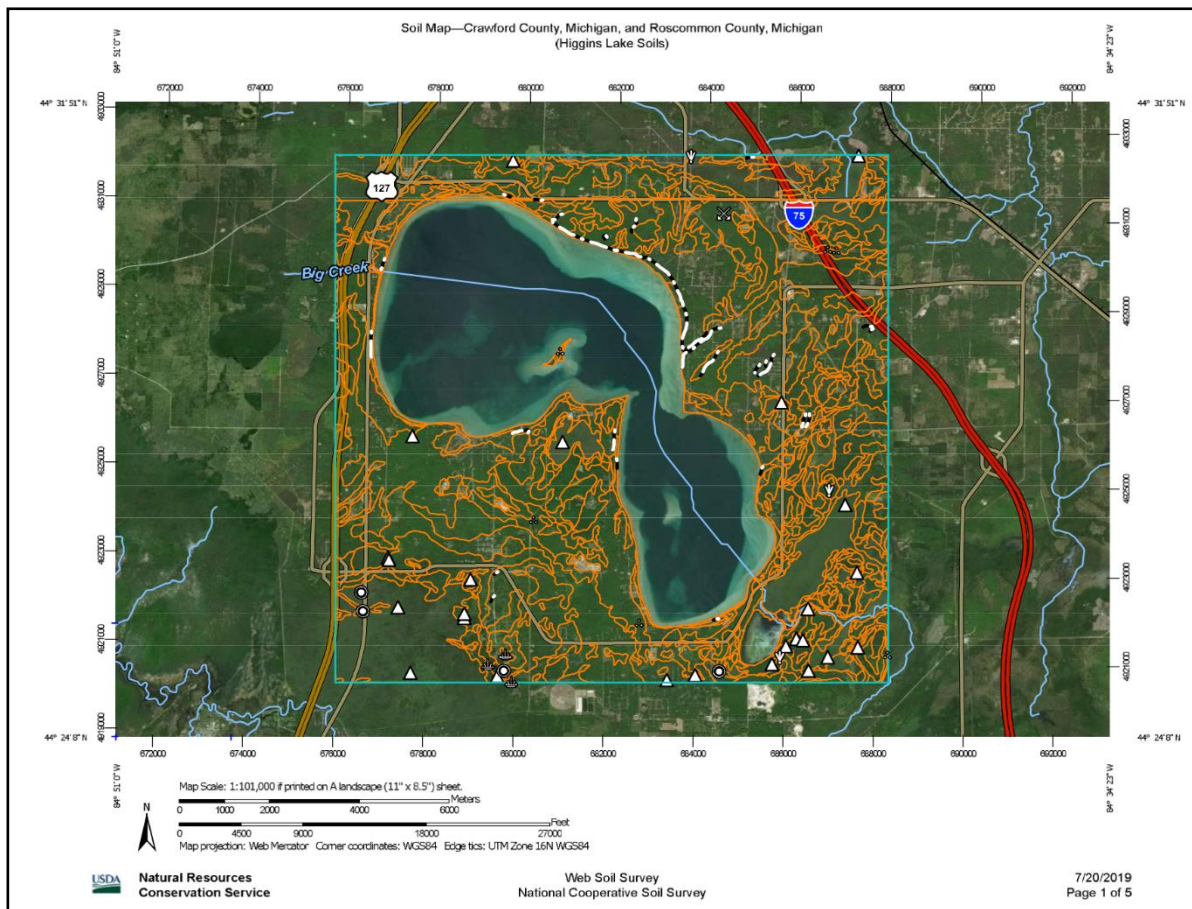


Figure 5. NRCS-USDA soils map for Higgins Lake shoreline soils.

The majority of the soils around Higgins Lake are Graycalm and Klacking sands which are very deep and highly drained soils that are present around moraines and kame deltas. There are many areas around the lake on Graycalm sand with high slopes (>6%) which may be prone to erosion on properties without proper erosion control management and also during periods of high water.

There are also organic saturated soils such as the Tawas-Lupton mucks, present around the lake that are very deep, very poorly drained soils with the potential for ponding. Ponding occurs when water cannot permeate the soil and accumulates on the ground surface which then many runoff into nearby waterways such as the lake and carry nutrients and sediments into the water. Excessive ponding of such soils may lead to flooding of some low-lying shoreline areas, resulting in nutrients entering the lake via surface runoff since these soils do not promote adequate drainage or filtration of nutrients.

The mucks located in the wetlands may become ponded during extended rainfall and the wetlands can serve as a source of nutrients to the lake. When the soils of the wetland are not saturated, the wetland can serve as a sink for nutrients and the nutrients are filtered by wetland plants.

4.0 HIGGINS 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 Higgins Lake is affected by both land use practices and climatic events. Climatic factors (i.e. spring runoff, heavy rainfall) may alter water quality in the short term; whereas, anthropogenic (man-induced) factors (i.e. shoreline development, lawn fertilizer use) alter water quality over longer time periods. Since many lakes have a fairly long hydraulic residence time, the water may remain in the lake for years and is therefore sensitive to nutrient loading and pollutants. Furthermore, lake water quality helps to determine the classification of particular lakes (Table 3). Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a*, and low in transparency are classified as eutrophic; whereas those that are low in nutrients and chlorophyll-*a*, and high in transparency are classified as oligotrophic. Lakes that fall in between these two categories are classified as mesotrophic. Higgins Lake is classified as an oligotrophic (nutrient-poor) lake due to the low nutrients and high Secchi transparency and low chlorophyll-*a* concentrations.

Table 3. General Lake Trophic Status Classification Table.

<i>Lake Trophic Status</i>	<i>Total Phosphorus (mg L⁻¹)</i>	<i>Chlorophyll-a (µg L⁻¹)</i>	<i>Secchi Transparency (feet)</i>
Oligotrophic	< 0.010	< 2.2	> 15.0
Mesotrophic	0.010-0.025	2.2 – 6.0	7.5 – 15.0
Eutrophic	> 0.025	> 6.0	< 7.5

4.1 Water Quality Parameters

Parameters such as dissolved oxygen (in mg/L), water temperature (in °C), specific conductivity (mS/cm), turbidity (NTU's), total dissolved solids (mg/L), total dissolved solids (mg/L), pH (S.U.), total alkalinity (mg CaCO₃/L), total phosphorus and ortho-phosphorus (also known as soluble reactive phosphorus or SRP measured in mg/L), total Kjeldahl nitrogen and total inorganic nitrogen (in mg/L), chlorophyll-a (in µg/L), and Secchi transparency (in feet).

All of these parameters respond to changes in water quality and consequently serve as indicators of change. The deep basin results are discussed below and are presented in Tables 4-13. A map showing the sampling locations for all water quality samples is shown below in Figure 6.

All water samples and readings were collected at the five deepest basins on August 12, 2022 with the use of a Van Dorn horizontal water sampler and calibrated Eureka Manta II® multi-meter probe with parameter electrodes, respectively. All samples were taken to a NELAC (EPA)-certified laboratory for analysis. Whenever possible, historical data comparisons were made for certain parameters that utilized similar sampling locations and methods as those used in this study.

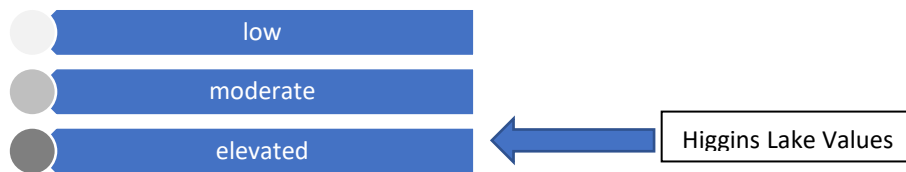


Figure 6. Locations for deep basin water quality sampling in Higgins Lake (August 12, 2022).

4.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water column. In general, dissolved oxygen levels should be greater than 5 mg/L to sustain a healthy warm-water fishery and even higher around 6 mg/L for trout. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. Dissolved oxygen was measured in milligrams per liter (mg/L) with the use of a calibrated Eureka Manta II® dissolved oxygen meter. **Dissolved oxygen (DO) concentrations in the deep basins ranged from 7.5-12.9 mg/L on August 12, 2022, with the highest values measured at the mid-depth and lowest values near the lake bottom.**

Many of the surface and mid-depth concentrations were above 100% saturation, which is favorable. The bottom of the lake produces a biochemical oxygen demand (BOD) due to microbial activity attempting to break down high quantities of organic plant matter, which reduces dissolved oxygen in the water column at depth. Furthermore, the lake bottom is distant from the atmosphere where the exchange of oxygen occurs. A decline in the dissolved oxygen concentrations to near zero may result in an increase in the release rates of phosphorus (P) from lake bottom sediments. **The deep basins exhibit a heterograde oxygen curve where the metalimnion (middle water layer) is higher in dissolved oxygen than the surface (epilimnion) layer and the bottom (hypolimnion). This is usually due to the presence of elevated photosynthetic activity by phytoplankton in the metalimnion.**



4.1.2 Water Temperature

A lake's water temperature varies within and among seasons and is nearly uniform with depth under the winter ice cover because lake mixing is reduced when waters are not exposed to the wind. When the upper layers of water begin to warm in the spring after ice-off, the colder, dense layers remain at the bottom. This process results in a "thermocline" that acts as a transition layer between warmer and colder water layers. During the fall season, the upper layers begin to cool and become denser than the warmer layers, causing an inversion known as "fall turnover" (Figure 7). In general, shallow lakes will not stratify and deeper lakes may experience single or multiple turnover cycles. Water temperature was measured in degrees Celsius (°C) with the use of a calibrated Eureka Manta II® submersible thermometer.

The August 12, 2022 water temperatures of Higgins Lake demonstrated strong thermoclines and are indicative of a seasonally mixed (dimictic) lake that mixes completely around twice per year (spring and fall).

On August 12, 2022, water temperatures ranged from 23.2°C at the surface to 6.5°C at the bottom of the five deep basins. Deep basin #3 exhibited the strongest stratification with the highest water temperature difference of 16.5°C. These water temperatures are similar to those measured in 2019.

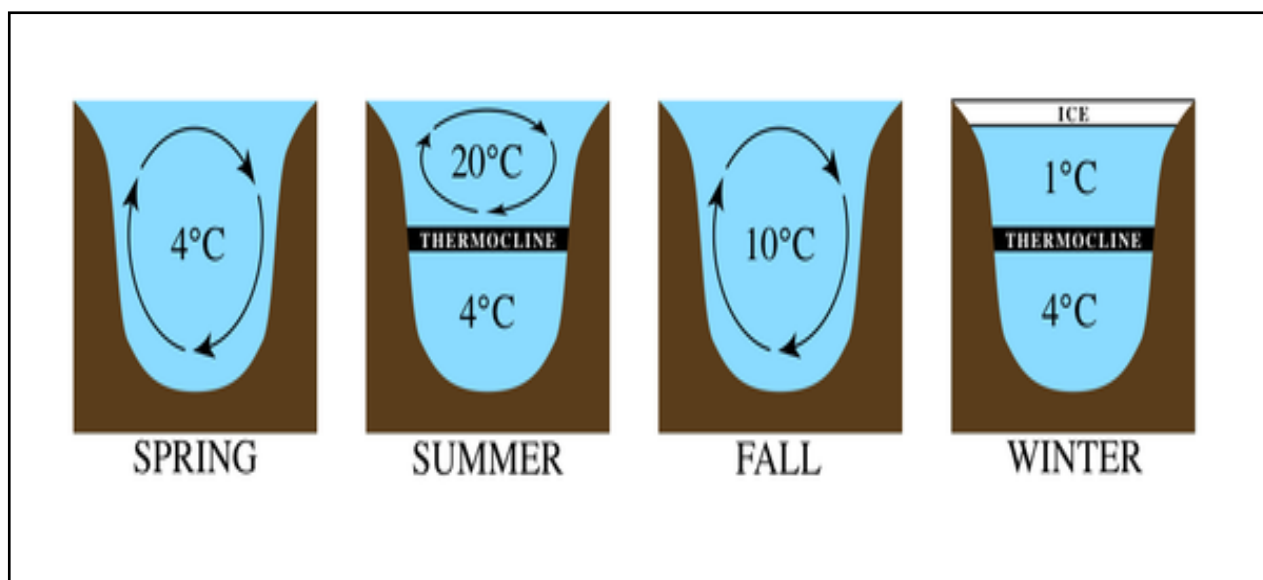
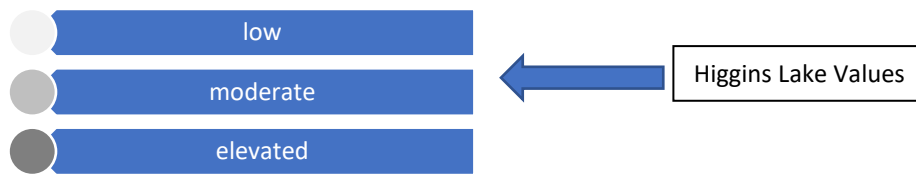


Figure 7. The lake thermal stratification process.

4.1.3 Specific Conductivity

Specific conductivity is a measure of the number of mineral ions present in the water, especially those of salts and other dissolved inorganic substances that can conduct an electrical current. Specific conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Specific conductivity was measured in micro Siemens per centimeter ($\mu\text{S}/\text{cm}$) with the use of a calibrated Eureka Manta II[®] specific conductivity probe and meter. **Specific conductivity values for Higgins Lake were variable among depths at the deep basins and ranged from 261-277 mS/cm on August 12, 2022 which are moderate values and lower than in 2019.** The highest specific conductivity values were recorded at the lake bottom. Since these values are moderate for an inland lake, the lake water contains ample dissolved metals and ions such as calcium, potassium, sodium, chlorides, sulfates, and carbonates. **Historical values reported by the USEPA were around 230 mS/cm, so the values have increased with development, which is expected.**

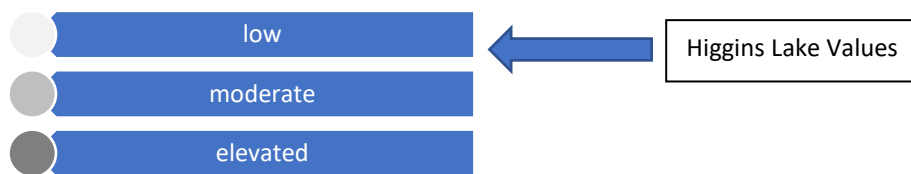
Baseline parameter data such as specific conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Higgins Lake over a long period of time, or to trace the origin of a substance to the lake in an effort to reduce pollutant loading. Elevated conductivity values over 800 mS/cm can negatively impact aquatic life.



4.1.4 Turbidity, Total Dissolved Solids, and Total Suspended Solids

Turbidity

Turbidity is a measure of the loss of water transparency due to the presence of suspended particles. The turbidity of water increases as the number of total suspended particles increases. Turbidity may be caused by erosion inputs, phytoplankton blooms, storm water discharge, urban runoff, re-suspension of bottom sediments, and by large bottom-feeding fish such as carp. Particles suspended in the water column absorb heat from the sun and raise water temperatures. Since higher water temperatures generally hold less oxygen, shallow turbid waters are usually lower in dissolved oxygen. Turbidity was measured in Nephelometric Turbidity Units (NTU’s) with the use of a calibrated Lutron® turbidity meter. The World Health Organization (WHO) requires that drinking water be less than 5 NTU’s; however, recreational waters may be significantly higher than that. **The turbidity of Higgins Lake was low and ranged from 0.1-2.0 NTU’s during the August 12, 2022 sampling event.** On the day of sampling, the winds were calm in the morning, and turbidity was not likely influenced by much re-suspension of sediments although bottom samples are usually higher in turbidity. These numbers also correlate with the measured high transparency and low chlorophyll-a concentrations.

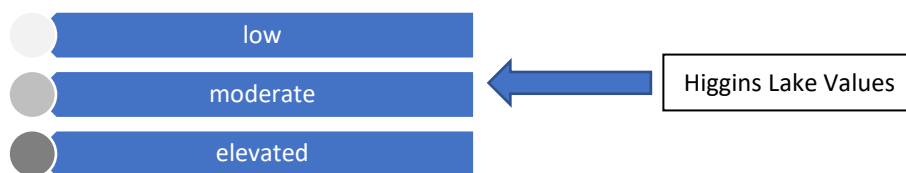


Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the amount of dissolved organic and inorganic particles in the water column.

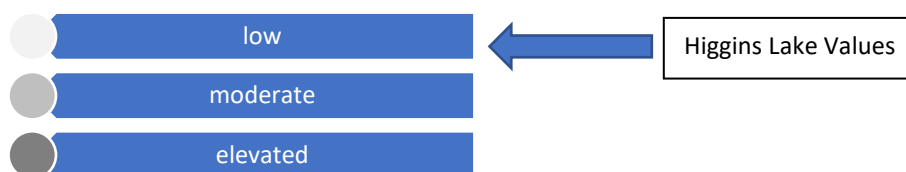
Such solids consist of organic materials, metals, minerals, and salts. Particles dissolved in the water column absorb heat from the sun and raise the water temperature and increase conductivity. Total dissolved solids were measured with the use of a calibrated Eureka Manta II® meter in mg/L. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities.

The TDS in Higgins Lake on August 12, 2022 ranged from 166-177 mg/L for the deep basins which is moderate for an inland lake and correlates with the measured moderate conductivity. These concentrations were slightly higher than in 2019 but are still within a very healthy range.



Total Suspended Solids (TSS)

Total suspended solids is a measure of the number of suspended particles in the water column. Particles suspended in the water column absorb heat from the sun and raise the water temperature. Total suspended solids were measured in mg/L and analyzed in the laboratory with Method SM 2540 D-11. The lake bottom contains many fine sediment particles that are easily perturbed from winds and wave turbulence. Spring values would likely be higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The TSS concentrations in Higgins Lake on August 12, 2022, were all ≤ 10 mg/L. These concentrations are ideal and support high water clarity. These concentrations were also slightly lower than in 2019.



4.1.5 pH

pH is a measure of acidity or basicity of water. pH was measured with a calibrated Eureka Manta II® pH electrode and pH-meter in Standard Units (S.U). The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 7.0 to 9.5 S.U. Acidic lakes (pH < 7) are rare in Michigan and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC).

The pH of Higgins Lake water ranged from 7.8-8.4 S.U. during the August 12, 2022 sampling event with the lowest values measured near the lake bottom. This range of pH is neutral to alkaline on the pH scale and is ideal for an inland lake. pH tends to rise when abundant aquatic plants are actively growing through photosynthesis or when abundant marl deposits are present.

4.1.6 Total Alkalinity

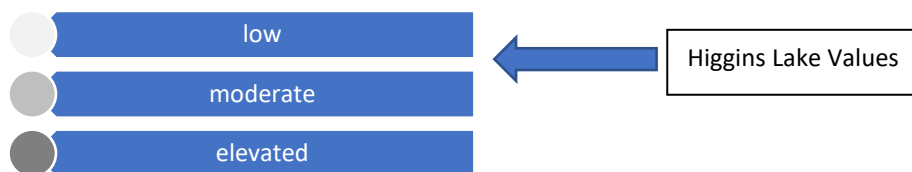
Total alkalinity is a measure of the pH-buffering capacity of lake water. Lakes with high alkalinity (> 150 mg/L of CaCO₃) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of CaCO₃ and are categorized as having “hard” water. Total alkalinity was measured in milligrams per liter of CaCO₃ through the acid titration Method SM 2320 B-11.

Total alkalinity in the deep basins ranged from 85-120 mg/L of CaCO₃ during the sampling August 12, 2022 sampling event, which represents a moderate alkalinity and may be a characteristic of the lake sediments and geology. These numbers are similar to those measured in 2019 with the highest concentration lower in 2022. Total alkalinity may change on a daily basis due to the re-suspension of sedimentary deposits in the water and respond to seasonal changes due to the cyclic turnover of the lake water.

4.1.7 Total Phosphorus and Ortho-Phosphorus (SRP)

Total Phosphorus

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Lakes which contain greater than 0.020 mg/L (or 20 µg/L) of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to the higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Phosphorus may also be released from sediments as pH increases. Total phosphorus was measured in milligrams per liter (mg/L) with the use of Method EPA 200.7 (Rev. 4.4). **The total phosphorus (TP) concentrations in the lake deep basins ranged from <0.010-0.043 mg/L during the August 22, 2019 sampling event but were all <0.010 mg/L during the August 12, 2022 sampling event.** In 2019, the highest concentration was measured near the middle of deep basin #4 and the reason for this elevated concentration is unknown. Previous studies (Minnerick, 2001) noted that phosphorus was elevated nearshore relative to the open waters which is indicative of septic system leachate entering the groundwater. An earlier USEPA study (1975) determined that the major contributing sources of phosphorus to Higgins lake in order of magnitude include direct precipitation, septic systems, minor tributaries, and Big Creek. Figure 8 demonstrates the trends in mean TP concentrations with time from the surface waters of Higgins Lake.



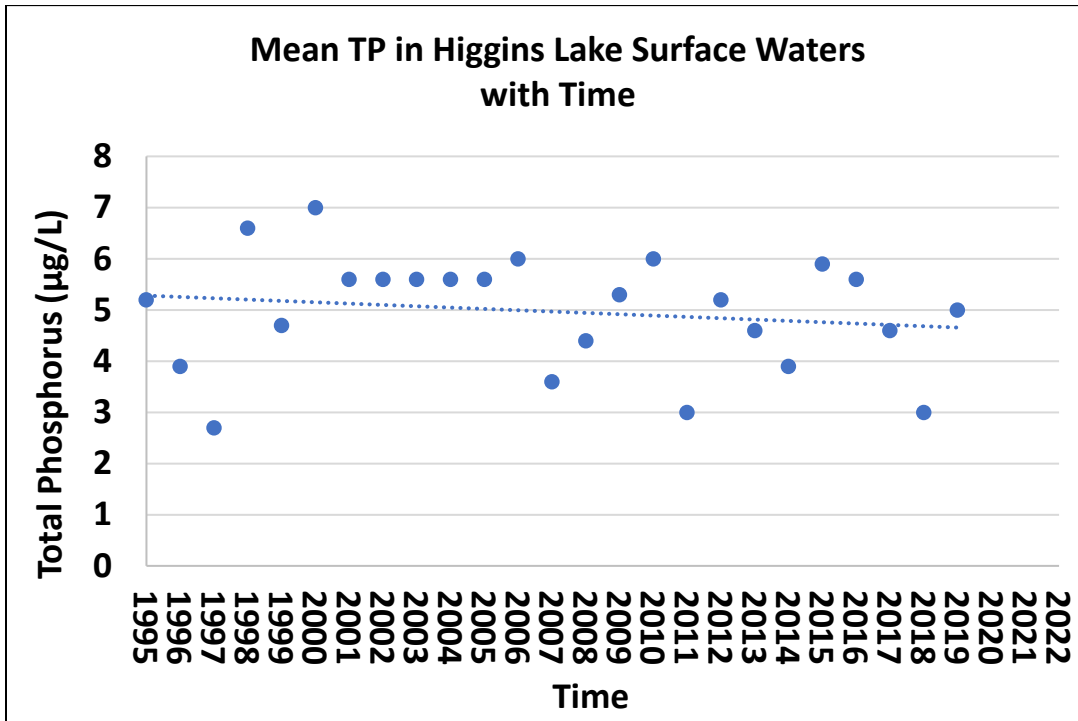
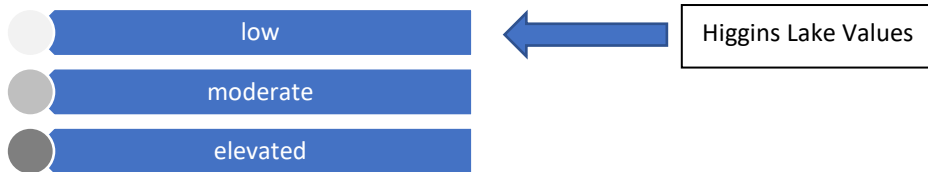


Figure 8. Trends in mean total phosphorus (in µg/L) with time in the surface waters of the Higgins Lake deep basins. Data from USEPA (1975), CLMP (2001-2018), and RLS (2019 and 2022). Note: comparisons for the hypolimnion could not be made due to differences in sampling methodology.

Ortho-Phosphorus

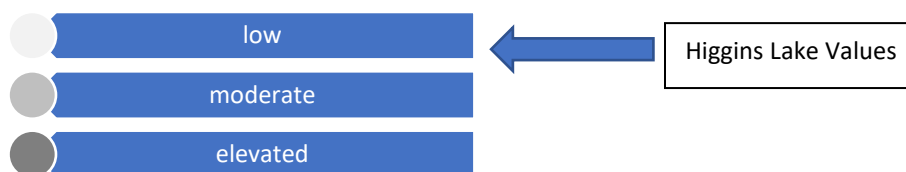
Ortho-Phosphorus (also known as soluble reactive phosphorus or SRP) was measured with Method SM 4500-P (E-11). SRP refers to the most bioavailable form of P used by all aquatic life. All of the SRP concentrations collected on August 12, 2022 were <0.010 mg/L which is favorable and identical to 2019. Since the SRP concentrations were all low, less of the TP was available for algal growth which helps to keep chlorophyll-a concentrations low.



4.1.8 Total Kjeldahl Nitrogen and Total Inorganic 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. TKN was measured with Method EPA 351.2 (Rev. 2.0) and Total Inorganic Nitrogen (TIN) was calculated based on the aforementioned three different forms of nitrogen. Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e. burning of fossil fuels), wastewater sources from developed areas (i.e. runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen (N: P > 15), phosphorus may be the limiting nutrient for phytoplankton and aquatic macrophyte growth, which is correct for Higgins Lake. Alternatively, in lakes with low nitrogen concentrations (and relatively high phosphorus), the blue-green algae populations may increase due to the ability to fix nitrogen gas from atmospheric inputs. Lakes with a mean TKN value of 0.66 mg/L may be classified as oligotrophic, those with a mean TKN value of 0.75 mg/L may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg/L may be classified as eutrophic. **Higgins Lake contained low concentrations of TKN at all depths ($\leq 0.50\text{-}0.7$ mg/L) on August 12, 2022, which are normal for an inland lake of similar size.** An earlier USEPA study (1975) determined that the major contributing sources of nitrogen to Higgins lake in order of magnitude include direct precipitation, septic systems, minor tributaries, and Big Creek.

The total inorganic nitrogen (TIN) consists of nitrate (NO_3^-), nitrite (NO_2^-), and ammonia (NH_3) forms of nitrogen without the organic forms of nitrogen. **The TIN concentrations were all <0.10 mg/L which is low. Interestingly, the lab reported ammonia concentrations that ranged from $<0.010\text{-}0.020$ mg/L which are low and favorable.**

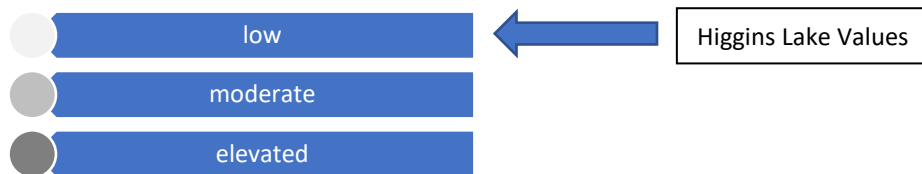


4.1.9 Chlorophyll-a and Algae

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. High chlorophyll-*a* concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 $\mu\text{g/L}$ are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 $\mu\text{g/L}$ are found in nutrient-poor or oligotrophic lakes.

Chlorophyll-*a* was measured in micrograms per liter ($\mu\text{g/L}$) with Method SM 10200H. The chlorophyll-*a* concentrations in Higgins Lake were determined by collecting a composite sample of the algae throughout the water column at the deep basin sites from just above the lake bottom to the lake surface. **The chlorophyll-*a* concentration in the deep basins ranged from 0-0.7 $\mu\text{g/L}$ during the August 12, 2022 sampling event. These concentrations were very low and are indicative of unproductive waters.**

Algal genera from a composite water sample collected from the deep basins of Higgins Lake were analyzed under a Zeiss® compound brightfield microscope. The genera present included the Chlorophyta (green algae): *Scenedesmus* sp., *Closterium* sp., *Cosmarium* sp., *Chlorella* sp., *Akinestrodesmus* sp.; the Cyanophyta (blue-green algae): *Polycystis* sp.; the Bascillariophyta (diatoms): *Fragilaria* sp., *Stephanodiscus* sp., *Amphora* sp., *Achnantheidium* sp., *Melosira* sp., and *Navicula* sp. The aforementioned species indicate a moderately diverse algal flora and represent a relatively balanced freshwater ecosystem, capable of supporting a strong zooplankton community in favorable water quality conditions. **The diatoms were the most abundant, followed by the single-celled green algae. Diatoms are indicators of excellent water quality and may impart a brownish color to the lake bottom and other substrates where they grow. Additionally, diatoms convert CO_2 to oxygen.** Some of the aforementioned algae are known for being benthic genera; however, re-suspension of benthic algae into the water column should be considered during elevated boat and wave activity which is common in Higgins Lake. Figure 9 demonstrates the changes in mean chlorophyll-*a* concentrations in Higgins Lake with time.



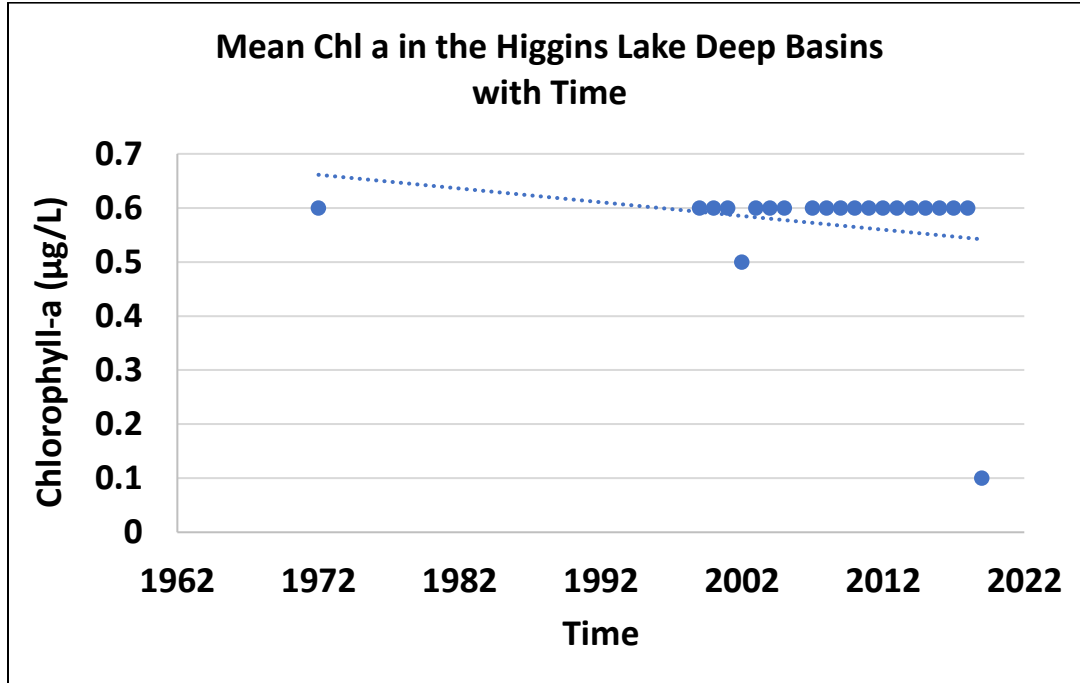


Figure 9. Trends in mean chlorophyll-*a* with time in Higgins Lake (1975-2019). Data from USEPA (1975), CLMP (2001-2018), and RLS (2019 and 2022).

4.1.10 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and is measured with the use of an 8-inch diameter standardized Secchi disk. Secchi disk transparency is measured in feet (ft.) or meters (m) by lowering the disk over the shaded side of a boat around noon and taking the mean of the measurements of disappearance and reappearance of the disk (Figure 10). Elevated Secchi transparency readings allow for more aquatic plant and algae growth. Eutrophic systems generally have Secchi disk transparency measurements less than 7.5 feet due to turbidity caused by excessive planktonic algae growth. **The Secchi transparency of Higgins Lake was measured on August 12, 2022 and ranged from 31.1-35.2 feet over the deep basins which are favorable measurements. Measurements were collected during calm conditions.** This transparency indicates a low quantity of suspended particles and algae throughout the water column which would result in better water clarity. Secchi transparency is variable and depends on the amount of suspended particles in the water (often due to windy conditions of lake water mixing) and the amount of sunlight present at the time of measurement. **Secchi transparency has increased throughout time (Figure 11) due to the presence and abundance of both Zebra and Quagga Mussels which filter the algae out of the water for food.**

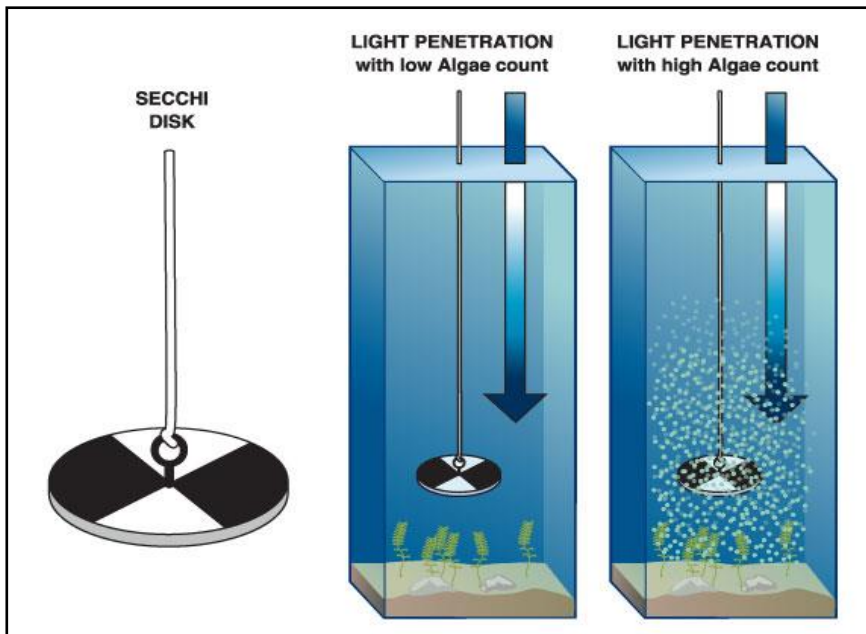


Figure 10. Measurement of water transparency with a Secchi disk.

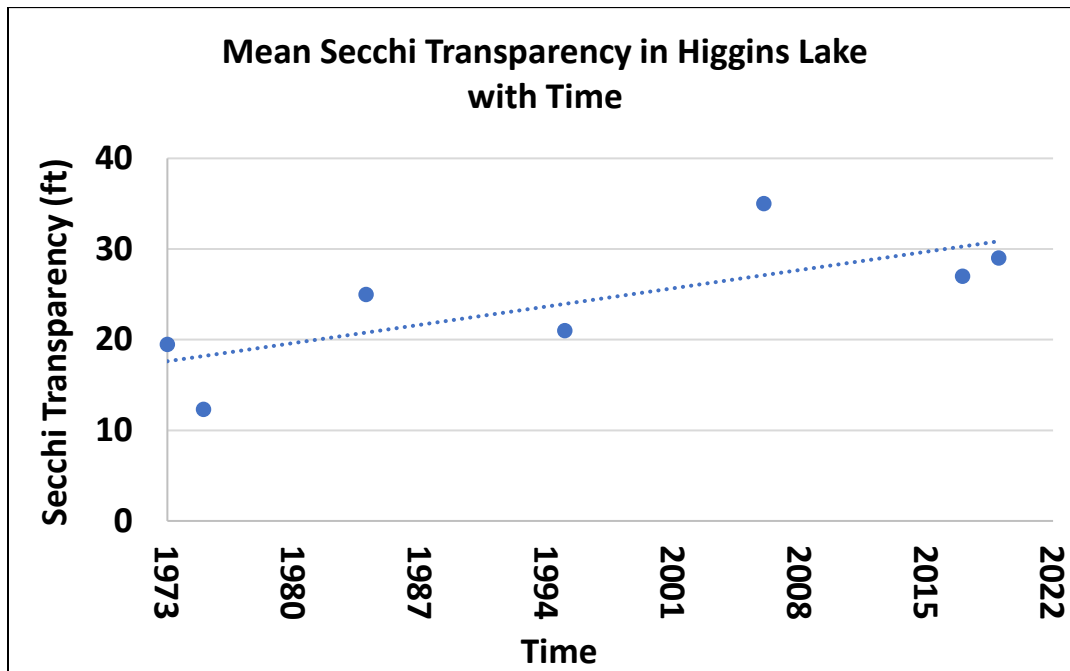


Figure 11. Trends in Secchi transparency with time in Higgins Lake (1975-2022). Data from USEPA (1975), CLMP (2001-2018), and RLS (2019 and 2022).

4.1.11 *E. coli* Bacteria

Although *E. coli* bacteria were not collected for this study, previous historical data on *E. coli* has demonstrated some issues around the lake with waterfowl droppings and septic leachate. The HLPOA along with high school student volunteers from Roscommon high school, have conducted many *E. coli* sampling events and utilized State standards for beaches with closings issued at >1000 MPN (most probable number) per 100 mL, and advisories issued with *E. coli* concentrations of >235 MPN/100 ml. Their results can be found online at: <https://hlpoa.org/higgins-lake/environmental-lake-level/water-quality/>. Some *E. coli* bacteria concentrations have been elevated in surface waters over the past five years.

An excellent online resource by EGLE advertises the closures and advisories for many water bodies in Michigan, including Higgins Lake. This site can be found at: <http://egle.state.mi.us/beach/>

Table 4. Higgins Lake physical water quality parameter data collected at deep basin #1 (August 12, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	DO Sat (%)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	22.8	8.6	99.1	8.2	262	168	0.3	35.2
5	22.5	8.8	100	8.3	262	168	0.3	
10	22.5	8.9	101	8.3	262	168	0.3	
15	12.0	12.8	115	8.3	261	168	0.3	
20	9.8	12.6	110.2	8.2	263	168	0.3	
25	9.3	12.1	105.4	8.1	264	169	0.4	
30	8.7	7.5	64.6	7.8	277	177	0.4	

Table 5. Higgins Lake chemical water quality parameter data collected at deep basin #1 (August 12, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH ₃ (mg/L)	NO ₂ ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	TSS (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	<0.50	<0.10	<0.010	<0.010	0.010	<0.10	<0.10	--	0.360	89
15	<0.50	<0.10	<0.010	<0.010	0.016	<0.10	<0.10	--	--	92
30	<0.50	<0.10	<0.010	<0.010	0.012	<0.10	<0.10	10	--	88

Table 6. Higgins Lake physical water quality parameter data collected at deep basin #2 (August 12, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	DO Sat (%)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	22.9	8.8	100	8.2	263	168	0.2	31.1
5	22.5	8.9	100.7	8.3	263	168	0.2	
10	22.4	8.9	100.5	8.3	263	168	0.3	
15	11.9	12.4	115.8	8.3	261	167	0.3	
20	9.9	12.3	108.2	8.2	265	166	0.3	
25	9.4	11.4	98.9	8.0	266	170	0.4	
29	8.8	7.8	67.8	7.8	274	176	0.4	

Table 7. Higgins Lake chemical water quality parameter data collected at deep basin #2 (August 12, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH ₃ (mg/L)	NO ₂ - (mg/L)	NO ₃ - (mg/L)	TSS (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	<0.50	<0.10	<0.010	<0.010	<0.010	<0.10	<0.10	<10	0	85
15	<0.50	<0.10	<0.010	<0.010	0.020	<0.10	<0.10	--	--	87
29	<0.50	<0.10	<0.010	<0.010	<0.010	<0.10	<0.10	<10	--	93

Table 8. Higgins Lake physical water quality parameter data collected at deep basin #3 (August 12, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	DO Sat (%)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	23.0	8.8	100.7	8.3	264	169	0.1	31.9
5	22.3	9.0	101.1	8.3	263	168	0.2	
10	22.1	9.0	100.2	8.4	263	169	0.2	
15	11.9	12.5	115.3	8.4	261	167	0.2	
20	9.7	12.9	114.3	8.3	263	168	0.2	
25	8.0	15.6	131.1	8.2	263	169	0.2	
30	7.0	11.9	99.8	8.1	264	169	0.3	
35	6.7	10.7	88.6	8.0	266	170	0.6	
40	6.5	7.5	61.5	7.8	273	174	2.0	

Table 9. Higgins Lake chemical water quality parameter data collected at deep basin #3 (August 12, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH ₃ (mg/L)	NO ₂ - (mg/L)	NO ₃ - (mg/L)	TSS (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	<0.50	<0.10	<0.010	<0.010	0.010	<0.10	<0.10	--	0.710	86
20	<0.50	<0.10	<0.010	<0.010	0.012	<0.10	<0.10	--	--	86
40	<0.50	<0.10	<0.010	<0.010	0.012	<0.10	<0.10	10	--	92

Table 10. Higgins Lake physical water quality parameter data collected at deep basin #4 (August 12, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	DO Sat (%)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	23.2	8.8	102.3	8.3	264	169	0.1	32.3
5	22.4	8.9	102.4	8.4	263	168	0.1	
10	22.3	9.0	103.1	8.4	263	168	0.2	
15	11.7	12.5	116.8	8.4	261	167	0.3	
20	9.6	12.9	107.1	8.3	263	168	0.4	
25	8.9	12.1	106.6	8.2	265	169	0.4	
30	8.3	7.6	65.2	8.0	275	176	1.0	

Table 11. Higgins Lake chemical water quality parameter data collected at deep basin #4 (August 12, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH ₃ (mg/L)	NO ₂ ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	TSS (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.70	<0.10	<0.010	<0.010	0.018	<0.10	<0.10	--	0	89
15	<0.50	<0.10	<0.010	<0.010	0.014	<0.10	<0.10	--	--	89
30	<0.50	<0.10	<0.010	<0.010	0.010	<0.10	<0.10	10	--	110

Table 12. Higgins Lake physical water quality parameter data collected at deep basin #5 (August 12, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	DO Sat (%)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	23.0	8.9	104.8	8.3	263	168	0.1	33.2
5	22.5	8.9	102.0	8.3	263	168	0.1	
10	21.8	9.0	101.6	8.3	263	168	0.3	
15	12.0	12.2	113.7	8.3	262	168	0.3	
20	9.8	12.2	107.6	8.2	265	167	0.9	
24	9.4	11.5	102.1	8.1	266	170	2.0	

Table 13. Higgins Lake chemical water quality parameter data collected at deep basin #5 (August 12, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH₃ (mg/L)	NO₂⁻ (mg/L)	NO₃⁻ (mg/L)	TSS (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	<0.50	<0.10	<0.010	<0.010	<0.010	<0.10	<0.10	--	0	90
43	<0.50	<0.10	<0.010	<0.010	0.012	<0.10	<0.10	--	--	92
87	<0.50	<0.10	<0.010	<0.010	<0.010	<0.10	<0.10	<10	--	120

4.2 Higgins Lake Aquatic Vegetation Communities

Aquatic plants (macrophytes) are an essential component in the littoral zones of most lakes in that they serve as suitable habitat and food for macroinvertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (if in the rooted growth form), and contribute to the cycling of nutrients such as phosphorus and nitrogen upon decay. In addition, decaying aquatic plants contribute organic matter to lake sediments which further supports healthy growth of successive aquatic plant communities that are necessary for a balanced aquatic ecosystem. An overabundance of aquatic vegetation may cause organic matter to accumulate on the lake bottom faster than it can break down. Aquatic plants generally consist of rooted submersed, free-floating submersed, floating-leaved, and emergent growth forms. The emergent growth form (i.e., Cattails, Native Loosestrife) is critical for the diversity of insects onshore and for the health of nearby wetlands. Submersed aquatic plants can be rooted in the lake sediment (i.e., Milfoils, Pondweeds), or free-floating in the water column (i.e., Coontail). Nonetheless, there is evidence that the diversity of submersed aquatic macrophytes can greatly influence the diversity of macroinvertebrates associated with aquatic plants of different structural morphologies (Parsons and Matthews, 1995). Therefore, it is possible that declines in the biodiversity and abundance of submersed aquatic plant species and associated macroinvertebrates, could negatively impact the fisheries of inland lakes. Alternatively, the overabundance of aquatic vegetation can compromise recreational activities, aesthetics, and property values.

A whole-lake scan of the aquatic vegetation in Higgins Lake was conducted on July 15-20, and August 2-5, 2022 with a WAAS-enabled Lowrance HDS 9[®] GPS with variable frequency transducer. This data included 113,989 data points which were uploaded to a cloud software program to reveal maps that displayed depth contours, sediment hardness, and aquatic vegetation biovolume (Figure 12). On the biovolume scan map, the color blue refers to areas that lack vegetation. The color green refers to low-lying vegetation. The colors red/orange refer to tall-growing vegetation. There are many areas around the littoral (shallow) zone of the lake that contain low-growing plants like Chara or Southern Naiad. For this reason, the scans are conducted in conjunction with a whole lake GPS Point Intercept survey to account for individual species identification of all aquatic plants in the lake. Table 14 shows the biovolume categories by plant cover on July 15-20, 2022.

The GPS Point Intercept survey is sometimes used with an Aquatic Vegetation Assessment Site (AVAS) Survey method to assess the relative abundance of submersed, floating-leaved, and emergent aquatic vegetation within and around the littoral zones of inland lakes. With this survey method, the littoral zone areas of the lakes are divided into lakeshore sections approximately 100 - 300 feet in length.

Each AVAS segment is sampled using visual observation, dependent on water clarity, and weighted rake tows to verify species identification. The species of aquatic macrophytes present and density of each macrophyte are recorded onto an AVAS data sheet. Each separate plant species found in each AVAS segment is recorded along with an estimate of each plant density. Each macrophyte species corresponds to an assigned number. There are designated density codes for the aquatic vegetation surveys, where a = found (occupying < 2% of the surface area of the lake), b = sparse (occupying 2-20% of the surface area of the lake), c = common, (occupying 21-60% of the surface area of the lake), and d = dense (occupying > 60% of the surface area of the lake). In addition to the particular species observed (via assigned numbers), density information above was used to estimate the percent cumulative coverage of each species within the AVAS site. Where shallow areas were present in the open waters of the lake, individual AVAS segments were sampled at those locations to assess the macrophyte communities in offshore locations. This is particularly important since exotics often expand in shallow island areas located offshore in many lakes.

For Higgins Lake, RLS conducted rake tosses at each GPS location and applied the AVAS relative abundance designation for each site. Since the littoral zone of Higgins Lake varies in width around the lake basin, AVAS segments were not favored relative to Point-Intercept sampling sites. This approach provided for geo-referenced, repeatable surveys that can be compared among years. The same locations were sampled in 2019 and 2022 with some additional points added in 2022 for even more detail. It is important to note that it is impossible to account for every aquatic plant in the lake basin. The purpose of the survey is to provide a sound estimate of the aquatic vegetation population.

The GPS Point-Intercept/AVAS survey of Higgins Lake was conducted on July 15-20, 2022 and August 2-5, 2022, and consisted of 3,085 sampling locations around the littoral zone which includes the area around the islands (Figure 13). Data were placed in a table showing the relative abundance of each aquatic plant species found and a resultant calculation showing the frequency of each plant. It is important to remember that these surveys cannot account for every single aquatic plant stem given the area of the lake. In addition, they account for the aquatic vegetation from the shoreline out to the drop-off. Many of the areas around Higgins Lake contain steep drop-offs where EWM and other plants may root on the steep slope but could not likely be removed given the inherent occupational danger and ability to isolate removal areas with steep slopes and great depths present. The biovolume scan shows that the entire lake bottom was accounted for in the lake survey, but as with any scientific survey, the data is an overall estimate of the existing aquatic vegetation population based on a favorable sample size.

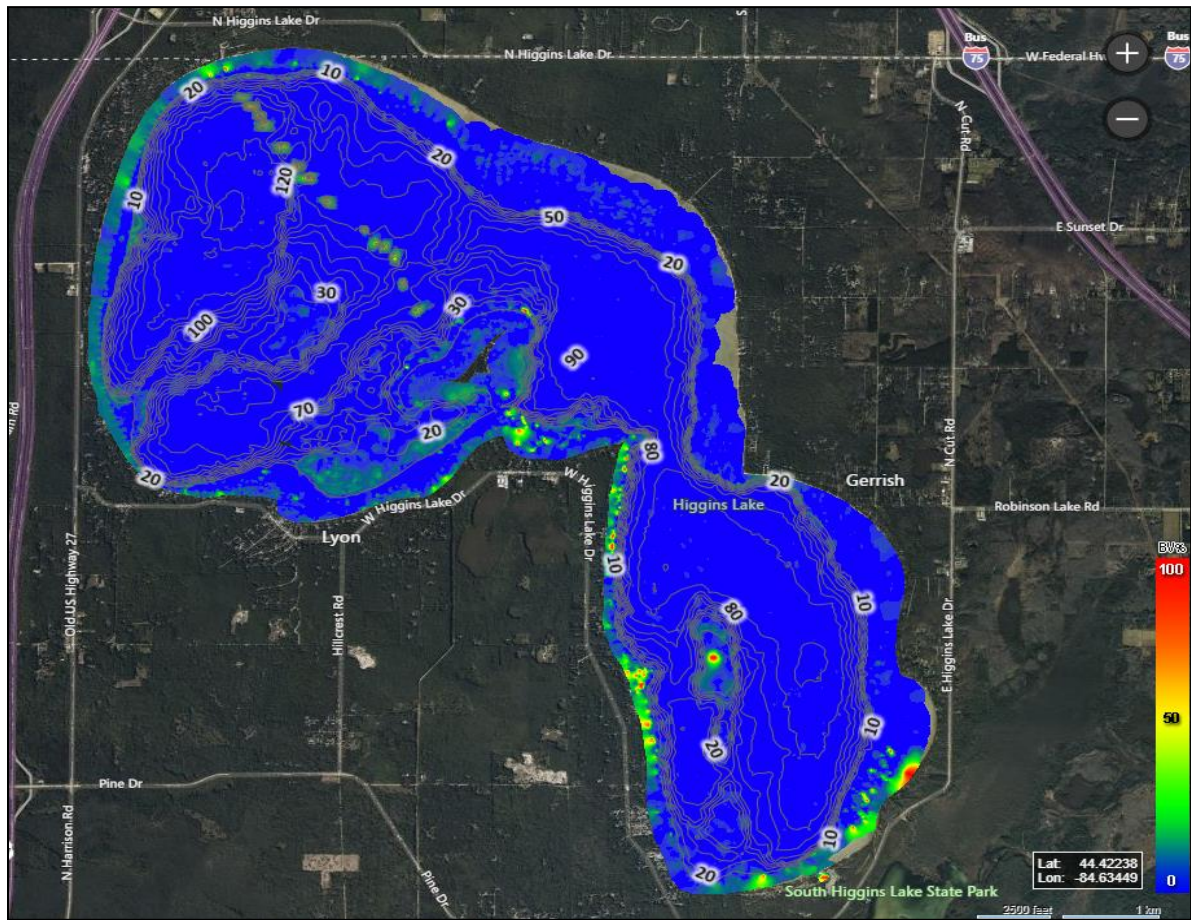


Figure 12. Aquatic plant biovolume of all aquatic plants in Higgins Lake, Roscommon County, Michigan (July 15-20, and August 2-5, 2022). Note: Red color denotes high-growing aquatic plants, green color denotes low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

Table 14. Higgins Lake aquatic vegetation biovolume by bottom cover category (relative cover on August 21-23, 2019 and July 15-20, and August 2-5, 2022).

Aquatic Vegetation Biovolume Cover Category	% Relative Cover of Bottom by Category 2019	% Relative Cover of Bottom by Category 2022
0-5%	96.0	98.6
5-20%	2.8	0.0
20-40%	0.3	0.6
40-60%	0.1	0.1
60-80%	0.1	0.1
>80%	0.7	0.6

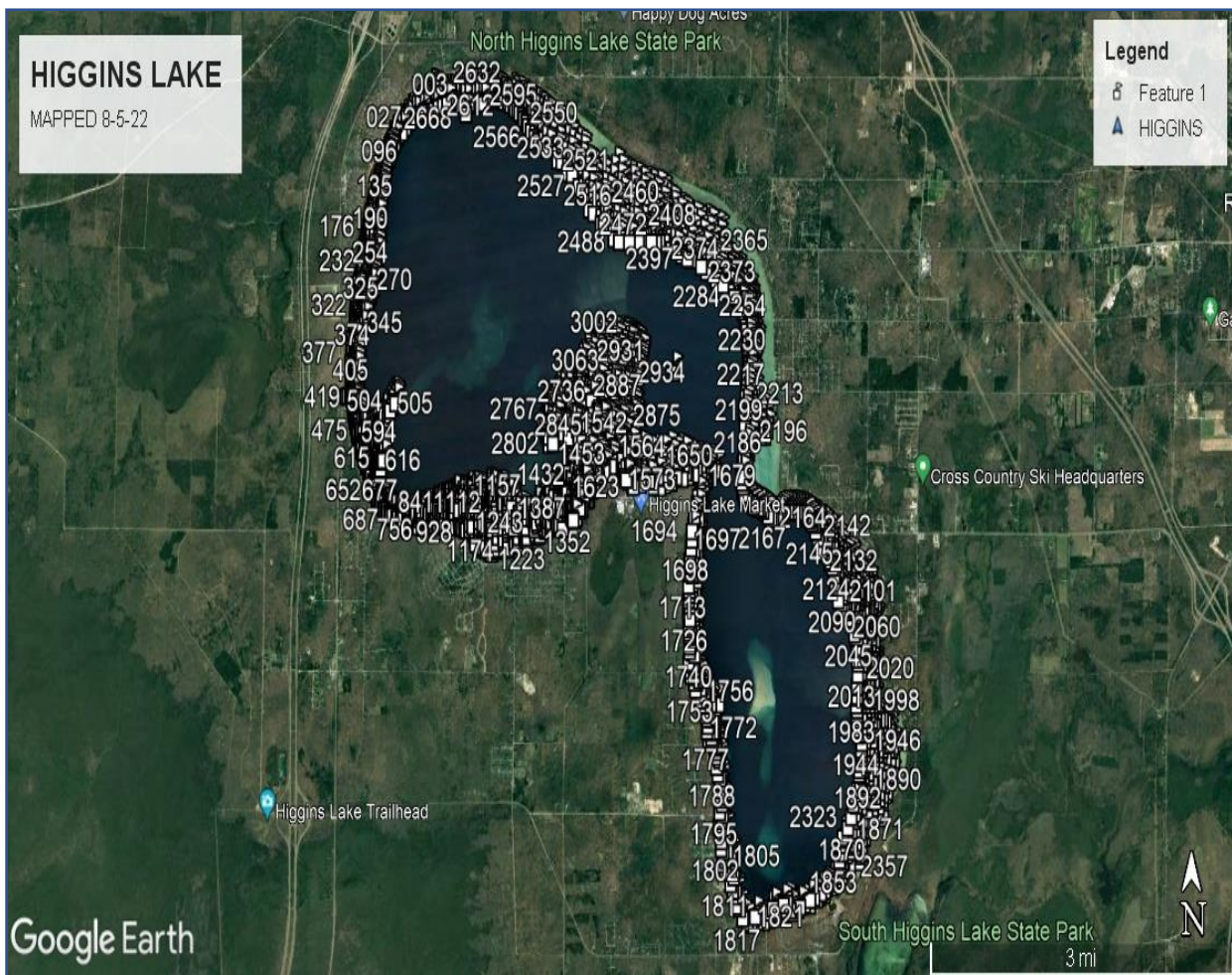


Figure 13. Aquatic vegetation sampling locations in Higgins Lake (July 15-20, and August 2-5, 2022).

4.2.1 Higgins Lake Native Aquatic Macrophytes

There are hundreds of native aquatic plant species in the waters of the United States. The most diverse native genera include the Potamogetonaceae (Pondweeds) and the Haloragaceae (Milfoils). Native aquatic plants may grow to nuisance levels in lakes with abundant nutrients (both water column and sediment) such as phosphorus, and in sites with high water transparency. The diversity of native aquatic plants is essential for the balance of aquatic ecosystems because each plant harbors different macroinvertebrate communities and varies in fish habitat structure.

In 2022, Higgins Lake contained 19 native submersed and 2 emergent aquatic plant species, for a total of 21 native aquatic macrophyte species (Table 15). In 2022, there was a new native aquatic plant species present (American Pondweed, *Potamogeton nodosus*) which is encouraging for an increase in biodiversity. A total of 4 native aquatic plant species increased in frequency in 2022 from 2019 and included Flat-stem Pondweed, Claspingleaf Pondweed, Wild Celery, and Spikerush. These species occupy more space in certain areas and may allow for those areas to look “weedier” than in 2019, but many other areas declined. This finding also supports the measured aquatic vegetation biovolume with increased cover in the 0-5% and 20-40% categories that would correspond to increases in the native species just mentioned in terms of position in the water column. Some areas of Wild Celery may represent low biovolume (0-5%) due to the presence of marl deposits that weigh the leaf blades down. Changes in all aquatic vegetation communities occur each year on inland lakes with each year demonstrating different plant frequencies and distributions. Relative abundance for each aquatic plant species is shown in Table 16. Photos of all native aquatic plants are shown below in Figures 14-31. The emergent macrophytes may be found along the shoreline of the lake. Additionally, the lower-growing species were found throughout the littoral zone and the higher-growing pondweeds were present in the deeper waters of the littoral zone where they were protected from wave action.

The dominant aquatic plants in the main part of the lake in 2022 included the native macro alga Chara (38.7% of the sampling locations), the submersed, large-leaf pondweed (6.8% of the sampling locations), and Illinois pondweed (5.0% of the sampling locations). The pondweeds grow tall in the water column and serve as excellent fish cover. Higgins Lake contains a very low amount of aquatic vegetation for a lake of its size and thus protection of all native aquatic plant species is critical for the lake ecosystem. The relative abundance of rooted aquatic plants (relative to non-rooted plants) in the lake suggests that the sediments are the primary source of nutrients (relative to the water column), since these plants obtain most of their nutrition from the sediments. The non-vascular aquatic moss *Taxiphyllum* sp. (Java moss) was also found in a few locations in deeper waters as it can grow well in lower light conditions. It was found growing along the bottom on rocks and larger substrates.

Table 15. Higgins Lake native aquatic vascular plants (July 15-20, and August 2-5, 2022) and 2019 individual species frequencies. Note: RLS also found the aquatic moss (*Taxiphyllum* sp.) which is non-vascular.

<i>Native Aquatic Plant Species Name</i>	<i>Native Aquatic Plant Common Name</i>	<i>2019 Freq</i>	<i>2022 Freq</i>	<i>Native Aquatic Plant Growth Habit</i>
<i>Chara vulgaris</i>	Muskgrass	50.1	38.7	Submersed, Rooted
<i>Tolypella</i> sp.	Native Stonewort	0.2	0.1	Submersed, Rooted
<i>Stuckenia pectinata</i>	Sago Pondweed	3.4	0.1	Submersed, Rooted
<i>Potamogeton zosteriformis</i>	Flat-stem Pondweed	0.04	0.6	Submersed, Rooted
<i>Potamogeton illinoensis</i>	Illinois Pondweed	6.5	5.0	Submersed, Rooted
<i>Potamogeton nodosus</i>	American Pondweed	0	0.2	Submersed, Rooted
<i>Potamogeton perfoliatus</i>	Clasping-leaf Pondweed	0.3	2.8	Submersed, Rooted
<i>Potamogeton richardsonii</i>	Clasping-leaf Pondweed	0.3	2.8	Submersed, Rooted
<i>Potamogeton amplifolius</i>	Large-leaf Pondweed	7.5	6.8	Submersed, Rooted
<i>Potamogeton gramineus</i>	Variable-leaf Pondweed	7.5	0.2	Submersed, Rooted
<i>Potamogeton pusillus</i>	Slender Pondweed	0.7	0.4	Submersed, Rooted
<i>Potamogeton foliosus</i>	Leafy Pondweed	0.2	0.2	Submersed, Rooted
<i>Potamogeton natans</i>	Floating-leaf Pondweed	0.5	0.1	Submersed, Rooted
<i>Potamogeton praelongus</i>	White-stem Pondweed	0.08	0.04	Submersed, Rooted
<i>Potamogeton diversifolius</i>	Water thread Pondweed	0.04	0.04	Submersed, Rooted
<i>Myriophyllum sibiricum</i>	Northern Watermilfoil	0.2	0.2	Submersed, Rooted
<i>Elodea canadensis</i>	Common Waterweed	1.2	0.9	Submersed, Rooted
<i>Vallisneria americana</i>	Wild Celery	2.5	2.8	Submersed, Rooted
<i>Najas guadalupensis</i>	Southern Naiad	5.0	1.0	Submersed, Rooted
<i>Typha latifolia</i>	Cattails	0.04	0.04	Emergent
<i>Eleocharis acicularis</i>	Spikerush	0.04	0.1	Emergent

Table 16. Higgins Lake native aquatic vascular plants (July 15-20, and August 2-5, 2022) by relative abundance.

<i>Native Aquatic Plant Species Name</i>	<i>Native Aquatic Plant Common Name</i>	<i>“a” Level</i>	<i>“b” Level</i>	<i>“c” Level</i>	<i>“d” Level</i>
<i>Chara vulgaris</i>	Muskgrass	354	300	279	60
<i>Tolypella</i> sp.	Native Stonewort	1	1	0	0
<i>Stuckenia pectinata</i>	Sago Pondweed	2	1	0	0
<i>Potamogeton zosteriformis</i>	Flat-stem Pondweed	14	2	0	0
<i>Potamogeton illinoensis</i>	Illinois Pondweed	38	86	4	0
<i>Potamogeton nodosus</i>	American Pondweed	0	4	0	0
<i>Potamogeton perfoliatus</i>	Clasping-leaf Pondweed	53	20	0	0
<i>Potamogeton richardsonii</i>	Clasping-leaf Pondweed	3	1	0	0
<i>Potamogeton amplifolius</i>	Large-leaf Pondweed	120	51	2	1
<i>Potamogeton gramineus</i>	Variable-leaf Pondweed	2	1	1	0
<i>Potamogeton pusillus</i>	Slender Pondweed	2	8	0	0
<i>Potamogeton foliosus</i>	Leafy Pondweed	3	2	0	0
<i>Potamogeton natans</i>	Floating-leaf Pondweed	2	1	0	0
<i>Potamogeton praelongus</i>	White-stem Pondweed	0	1	0	0
<i>Potamogeton diversifolius</i>	Water thread Pondweed	1	0	0	0
<i>Myriophyllum sibiricum</i>	Northern Watermilfoil	1	2	1	0
<i>Elodea canadensis</i>	Common Waterweed	8	10	3	3
<i>Vallisneria americana</i>	Wild Celery	39	30	3	0
<i>Najas guadalupensis</i>	Southern Naiad	0	0	1	1
<i>Typha latifolia</i>	Cattails	0	0	0	1
<i>Eleocharis acicularis</i>	Spikerush	2	0	1	0

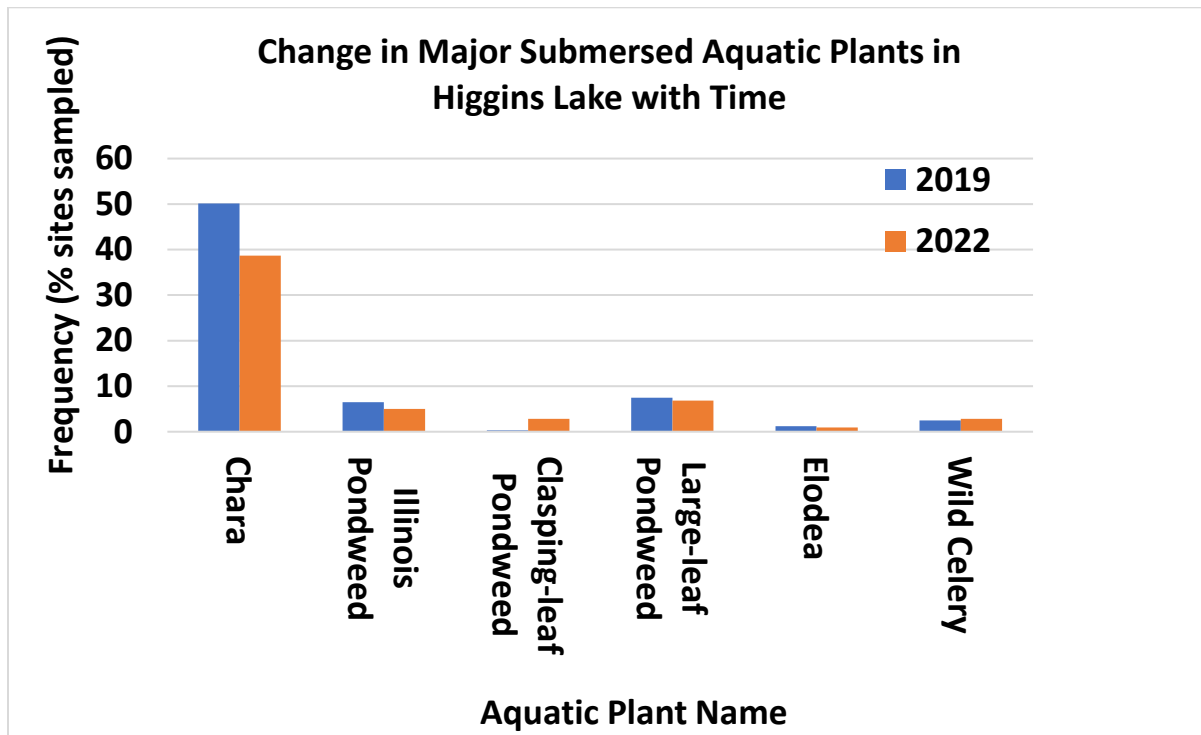


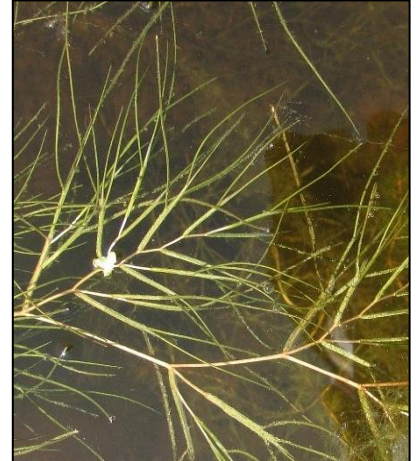
Figure 14. Change in major submersed aquatic plant taxa present in Higgins Lake 2019 and 2022.



**Figure 15. Chara
(Muskgrass)**



Figure 16. *Tolypella* sp.



**Figure 17. Sago
Pondweed**



**Figure 18. Flat-Stem
Pondweed**



**Figure 19. Illinois
Pondweed**



**Figure 20. Claspingleaf
Pondweed**



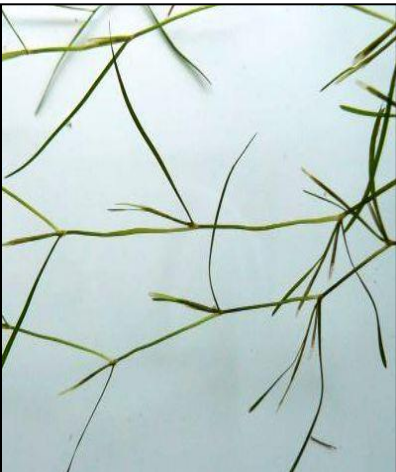
**Figure 21. Large-leaf
Pondweed**



**Figure 22. Variable-leaf
Pondweed**



**Figure 23. Slender
Pondweed**



**Figure 24. Leafy
Pondweed**



**Figure 25. White-stem
Pondweed**



**Figure 26. Water thread
Pondweed**



Figure 27. Northern Watermilfoil



Figure 28. Common Waterweed



Figure 29. Wild Celery



Figure 30. Southern Naiad



Figure 31. Cattails



Figure 32. Spikerush

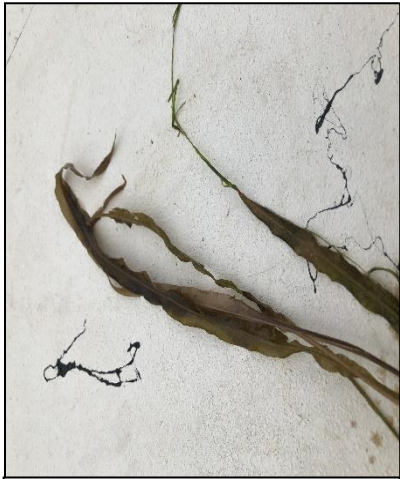


Figure 33. American Pondweed

4.2.2 Higgins Lake Exotic Aquatic Macrophytes

Exotic aquatic plants (macrophytes) are not native to a particular site and are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially if the lake has public access sites), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem. Eurasian Watermilfoil (*Myriophyllum spicatum*; Figure 34) is an exotic aquatic macrophyte first documented in the United States in the 1880's (Reed 1997), although other reports (Couch and Nelson 1985) suggest it was first found in the 1940's.

In recent years, this species has hybridized with native milfoil species to form hybrid species. Eurasian Watermilfoil has since spread to thousands of inland lakes in various states through the use of boats and trailers, waterfowl, seed dispersal, and intentional introduction for fish habitat. Eurasian Watermilfoil is a major threat to the ecological balance of an aquatic ecosystem through causation of significant declines in favorable native vegetation within lakes (Madsen et al. 1991), in that it forms dense canopies and may limit light from reaching native aquatic plant species (Newroth 1985; Aiken et al. 1979). Additionally, Eurasian Watermilfoil can alter the macroinvertebrate populations associated with particular native plants of certain structural architecture (Newroth 1985).

Approximately 4.0 acres of Eurasian Watermilfoil were found in Higgins Lake during the July 15-20, 2022 survey. This includes the milfoil present in the main basin as well as in the south Lagoon. Eurasian Watermilfoil growth in Higgins Lake is capable of producing dense surface canopies in shallow areas; however, many plant beds were small and covered with marl precipitate which can reduce the growth rate of the plant. The species of invasive aquatic plants present, and relative abundance of each plant are recorded and then the amount of cover in the littoral zone is calculated. Exotic aquatic plant species that have been found in Higgins Lake are shown in Table 17 below and discussions of key invasives also follow below. Additionally, some milfoil was found to have Zebra Mussels attached to the stems which allows the plants to serve as another substrate for these invasive mussels. The distribution of milfoil throughout Higgins Lake is shown below in Figure 35.



Figure 34. Hybrid Eurasian Watermilfoil plant with seed head and fragments.

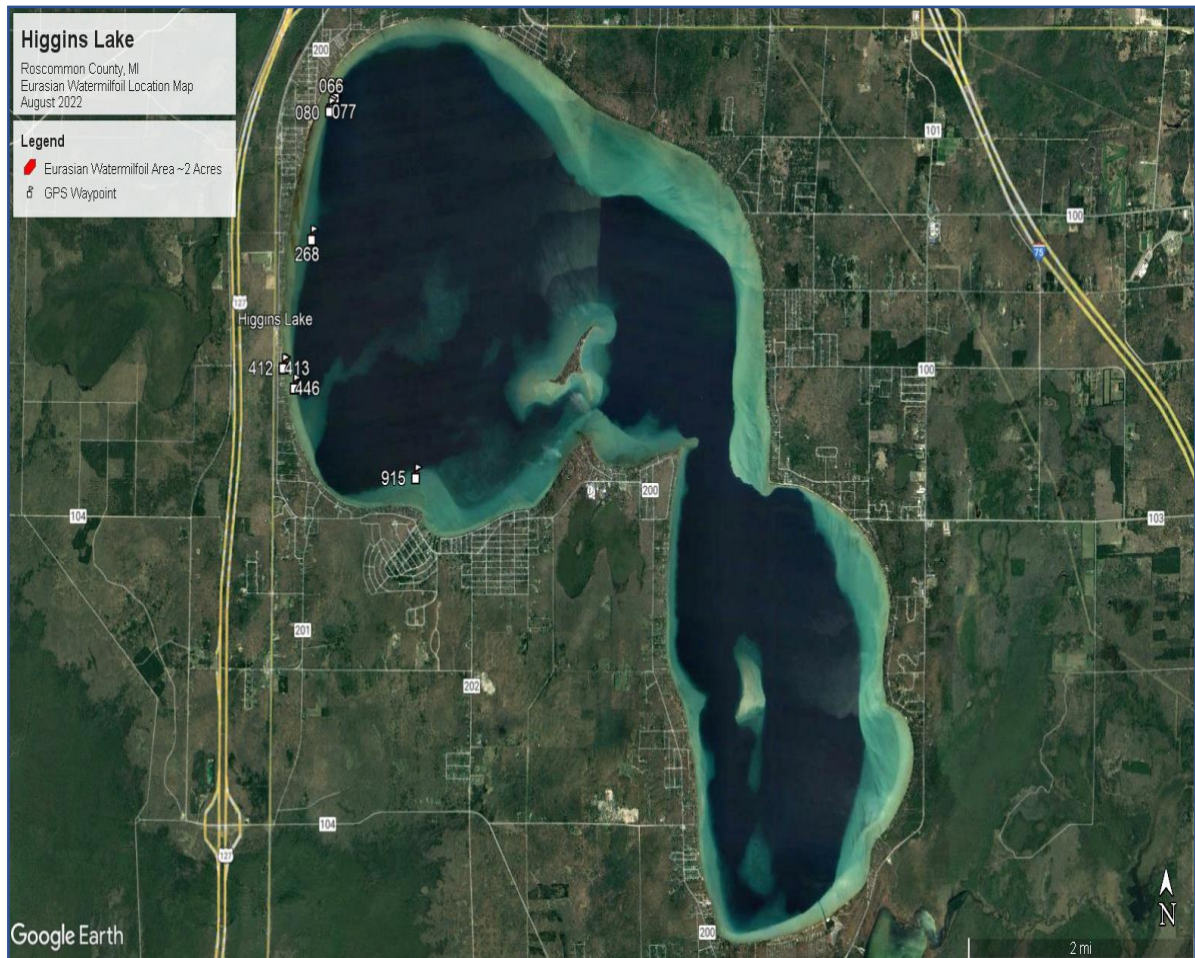


Figure 35. EWM distribution in Higgins Lake (July 15-20, and August 2-5, 2022). Note: Additional growth was reported by lake professionals later in the 2022 season which can occur at any time. This map does not show the EWM present in the south state park lagoon, where active removal was being conducted.

Starry Stonewort (*Nitellopsis obtusa*; Figure 36) is an invasive macro alga that has invaded many inland lakes and was originally discovered in the St. Lawrence River. The “leaves” appear as long, smooth, angular branches of differing lengths. The alga has been observed in dense beds at depths beyond several meters in clear inland lakes and can grow to heights in excess of a few meters. It prefers clear alkaline waters and has been shown to cause significant declines in water quality and fishery spawning habitat. Individual fragments can be transported to the lake via waterfowl or boats. These conditions make Higgins Lake vulnerable to its growth. It is light-limited in the deeper waters, although some free-floating fragments were found in the deeper waters. The shallows are often high-energy which may also slow down its colonization. **Approximately 2.2 acres were found throughout the lake were present in the main lake basin and in the South Park boat launch lagoon (Figure 37).**

This lagoon is currently acting as a breeding ground for the Starry Stonewort which is allowing for spread into the open waters of the lake. A rigorous management program is proposed below for this plant and Eurasian Watermilfoil.



Figure 36. A fragment of Starry Stonewort.

Table 17. Higgins Lake exotic aquatic plant species (August 21-23, 2019 and July 15-20, and August 2-5, 2022).

<i>Exotic Aquatic Plant Species</i>	<i>Exotic Aquatic Plant Common Name</i>	<i>Exotic Aquatic Plant Growth Habit</i>	<i>2019 Abundance</i>	<i>2022 Abundance</i>
<i>Myriophyllum spicatum</i>	Eurasian Watermilfoil	Submersed	21.2 acres	4.0 acres
<i>Nitellopsis obtusa</i>	Starry Stonewort	Submersed	2.5 acres	2.2 acres

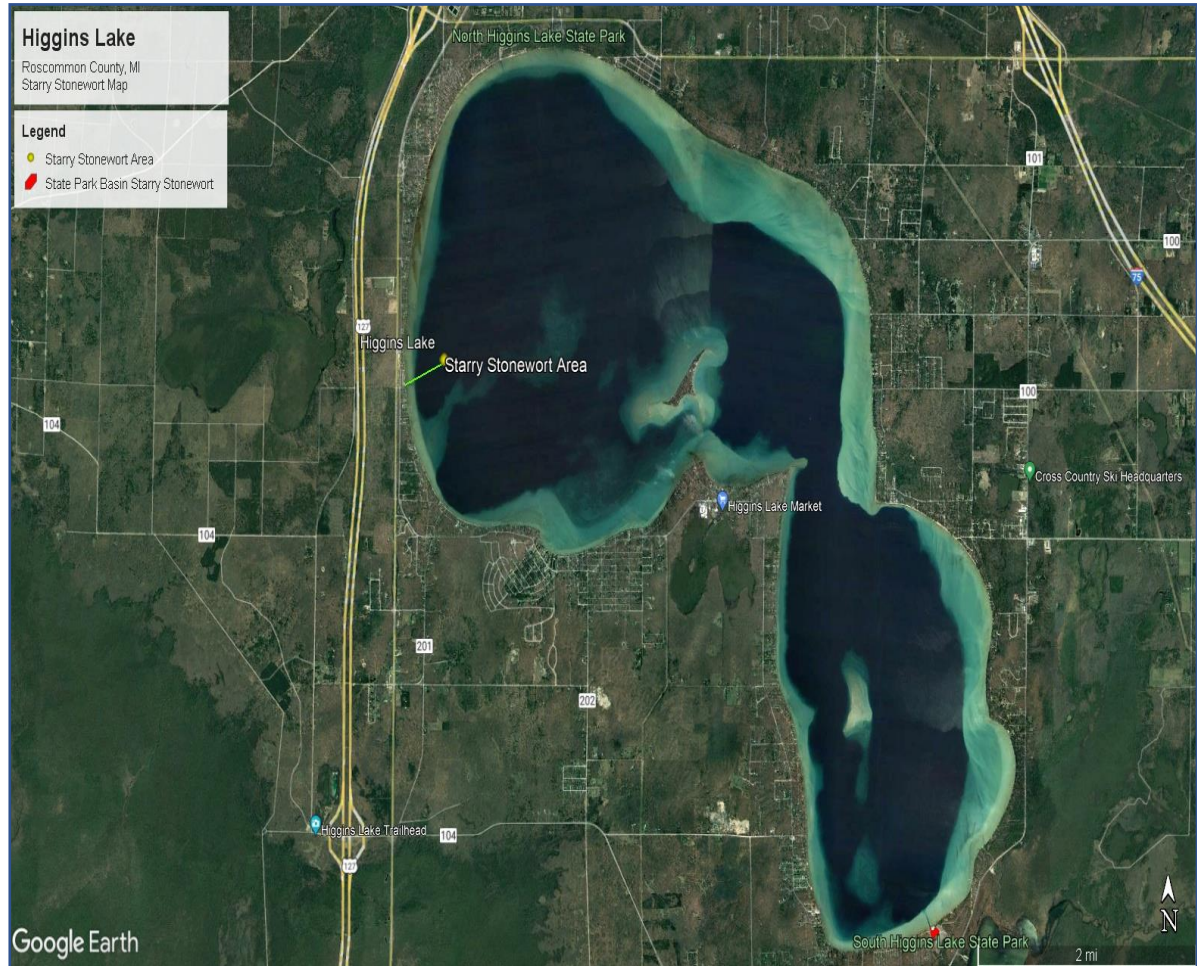


Figure 37. Starry Stonewort distribution in the main basins of Higgins Lake (July 15-20, and August 2-5 , 2022). A total of 0.2 acres of Starry Stonewort was found in the main basin and an additional 2.0 acres combined with EWM in the South State Park Lagoon. The total of Starry Stonewort found in 2022 was 2.2 acres.

4.3 Higgins Lake Food Chain: Zooplankton and Macroinvertebrates

The zooplankton and macroinvertebrates make up the food chain base in an aquatic ecosystem and thus are integral components. Zooplankton are usually microscopic, but some can be seen with the unaided eye. Macroinvertebrates can be readily seen and are also known as aquatic insects or bugs. The zooplankton migrate throughout the water column of the lake according to daylight/evening cycles and are prime food for the lake fishery. Macroinvertebrates can be found in a variety of locations including on aquatic vegetation, near the shoreline, and in the lake bottom sediments. The biodiversity and relative abundance of both food chain groups are indicative of water quality status and productivity.

Lake Zooplankton

A zooplankton tow using a Wildco® pelagic plankton net (63 micrometer) with collection jar (Figure 38) was conducted by RLS scientists on August 12, 2022 over the 5 deep basins of Higgins Lake. The plankton net was left at depth for 30 seconds and then raised slowly to the surface at an approximate rate of 4 feet/second. The net was then raised above the lake surface and water was splashed on the outside of the net to dislodge any zooplankton from the net into the jar. The jar was then drained into a 125-mL bottle with a CO₂ tablet to anesthetize the zooplankton. The sample was then preserved with a 70% ethyl alcohol solution. Plankton sub-samples (in 1 ml aliquots) were analyzed under a Zeiss® dissection scope with the use of a Bogorov counting chamber. Taxa were keyed to species when possible and are shown in Tables 18-22 below.



Figure 38. A zooplankton collection tow net.

Table 18. Zooplankton taxa and count data from Higgins Lake Deep Basin #1 (August 12, 2022).

Cladocerans	Count	Copepods	Count	Rotifers	Count
<i>Daphnia longiremis</i>	29	<i>Cyclops</i> sp.	6	<i>Keratella</i> sp.	1
<i>Daphnia</i> spp.	15	<i>Nauplius</i> (var)	9		
<i>Leptodiptomus</i> sp.	8	<i>Mesocyclops edax</i>	43		
<i>Bosmina</i> sp.	14	<i>Acanthocyclops</i> sp.	4		
<i>Ceriodaphnia</i> sp.	7	<i>Nauplius</i> spp. (var)	6		

Table 19. Zooplankton taxa and count data from Higgins Lake Deep Basin #2 (August 12, 2022).

Cladocerans	Count	Copepods	Count	Rotifers	Count
<i>Daphnia longiremis</i>	21	<i>Cyclops</i> sp.	9	<i>Keratella</i> sp.	2
<i>Leptodiptomus</i> sp.	8	<i>Mesocyclops edax</i>	16	<i>Asplanchna</i>	4
<i>Bosmina</i> sp.	37	<i>Nauplius</i> (var)	3		
<i>Ceriodaphnia</i> sp.	8				
<i>Daphnia</i> spp.	12				

Table 20. Zooplankton taxa and count data from Higgins Lake Deep Basin #3 (August 12, 2022).

Cladocerans	Count	Copepods	Count	Rotifers	Count
<i>Daphnia</i> spp.	17	<i>Cyclops</i> sp.	9	<i>Keratella</i>	1
<i>Leptodiptomus</i> sp.	6	<i>Mesocyclops edax</i>	22		
<i>Bosmina</i> sp.	45	<i>Acanthocyclops</i> sp.	4		
<i>Ceriodaphnia</i> sp.	8	<i>Nauplius</i> (var)	4		
<i>Daphnia longiremis</i>	7				

Table 21. Zooplankton taxa and count data from Higgins Lake Deep Basin #4 (August 12, 2022).

Cladocerans	Count	Copepods	Count	Rotifers	Count
<i>Daphnia</i> spp.	13	<i>Nauplius</i> spp.	2	<i>Asplanchna</i>	1
<i>Daphnia longiremis</i>	5	<i>Cyclops</i> sp.	8		
<i>Leptodiptomus</i> sp.	7	<i>Mesocyclops edax</i>	5		
<i>Bosmina</i> sp.	24	<i>Acanthocyclops</i> sp.	5		
<i>Ceriodaphnia</i> sp.	6				
<i>Diaphanosoma</i> sp.	2				

Table 22. Zooplankton taxa and count data from Higgins Lake Deep Basin #5 (August 12, 2022).

Cladocerans	Count	Copepods	Count	Rotifers	Count
<i>Daphnia longiremis</i>	8	<i>Cyclops</i> sp.	8	<i>Keratella</i> sp.	1
<i>Leptodiptomus</i> sp.	5	<i>Mesocyclops edax</i>	15	<i>Asplanchna</i>	2
<i>Daphnia</i> spp.	7	<i>Nauplius</i> (var)	9		
<i>Bosmina</i> sp.	29				
<i>Ceriodaphnia</i> sp.	16				

Benthic Macroinvertebrates

Freshwater macroinvertebrates are ubiquitous, as even the most impacted lake contains some representatives of this diverse and ecologically important group of organisms. Benthic macroinvertebrates are key components of lake food webs both in terms of total biomass and in the important ecological role that they play in the processing of energy. Others are important predators, graze algae on rocks and logs, and are important food sources (biomass) for fish.

The removal of macroinvertebrates has been shown to impact fish populations and total species richness of an entire lake or stream food web (Lenat and Barbour 1994). In the food webs of lakes, benthic macroinvertebrates have an intermediate position between primary producers and higher trophic levels (fish) on the other side. Hence, they play an essential role in key ecosystem processes (food chain dynamics, productivity, nutrient cycling, and decomposition).

Restorative Lake Sciences collected benthic (bottom) aquatic macroinvertebrate samples at five locations (Figure 39) using an Ekman hand dredge sampler (Figure 40) on August 12, 2022 (Table 23). Macroinvertebrate samples were placed in small plastic buckets and analyzed in the RLS wet laboratory within 48 hours after collection using a hard-plastic sorting tray, tweezers, and a Zeiss® dissection microscope under 1X, 3X, and 10X magnification power. Macroinvertebrates were taxonomically identified using a key from: “The Introduction to the Aquatic Insects of North America”, by Merritt, Cummings, and Berg (2008) to at least the family level and genus level whenever possible. All macroinvertebrates were recorded including larval or nymph forms, mussels, snails, worms, or other “macro” life forms.

Genera found in the Higgins Lake sediment samples included midges (Chironomidae), Jute snails (Pleuroceridae), Wheel snails (Planorbidae), Right-handed snails (Lymnaeidae), Left-handed snails (Physidae), Stonefly larvae (Perlidae), and Zebra and Quagga Mussels (Dreissenidae). In 2019, the presence of Asian clams and Banded Mystery Snails was noted, but these were not present in the 2022 samples. Of all the species found, all were native except for the Zebra and Quagga Mussels, the Asian clam, and the Mystery snails. While the majority of the species were native, some are located universally in low quality and high-quality water. The midge larvae family Chironomidae can be found in both high- and low-quality water (Lenat and Barbour 1994). RLS also found native grey crayfish (*Orconectes* sp.) under a few larger rocks in the shelf littoral zone in 2022 as in 2019.

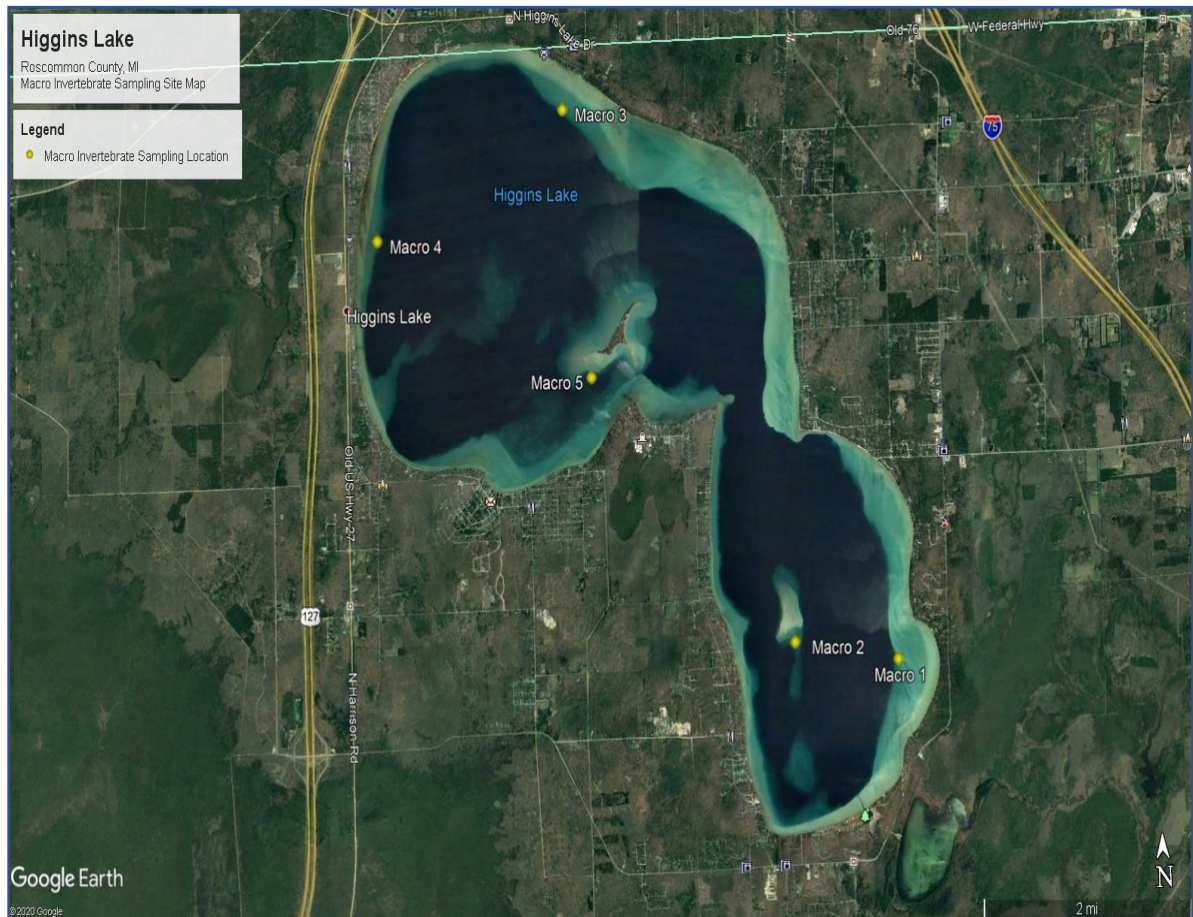


Figure 39. Sampling locations for macroinvertebrates in Higgins Lake (August 12, 2022).



Figure 40. An Ekman hand dredge for sampling lake sediments.

Native lake macroinvertebrate communities can and have been impacted by exotic and invasive species. A study by Stewart and Haynes (1994) examined changes in benthic macroinvertebrate communities in southwestern Lake Ontario following the invasion of Zebra and Quagga mussels (*Dreissena* spp.). They found that *Dreissena* had replaced a species of freshwater shrimp as the dominant species. However, they also found that additional macroinvertebrates actually increased in the 10-year study, although some species were considered more pollution-tolerant than others. This increase was thought to have been due to an increase in *Dreissena* colonies increasing additional habitat for other macroinvertebrates. **The moderate alkalinity of Higgins Lake allows for accelerated growth of Zebra Mussels and Quagga Mussels since they need ample alkalinity (calcium carbonate) for their shells and were prevalent throughout the lake.**

In addition to exotic and invasive macroinvertebrate species, macroinvertebrate assemblages can be affected by land-use. Stewart et al. (2000) showed that macroinvertebrates were negatively affected by surrounding land-use. They also indicated that these land-use practices are important to the restoration and management of lakes. Schreiber et al., (2003) stated that disturbance and anthropogenic land use changes are usually considered to be key factors facilitating biological invasions.

Table 23. Macroinvertebrates found in Higgins Lake, Roscommon County, MI (August 12, 2022).

<i>Site S1</i>	Family	Genus or Species	Number	Common name
	Chironimidae	<i>Chironomus</i> spp.	1	Midges
	Planorbidae	<i>Planorbis</i> sp.	6	Wheel snails
	Perlidae	<i>Capnia</i> sp.	6	Stonefly larvae
	Dreissenidae	<i>Dreissena bugensis</i>	2	Quagga mussels
	Lymnaeidae	<i>Lymnaea</i> sp.	7	Right-handed snail
	Physidae	<i>Physa</i> spp.	12	Left-handed snail
		Total	34	
<i>Site S2</i>	Family	Genus	Number	Common name
	Planorbidae	<i>Planorbis</i> sp.	8	Wheel snails
	Chironomidae	<i>Chironomus</i> spp.	2	Midges
	Dreissenidae	<i>Dreissena polymorpha</i>	1	Zebra mussels
	Lymnaeidae	<i>Lymnaea</i> sp.	7	Right-handed snail
	Physidae	<i>Physa</i> spp.	9	Left-handed snail
	Perlidae	<i>Capnia</i> sp.	4	Stonefly larvae
		Total	31	
<i>Site S3</i>	Family	Genus	Number	Common name
	Perlidae	<i>Capnia</i> sp.	5	Stonefly larvae
	Pleuroceridae	<i>Pachychilus</i> sp.	9	Jute snails
	Planorbidae	<i>Planorbis</i> sp.	7	Wheel snails
	Tipulidae	<i>Tipula</i> sp.	4	Cranefly larvae
		Total	25	
<i>Site S4</i>	Family	Genus	Number	Common name
	Tipulidae	<i>Tipula</i> sp.	6	Cranefly larvae
	Pleuroceridae	<i>Pachychilus</i> sp.	11	Jute snails
	Dreissenidae	<i>Dreissena polymorpha</i>	1	Zebra mussels
	Perlidae	<i>Capnia</i> sp.	7	Stonefly larvae
		Total	25	
<i>Site S5</i>	Family	Genus	Number	Common name
	Tipulidae	<i>Tipula</i> sp.	4	Cranefly larvae
	Chironomidae	<i>Chironomus</i> spp.	1	Midges
	Planorbidae	<i>Planorbis</i> sp.	9	Wheel snails
	Dreissenidae	<i>Dreissena bugensis</i>	2	Quagga mussels
		Total	16	

***Spongilla lacustris* (Freshwater Sponge)**

Spongilla lacustris is a freshwater sponge with a rich green color and rough spicules on its surface. These organisms are in the animal Kingdom and have holes in them to allow for water passage to bring food such as algae and bacteria (Gernert et al., 2005) into their cells. The sponges have a large opening called an osculum which also allows for filtration and entry of food sources. *S. lacustris* is an indicator of clean and healthy waters and is found in North America, Europe, and Asia. The sponge grows until October in north temperate climates and overwinters as gemmules (Frost et al., 1982). The sponge has the ability to reproduce both sexually and asexually. **This sponge was found in many areas of Higgins Lake and was mostly associated with rocks and macrophytes in the lake in deeper waters** (Figure 41).



Figure 41. *Spongilla lacustris* from Higgins Lake.

4.4 Higgins Lake Fishery

Currently, Higgins Lake has healthy populations of Walleye, Smallmouth Bass, Northern Pike, Yellow Perch, Lake Trout, Whitefish, White Sucker, Brown Trout, Rainbow Trout, and Spot tail Shiners. **The MDNR (Michigan Department of Natural Resources) has an extensive stocking history in Higgins Lake beginning with Lake and Brown Trout in 1979 and continuing throughout 2022 with Lake, Brown, and Rainbow Trout.** A summary table showing the Higgins Lake fish stocking history with the quantity and average length stocked is shown below in Table 24.

Table 24. Fish stocking history in Higgins Lake (MDNR; 1979-2022).

Year	Fish Stocked	# Fish Stocked	Average Length Range (inches)
1979	Lake Trout; Brown Trout	50,000;17,000	4.9;6.7
1980	Lake Trout; Brown Trout	50,000;25,000	4.9;6.9
1981	Lake Trout; Splake; Brown Trout	25,000; 22,000;25,000	5.2; 5.7-6.1;5.1-7.2
1982	Splake; Lake Trout; Brown Trout; Atlantic Salmon	25,000; 25,000;20,000;1,629	7.2-7.4;5.5;6.7;4.5
1983	Splake; Brown Trout	50,000;26,900	5.7-6.3;5.2
1984	Lake Trout	125,798	3.2-29.7
1985	Splake; Lake Trout; Brown Trout	25,000; 25,000;20,330	5.2;5.2;6.3
1986	Rainbow Trout; Brown Trout	8,000;4,600	6.9;7.1
1987	Lake Trout; Brown Trout	1,550;17,672	7.4-20.9;6.7-7.2
1991	Rainbow Trout; Lake Trout; Brown Trout	7,055; 34,900; 65,000	6.7; 5.2;5.8-6.7
1995	Rainbow Trout	81,644	2.9
2006	Rainbow Trout	2,000	7.7
2008	Rainbow Trout	27,400	6.3-7.0
2009	Rainbow Trout	32,300	6.7
2010	Rainbow Trout; Brown Trout	25,528;12,008	5.9;4.0-5.1
2011	Rainbow Trout; Brown Trout	25,900;15,000	5.8-6.4;4.0
2012	Rainbow Trout; Lake Trout	30,000;40,000	6.9;6.0
2013	Rainbow Trout; Lake Trout	30,498;45,000	7.1;4.9-5.5
2014	Rainbow Trout; Lake Trout	31,000;39,388	6.8;5.6
2015	Rainbow Trout; Lake Trout	31,000;31,300	6.1-6.5;5.4
2016	Rainbow Trout; Lake Trout	30,000;35,944	6.5;5.9-6.5
2017	Rainbow Trout; Lake Trout	40,377;40,158	6.1-6.2;5.6

2018	Rainbow Trout; Lake Trout; Brown Trout	60,000;40,500;25,000	3.4-7.1;5.0;7.2
2019	Rainbow Trout; Lake Trout; Brown Trout	27,500;31,973;25,000	7.2;5.3;7.4
2020	Brown Trout; Lake Trout; Rainbow Trout	27,464; 34,755; 25,300	7.1-19.5; 5.5; 7.2-17.8
2021	Brown Trout; Lake Trout	25,000; 67,017	7.0; 3.7-5.5
2022	Lake Trout; Rainbow Trout; Brown Trout	142,100; 11,260; 25,000	3.9-5.4; 7.0; 7.2

5.0 HIGGINS LAKE MANAGEMENT METHODS

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

5.1 Higgins Lake Aquatic Plant Management

The management of submersed nuisance invasive aquatic plants is necessary in Higgins Lake due to accelerated growth and distribution. Management options should be environmentally and ecologically-sound and financially feasible. Options for control of aquatic plants are limited yet are capable of achieving strong results when used properly. Implementation of more growth of favorable native aquatic plants (especially the low growing native plants) in Higgins Lake to provide for a healthier lake is recommended though this may require significant increases in water clarity along with reductions in invasive plant cover. All aquatic vegetation should be managed with solutions that will yield the longest-term results. The following sections detail invasive species prevention and community education.

5.1.1 *Aquatic Invasive Species Prevention & Boat Washing Stations*

An exotic species is a non-native species that does not originate from a particular location. When international commerce and travel became prevalent, many of these species were transported to areas of the world where they did not originate. Due to their small size, insects, plants, animals, and aquatic organisms may escape detection and be unknowingly transferred to unintended habitats.

The first ingredient to successful prevention of unwanted transfers of exotic species to Higgins Lake is awareness and education (Figures 42 and 43). The exotic species of concern have been listed in this report. Other exotic species on the move could be introduced to the riparians around Higgins Lake through the use of a professionally developed educational newsletter or through public workshops on the health of the Higgins Lake ecosystem.

Public boat launches are a primary area of vector transport for all invasive species and thus boat washing stations have become more common. With over 13 million registered boaters in the U.S. alone, the need for reducing transfer of aquatic invasive species (AIS) has never been greater. The Minnesota Sea Grant program identifies five major boat wash scenarios which include: 1) Permanent washing stations at launch sites, 2) Portable drive-thru or transient systems, 3) Commercial car washes, 4) Home washing, and 5) Mandatory vs. volunteer washing.

Boat washing stations promote the Clean Waters Clean Boats volunteer education program by educating boaters to wash boating equipment (including trailers and bait buckets) before entry into every lake. Critical elements of this education include: 1) How to approach boaters, 2) Demonstration of effective boat and trailer inspections and cleaning techniques, 3) The recording of important information, 4) Identification of high-priority invasive species, and 5) Sharing findings with others.

Three boat washing stations are in place on Higgins Lake, which allows for the HLPOA, HLF, MDNR, EGLE, and others to collaborate efforts. Figures 44-45 show a boat washing station at the South State Park and the use of that station to prevent the spread of invasives into Higgins Lake.

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

- 1) USDA: <https://www.invasivespeciesinfo.gov/us/Michigan>
- 2) Michigan Wildlife Federation Invasive animals, plants list, and native plants/animals list: <https://www.Michiganwildlife.org/wildlife>
- 3) Stop Aquatic Hitchhikers!: www.protectyourwaters.net

Recently, MSU partnered with EGLE to study the various forms of boat washing stations (including the innovative CD3 units) on the lake to analyze effectiveness of invasive removal, behavior patterns and preference for use, and short and long-term cost effectiveness of each system. This will assist in the placement of specific types of wash stations around other portals of entry around the lake. Figure 46 shows all of the probable areas of boat launch access around Higgins Lake. Boat washing stations and invasive species prevention signs are recommended at all of these sites where practical.



Figure 42. An aquatic invasive prevention sign for public access sites.



Figure 43. An aquatic hitchhiker (milfoil).



Figure 44. A public boat washing station at North Higgins Lake State Park.



Figure 45. A responsible boat owner using the Higgins Lake boat washing station in 2019.

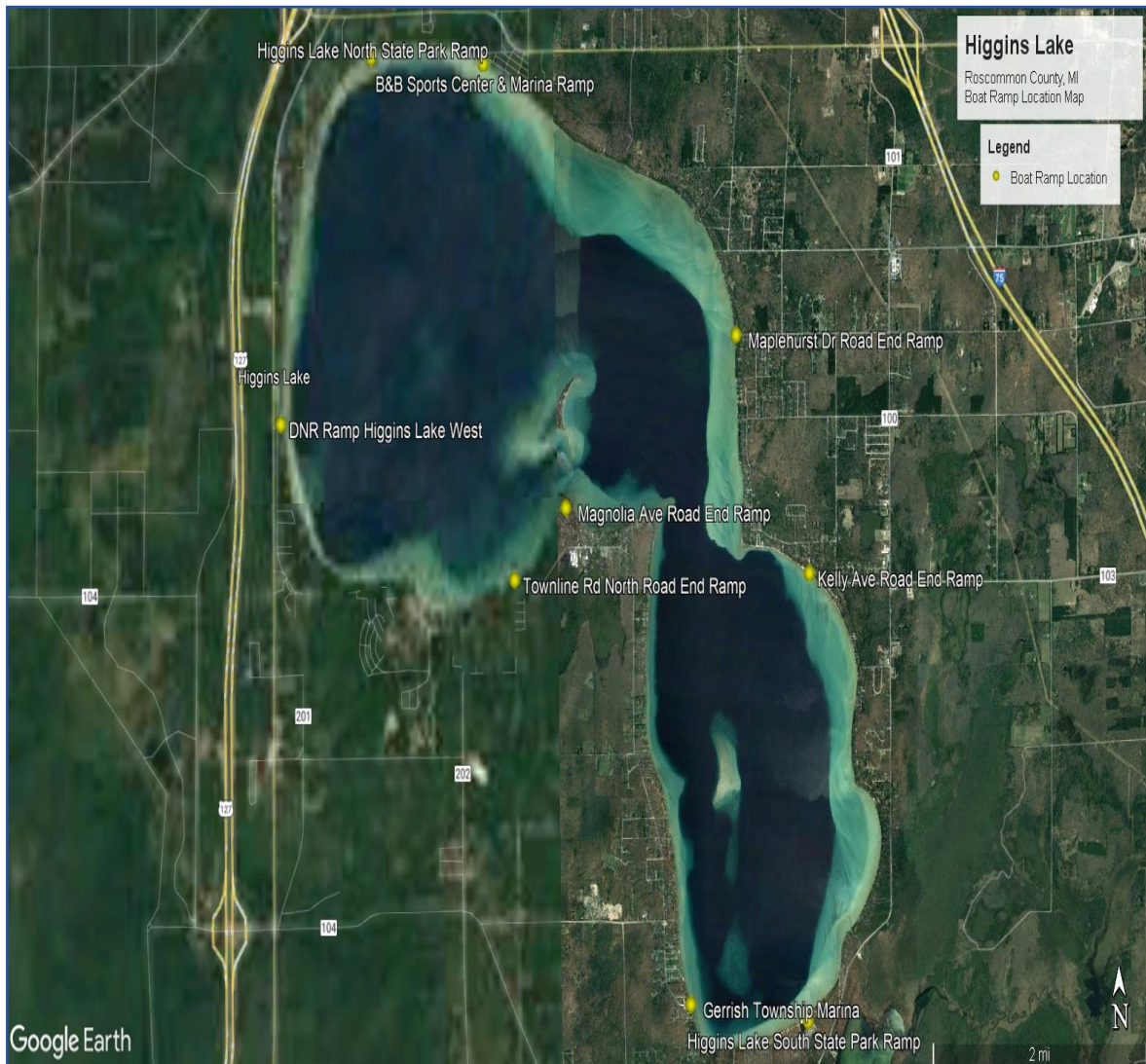


Figure 46. Higgins Lake boat launch access sites (RLS, 2022).

Zebra Mussels and Quagga Mussels

Zebra Mussels (*Dreissena polymorpha*; Figure 47) were first discovered in Lake St. Clair in 1988 and likely arrived in ballast water or on shipping vessels from Europe (McMahon 1996). They are easily transferred to other lakes because they inherit a larval (nearly microscopic) stage where they can easily avoid detection. The mussels then grow into the adult (shelled) form and attach to substrates (i.e. boats, rafts, docks, pipes, aquatic plants, and lake bottom sediments) with the use of byssal threads. The fecundity (reproductive rate) of female Zebra Mussels is high, with as many as 40,000 eggs laid per reproductive cycle and up to 1,000,000 in a single spawning season (Mackie and Schlosser 1996).

Although the mussels only live 2-3 years, they are capable of great harm to aquatic environments. In particular, they have shown selective grazing capabilities by feeding on the preferred zooplankton food source (green algae) and expulsion of the non-preferred blue green algae (cyanobacteria).

Additionally, they may decrease the abundance of beneficial diatoms in aquatic ecosystems (Holland 1993). Such declines in favorable algae, can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations. Zebra Mussels are viewed by some as beneficial to lakes due to their filtration capabilities and subsequent contributions to increased water clarity. However, such water clarity may allow other photosynthetic aquatic plants to grow to nuisance levels (Skubinna et al. 1995).

Quagga Mussels (*Dreissena bugensis*; Figure 47) are native to the Ukraine and have created an economical burden to the Great Lakes fishery due to their great ability to alter the planktonic food chain in the lakes. They currently outrank the Zebra Mussels in abundance in the Great Lakes and are capable of filtering larger quantities of water and therefore assimilating more plankton. These mussels were shown to be highly selective in choosing naked flagellates such as *Rhodomonas* as well as larger diatoms (NOAA research; noaa.gov). Both Zebra and Quagga mussels are prevalent in Higgins Lake which has likely led to increased water clarity through reduction of planktonic algae in the water column.

The recommended prevention protocols for further introduction of zebra and quagga mussels includes steam-washing all boats, boat trailers, jet-skis, and floaters prior to placing them into Higgins Lake. Fishing poles, lures, and other equipment used in other lakes (and especially the Great Lakes) should also be thoroughly steam-washed before use in Higgins Lake. Additionally, all solid construction materials (if recycled from other lakes) must also be steam-washed. Boat transom wells must always be steam-washed and emptied prior to entry into the lake. Excessive waterfowl should also be discouraged from the lake since they are a natural transportation vector of the microscopic zebra mussel larvae or mature adults. Merganser control currently being executed for swimmer's itch control may assist with reductions in mussel transport for future years.

There are also concerns about other invasive bivalves such as the Asian Clam (*Corbicula fluminea*; Figure 48). This clam is native to eastern and southern Asia. It was first noted in the Columbia River in Washington in 1938 but has now been located in 44 states. Clam larvae can attach to bait, boats, and vegetation or waterfowl, among many other things. The clams grow quickly and around 2,000 clams can occupy one square meter. These clams are hermaphroditic and can cross and self-fertilize. Like the zebra and quagga mussels, they also utilize byssal threads to attachment. They use the sediments and the water column as nutrition sources. They are not present in Higgins Lake but are on the move.



Figure 47. Zebra Mussels and Quagga Mussels
(Photo courtesy of Michigan Sea Grant).



Figure 48. An Asian Clam. ©Restorative Lake Sciences.

Invasive Aquatic Plants

In addition to Eurasian Watermilfoil (*M. spicatum*), many other invasive aquatic plant species have been introduced into waters of the North Temperate Zone. The majority of exotic aquatic plants do not depend on high water column nutrients for growth, as they are well-adapted to using sunlight and minimal nutrients for successful growth but excess nutrients often result in exacerbated growth. These species have similar detrimental impacts to lakes in that they decrease the quantity and abundance of native aquatic plants and associated macroinvertebrates and consequently alter the lake fishery. Such species include *Hydrilla verticillata* (Figure 49) and *Trapa natans* (Water Chestnut; Figure 50). *Hydrilla* was introduced to waters of the United States from Asia in 1960 (Blackburn et al. 1969) and is a highly problematic submersed, rooted, aquatic plant in tropical waters. Many years ago, *Hydrilla* was found in Lake Manitou (Indiana, USA) and the lake public access sites were immediately quarantined in an effort to eradicate it. *Hydrilla* retains many physiologically distinct reproductive strategies which allow it to colonize vast areas of water and to considerable depths, including fragmentation, tuber and turion formation, and seed production. Currently, the methods of control for *Hydrilla* include the use of chemical herbicides, rigorous mechanical harvesting, and Grass Carp (*Ctenopharyngodon idella* Val.), with some biological controls currently being researched.

Water Chestnut (*Trapa natans*) is a non-native, annual, submersed, rooted aquatic plant that was introduced into the United States in the 1870's yet may be found primarily in the northeastern states. The stems of this aquatic plant can reach lengths of 12-15 feet, while the floating leaves form a rosette on the lake surface. Seeds are produced in July and are extremely thick and hardy and may last for up to 12 years in the lake sediment.

If stepped on, the seed pods may even cause deep puncture wounds to those who recreate on the lakes. Methods of control involve the use of mechanical removal and chemical herbicides. Biological controls are not yet available for the control of this aquatic invasive plant.

Additional invasives that have been recently located in the Midwest include the following:

1. ***Cabomba caroliniana* (Fanwort; Figure 51):** This submersed aquatic plant is rooted and can fragment readily and may produce flowers on the surface in shallow waters. This plant can survive out of the sediment (free-floating) for several weeks and thus makes it a spread threat.
2. ***Hydrocharis morsus-ranae* (European Frog bit; Figure 52):** This plant is free-floating and can move around a lake, despite having a well-developed root system. It can spread with the formation of runners and form large, dense mats on the lake surface and adjacent to shoreline areas.
3. ***Hydrocotyle americana* (Water Pennywort; Figure 53):** This floating-leaved plant can grow adjacent to lake shorelines and in shallow waters such as bogs and ponds. It can spread through the production of underground stolons and tubers which can be dense.
4. ***Marsilea quadrifolia* (European Water clover; Figure 54):** This floating-leaved aquatic plant is sold as a pond or shoreline ornamental and thus is a threat to lake shoreline habitats. The plant can grow up to 8 inches tall and can form very dense stands that can outcompete other native shoreland species. It is able to adjust its angle to harvest more sunlight for enhanced growth.



Figure 49. Hydrilla



Figure 50. Water Chestnut



Figure 51. Fanwort



Figure 52. European Frog bit

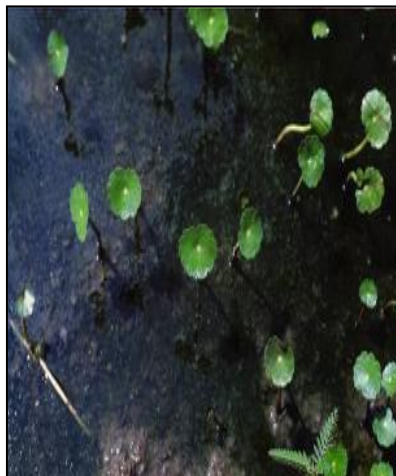


Figure 53. Water Pennywort



Figure 54. European Water Clover

5.1.2 Aquatic Herbicides and Applications

The use of aquatic chemical herbicides is regulated by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) and requires a permit. Aquatic herbicides are generally applied via an airboat or skiff equipped with mixing tanks and drop hoses (Figure 55). The permit contains a list of approved herbicides for a particular body of water, as well as dosage rates, treatment areas, and water use restrictions. Contact and systemic aquatic herbicides are the two primary categories used in aquatic systems.

Contact herbicides such as diquat, flumioxazin, and hydrothol cause damage to leaf and stem structures; whereas systemic herbicides are assimilated by the plant roots and are lethal to the entire plant. Wherever possible, it is preferred to use a systemic herbicide for longer-lasting aquatic plant control of invasives. **In Higgins Lake, the use of contact herbicides (such as diquat and flumioxazin) would be highly discouraged since those offer short-term control of plants and are most commonly used on nuisance native aquatic plant species. The native aquatic plants within Higgins Lake are very sparse and should all be protected.**

Algaecides such as copper sulfate should also be avoided on Higgins Lake. Copper accumulates in lake sediments and bio-persists over time. It is harmful to sediment biota and can be released into the water column with sediment perturbations. Fortunately, algae are scarce in Higgins Lake and the current swimmer's itch program does not use copper sulfate for effective control.

Systemic herbicides such as 2, 4-D and triclopyr are the two primary systemic herbicides used to treat milfoil that occurs in a scattered distribution. Fluridone (trade name, SONAR®) is a systemic whole-lake herbicide treatment that is applied to the entire lake volume in the spring and is used for extensive infestations. The objective of a fluridone treatment is to selectively control the growth of milfoil in order to allow other native aquatic plants to germinate and create a more diverse aquatic plant community. Due to the low scattered abundance of milfoil in Higgins Lake (given its size), the use of fluridone is not recommended. RLS recommends that no aquatic herbicides be used in Higgins Lake unless the distribution of invasives exceeds the capacity for use of a DASH boat. **If the spread of EWM exceeds the ability for DASH in the future for effective control, then a new systemic herbicide ProcellaCOR® can be used as in 2022 and is highly target-specific. The product is costly but has longer-lasting control relative to older systemic herbicides. In Higgins Lake, the dose of herbicide required to effectively treat EWM in deeper waters would be very high which would also greatly increase the cost.**



Figure 55. A boat used to apply aquatic herbicides in inland lakes.

5.1.3 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 56). The mechanical harvester collects numerous loads of aquatic plants as they are cut near the lake bottom. The plants are off-loaded onto a conveyor and then into a dump truck. Harvested plants are then taken to an offsite landfill or farm where they can be used as fertilizer. Mechanical harvesting is preferred over chemical herbicides when primarily native aquatic plants exist, or when excessive amounts of plant biomass need to be removed.

Mechanical harvesting is usually not recommended for the removal of Eurasian Watermilfoil since the plant may fragment when cut and re-grow on the lake bottom. Additionally, it is often not practical for very large lakes, given the long transfer times to offload harvested vegetation. Due to the lack of overall native aquatic vegetation and distribution of invasives in open water areas, mechanical harvesting is not recommended for Higgins Lake.



Figure 56. A mechanical harvester used to remove aquatic plants.

5.1.4 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 57) or Weed Rollers (Figure 58) have been used to reduce weed growth in small areas such as in beach areas and around docks. The benthic mats are placed on the lake bottom in early spring prior to the germination of aquatic vegetation. They act to reduce germination of all aquatic plants and lead to a local area free of most aquatic vegetation. Benthic barriers may come in various sizes between 100-400 feet in length.

They are anchored to the lake bottom to avoid becoming a navigation hazard. The cost of the barriers varies among vendors but can range from \$100-\$1,000 per mat. Benthic barrier mats can be purchased online at: www.lakemat.com or www.lakebottomblanket.com. The efficacy of benthic barrier mats has been studied by Laitala et al. (2012) who report a minimum of 75% reduction in invasive milfoil in the treatment areas. Lastly, benthic barrier mats should not be placed in areas where fishery spawning habitat is present and/or spawning activity is occurring.

Weed Rollers are electrical devices which utilize a rolling arm that rolls along the lake bottom in small areas (usually not more than 50 feet) and pulverizes the lake bottom to reduce germination of any aquatic vegetation in that area. They can be purchased online at: www.crary.com/marine or at: www.lakegroomer.net.

Both methods are useful in recreational lakes such as Higgins Lake and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth if it becomes prevalent in future years. Fortunately, the Higgins Lake bottom is not highly colonized with aquatic vegetation and these methods are not needed in most areas.

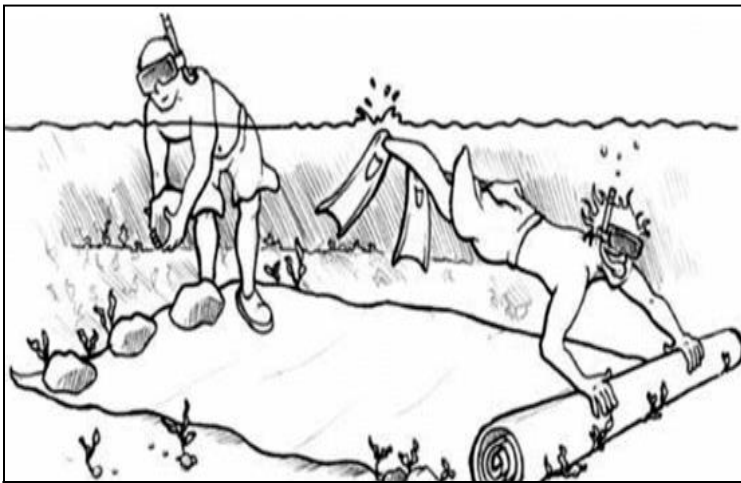


Figure 57. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.



Figure 58. A Weed Roller.

5.1.5 Diver Assisted Suction Harvesting (DASH)

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 59) involves hand removal of individual plants by a SCUBA diver in selected areas of lake bottom with the use of a hand-operated suction hose. Samples are dewatered on land or removed via fabric bags to an offsite location. **This method is costly on a large scale and so it is used on a spot-removal basis or in small lagoons. It has been used to remove nuisance invasive aquatic vegetation in the South State Park Lagoon in 2019-2022 with good success and has led to a reduction in invasives in the lake overall.**

Because this activity may cause re-suspension of sediments (Nayar et al., 2007), increased turbidity and reduced clarity of the water can occur. Permitting requirements include the use of a turbidity curtain that reduce the transport of solids to locations outside of treatment areas and also help define areas where intensive aquatic vegetation removal efforts are being implemented. This method would be feasible given the sparse distribution of invasive Eurasian Watermilfoil and Starry Stonewort scattered throughout Higgins Lake. It would be a non-chemical approach that would include removal of the roots for long-term, sustainable, control of invasive plants.



Figure 59. A DASH boat used in the South State Park Lagoon for aquatic plant removal.

5.2 Higgins Lake Early Detection Rapid Response Protocol (EDRR) Development

An exotic species is a non-native species that does not originate from a particular location. When international commerce and travel became prevalent, many of these species were transported to areas of the world where they did not originate. Due to their small size, insects, plants, animals, and aquatic organisms may escape detection and be unknowingly transferred to unintended habitats.

The first ingredient to successful prevention of unwanted transfers of exotic species to Higgins Lake is awareness and education. In the 2019 Higgins Lake Management Plan, RLS recommended continued boat washing stations and other prevention techniques. Additionally, RLS recommended development of an “Early Detection, Rapid Response or EDRR” protocol for Higgins Lake that would be adaptive and change with time and possible initiation of a new invasive species. Aquatic vegetation is much easier to detect than smaller shelled organisms or other smaller specimens. **There is already a protocol in place for Eurasian Watermilfoil and Starry Stonewort in that Diver Assisted Suction Harvesting (DASH) is pursued in areas where either of these submersed invasives are found. Thus, there is a need for additional protocols in place for new invasives that may appear in Higgins Lake at any time.**

Higgins Lake is a pristine clearwater natural glacial lake that attracts many visitors and hosts many waterfront properties. There are many vectors of possible transport of invasive species as previously discussed (i.e., boat launches, waterfowl, release of water garden plants). **At any time, an invasive species (plant or animal) can enter the lake ecosystem from such vectors and remain undetected in the absence of regular whole-lake surveys. The purpose of an EDRR protocol is to allow for quick detection and decision-making in an attempt to eradicate a new invasive species in or around the lake.**

Higgins Lake contains a diverse native aquatic plant community with 19 submersed, 0 floating-leaved, and 2 emergent native aquatic plant species as determined by the most recent July/August, 2022 whole lake aquatic vegetation survey and scan.

The section below provides an outline of key components that should be developed as part of the EDRR for Higgins Lake which will take time and is adaptive over time based on treatment of existing invasives and the probability of threat from ones that may occur in the lake at any time.

1. PREVENTION OF AQUATIC INVASIVE SPECIES (AIS)

a. Signage at launches and access sites

An overlooked component of any lake improvement program is prevention. This means providing the public with information that empowers them to keep the spread of invasives in a lake at a low or undetectable level. Prevention signs for aquatic invasive species (AIS) should be placed at all access entry locations and should include detailed identifying information related to an individual invasive species. Signs are often available at no to low cost from the MDNR, EGLE, or other collaborative partners.

b. Education sessions for riparians/stakeholders about AIS

Education of all lake residents is often impossible as individual schedules are often divergent. Thus, hosting a local educational session or workshop can be useful for handing out brochures to share with others not present. Additionally, workshops often allow for up-close inspections of actual invasive specimens that people may take photographs of for optimized identification.

c. Boat wash at launch

RLS recommended the use of boat washing stations since they are currently installed at the north, west, and south regions of Higgins Lake. There are still other areas where they could be placed to assure access at all possible entry points.

2. EARLY DETECTION AND RAPID RESPONSE (EDRR) PLAN CRITICAL ELEMENTS

a. Aquatic Vegetation Surveys

RLS recommends that a whole-lake aquatic plant survey be conducted each year but due to the lake depth could be conducted every two years using the same protocol to map invasives and generate detailed polygon maps for treatment. The surveys should cover all habitats, including on-shore, near-shore, and the deep zones. Although survival of submersed plants is unlikely in deep zones, some free-floating invasives can sink to the bottom and survive for a period of time. The surveys should include geo-referenced locations that cite individual GPS locations and the species and relative abundance of each species present.

b. Confirmation of Invasive Species and Mapping/Delineation of Distribution.

If an invasive species is found, the geo-reference location is stored for re-visitation and a voucher sample of the specimen is collected for laboratory validation of invasive species name. Various taxonomic keys are present for the proper identification of invasives. If the species occupies more than a single GPS location, then polygons will be developed based on delineated area of the species. These polygons are then uploaded onto a map that can be used for precise management.

c. Treatment Selection and Permitting

Once the invasive species has been properly identified, located, and mapped, a treatment plan can be executed. Knowledge of specific treatment options by a professional is required for a successful long-term outcome. There are chemical, physical, and mechanical methods that could be used for each specific invasive species. The decision should be based on imminent need, community philosophy, ability to be successfully permitted by the State, and cost. RLS will work with the HLPOA to develop species-specific recommendations for all possible invasives that may enter the lake.

d. Monitoring and Evaluation

After the target species has been treated, monitoring and evaluation is required to assure that treatment efficacy was positive. If the treatment area is very confined, then more site-conscious methods such as SCUBA may be needed. If the site is extensive, then detailed geo-referenced aquatic vegetation surveys are needed. The objective is to confirm that the target species is adequately suppressed and that no further spread is evident.

e. Collaboration and Engagement

A final but important phase of the EDRR is to establish ongoing collaboration and engagement. Education of the lake community and its visitors is critical to assist with identification of new invasives that may enter the lake at any time. Educational opportunities may include board meetings with the HLPOA, HLF, and MDNR, or other partners. In addition, newsletters can be distributed that introduce the appearance and characteristics of new invasives to the community. Press releases can also be useful for notifying the community of a new invasive species and its location. They are also useful for providing updates on the success of invasive species management. Social media is also another favorable platform for informing the public and especially people that may infrequently visit the lake or that do not live on the lake or have access to local press releases or newspapers. Educational workshops are highly valuable as they introduce the community to actual live specimens that should be swiftly addressed if found.

5.3 Higgins Lake Water Quality Improvement

In addition to lake improvement methods that improve the aquatic plant communities through prevention and control of invasive aquatic plant species, there are methods to improve the water quality within the lake basin-particularly nearshore waters that have been previously determined to have increasing phosphorus concentrations due to septic leachate. **It is also recommended that a whole-lake sewer system be installed around Higgins Lake to reduce the measured septic leachate inputs that may cause further water quality degradation with time if the lake is to remain oligotrophic.**

5.3.1 Reduction of Nutrients & Pollutants into Higgins Lake

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

On ideal soil types, microbes in the soil are able to decompose nutrients and reduce the probability of groundwater contamination. However, many lakes in Michigan contain soils that are not suitable for septic systems. Soils that are not very permeable, prone to saturation or ponding, and have mucks exist around many lakes and currently have properties with septic systems.

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

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

Spence-Cheruvilil and Soranno (2008) studied 54 inland lakes in Michigan and found that total aquatic plant cover (including submersed plants) was most related to secchi depth and mean depth. However, they also determined that man-made land use activities are also predictors of aquatic plant cover since such variables can also influence these patterns of growth. Prior to changes in offshore aquatic plant communities, an additional indicator of land use impacts on lake water quality in oligotrophic lakes (lakes that are low in nutrients) includes changes in periphytic algae associated with development nearshore. **Such algae can determine impacts of septic leachate before other more noticeable changes offshore are found (Rosenberger et al., 2008). This has also been previously shown by Lowe and Kociolek (2016) where abundant areas of benthic algae were found in the shallow nearshore zones of Higgins Lake.**

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

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

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

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

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

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

In conclusion, a lake-wide sewer system is recommended for Higgins Lake since the nearshore nutrients have been increasing with time (Martin et al., 2014; Minnerick, 2001) if the lake is to remain oligotrophic for a long period of time. As explained earlier in the geology section of this report, the lake has a high water table and contains mostly sands which are highly permeable. Since groundwater flow into the lake is on average over 1 foot per day (Minnerick et al., 2001), the opportunities for long-term loading of nutrients to nearshore areas remains high. Septic systems generally are only viable for 20 years until they have to be replaced so the cost of a community-wide sewer should be considered with septic system replacement costs over time.

Based on the high mean ratio of nitrogen to phosphorus in Higgins Lake (i.e., N: P = 36), any additional inputs of phosphorus to the lake are likely to create additional algal and aquatic plant growth, especially nearshore. This defines a P-limited aquatic ecosystem. Accordingly, RLS recommends the following procedures to protect the water quality of Higgins Lake:

- 1) Avoid the use of lawn fertilizers that contain phosphorus (P). P is the main nutrient required for aquatic plant and algae growth, and plants grow in excess when P is abundant. When possible, water lawns with lake water which usually contains adequate P for successful lawn growth. If you must fertilize your lawn, assure that the middle number on the bag of fertilizer reads "0" to denote the absence of P. If you must fertilize, use low N in the fertilizer or use lake water. Education of riparians on this issue is important as is understanding what they may use for fertilizers and where they are purchased.

- 2) Have all septic systems **annually inspected if possible or at least every two years.** This includes both the tank and the drain field. Septic inputs have been shown to be the second largest contributor of both nitrogen and phosphorus to Higgins Lake. For more information on septic care, visit the EPA website at: <http://www.epa.gov/septic>
- 3) Preserve riparian vegetation buffers around the shoreline, since they act as a filter to catch nutrients and pollutants that occur on land and may run off into the lake. As an additional bonus, Canada geese (*Branta canadensis*) usually do not prefer lakefront lawns with dense riparian vegetation because they are concerned about the potential of hidden predators within the vegetation. Valuable information can be found on the Michigan Natural Shoreline Partnership website at: www.mishorelinepartnership.org
- 4) Do not burn leaves near the lake shoreline since the ash is a high source of P. The ash is lightweight and may become airborne and land in the water eventually becoming dissolved and utilized by aquatic vegetation and algae.
- 5) Assure that all areas that drain into the lake from the surrounding land are vegetated and that no fertilizers are used in areas with saturated soils.
- 6) Avoid dumping any solvents, chemicals, or debris into the lake. These can all harm fish, wildlife, and humans.
- 7) Never dump leaves or chemicals into storm drains as these often lead to waterways.
- 8) At a minimum, have annual or bi-annual septic tank and drain field inspections. Septic systems and drain fields can contribute high nutrient and bacteria loads to the lake which are costly to mitigate.
- 9) Allow trees to grow near the shoreline for erosion control but be sure to rake away leaves in the fall. Do not rake leaves into the lake and instead dispose of leaves as yard waste.
- 10) Do not feed any waterfowl. Although this is enjoyable, they have plenty of food in the lake and their feces are high in nutrients and bacteria.
- 11) Do not allow any rubber from water balloons, firework debris, plastic, Styrofoam, or food containers to enter the lake. Most of this will require hundreds of years to break down and is harmful to the lake.

- 12) Be a responsible lake steward! Attend lake association meetings and learn about issues on the Higgins Lake Property Owners Association website at www.hlpoa.org.

5.3.2 Higgins Lake Erosion and Sediment Deposition

In addition to the proposed protection of native aquatic plants and control of invasives in Higgins Lake, it is recommended that BMP's be implemented to improve the lake's water quality. The guidebook, *Lakescaping for Wildlife and Water Quality* (Henderson et al. 1998) provides the following guidelines:

- 1) Maintenance of brush cover on lands with steep slopes (those > 6%)
- 2) Development of a vegetation buffer zone 25-30 feet from the land-water interface with approximately 60-80% of the shoreline bordered with vegetation
- 3) Limiting boat traffic and boat size to reduce wave energy and thus erosion potential
- 4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion
- 5) Using only native genotype plants (those native to Higgins Lake or the region) around the lake since they are most likely to establish and thrive than those not acclimated to growing in the area soils. A local horticultural supply center would likely have a list of these species.
- 6) The construction of impervious surfaces (i.e., paved roads and walkways, houses) should be minimized and kept at least 100 feet from the lakefront shoreline to reduce surface runoff potential.
- 7) All wetland areas around Higgins Lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat.
- 8) Erosion of soils into the water may lead to increased turbidity and nutrient loading to the lake. Seawalls should consist of rip-rap (stone, rock), rather than metal or concrete, due to the fact that rip-rap offers a more favorable habitat for lakeshore organisms, which are critical to the ecological balance of the lake ecosystem. Rip-rap should be installed in front of areas where metal seawalls are currently in use. The rip-rap should extend into the water to create a presence of microhabitats for enhanced biodiversity of the aquatic organisms within Higgins Lake. Planting of emergent aquatic plants around Higgins Lake may offer stabilization of shoreline sediments and assist in protection of areas prone to erosion.

Erosion Control/Shoreline Survey:

A historical study on erosion at road ends was conducted in 1993 by community partners which included the Roscommon County Road Commission, the Crawford-Roscommon Soil and Water Conservation District, the USDA Soil Conservation Service, Gerrish and Lyons Townships, the Higgins Lake Foundation, the Higgins Lake Property Owners Association, the Higgins Lake Civic Association, the Michigan Department of Natural Resources, Surface Water Quality Division, and the Huron Pines Resource Conservation and Development Council (Roscommon County Resource Conservation and Development Committee Report, 1993). This evaluation showed the impacts that road ends had on sediment transport to Higgins Lake.

RLS located areas of erosion around the Higgins Lake shoreline on August 21-23, 2019 and again on July 15-20, 2022. A variety of erosion conditions were observed within Higgins Lakes shorelines that are typical of high-energy lakes. Erosion was generally slight to moderate, but areas of significant erosion were found in some locations. This erosion negatively impacts numerous resources such as public use areas through water quality from the soils eroding into the lake, fisheries and wildlife habitat being diminished from both turbidity, and a lack of suitable vegetative cover.

The fetch in Higgins Lake, which is the distance across the greatest length of the lake to produce a wind-driven wave, is approximately 6.5 miles which can lead to waves with heights exceeding 6.5 feet. Sustained southerly or northerly wind speeds could produce waves that are between 1.0-6.5 ft high. Shoreline bathymetry also plays a big part in determining the degree of erosion at a particular shoreline site. Sites with straight shorelines and points that are exposed to long wind fetches from prevailing wind directions, are vulnerable to more frequent and higher waves. Additionally, where the water deepens abruptly and there is less resistance or bottom roughness to influence the wave, exposed shorelines are susceptible to larger waves. Lastly, heavy human foot traffic and mowed areas all contribute to substantial shoreline erosion in certain reaches of the lake. A loss of vegetative cover in these locations accelerates erosion and sedimentation.

Additional steps needed would include a detailed assessment in order to prioritize sites based on severity, feasibility, costs, landowner willingness, and other factors. There is a wide range of erosion control methods that can be used in a cost-effective manner to address the shoreline erosion problems. Higher priority should go to sites where structures or amenities are threatened. Figures 60-62 demonstrate areas around the lake with different types of erosion including hill erosion, bank erosion, bank undercutting, and low stabilization.



Figure 60. Shoreline erosion on Higgin Lake with bank undercutting (August 21-23, 2019).



Figure 61. Higgins Lake shoreline erosion (August 21-23, 2019).



Figure 62. Higgins Lake shoreline erosion exposing tree roots (August 21-23, 2019).

6.0 HIGGINS LAKE MANAGEMENT PLAN CONCLUSIONS AND RECOMMENDATIONS

Higgins Lake is facing significant issues that may degrade water quality, including inputs of nutrients and sediments from septic systems, surrounding tributaries, and shoreline erosion which leads to a decline in lake health over time.

Recent management efforts to reduce Eurasian Watermilfoil and Starry Stonewort have been very successful and temporary eradication may be possible in the future. Management of both invasive species would be best achieved with the DASH method in place of herbicides or harvesting. This is due to the scattered distribution of both invasives in the lake and relative difficulty of removing such small areas of cover with herbicides that drift. Individual GPS points can be given to the DASH operator and the plant beds can be removed by the roots while preserving the nearby native aquatic plants. **Systemic herbicides such as 2,4-D and ProcellaCOR® were used in the South State Park Lagoon in 2019-2022 and this would be another option for controlling milfoil in that area; however, Starry Stonewort is best removed with DASH due to its low long-term response to any herbicides or algaecides. DASH was successfully implemented in 2019-2022 and should continue.**

RLS highly recommends that the MDNR and other parties involved in the active removal of invasives coordinate with RLS, HLPOA, and HLF as a team to better understand the quantity and locations of invasives removed each year and combine efforts of SCUBA implemented from the HLF and the GPS Point-Intercept survey from RLS working for the HLPOA. RLS may be able to provide these parties with additional data on other areas found during the surveys. Appendix A demonstrates the areas where DASH removed invasives in 2022. As previously stated, annual variations in environmental factors such as seedbank ecology are likely to alter the quantity and distribution of invasives over time. In some years, a hard winter or reduced seedbank productivity may lead to reduced overall growth. Thus, it is difficult to discern whether DASH or natural environmental factors have resulted in declines over time. The importance lies with the ability to reduce invasives over time using as many methods as possible for surveys. The Point-Intercept survey is recommended from the shore to the drop-off (littoral zone) and SCUBA may be best used on the drop-offs. It should be noted that milfoil or Starry Stonewort fragments may escape with offshore DASH activity in the lake basin since it is nearly impossible for turbidity curtains to contain these plants at such depths as the curtains do not have adequate length. The curtains are most effective in shallow areas such as the Lagoon.

In 2022, RLS initiated an Early Detection-Rapid Response (EDRR) Protocol for future invasives that may enter the lake. This protocol is adaptive and should be revised each year when new information is available. RLS can provide more species-specific control information in 2023 if future treatment efforts may include herbicides or different approaches from DASH as each species has a different response to various products and doses.

RLS recommends that a professional limnologist/aquatic botanist should perform regular GPS-guided whole-lake surveys each summer/early fall to monitor the growth and distribution of all invasives prior to and after DASH treatments to determine treatment efficacy. Continuous monitoring of the lake for potential influxes of other exotic aquatic plant genera (i.e., *Hydrilla*) that could also significantly disrupt the ecological stability of Higgins Lake is critical. The lake manager should oversee all management activities and would be responsible for the creation of aquatic plant management survey maps, direction of the DASH operator to target-specific areas of aquatic vegetation for removal, implementation of watershed best management practices, administrative duties such as the processing of contractor invoices, and lake management education. Currently, Higgins Lake has a low quantity of native aquatic vegetation and so management efforts must include preservation of native aquatic plant species.

The boat washing stations present at three of the access sites have been effective at educating visitors to clean their boats and trailers and at reducing the spread of invasive aquatic plant species. **More stations are recommended at other access sites identified earlier in this evaluation.**

Swimmer's itch continues to be effectively managed with reductions in resident merganser populations and through verification of parasite reductions from the Stagnicola snails. Continued efforts to reduce these parasites and also reduce the goose population are recommended. The use of copper sulfate should never again be considered for Higgins Lake since it bioaccumulates in the lake sediments and may harm lake benthos and macroinvertebrates.

The lake has a healthy population of prized fishes (such as Rainbow, Brown, and Lake Trout) that are stocked regularly by the MDNR with additional stocking in 2022. In addition, there is an abundance of healthy zooplankton and macroinvertebrates such as crayfish and freshwater sponges, among numerous others. All of these organisms are indicative of very healthy waters.

Higgins Lake has overall low nutrient concentrations in the deep basins but nearshore increases in nitrogen and phosphorus have been previously studied and are likely due to septic inputs. Additionally, the HLPOA worked with Michigan State University (MSU) in 2022 to measure possible pharmaceuticals in the surface lake waters of Higgins Lake.

There were various antibiotics and other substances that were present above the detection levels, which is of concern. The only possible mechanisms of transport of these substances into the lake consist of septic field leachate or incoming waters such as runoff and tributaries. The next revision of this management plan will be associated with three years of consistent water quality data and thus trends over time can be created for all parameters.

A lake-wide sewer is recommended to reduce these and other nutrient inputs to the lake if the lake is to remain oligotrophic. The tributaries possess higher nutrient concentrations than the lake and are thus nutrient sources to the lake. Maintenance of tributary areas is important to allow for nutrient reductions over time. This may include removal of leaves and debris and upstream land use improvements (such as erosion stabilization). The water clarity of the lake continues to increase due to the ability of both Zebra and Quagga Mussels to filter phytoplankton out of the water column. Not much can be done to eradicate these invasives at this time which is why prevention is so important to reduce future populations. Annual water quality monitoring is recommended to continue to evaluate long-term trends and impacts of management practices.

A few areas around the lake (aside from road ends) were found to have shoreline erosion during the 2019 evaluation and these areas should be stabilized with rip-rap or soft shoreline emergent vegetation.

Lastly, a riparian education program is recommended through the continued development of this management plan and through holding future educational workshops. Such workshops may include dispersal of relevant lake information and also identification of local lake biota so that residents know to be vigilant of certain invasives.

A complete list of recommended lake improvement options for this proposed lake management plan can be found in Table 25 below. It is important to coordinate these methods with objectives so that baseline conditions can be compared to post-treatment/management conditions once the methods have been implemented.

Table 25. List of Higgins Lake proposed improvement methods with primary and secondary goals and locations for implementation.

Proposed Improvement Method	Primary Goal	Secondary Goal	Where to Implement
Installation of lake-wide sewer	To reduce nutrients inputs from septic systems	To improve nearshore water quality parameters	Lake-wide
DASH boat removal of invasive milfoil and Starry Stonewort in lake and Lagoon	Remove invasives in lake and Lagoon at South State Park	Use in place of aquatic herbicides	Entire lake where invasives present
Bi-annual water quality monitoring of lake and drains	Monitor lake health over time	Use long-term and current data to drive management decisions relative to BMP's	Lake deep basins and major tributaries
Continued Development of Early Detection Rapid Response Protocol for new invasives	Generate a clear strategy for dealing with new invasives that may be found in the lake	Allow for less long-term spread of any new invasives with early detection	Entire lake
Boat launch washing stations	To reduce entry of invasives into Higgins Lake	To reduce exit of invasives from Higgins Lake	At ALL public access sites noted in this report.
Swimmer's Itch control with continued merganser population control	Reduce presence of parasite from mergansers	Reduce merganser population which also reduces nutrients and bacteria in lake	Entire lake
Annual lake surveys pre- and post-treatment	To determine efficacy of DASH treatments on invasives	To determine ability of native aquatic vegetation biodiversity to recover post-management implementation	Entire lake

Shoreline Erosion Inventory	To determine individual properties that need shoreline erosion stabilization practices	Reduce associated solids and nutrients that enter lake	Lake-wide; Entire shoreline
Riparian/Community Education	To raise awareness of lake issues and empower all to participate in lake protection	Long-term sustainability requires ongoing awareness and action	Entire lake community and those who frequent the lake; may also include relevant MDNR and other stakeholders

6.1 Cost Estimates for Higgins Lake Improvements

The proposed lake improvement and management program for Higgins Lake is recommended to begin as soon as possible. Since dredging is likely to be the costliest improvement, it may be conducted over a period of five years or more to reduce annual cost. A breakdown of estimated costs associated with the various proposed treatments in Higgins Lake is presented in Table 26. It should be noted that proposed costs are estimates and may change in response to changes in environmental conditions (i.e., increases in aquatic plant growth or distribution, or changes in herbicide costs). Note that this table is adaptive and is likely to change.

Table 26. Higgins Lake proposed lake management program costs. NOTE: All items are estimates only and are likely to change based on acquisition of formal quotes from qualified vendors.

Proposed Higgins Lake Improvement Item	Estimated Annual Costs
Professional services (limnologist management of lake, aquatic vegetation surveys, DASH oversight, education) ⁴	\$33,000
Boat washing stations	~\$29,000 per site
DASH boat removal of current invasive EWM and SS	~\$20,000
Early Detection Rapid Response Protocol Guide (Expanded)	~\$8,000
Continued water quality sampling of lake deep basins and 3 major tributaries	~\$15,000
Continued Swimmer's Itch Control	~\$10,000
Contingency ⁵	\$11,500
Total Annual Estimated Cost	\$126,500

7.0 SCIENTIFIC REFERENCES

- Aiken, S.G., P.R. Newroth, and I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. *Canadian Journal of Aquatic Plant Science* 59: 201-215.
- Blackburn, R.D., L.W. Weldon, R.R. Yeo, and T.M. Taylor. 1969. Identification and distribution of certain similar-appearing submersed aquatic weeds in Florida. *Hyacinth Control Journal* 8:17-23.
- Couch, R., and E. Nelson 1985. *Myriophyllum spicatum* in North America. Pp. 8-18. In: Proc. First Int. Symp. On Watermilfoil (*M. spicatum*) and related Haloragaceae species. July 23-24, 1985. Vancouver, BC, Canada. Aquatic Plant Management Society, Inc.
- Eiswerth, M.E., S.G. Donaldson, and W.S. Johnson. 2000. Potential environmental impacts and economic damages of Eurasian Watermilfoil (*M. spicatum*) in Western Nevada and Northeastern California. *Weed Technology* 14(3):511-518.
- Frost, T.M., G.S. De Nagy, and J.J. Gilbert. 1982. Population dynamics and standing biomass of the freshwater sponge *Spongilla lacustris*. *Ecology* 63(5): 1203-1210.
- Gernert, C., F.O. Glöckner, G. Krohne, and U. Hentschel. 2005. Microbial diversity of the freshwater sponge *Spongilla lacustris*. *Microbial Ecology* 50:206-212.
- Gosch, N. J. C., Phelps, Q. E. and D.W. Willis. 2006. Habitat characteristics at bluegill spawning colonies in a South Dakota glacial lake. *Ecology of Freshwater Fish*, 15: 464–469. doi: 10.1111/j.1600-0633.2006.00178. x.
- Halstead, J.M., J. Michaud, and S. Hallas-Burt. 2003. Hedonic analysis of effects of a non-native invader (*Myriophyllum heterophyllum*) on New Hampshire (USA) lakefront properties. *Environmental Management* 30 (3): 391-398.
- Henderson, C.L., C. Dindorf, and F. Rozumalski. 1998. Lakescaping for Wildlife and Water Quality. Minnesota Department of Natural Resources, 176 pgs.
- Herrick, B.M., and Wolf, A.T. 2005. Invasive plant species in diked vs. undiked Great Lakes wetlands. *Journal of Great Lakes Research*, Internat. Assoc. Great. Lakes. Res. 31(3): 277-287.
- Holland, R.E. 1993. Changes in planktonic diatoms and water transparency in Hatchery Bay, Bass Island Area, Western Lake Erie since the establishment of the zebra mussel, *Journal of Great Lakes Research* 19:617-624.
- Laitala, K.L., T.S. Prather, D. Thill, and B. Kennedy. 2012. Efficacy of benthic barriers as a control measure for Eurasian Watermilfoil (*Myriophyllum spicatum*). *Invasive Plant Science* 5(2):170-177.
- Lenat, D.R. and M.T. Barbour. Using benthic macroinvertebrate community structure for rapid, cost-effective, water quality monitoring: rapid bioassessment. Biological monitoring of aquatic systems. Lewis Publishers, Boca Raton, Florida (1994): 187-215.
- Lillie, R.A., and J. Budd. 1992. Habitat architecture of *Myriophyllum spicatum* L. as an Index to habitat quality for fish and macroinvertebrates. *Journal of Freshwater Ecology* 7(2): 113-125.

- Lowe, R., and P. Kociolek. 2016. Higgins Lake Property Owners Association Algae and Water Quality Sampling Project. 5 pgs.
- Lyons, J. 1989. Changes in the abundance of small littoral-zone fishes in Lake Mendota, Wisconsin. *Canadian Journal of Zoology* 67:2910-2916, 10.1139/z89-412
- Mackie, G.L., and D.W. Schloesser. 1996. Comparative biology of Zebra Mussels in Europe and North America: An Integrative and Comparative Biology 36(3):244-258.
- Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies, *Journal of Aquatic Plant Management* 29, 94-99.
- Manny B.A., Johnson W.C., Wetzel R.G. (1994) Nutrient additions by waterfowl to lakes and reservoirs: predicting their effects on productivity and water quality. In: Kerekes J.J. (eds) Aquatic Birds in the Trophic Web of Lakes. Developments in Hydrobiology, vol 96. Springer, Dordrecht.
- Margenau, T.L., AveLallemant, S.P., Giebtbrock, D., and S. Schram. 2008. Ecology and management of northern pike in Wisconsin. *Hydrobiologia* 601(1):111-123.
- McMahon, R.F., and C.J. Williams. 1986. A reassessment of growth rate, life span, life cycles, and population dynamics in a natural population dynamics in a natural population and field caged individuals of *Corbicula fluminea* (Müller) (Bivalvia: Corbicula). Am. Malacol. Bull. Spec. ed. No. 2:151-166.
- Merritt, R., W. Cummins, and M.B. Berg. 2008. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co. 1158 pgs.
- Nayar, S., DJ Miller, A. Hunt, BP Goh, and LM Chou. 2007. Environmental effects of dredging on sediment nutrients, carbon, and granulometry in a tropical estuary. *Environmental Monitoring and Assessment* 127(1-3):1-13.
- Newroth, P.R. 1985. A review of Eurasian watermilfoil impacts and management in British Columbia. Pp. 139-153. In: Proc. First Int. Symp. On watermilfoil (*M. spicatum*) and related Haloragaceae species. July 23-24, 1985. Vancouver, BC, Canada. Aquatic Plant Management Society, Inc.
- Parsons, J.K., and R.A. Matthews. 1995. Analysis of the camps between macroinvertebrates and macrophytes in a freshwater pond. *Northwest Science* 69: 265-275.
- Radomski, P. and T. J. Goeman. 2001. Consequences of human lakeshore development on emergent and floating-leaf vegetation abundance. *North American Journal of Fisheries Management* 21(1):46-61.
- Reed, C.G. 1977. History and disturbance of Eurasian milfoil in the United States and Canada. *Phytologia* 36: 417-436.
- Roscommon County Resource Conservation and Development Committee. 1993. Higgins Lake Stormwater, Sedimentation, and Road End Erosion Inventory. 88 pgs.
- Skelton, 1997. Higgins Lake tributary macroinvertebrate study. Biology and Environmental Science Department. St. Norbert College. 19 pp.
- Skubinna, J.P., T.G. Coon, and T.R. Batterson. 1995. Increased abundance and depth of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Michigan. *Journal of Great Lakes Research* 21(4): 476-488.

- Stewart, T.W. and J.M. Haynes. 1994. Benthic macroinvertebrate communities of southwestern Lake Ontario following invasion of *Dreissena*. *Journal of Great Lakes Research* 20(2): 479-493.
- Stewart, P.M., Butcher, J.T. and T.O. Swinford. 2000. Land use, habitat, and water quality effects on macroinvertebrate communities in three watersheds of a Lake Michigan associated marsh system. *Aquatic Ecosystem Health & Management*: 3(1):179-189.
- United States Environmental Protection Agency (1995). The Great Lakes – An Environmental Atlas and Resource Book, EPA 905-B-95-001, (after Brown).
- Valley, R., and M. T. Bremigan. 2002. Effects of selective removal of Eurasian watermilfoil on age-0 largemouth bass piscivory and growth in southern Michigan lakes. *Journal of Aquatic Plant Management* 40: 79-87.
- Water Quality Investigators. 1998. Higgins Lake, Gerrish and Lyons Townships, Roscommon County, Michigan 1998 Water Quality and Bottom Sediments Study. 24 pgs.
- Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Third Edition. Academic Press, 1006 pgs.

APPENDIX A

HIGGINS LAKE 2022 DASH LOCATION MAPS

