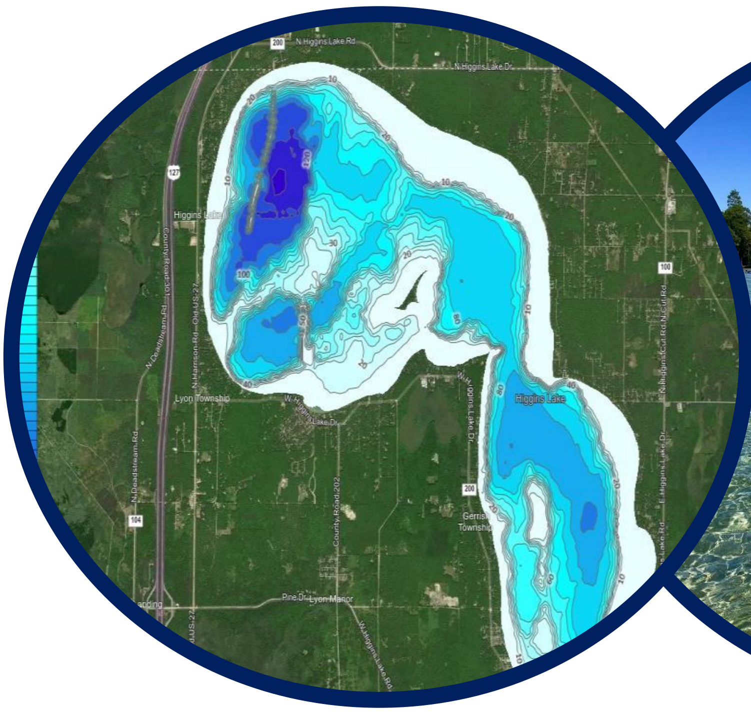
Higgins Lake Improvement Study and Management Plan
Roscommon County, Michigan



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

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March 2020

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.

Based on the current study, Higgins Lake contains two invasive aquatic plant species including approximately 21.2 acres of Eurasian Watermilfoil (*Myriophyllum spicatum*) and approximately 2.5 acres of invasive Starry Stonewort (*Nitellopsis obtusa*). Recommendations for prevention of invasives are offered later in this management plan report. There are a total of 18 submersed and 2 emergent native aquatic plant species in Higgins Lake that were present during the lake survey on August 21-23, 2019.

The overall cover of these native aquatic plants is low throughout the lake and thus preservation of them is critical for lake health. 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. Systemic herbicides such as 2,4-D were used in the South State Park Lagoon in 2019 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. A detailed, Early Detection- Rapid Response Protocol for future invasives that may enter the lake is recommended to be compiled ASAP for the lake community. 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 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. 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.

A lake-wide sewer is recommended to reduce these 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 and these areas should be stabilized with rip-rap or soft shoreline emergent vegetation. Guidance for these procedures was offered in Section 5.0 of this report.

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.

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 since from pollution which may negatively affect both surface and ground water. Since many inland lakes in Michigan are relatively small in size (i.e. less than 300 acres), they are inherently vulnerable to nutrient and pollutant inputs, due to the reduced water volumes and small surface areas. As a result, the living (biotic) components of the smaller lakes (i.e. fishery, aquatic plants, macro-invertebrates, benthic organisms, etc.) are highly sensitive to changes in water quality from watershed influences. Land use activities have a dramatic impact on the quality of surface waters and groundwater.

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

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

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

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

3.0 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 August 21-23, 2019. 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.

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 relative hardness of the lake bottom by category or hardness and percent over of each category (relative cover).

Lake Bottom Relative Hardness Category	# GPS Points in Each Category (Total =77,360)	% Relative Cover of Bottom by Category
0.0-0.1	13	0.02
0.1-0.2	38	0.05
0.2-0.3	40,342	52.2
0.3-0.4	12,852	16.6
>0.4	24,115	31.2

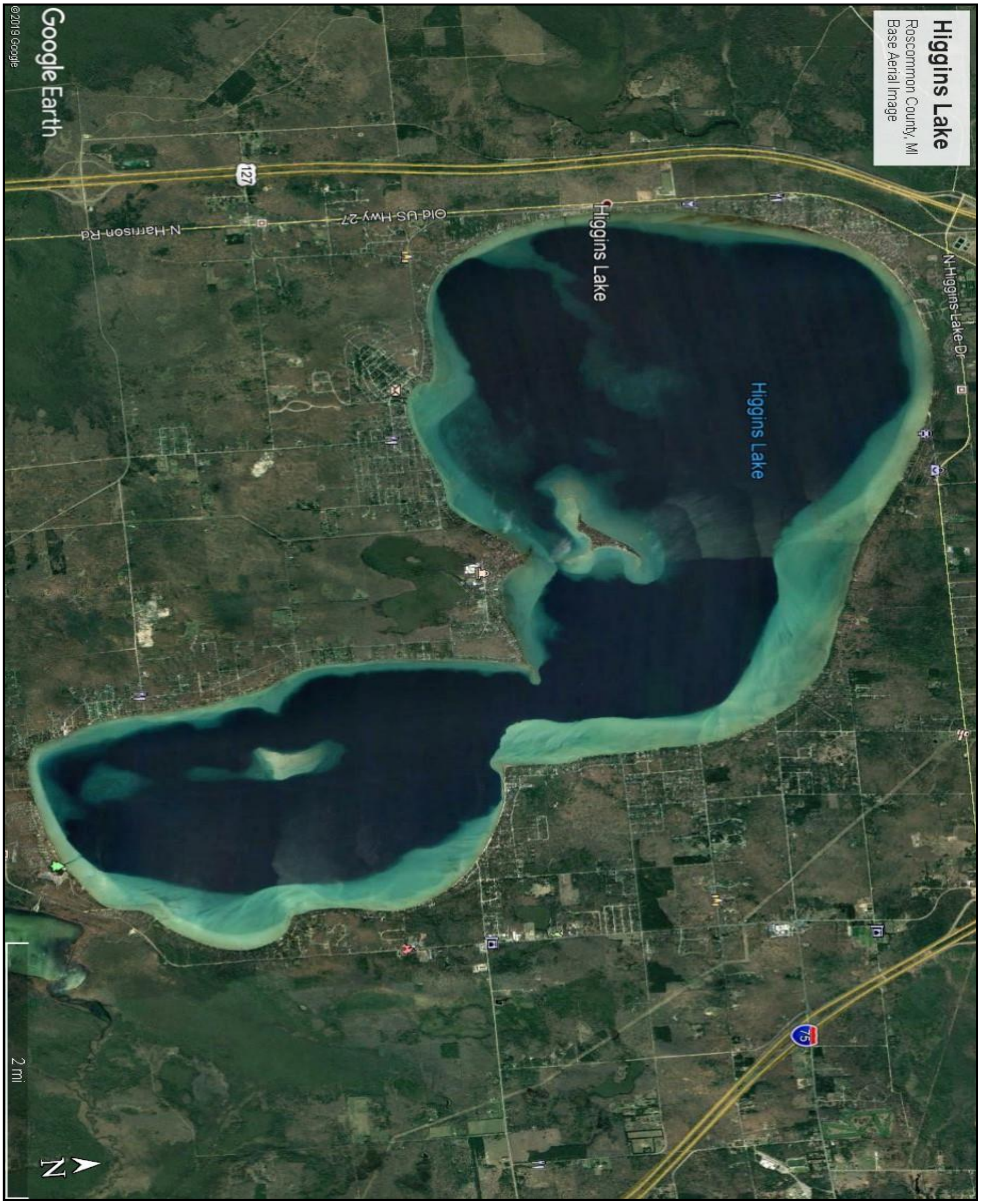


Figure 1. Higgins Lake Aerial Photo, Roscommon County, Michigan.

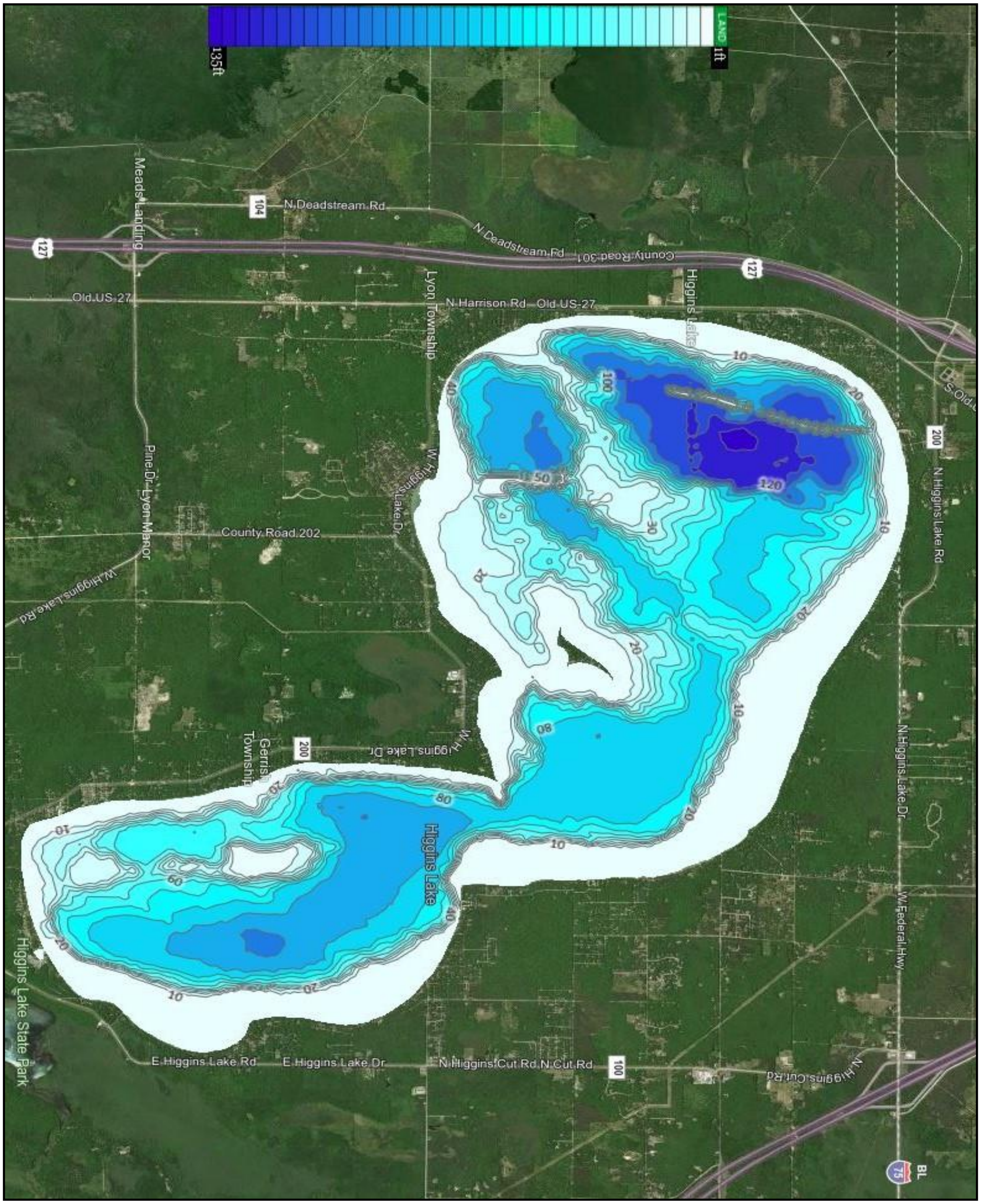


Figure 2. Higgins Lake Depth Contour Map, Roscommon County, Michigan.

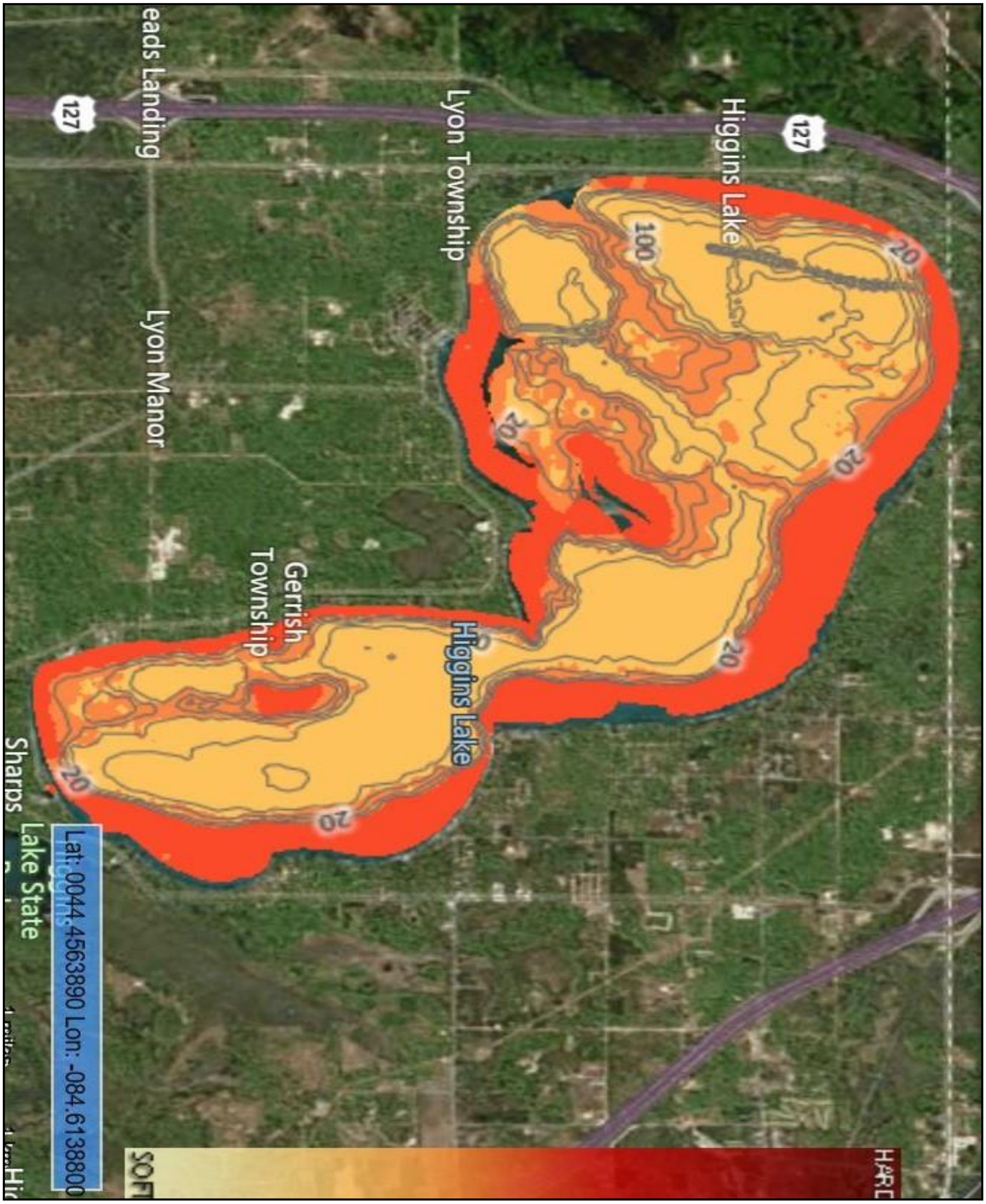


Figure 3. Higgins Lake Sediment Hardness Map, Roscommon County, Michigan.

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.

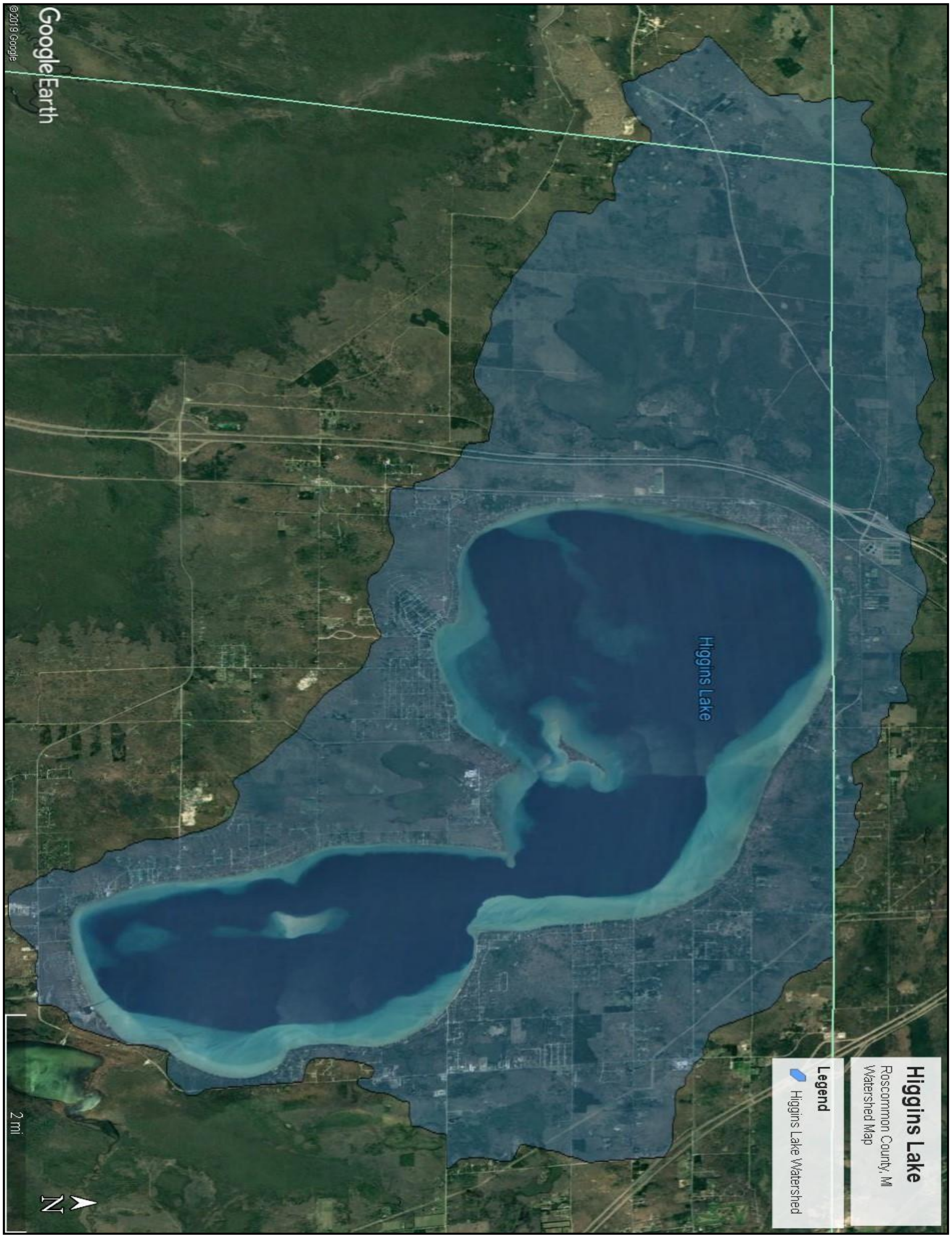


Figure 4. Immediate Watershed draining into Higgins Lake, Roscommon County, Michigan (Restorative Lake Sciences, 2019).

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).

USDA-NRCS Soil Series	*# Acres in Higgins Lake (Area of Interest on Map)*
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

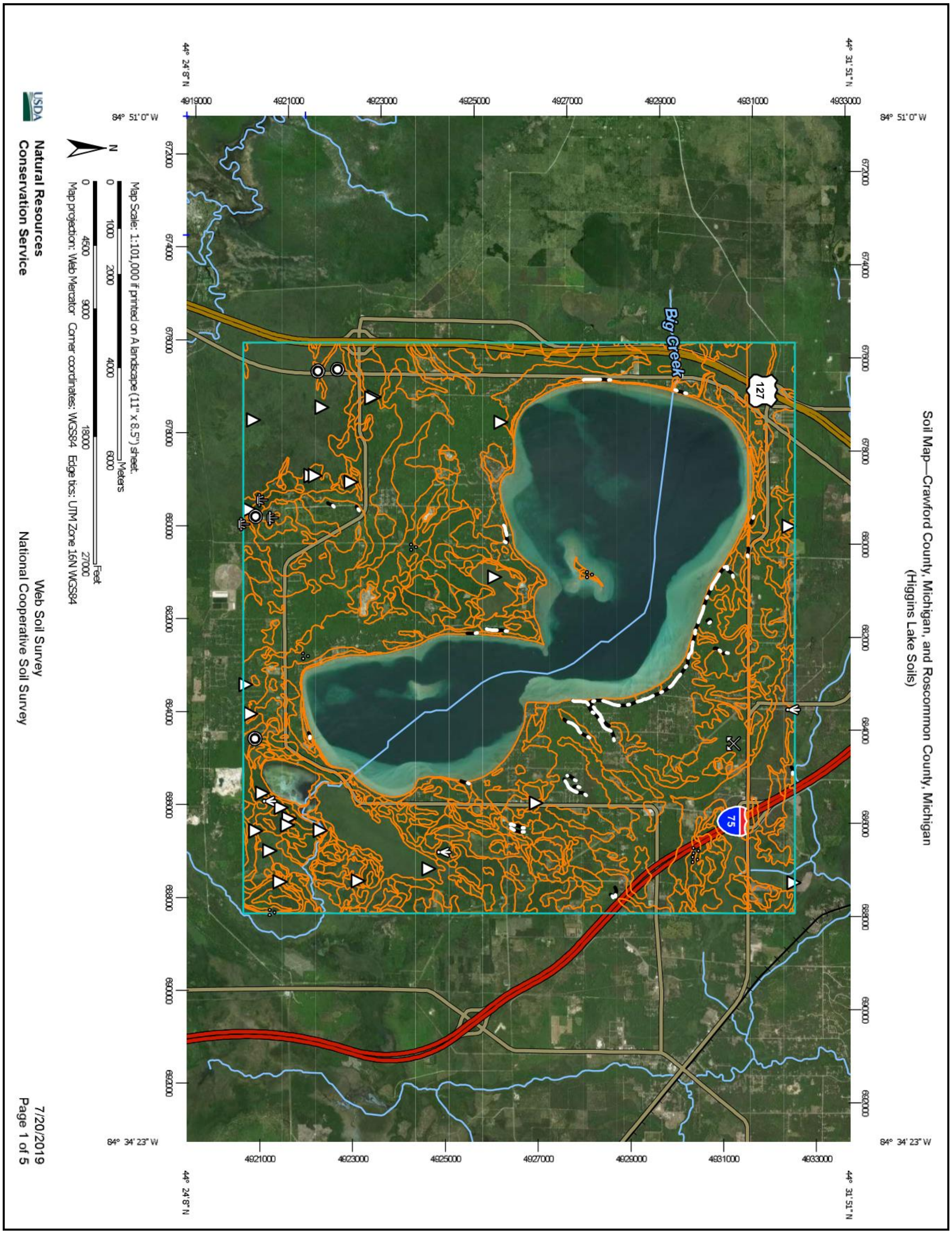


Figure 5. NRCS-USDA soils map for Higgins Lake shoreline soils.

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.

3.4 Higgins Lake Geology

On a geological scale, Pleistocene glaciation has shaped the surface topography of the Great Lakes Basin. The State of Michigan is located at the core of the Great Lakes Basin (USEPA, 1995). The Pleistocene age is a recent geologic age that ranges in age between 2.2 and 2.5 million years ago. The Great Lakes Basin, as defined by the watersheds that drain into the Great Lakes Basin, includes about 85% of the freshwater in North America and 20% of the world's fresh water (USEPA, 1995). The basin covers an area approximately 94,000 square miles including about 10% of the U.S. population and 30% of the Canadian population (USEPA, 1995). The water resources of the Great Lakes Basin are being besieged on all fronts due to population growth, point and non-point source pollution (including septic tank system discharge), climactic cycles, etc. The Great Lakes themselves are the largest surface water body on our Earth. Their continued protection is even more crucial as we go forward in time because they are a critical resource of not only to our Great Lakes region but also to our entire world.

Bedrock Geology

The bedrock geology of the Great Lakes, (i.e. the specific sequence of rock units which occur underneath the surface Pleistocene glacial sediments), can be subdivided into rocks of the Precambrian and Phanerozoic age. The Precambrian aged rocks present in the Great Lakes basin is the result of three major episodes of geologic activity with each followed by a long period of erosion (Bornhorst and Brandt, 2009; Percival and Easton, 2007).

Precambrian rocks are not present at the surface in the Lower Peninsula as they are buried under younger rocks of the Phanerozoic age (and then covered with the most recently deposited surface glacial sediments present in the northern Lower Peninsula) in the Michigan Basin. Precambrian rocks are present at the surface along the margins of the Great Lakes Basin in northern Wisconsin, the northern half of Minnesota, in northern Ontario north of and east of Lake Superior, and east of Georgian Bay and northern Lake Huron.

During the late Cambrian era of the Phanerozoic, seas encroached on the Precambrian bedrock of the Great Lakes Basin and sand accumulated on the shore and shallow seas which formed the sandstones of the Pictured Rocks of the northeast Upper Peninsula. From about 500 Ma (or millions of years before the present) to 300 Ma, the bedrock was submerged below shallow seas to dry land and during this time an interval up to 14,000 feet of sandstone, shale, limestone, dolostone, and salt were deposited in the Michigan Basin (Bornhorst and Brandt, 2009). A "missing section" of rocks formed from about 300 Ma to 2.5 Ma are not present in the Michigan Basin (Velbel, 2009). The west central part of the Michigan Basin contains red sandstones and shales, limestone, and gypsum which were deposited on eroded Paleozoic rocks during thee Jurassic at about 175 Ma (Velbel, 2009).

Unconsolidated Pleistocene Glacial Deposits

During the Pleistocene age, multiple repeated advances of continental glaciers that were up to one mile thick and originating from the north, scoured and altered the surface of the bedrock in the Great Lakes basin. The Great Lakes occupy the basins carved out by these glaciers (Larson and Kincare, 2009). The generally south moving glacial ice incorporated eroded bedrock as it moved converting it to sand, silt, clay and gravel. The advancing glacier moves the sediment load as the ice moves. The larger the individual particle being moved by a glacier, the longer distance it can be transported. Individual clasts are only moved a short distance from their place of origin in the bedrock, usually less than about 10 miles or 16 miles (Salonen, 1986). Rocks can be transported much larger distances of thousands of kilometers. Glacial erratics are large pieces of rocks generally ranging from 1.5 to over 10 feet in diameter and are commonly present in the northern part of the Lower Peninsula of Michigan. A glacier retreats by melting and the rocks picked up in it are dropped on to the surface as a blanket of loose, unconsolidated debris which fill depressions carved out of the bedrock surface by the glacier resulting in ridges when the advance and retreat of the glacier was balanced. This glacial debris also occurs in other forms as it is redistributed by meltwater exiting the glacier. The finest clay-sized material is carried by meltwater until it settles out in glacial lakes that lie in front of the retreating glacier. Thick, varved clays in a flat (planar) topographic setting also occur. The unconsolidated glacial debris is an important component in shaping the topography in combination with the undulation of the top of the bedrock surface. The youngest of these several episodes to have impacted the Great Lakes Basin is called "the Wisconsin episode", which lasted from 0.055 Ma to 0.01 Ma (55,000 to 10,000 years ago). The maximum advance of glacial ice occurred about 20,000 years ago.

The last glaciers retreated from the Great Lakes basin about 10,000 years ago. The glaciers played an important role in determining the bedrock available for human use and their residual unconsolidated debris from the Wisconsinan glacial episode also provided abundant sand and gravel (and containing groundwater-bearing units) used throughout the region.

Physical and Glacial Setting

The High Plains is located in the central to north central region of the Lower Peninsula of Michigan (Schaetzl et. *al*. 2016). The High Plains is a large interlobate area of the Laurentide Ice Sheet (Rieck and Winters, 1993[8]), bounded in part by the Cadillac Morainic Uplands associated with the Lake Michigan Lobe to the west, and the West Branch Moraine of the Saginaw Lobe to the southeast (Schaetzl et. al. 2016[7]). There is debate as to what this apparent discrete glacial lobe should be called in the High Plains, but the general consensus of researchers is that the ice entered from the north and northeast.

The High Plains contain glacial deposits that exceed 200 meters (655 feet) in thickness. Soil and sediment textures in the High Plains are almost uniformly sandy except in many swamps present in the area that are underlain by the widespread occurrence of low permeability clays and silts at depth. Most of the coarse-textured sediment in the High Plains is associated with glaciofluvial and glaciolacustrine processes (Schaetzl et *al*., 2016). The High Plans also has a significant amount of relief, where local relief exceeds 50 to 80 meters (163 to 262 feet) due to the deeply incised river valleys and from the large morainic systems that ring the southern and western margins of the High Plains, (i.e. the Cadillac and West Branch Morainic systems), respectively.

The Origin of Higgins Lake: Kame Deltas Study, "Houghton Lake Basin", MI (Schaetzl et *al*., 2016)

A 2016 study was conducted by Schaetzl et al., (2016) in conjunction with an undergraduate Honors Seminar at Michigan State University and entitled "Kame deltas provide evidence for a new glacial lake and suggest early glacial retreat from central lower Michigan, USA". This study yielded new information related to the glacial history of the "Houghton Lake Basin" which also includes the Higgins Lake area. Leuhmann (2015) developed an inventory of the Pleistocene of southern Michigan deltas but did not study them in detail. This previously unknown proglacial lake- Glacial Lake Roscommon, was also identified during this study, and is located in the large interlobate upland area of the central High Plains. The glacial kames identified and investigated in this study are located in northeast portions and just northeast of modern day Higgins Lake. Further study is necessary on the Glacial Lake Roscommon and its geomorphic evolution. A lake could have existed only if ice had started to retreat from the area, while the modern (and lowest) outlet to the "Houghton Lake Basin" at the Muskegon River, remained blocked by the Lake Michigan Lobe, Saginaw Lobe, or their deposits.

The goals of this study were to document and characterize the geomorphology of these two deltas and to establish the age of one of the deltas, thereby identifying the timing of the ice retreat in this part of Michigan.

The geomorphology (which is the study of the physical features on the earth surface and their relation to its geological structures) of the "Houghton Lake Basin" has been shaped by the effects of glacial fluvio-deltaic processes. Fluvial refers to deposits of or found in a river. Deltas are relatively flat areas at the mouth of a river or river system that form where rivers or river systems deposit more sediment into a standing body of water than can be carried away by erosive forces of currents, waves and tides. These erosive forces act on the deltaic sediment, finally determining the form, shape, extent and sedimentology of the delta. Both of these kame deltas, located in central Lower Michigan, formed in association with large, sandy, ice-contact ridges marking a stationary position of the Laurentide Ice Sheet as it retreated from the uplands of central Lower Michigan during Marine Isotope Stage. The current Houghton and Higgins Lakes are located in between the advancing and retreating ice marginal positions as they are remnants of the Glacial Lake Roscommon.

Both deltas occur on the southern sides of their respective ridges which implies that ice retreat within the "Houghton Lake Basin" was from southwest to northeast. The 2016 Schaetzl et *al*., (2016) study named this ice lobe the Mackinac Lobe because it likely advanced into the region across the Mackinac Straits area. The deltas were named the South Branch (SB) Delta and the Cottage Grove (CG) Delta. The South Branch (SB) Delta, the easternmost feature, was named for its location in South Branch Township, Crawford County. The SB Delta is associated with a large, ice-contact ridge named the Coy Kamic Ridge by Burgess in 1977. The SB Delta is much thicker than the CG Delta measuring 22 to 27 meters (72 to 88 feet) in thickness. The Cottage Grove Delta, located farther west and south, is associated with the North Higgins Lake Ridge. The Cottage Grove Delta was named after the Cottage Grove Land Association that currently owns the property. The CG Delta is much thinner than the SB Delta, containing 7 to 10 meters (23 to 33 feet) of sandy sediment above the former lake floor. Both the South Branch and Cottage Grove Deltas are forested upland areas composed of excessively drained, sandy soils.

Both of the kame deltas identified in this study are composed of well-sorted fine and medium grained sands with little gravel, with broad, nearly flat surfaces and comparatively steep fronts. Samples from the upper 1.5 meters of the delta show little spatial variation in texture, aside from general fining toward their center margins.
According to Schaetzl et. al, the second goal to this 2016 study is the dating of sandy, fluvio-deltaic sediment by optically stimulated luminescence (OSL) techniques (Fuchs and Owen, 2008). Six samples were recovered from the Cottage Grove (CG) Delta for OSL dating. Two samples each were collected from the following sectors of the CG Delta: a) areas of low slope gradient on the coarse-textured center of the delta, b) the sloping outer margins of the delta and c) bottom of the wide and deep gullies from the delta periphery.

The OSL samples were collected from between 115 and 150 cm (45 to 59 inch) depth in sediment that was freshly exposed in 2 meter deep pits which contained uniform, well-sorted, little to no stratification, fine and medium grained sands that lacked bedding structures. OSL analyses were performed in the Optical Dating and Dosimetry Lab at North Dakota State University. The ages were determined from clean quartz sand extracts in the grain size range 150 to 250 um (0.15 to 0.25 cm) using single aliquot regenerative dose (SAR) procedures. Refer to the study for specifics for references that describe how sample preparation, data collection, and data analysis methodology dose rate calculations were conducted. Five of six OSL ages from the Cottage Grove Delta, located north of the current north Higgins Lake area, and were within ± 1,000 years of one another, with a mean age of 23.1 ± 0.4 kA (or 400 years). These ages suggest that the Mackinac Lobe had started to retreat from the region considerably earlier than previously thought, even while the ice was near its maximum extent in Illinois and Indiana, and the remainder of Michigan was ice-covered. Thick and deep fine-textured glacial sediment deposits, which underlie much of the region, probably date to this time. This study provides the first evidence of this very early ice retreat from central Lower Michigan, occurring almost 4,000 years before the southern margin of the ice (Saginaw Lobe) had started its retreat from the state. This study has also brought to light additional information about the glacial sediment distribution and depositional setting in the High Plains area which will aid those who work in the subsurface performing geological and hydrogeological studies.

Hydrogeology and Groundwater Flow Regimes

The hydrogeology of the Higgins and Houghton Lake area is generally constrained by sediment type and variation, topographic elevation, proximity to surface water (lakes, streams, rivers and creeks) and position with respect to underlying and deeper groundwater bearing sediments, and depth to and type of bedrock. Groundwater is found at various depths in both unconsolidated sediments and in various types of bedrock. In order for a groundwater-bearing unit to be considered a viable source of drinking water, and be qualify to be termed an aquifer, it must meet certain water quality standards and supply sufficient water volume for the specific use for which a producing well is installed (i.e. private residential, agricultural or municipal supply). Some groundwater aquifers flow naturally (without need for water recovery by pumping) and are called artesian. Groundwater can also be present in insufficient quantities to be to be recovered by sustained pumping, in both unconsolidated sediments and bedrock, and are not considered to be present in an aquifer. However, individual groundwater-bearing units, regardless of their inability to yield an aquifers' volume of water in any particular area where various types of production wells have been drilled to recover specific volumes of their groundwater, is due to limitations of the following physical properties: a) porosity (the volume of pores containing air/unit volume of sediment or bedrock), b) permeability (the interconnectedness of these pores and the ease that water is transmitted) and c) thickness and lateral extent.

Each groundwater-bearing unit present in the subsurface is an important part of the entire hydrogeologic cycle continuum because individual groundwater-bearing units may be hydraulically connected to adjoining groundwater-bearing units due to changes in lithology, structural constraints, etc., will result in sufficient porosity, permeability, thickness and lateral extent to become an aquifer. The aquifers in glacial sediments in the Great Lakes basin are not as large as many of the known larger aquifers due mainly to the way glacial sediments are deposited and the limited area these glacial sediments are laterally persistent in the Great Lakes basin. However, glacial aquifers are just as important as other aquifers around the world because glacial aquifers are a major source of groundwater in the northern part of the Lower Peninsula of Michigan. Some aquifers, such as the Ogalalla Aquifer, a shallow water-table or unconfined aquifer, is one of the world's largest and underlies over 174,000 square miles including the High Plains of Texas, New Mexico, Oklahoma, Kansas, Colorado and Nebraska.

Groundwater-bearing units in unconsolidated sediments can be either unconfined or confined, i.e. not under pressure or under pressure, respectively. The uppermost groundwater-bearing units in unconsolidated sediments are generally unconfined in the upper 30 feet of the subsurface and the depth to the top of the groundwater table or its elevation, surveyed to an established datum, is the same as the measured level of the top of groundwater table in the subsurface. Confined aquifers are present in deeper levels of unconsolidated sediment and in bedrock. In a confined aquifer, the depth to top of the groundwater table elevation, can be higher or lower in a well, surveyed to an established datum, depending if the groundwater is moving upward or downward, respectively, with respect to the confined groundwater level in the subsurface.

The groundwater surface (also known as the potentiometric surface), is a smooth surface, flows in 3-dimensions, from higher elevation to lower elevation, and the direction of flow is controlled by many factors including proximity to the closest surface water body, fluctuations in sediment/bedrock porosity and permeability, topography, structural constraints, etc. Groundwater flows from higher to lower elevation. Multiple groundwater-bearing units may be present in any given area. Groundwater flow in any area, in the upper and lower groundwater-bearing units likely has a local and regional flow component which can vary in both direction and slope (gradient) within the constraints imposed by the geologic and hydrogeology in the subsurface. However, only specific site information obtained from direct physical measurements in the subsurface, obtained to the level of accuracy required, will ultimately provide the answers as to which direction and gradient groundwater will flow.

Geology and Groundwater in Higgins Lake

Some general statements about the uppermost groundwater-bearing and deeper groundwater-bearing units can be made that occur in both the flat topographic areas and the upland areas in the Houghton and Higgins Lake areas based on general hydrogeologic principals. In the flat topographic areas between ridges, such as in the vicinity of the marshes surrounding Houghton and Higgins Lakes and the Muskegon River, depth to the first groundwater-bearing sediment will be shallow (less than 10 feet) and groundwater flow in the uppermost groundwater-bearing unit will likely be mainly toward these surface water bodies. However, relative to the location of other surface water bodies, such as creeks and streams, any changes in sediment type and distribution and other factors will also affect groundwater flow direction and gradient in the shallow groundwater-bearing units in the flat topographic areas near both Houghton and Higgins Lakes. In the upland areas with thick fine-textured sediment, the upper groundwater-bearing units will likely be much deeper. Groundwater flow will be dependent upon structural constraints, the proximity to surface water bodies including river systems, significant topographic elevation changes, regional groundwater effects and other factors.

Nearshore Higgins Lake Water Quality and Associated Relationship to Septic Systems

A study by (Martin et *al*., 2014) study provided water quality data for Higgins Lake, along with analysis of this newer data relative to prior water quality data collected by the United States Geological Survey (USGS), between 1995 to 2014, and the human wastewater systems around the lake. Samples were collected from 21 sites in the nearshore regions including some sites that overlapped with the USGS sampling points collected in the late 1990's

Higgins Lake, Michigan's 10th largest inland lake and one of its deepest, is experiencing changes in water quality, underwater vegetation, invasive species, and Swimmer's itch. Many of these changes are occurring in the large shallow area, located near shore, and called the shelf. This broad shallow area limits mixing of near-shore waters with deeper basin waters especially during calm periods. Studies previously conducted by Minnerick (2001) and Martin et al., 2012 have revealed concentrations of nitrogen and phosphorus orders of magnitude higher in shelf water than in the deeper basins. The majority of the Higgins Lake shoreline is populated by septic tank systems. These septic systems may serve as a major source of nutrient contamination into the nearshore areas during the summer when seasonal homes are occupied.

Comparison of the 2014 water quality values to those from the 1990's dataset showed a significant increase in near-shore surface water total phosphorus (TP). The average concentration currently exceeds the 12 ug/l mesotrophic threshold with significant ecological changes occurring in the nearshore lake region. Specific conductivity levels have also risen, indicating increased pollutant loads have been added to the lake.

Statistical modeling was used to relate sampled concentrations of total phosphorus, nitrate and nitrite (NO_3 and NO_2), ammonia (NH_3) and Boron (B) and other water quality parameters to measures of septic system density and groundwater influx. These models support the finding that groundwater is a significant source of nutrients in the lake. Groundwater flow velocity into the lake, measured using a point-based seepage velocimeter, was the most significant variable explaining concentrations patterns, while combinations of hydraulic gradient (how much slope there is in the water table near the lake) and septic/parcel density were also important.

Temporal trends and spatial patterns in this data all support the hypothesis that the Camp Curnalia wastewater treatment plant has substantially improved water quality in the adjacent nearshore area, due mainly to groundwater inputs. Near Camp Curnalia at paired USGS/MSU sites, TP concentrations in groundwater have greatly decreased and nitrate (NO_3) and nitrite (NO_2) concentrations dropped below detection limits. Boron, an indicator of septic system inputs, also exhibited a significant decline in concentrations. Also, the specific conductivity in the Camp Curnalia area was the lowest in the partial shoreline survey.

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.

Lake Trophic Status	*Total Phosphorus ($mg\ L^{-1}$)*	*Chlorophyll-a ($\mu g\ L^{-1}$)*	*Secchi Transparency (feet)*
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 $CaCO_3$/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 21-23, 2019 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.

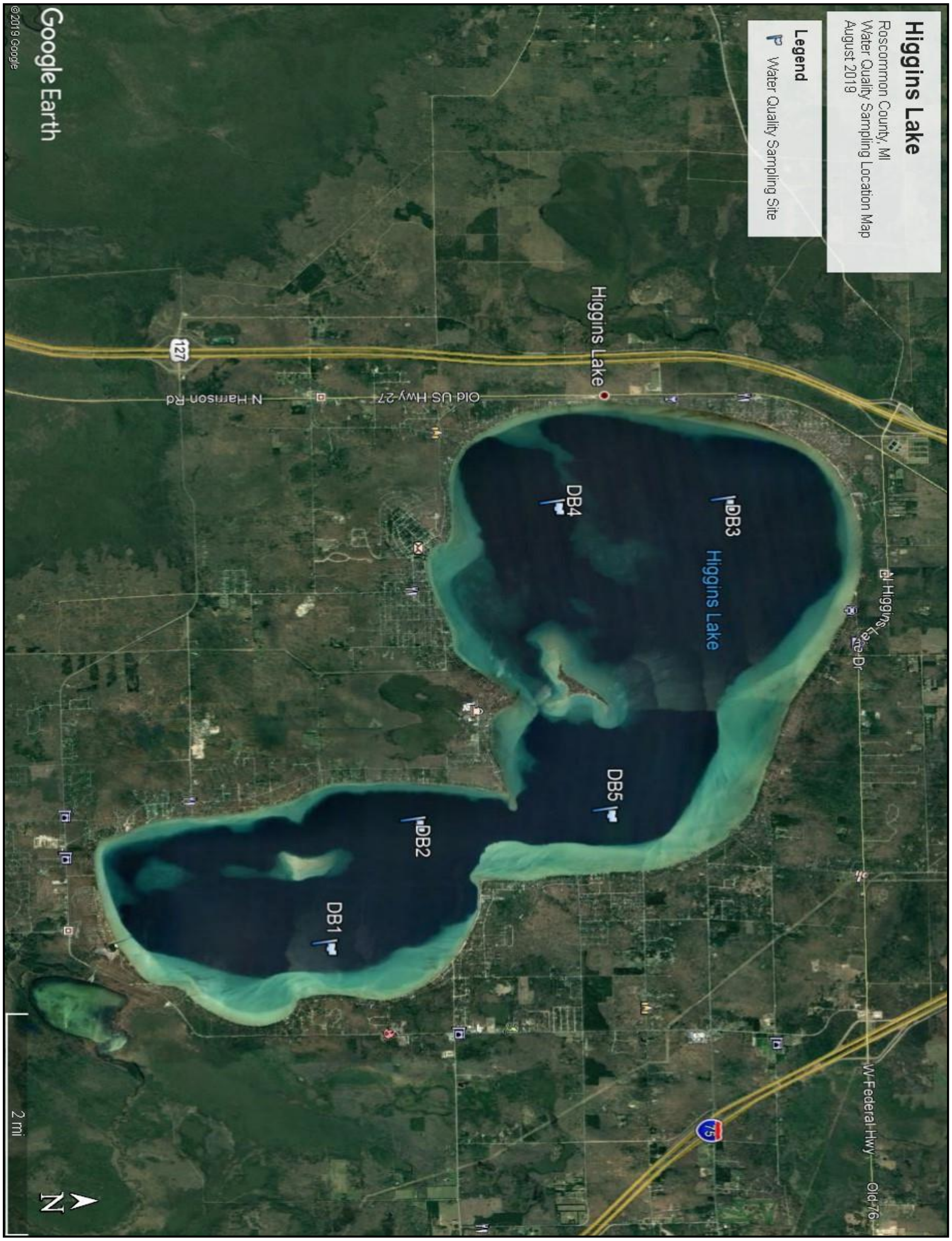
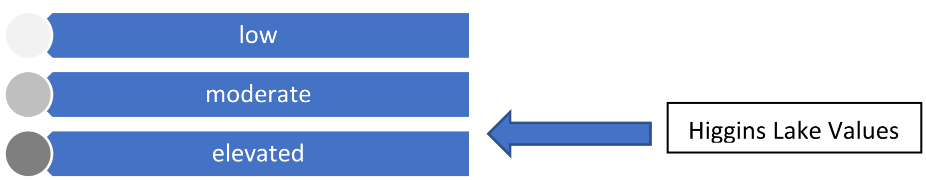


Figure 6. Locations for deep basin water quality sampling in Higgins Lake (August 21-23, 2019).

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 2.5-11.0 mg/L, with the highest values measured at the mid-depth and lowest values near the lake bottom. 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. All of the deep basins experienced substantial loss of DO with depth. Many of the surface and mid-depth concentrations were above 100% saturation which is favorable. 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 (ºC) with the use of a calibrated Eureka Manta II® submersible thermometer. The August 22, 2019 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 the day of sampling, water temperatures ranged from 23.1°C at the surface to 6.8°C at the bottom of the five deep basins. Deep basin #3 exhibited the strongest stratification with the highest water temperature difference of 16.2°C.

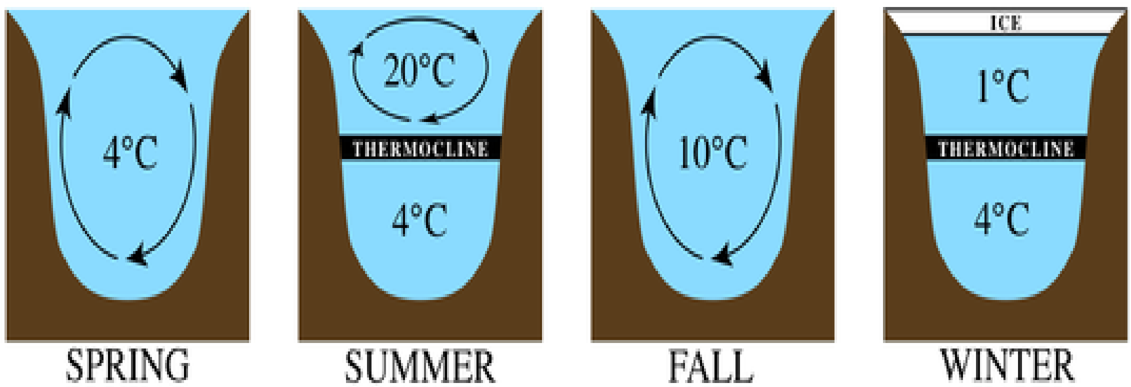
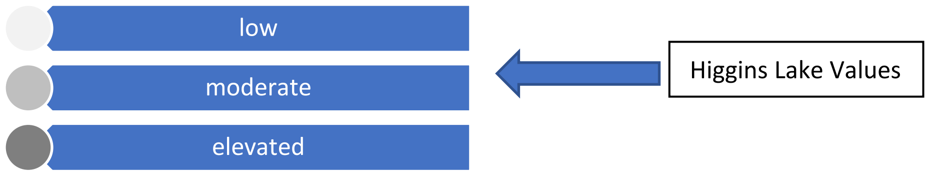


Figure 7. The lake thermal stratification process.

4.1.3 Specific Conductivity

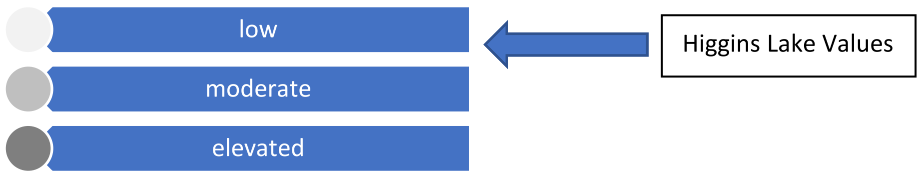
Specific conductivity is a measure of the number of mineral ions present in the water, especially those of salts and other dissolved inorganic substances that can conduct an electrical current. Specific conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Specific conductivity was measured in micro Siemens per centimeter (µS/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 264-308 mS/cm which are moderate values. The highest specific conductivity values were recorded in deep basin #3 which had the highest specific conductivity at the lake bottom of 308 mS/cm. Since these values are moderately high 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

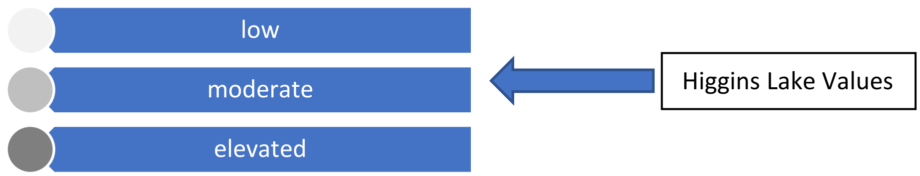
Turbidity

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 0.3-1.4 NTU's during the August 22, 2019 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.



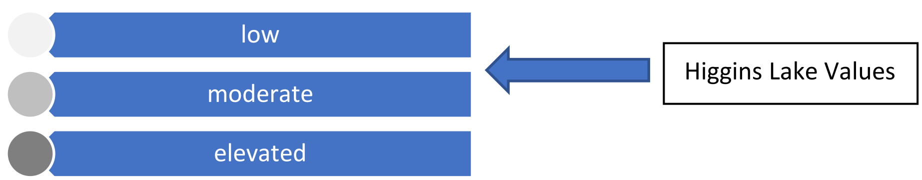
Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the amount of dissolved organic and inorganic particles in the water column. 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 22, 2019 ranged from 128-150 mg/L for the deep basins which is moderate for an inland lake and correlates with the measured moderate conductivity.



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 22, 2019, ranged from <10-20 mg/L, with the highest values located at the bottom of deep basin #4 and the surface of deep basin #2 . Ideally values should be < 10 mg/L.



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 7.5-8.2 S.U. during the August 22, 2019 sampling event with the lowest values measured near the lake bottom of deep basin #2 and the highest value recorded at the surface of deep basin #3. 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

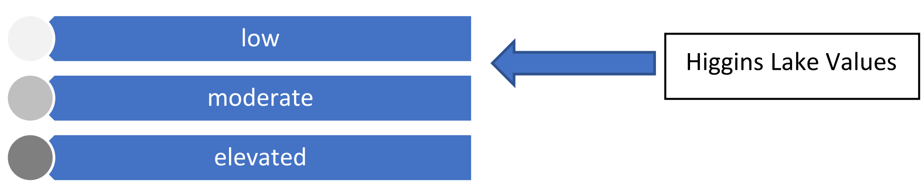
Total alkalinity is a measure of the pH-buffering capacity of lake water. Lakes with high alkalinity (> 150 mg/L of $CaCO_3$) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of $CaCO_3$ and are categorized as having “hard” water. Total alkalinity was measured in milligrams per liter of $CaCO_3$ through the acid titration Method SM 2320 B-11.

Total alkalinity in the deep basins ranged from 83-140 mg/L of $CaCO_3$ during the sampling event, which represents a moderate alkalinity and may be a characteristic of the lake sediments and geology. 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. 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.



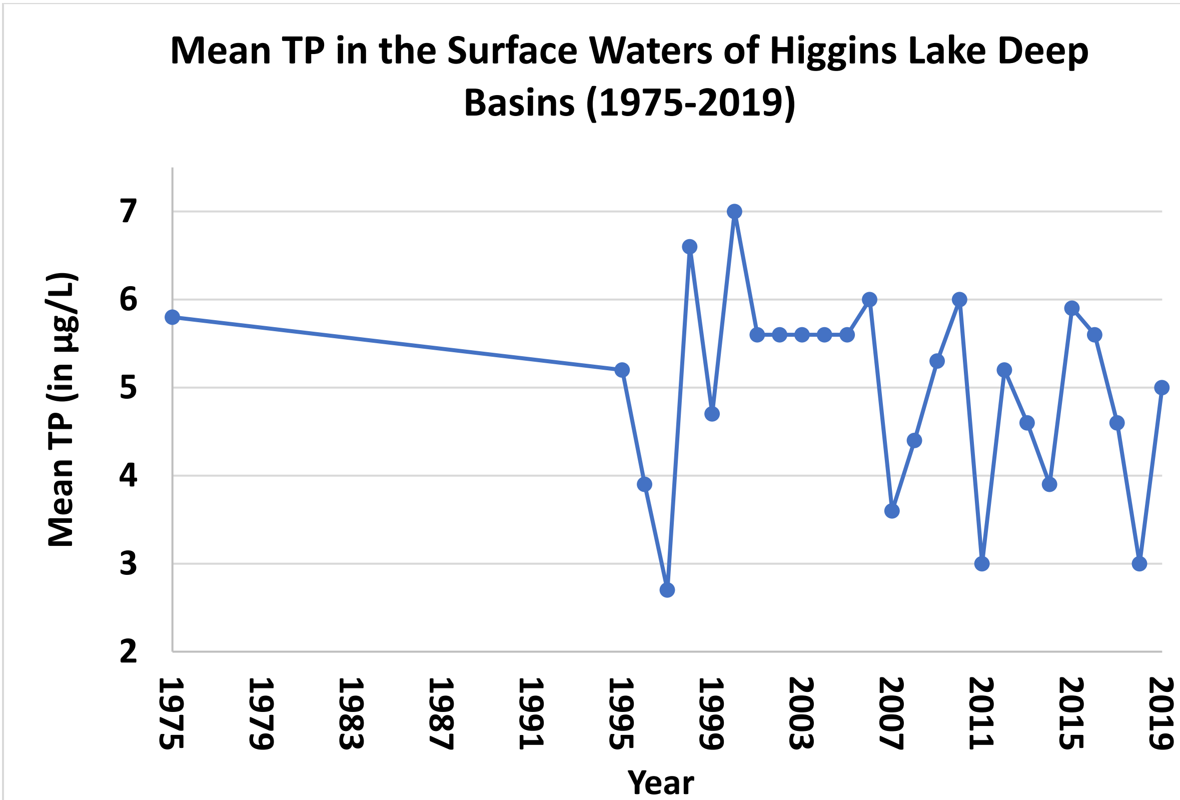
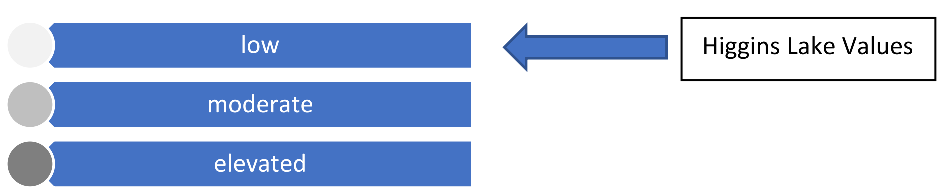


Figure 8. Trends in mean total phosphorus (in µg/L) with time in the surface waters of the Higgins Lake deep basins. Data from USEPA (1975), CLMP (2001-2018), and RLS (2019). Note: comparisons for the hypolimnion could not be made due to differences in sampling methodology.

Ortho-Phosphorus

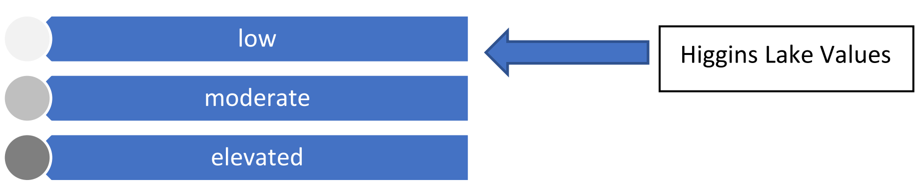
Ortho-Phosphorus (also known as soluble reactive phosphorus or SRP) was measured with Method SM 4500-P (E-11). SRP refers to the most bioavailable from of P used by all aquatic life. All of the SRP concentrations were <0.010 mg/L which is favorable. Since the SRP concentrations were all low, less of 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 (≤ 0.50 mg/L), which are normal for an inland lake of similar size. In the absence of dissolved oxygen, nitrogen is usually in the ammonia form and will contribute to rigorous submersed aquatic plant growth if adequate water transparency is present. 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 (NO3-), nitrite (NO2-), and ammonia (NH3) forms of nitrogen without the organic forms of nitrogen. The TIN concentrations ranged from <0.010-0.031 mg/L with the highest concentrations present at the bottom of the deep basin #2. These concentrations are low overall.

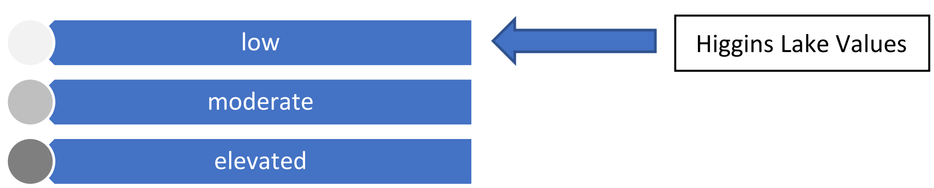


4.1.9 Chlorophyll-a and Algae

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 µg/L are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg/L are found in nutrient-poor or oligotrophic lakes.

Chlorophyll-*a* was measured in micrograms per liter (µg/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 0-0.4 µg/L during the August 22, 2019 sampling event. These concentrations were very low 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): *Mougeotia* sp., *Scenedesmus* sp., *Closterium* sp., *Chlorella* sp., *Lyngbya* sp.; the Cyanophyta (blue-green algae): *Polycystis* sp. and *Chroococcus* sp.; the Bascillariophyta (diatoms): *Fragilaria* sp., *Stephanodiscus* sp., *Amphora* sp., *Achnanthidium* sp., *Melosira* sp., and *Navicula* sp.; and the Chrysophyte, *Dinobryon* sp. which was quite abundant. 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 green algae. 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.



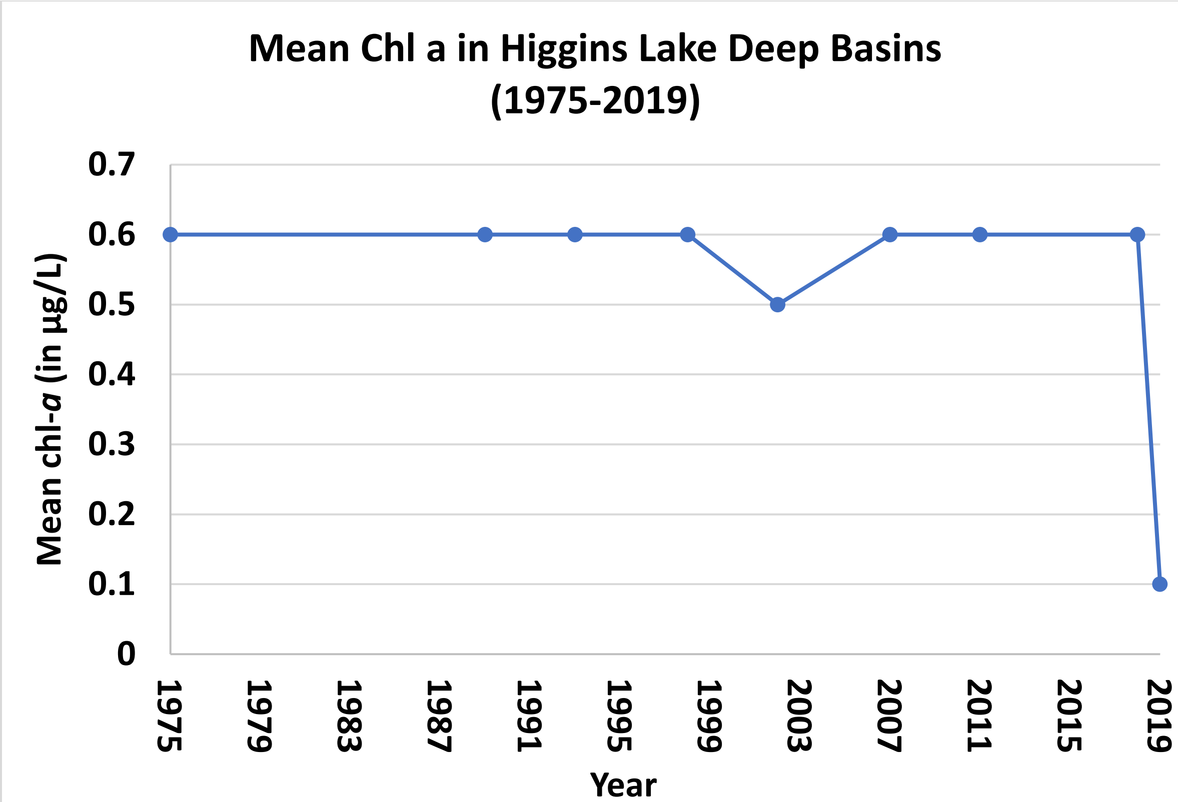
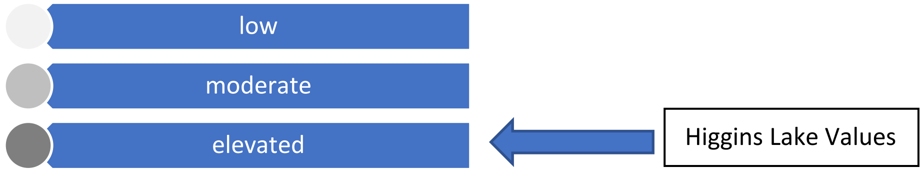


Figure 9. Trends in mean chlorophyll-*a* with time in Higgins Lake (1975-2019). Data from USEPA (1975), CLMP (2001-2018), and RLS (2019).

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 22, 2019 and ranged from 28.5-29.5 feet over the deep basins which are favorable measurements. Measurements were collected during calm conditions (winds out of the northwest at 5-10 mph in the early morning). 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.



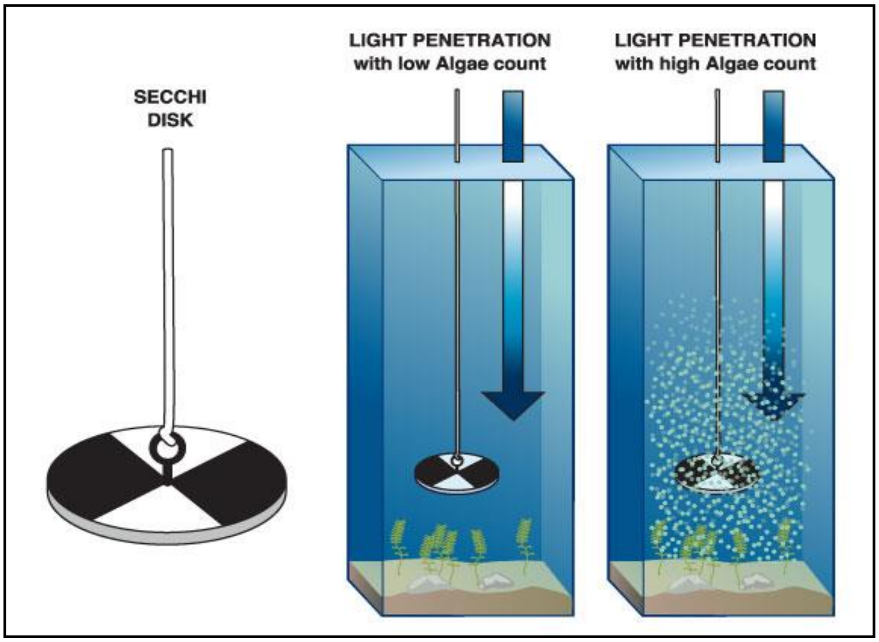


Figure 10. Measurement of water transparency with a Secchi disk.

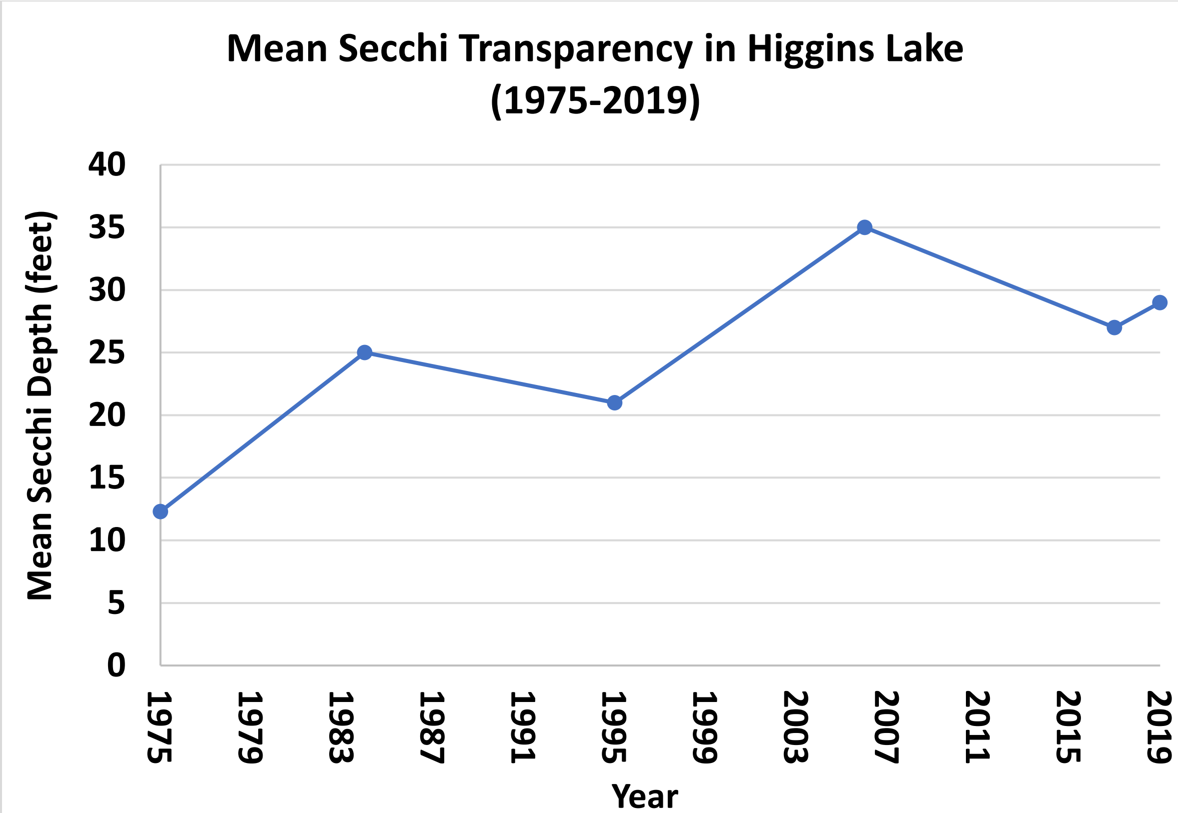


Figure 11. Trends in Secchi transparency with time in Higgins Lake (1975-2019). Data from USEPA (1975), CLMP (2001-2018), and RLS (2019).

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 22, 2019).

Depth (ft)	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	8.5	103	8.0	266	129	0.4	28.5
50	12.5	11.0	107	8.0	273	136	0.4	
100	8.9	3.0	25.2	7.6	295	147	0.5	

Table 5. Higgins Lake chemical water quality parameter data collected at deep basin #1 (August 22, 2019).

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	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	--	0.411	98
50	<0.50	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	--	--	91
100	<0.50	<0.010	0.011	<0.010	<0.010	<0.10	<0.10	14	--	100

Table 6. Higgins Lake physical water quality parameter data collected at deep basin #2 (August 22, 2019).

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	23.1	8.5	103	8.1	266	129	0.4	29.0
50	12.2	11.0	106	8.0	275	137	0.4	
100	8.8	2.9	25.1	7.5	297	147	0.7	

Table 7. Higgins Lake chemical water quality parameter data collected at deep basin #2 (August 22, 2019).

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	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	20	0	91
50	<0.50	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	--	--	86
100	<0.50	0.031	0.028	<0.010	0.031	<0.10	<0.10	<10	--	110

Table 8. Higgins Lake physical water quality parameter data collected at deep basin #3 (August 22, 2019).

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	103	8.2	264	128	0.3	29.0
67	10.5	10.4	104	8.0	279	140	0.5	
135	6.8	2.5	23.5	7.7	308	150	1.4	

Table 9. Higgins Lake chemical water quality parameter data collected at deep basin #3 (August 22, 2019).

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	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	--	0	99
67	<0.50	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	--	--	97
135	<0.50	0.019	0.011	<0.010	0.019	<0.10	<0.10	16	--	120

Table 10. Higgins Lake physical water quality parameter data collected at deep basin #4 (August 22, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	23.0	8.7	8.1	266	128	0.3	29.5
53	12.1	9.7	8.1	274	136	0.5	
106	8.7	3.4	7.8	299	147	0.9	

Table 11. Higgins Lake chemical water quality parameter data collected at deep basin #4 (August 22, 2019).

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	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	--	0	92
53	<0.50	<0.010	0.043	<0.010	<0.010	<0.10	<0.10	--	--	97
106	<0.010	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	20	--	140

Table 12. Higgins Lake physical water quality parameter data collected at deep basin #5 (August 22, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Turb. (NTU)	Secchi Depth (ft)
0	22.1	9.5	8.0	266	129	0.4	29.5
43	14.0	9.8	7.8	273	135	0.4	
87	7.9	4.9	7.6	276	138	0.6	

Table 13. Higgins Lake chemical water quality parameter data collected at deep basin #5 (August 22, 2019).

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	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	--	0	89
43	<0.50	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	--	--	83
87	<0.50	<0.010	<0.010	<0.010	<0.010	<0.10	<0.10	--	--	89

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. Higgins Lake currently lacks a high quantity of submersed aquatic vegetation which can create a favorable environment for algae to thrive since they both compete for water column nutrients.

A whole-lake scan of the aquatic vegetation in Higgins Lake was conducted on August 21-23, 2019 with a WAAS-enabled Lowrance HDS 9® GPS with variable frequency transducer. This data included 75,339 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 August 21-23, 2019.

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.

The GPS Point-Intercept/AVAS survey of Higgins Lake was conducted on August 21-23, 2019 and consisted of 2,564 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.

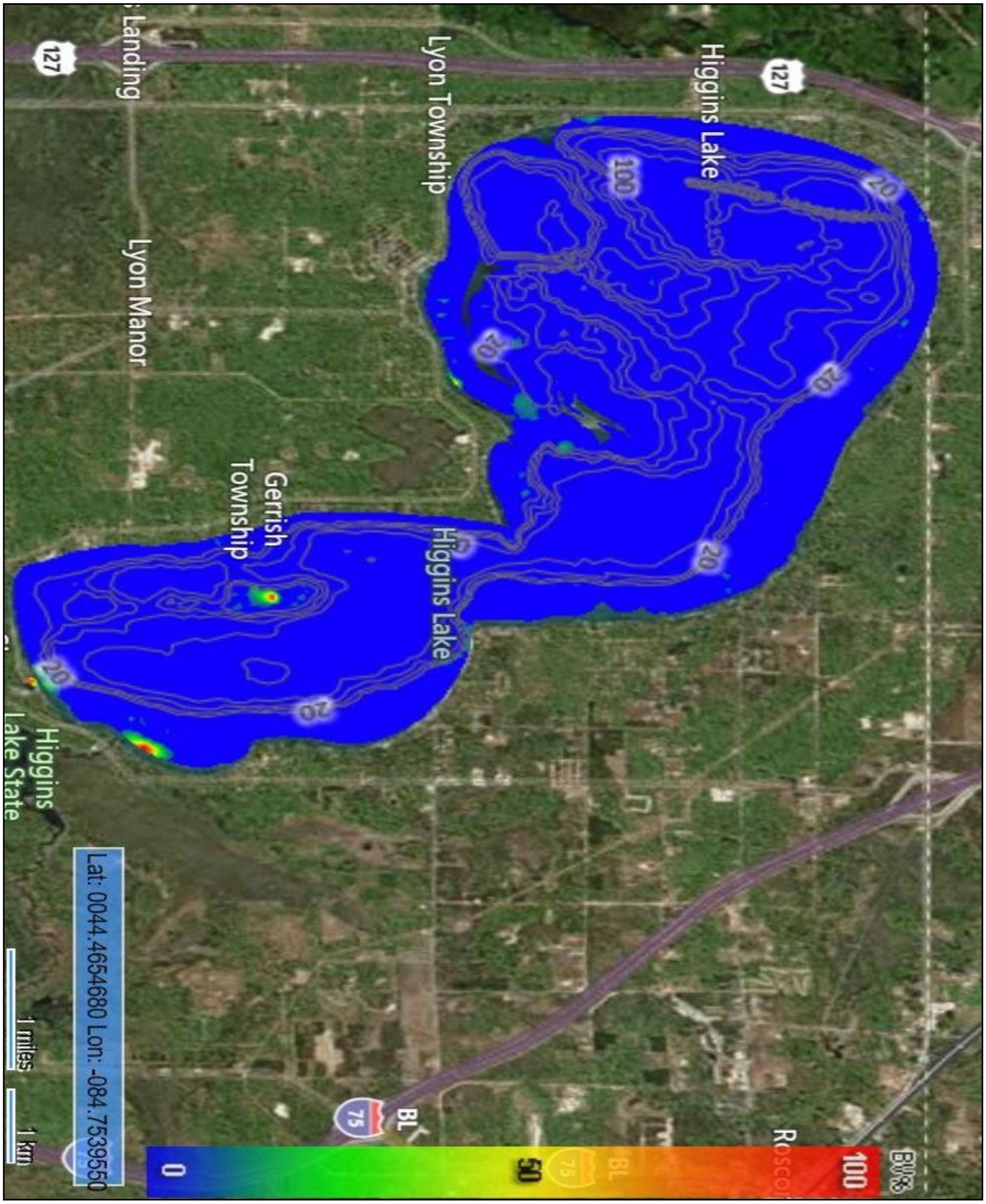


Figure 12. Aquatic plant biovolume of all aquatic plants in Higgins Lake, Roscommon County, Michigan (August 21-23, 2019). Note: Red color denotes high-growing aquatic plants, green color denoted low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

Table 14. Higgins Lake aquatic vegetation biovolume by bottom cover category (relative cover on August 21-23, 2019).

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

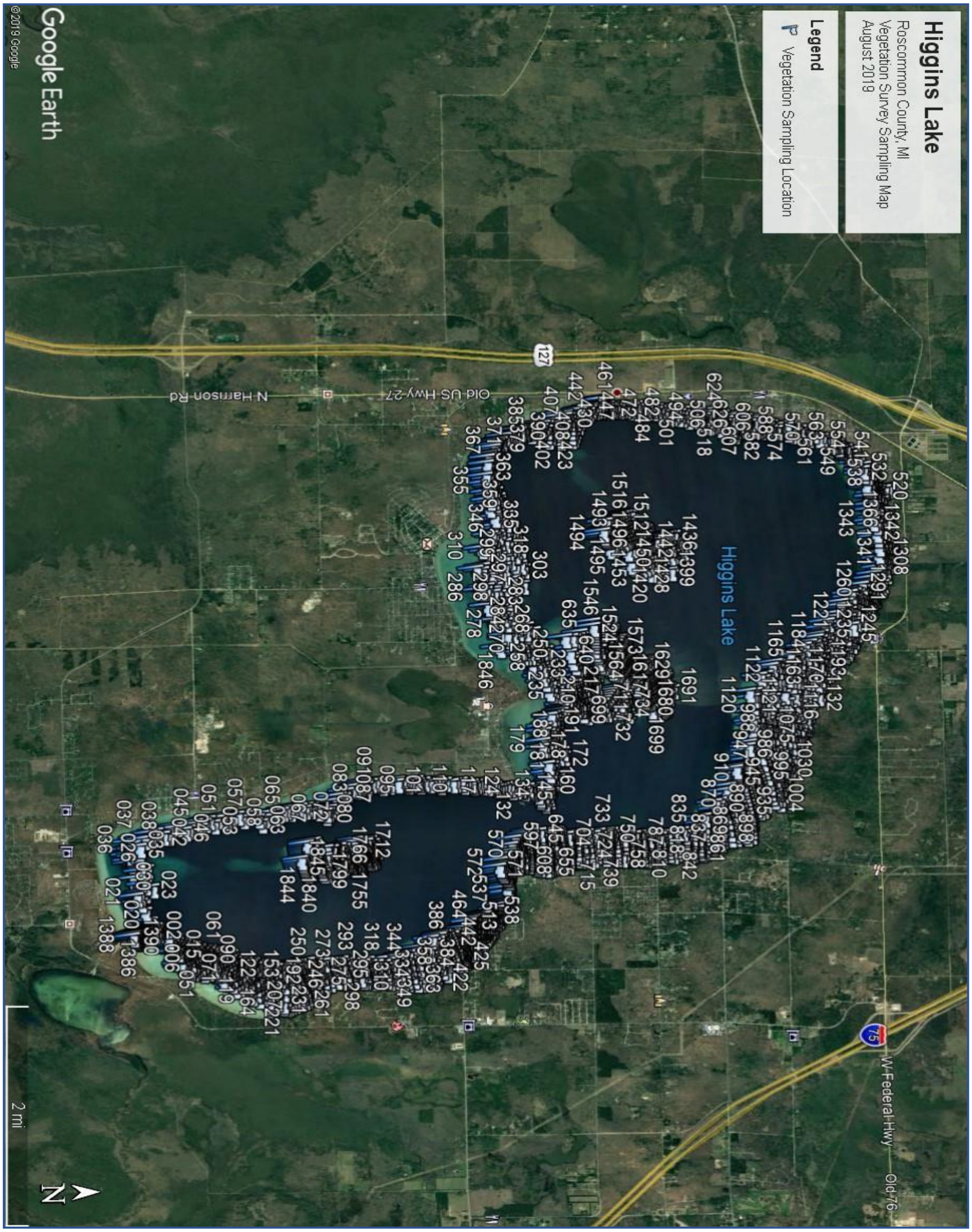


Figure 13. Aquatic vegetation sampling locations in Higgins Lake (August 21-23, 2019).

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.

Higgins Lake contained 18 native submersed and 2 emergent aquatic plant species, for a total of 20 native aquatic macrophyte species (Table 15). 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 included the native macro alga Chara (50.1% of the sampling locations), the submersed, large-leaf and variable-leaf pondweeds (both at 7.5% of the sampling locations), and Illinois pondweed (6.5% 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 (August 21-23, 2019). Note: RLS also found the aquatic moss (*Taxiphyllum* sp.) which is non-vascular.

Native Aquatic Plant Species Name	***Native Aquatic Plant Common Name***	***Higgins Lake Frequency***	***Native Aquatic Plant Growth Habit***
Chara vulgaris	Muskgrass	50.1	Submersed, Rooted
Tolypella sp.	Native Stonewort	0.2	Submersed, Rooted
Stuckenia pectinatus	Sago Pondweed	3.4	Submersed, Rooted
Potamogeton zosteriformis	Flat-stem Pondweed	0.04	Submersed, Rooted
Potamogeton illinoensis	Illinois Pondweed	6.5	Submersed, Rooted
Potamogeton perfoliatus	Clasping-leaf Pondweed	0.3	Submersed, Rooted
Potamogeton richardsonii	Clasping-leaf Pondweed	0.5	Submersed, Rooted
Potamogeton amplifolius	Large-leaf Pondweed	7.5	Submersed, Rooted
Potamogeton gramineus	Variable-leaf Pondweed	7.5	Submersed, Rooted
Potamogeton pusillus	Slender Pondweed	0.7	Submersed, Rooted
Potamogeton foliosus	Leafy Pondweed	0.2	Submersed, Rooted
Potamogeton natans	Floating-leaf Pondweed	0.5	Submersed, Rooted
Potamogeton praelongus	White-stem Pondweed	0.08	Submersed, Rooted
Potamogeton diversifolius	Waterthread Pondweed	0.04	Submersed, Rooted
Myriophyllum sibiricum	Northern Watermilfoil	0.2	Submersed, Rooted
Elodea canadensis	Common Waterweed	1.2	Submersed, Rooted
Vallisneria americana	Wild Celery	2.5	Submersed, Rooted
Najas guadalupensis	Southern Naiad	5.0	Submersed, Rooted
Typha latifolia	Cattails	0.04	Emergent
Eleocharis acicularis	Spikerush	0.04	Emergent

Table 16. Higgins Lake native aquatic vascular plants (August 21-23, 2019) by relative abundance.

Native Aquatic Plant Species Name	***Native Aquatic Plant Common Name***	***"a" Level***	***"b" Level***	***"c" Level***	***"d" Level***
Chara vulgaris	Muskgrass	694	17	232	5
Tolypella sp.	Native Stonewort	2	2	1	0
Stuckenia pectinatus	Sago Pondweed	38	5	1	0
Potamogeton zosteriformis	Flat-stem Pondweed	0	1	0	0
Potamogeton illinoensis	Illinois Pondweed	64	102	1	0
Potamogeton perfoliatus	Clasping-leaf Pondweed	2	6	0	0
Potamogeton richardsonii	Clasping-leaf Pondweed	2	8	3	0
Potamogeton amplifolius	Large-leaf Pondweed	150	32	9	1
Potamogeton gramineus	Variable-leaf Pondweed	77	112	4	0
Potamogeton pusillus	Slender Pondweed	5	13	0	0
Potamogeton foliosus	Leafy Pondweed	0	5	0	0
Potamogeton natans	Floating-leaf Pondweed	10	3	0	0
Potamogeton praelongus	White-stem Pondweed	1	1	0	0
Potamogeton diversifolius	Waterthread Pondweed	1	0	0	0
Myriophyllum sibiricum	Northern Watermilfoil	1	2	1	0
Elodea canadensis	Common Waterweed	12	5	8	5
Vallisneria americana	Wild Celery	23	29	11	1
Najas guadalupensis	Southern Naiad	69	52	6	0
Typha latifolia	Cattails	0	0	0	1
Eleocharis acicularis	Spikerush	0	0	1	0

Figure 14. Chara (Muskgrass)

Figure 15. *Tolypella* sp.

Figure 16. Sago Pondweed

Figure 17. Flat-Stem Pondweed

Figure 18. Illinois Pondweed

Figure 19. Clasping-leaf Pondweed

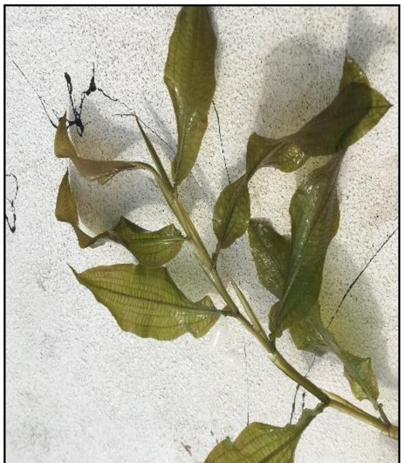


Figure 20. Large-leaf Pondweed

Figure 21. Variable-leaf Pondweed

Figure 22. Slender Pondweed

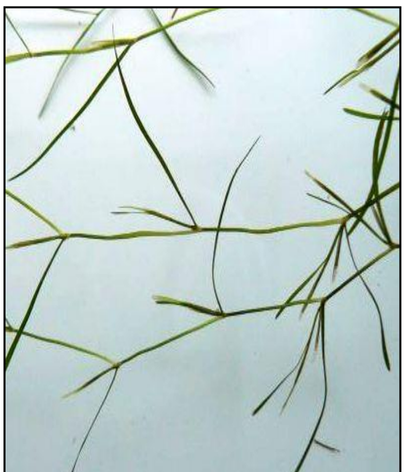


Figure 23. Leafy Pondweed

Figure 24. White-stem Pondweed

Figure 25. Water thread Pondweed

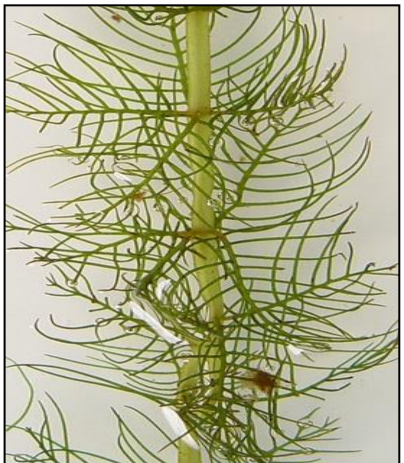


Figure 26. Northern Watermilfoil

Figure 27. Common Waterweed

Figure 28. Wild Celery

Figure 29. Southern Naiad

Figure 30. Cattails

Figure 31. Spikerush

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 32) 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 (Figure 33) 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 21.1 acres of Eurasian Watermilfoil was found in Higgins Lake during the August 21-23 survey and an intensive management program is proposed below. 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 (Figure 34) 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 (Figure 35). The distribution of milfoil throughout Higgins Lake is shown below in Figure 36.

Figure 32. Hybrid Eurasian Watermilfoil plant with seed head and fragments.

Figure 33. Eurasian Watermilfoil Canopy on an inland lake.

Figure 34. A Eurasian Watermilfoil stem from Higgins Lake.

Figure 35. Eurasian Watermilfoil stem with attached Zebra Mussel in Higgins Lake.

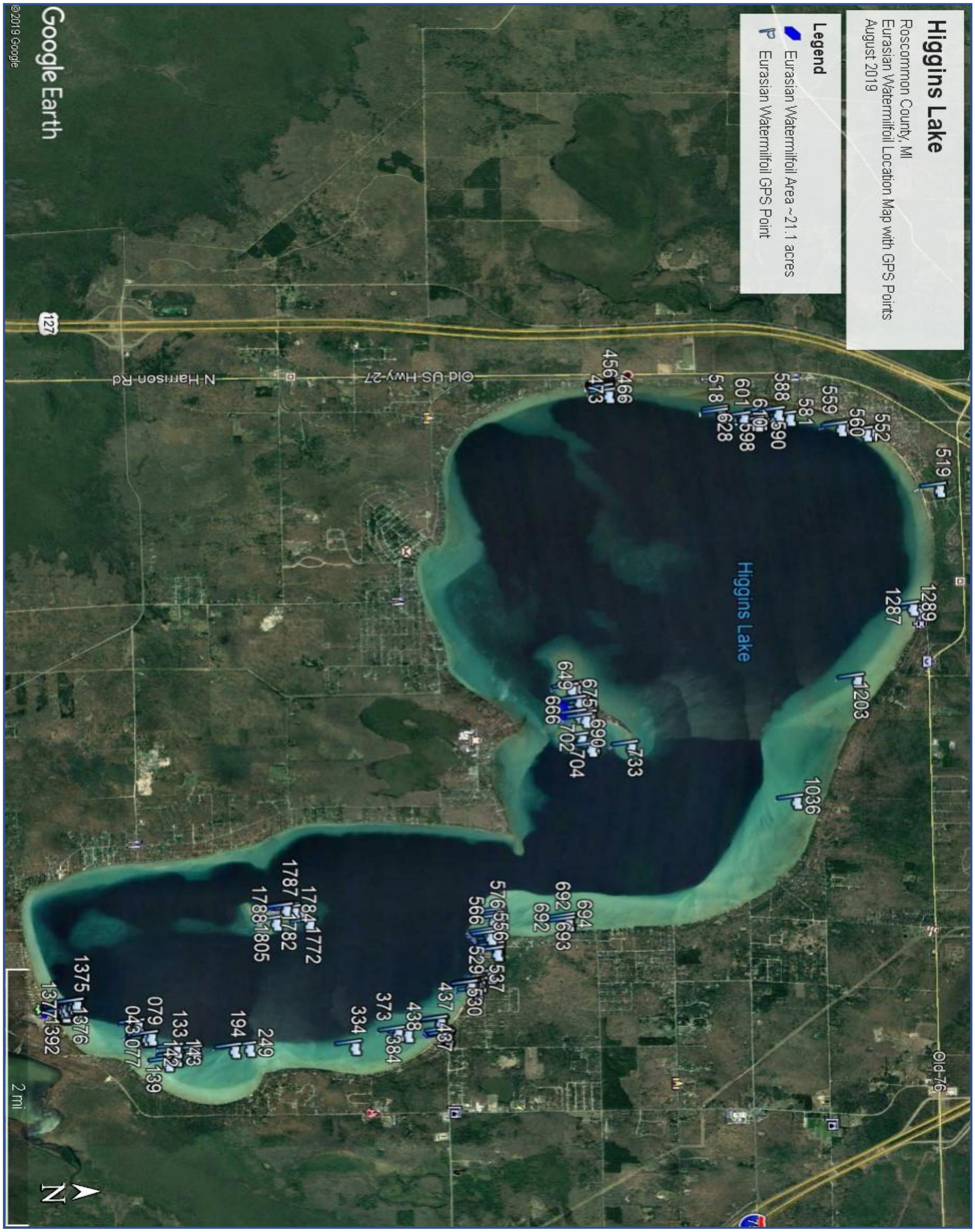


Figure 36. EWM distribution in Higgins Lake (August 21-23, 2019).

Starry Stonewort (*Nitellopsis obtusa*; Figure 37) 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 2.5 acres were found throughout the lake (Figure 38) with 1.9 acres present in the South Park boat launch lagoon (Figure 39). This lagoon is currently acting as a breeding grounds 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 37. A fragment of Starry Stonewort.

Table 17. Higgins Lake exotic aquatic plant species (August 21-23, 2019).

Exotic Aquatic Plant Species	***Exotic Aquatic Plant Common Name***	***Exotic Aquatic Plant Growth Habit***	***Abundance in or around Higgins Lake***
Myriophyllum spicatum	Eurasian Watermilfoil	Rooted, Submersed	~21.1 acres
Nitellopsis obtusa	Starry Stonewort	Rooted, Submersed	~2.5 acres

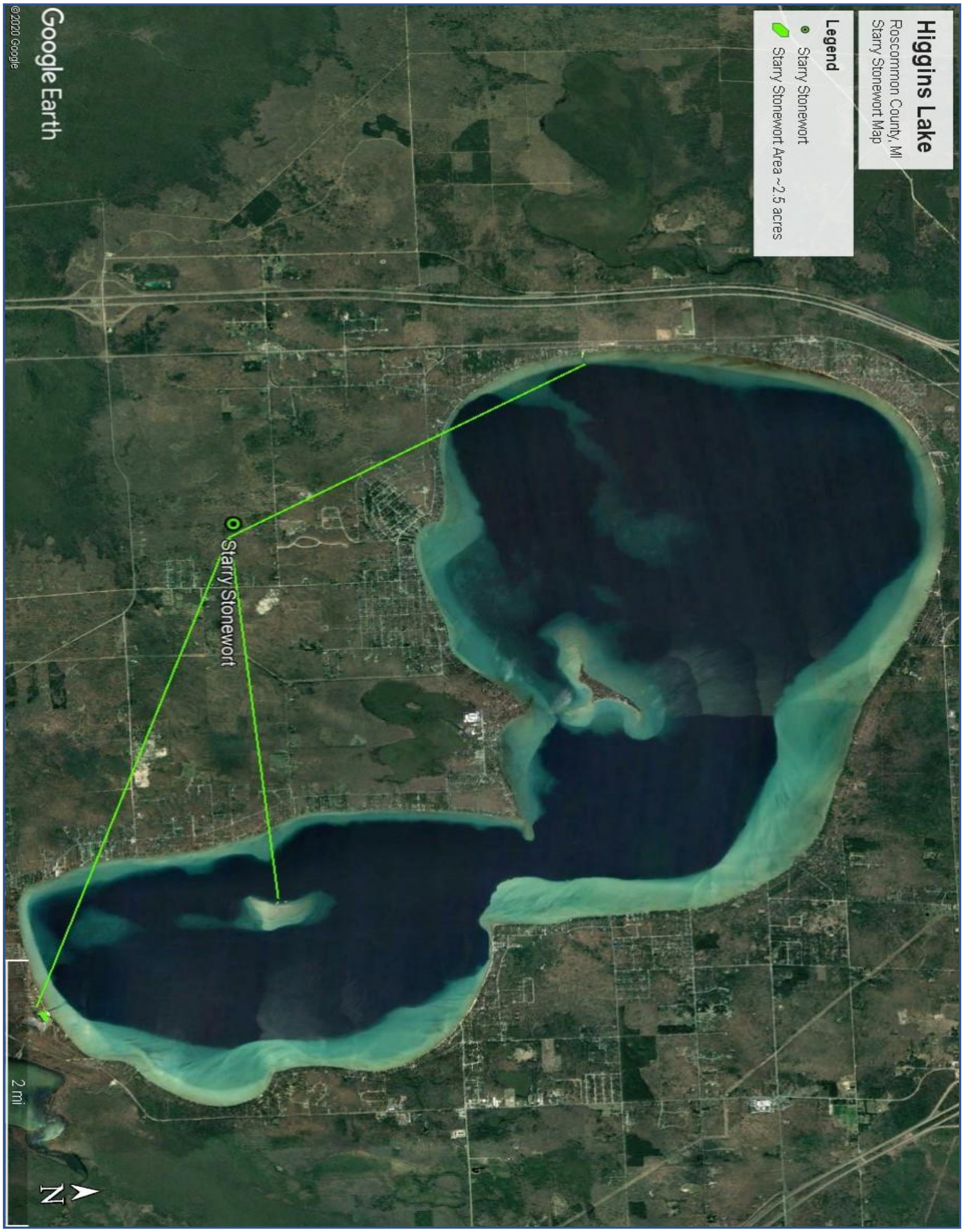


Figure 38. Starry Stonewort distribution in the main basins of Higgins Lake (August 21-23, 2019).

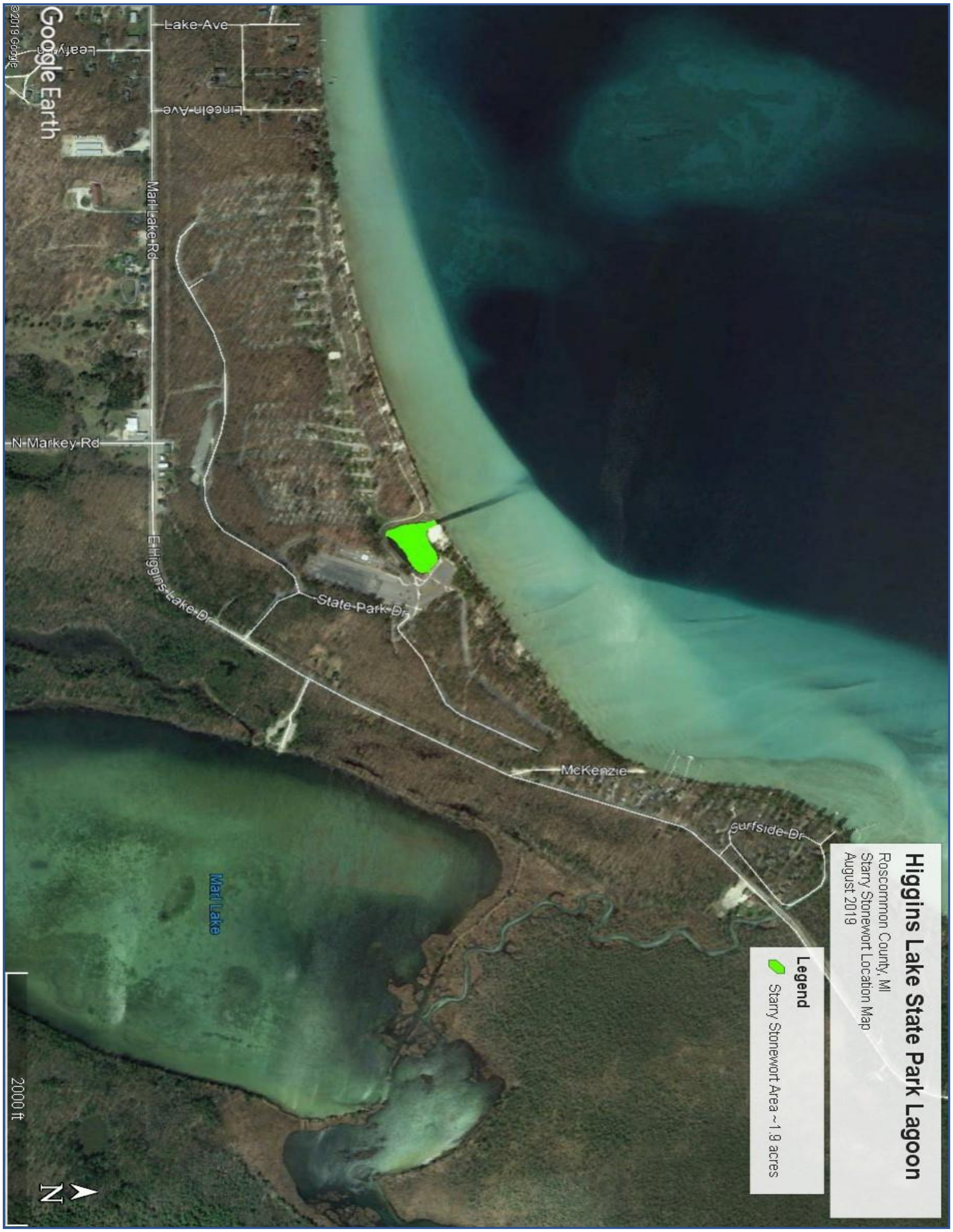


Figure 39. Starry Stonewort Distribution in the Lagoon (South Launch) of Higgins Lake (August 21-23, 2019).

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 40) was conducted by RLS scientists on August 21-23, 2019 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 40. A zooplankton collection tow net.

Table 18. Zooplankton taxa and count data from Higgins Lake Deep Basin #1 (August 21-23, 2019).

Cladocerans	Count	Copepods	Count	Rotifers	Count
Daphnia longiremis	23	***Cyclops* sp.**	12	***Keratella* sp.**	9
***Leptodiaptomus* sp.**	20	***Mesocyclops edax***	63		
***Bosmina* sp.**	9	***Acanthocyclops* sp.**	8		
***Ceriodaphnia* sp.**	9	***Nauplius* (var)**	7		
***Diaphanosoma* sp.**	14				

Table 19. Zooplankton taxa and count data from Higgins Lake Deep Basin #2 (August 21-23, 2019).

Cladocerans	Count	Copepods	Count	Rotifers	Count
Daphnia longiremis	25	***Cyclops* sp.**	15	***Keratella* sp.**	4
***Leptodiaptomus* sp.**	6	***Mesocyclops edax***	35		
***Bosmina* sp.**	22	***Acanthocyclops* sp.**	0		
***Ceriodaphnia* sp.**	11	***Nauplius* (var)**	9		
***Diaphanosoma* sp.**	7				

Table 20. Zooplankton taxa and count data from Higgins Lake Deep Basin #3 (August 21-23, 2019).

Cladocerans	Count	Copepods	Count	Rotifers	Count
Daphnia longiremis	12	***Cyclops* sp.**	17	--	--
***Leptodiaptomus* sp.**	0	***Mesocyclops edax***	33		
***Bosmina* sp.**	31	***Acanthocyclops* sp.**	1		
***Ceriodaphnia* sp.**	5	***Nauplius* (var)**	7		
***Diaphanosoma* sp.**	2				

Table 21. Zooplankton taxa and count data from Higgins Lake Deep Basin #4 (August 21-23, 2019).

Cladocerans	Count	Copepods	Count	Rotifers	Count
Daphnia longiremis	8	***Cyclops* sp.**	12	--	--
***Leptodiaptomus* sp.**	13	***Mesocyclops edax***	13		
***Bosmina* sp.**	39	***Acanthocyclops* sp.**	5		
***Ceriodaphnia* sp.**	8	***Nauplius* (var)**	16		
***Diaphanosoma* sp.**	0				

Table 22. Zooplankton taxa and count data from Higgins Lake Deep Basin #5 (August 21-23, 2019).

Cladocerans	Count	Copepods	Count	Rotifers	Count
Daphnia longiremis	2	***Cyclops* sp.**	19	***Keratella* sp.**	1
***Leptodiaptomus* sp.**	5	***Mesocyclops edax***	13		
***Bosmina* sp.**	37	***Acanthocyclops* sp.**	2		
***Ceriodaphnia* sp.**	13	***Nauplius* (var)**	6		
***Diaphanosoma* sp.**	4				

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 41) using an Ekman hand dredge sampler (Figure 42) on August 21, 2019 (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 (Chironomindae), Jute snails (Pleuroceridae), Wheel snails (Planorbidae), Right-handed snails (Lymnaeidae), Left-handed snails (Physidae), Banded Mystery and Chinese Mystery snails (Viviparidae), Asian clams (Cyrenidae), Stonefly larvae (Perlidae), and Zebra and Quagga Mussels (Dreissenidae). 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.

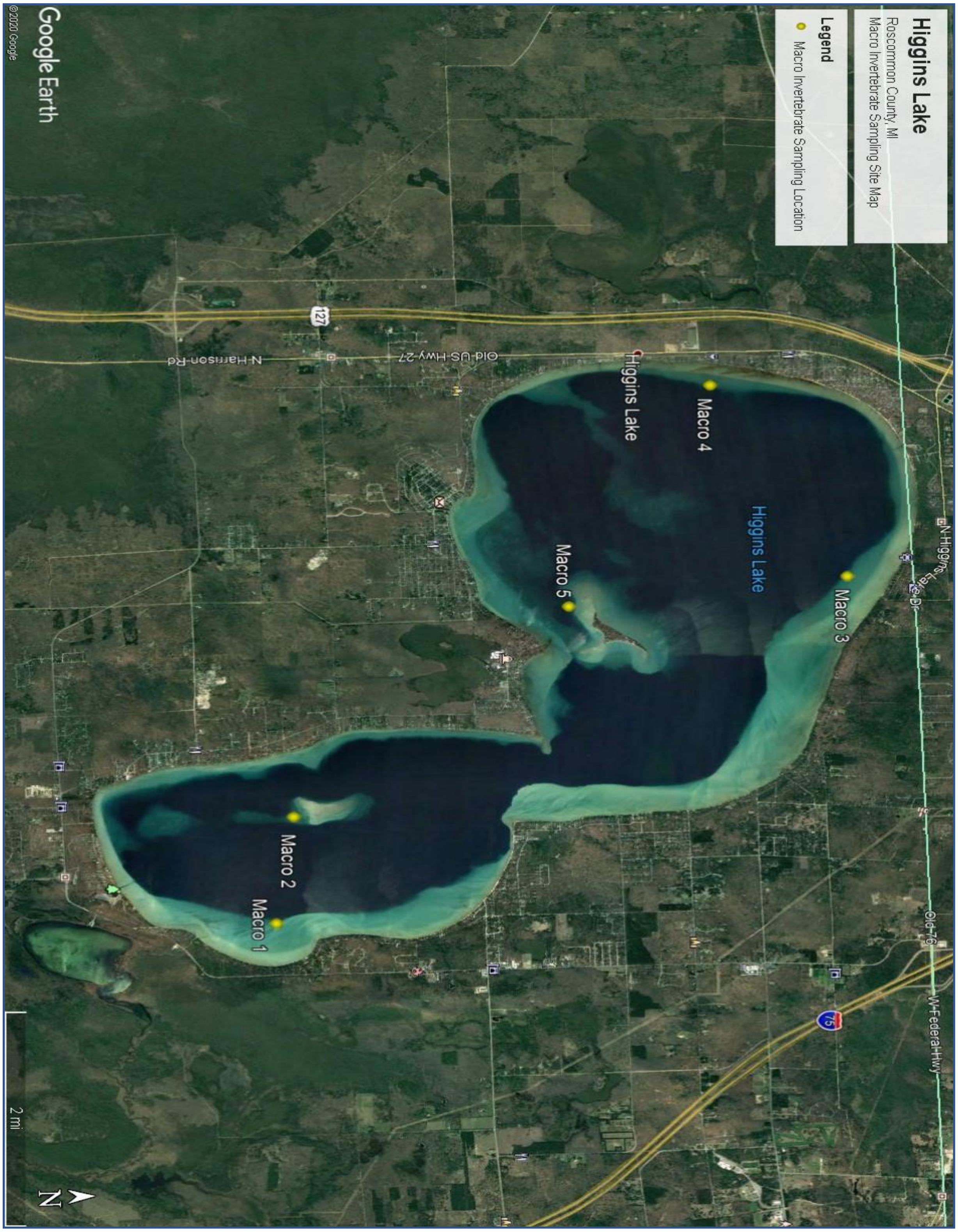


Figure 41. Sampling locations for macroinvertebrates in Higgins Lake (August 21, 2019).

Figure 42. 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 and of lakes. Schreiber et *al.*, (2003) stated that disturbance and anthropogenic land use changes are usually considered to be key factors facilitating biological invasions.

Table 23. Macroinvertebrates found in Higgins Lake, Roscommon County, MI (August 21-23, 2019).

Site S1	**Family**	**Genus or Species**	**Number**	**Common name**
	Chironimidae	*Chironomus* spp.	2	Midges
	Planorbidae	*Planorbis* sp.	3	Wheel snails
	Dreissenidae	*Dreissena polymorpha*	3	Zebra mussels
	Dreissenidae	*Dreissena bugensis*	1	Quagga mussels
	Lymnaeidae	*Lymnaea* sp.	7	Right-handed snail
	Physidae	*Physa* spp.	6	Left-handed snail
	Viviparidae	*Vivaparus mallaetus*	1	Chinese mystery snail
	Viviparidae	*Vivaparus gorgianus*	1	Banded Mystery snail
		Total	**15**	
Site S2	**Family**	**Genus**	**Number**	**Common name**
	Planorbidae	*Planorbis* sp.	9	Wheel snails
	Chironomidae	*Chironomus* spp.	12	Midges
	Dreissenidae	*Dreissena polymorpha*	3	Zebra mussels
	Lymnaeidae	*Lymnaea* sp.	4	Right-handed snail
	Physidae	*Physa* spp.	5	Left-handed snail
		Total	**9**	
Site S3	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	1	Jute snails
	Planorbidae	*Planorbis* sp.	6	Wheel snails
	Perlidae	*Capnia* sp.	2	Stonefly larvae
	Cyrenidae	*Corbicula fluminea*	1	Asian clam
		Total	**7**	
Site S4	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae	*Pachychilus* sp.	1	Jute snails
	Chironmidae	*Chironomus* sp.	6	Midges
	Dreissenidae	*Dreissena polymorpha*	1	Zebra mussels
	Perlidae	*Capnia* sp.	1	Stonefly larvae
		Total	**7**	
Site S5	**Family**	**Genus**	**Number**	**Common name**
	Chironomidae	*Chironomus* spp.	4	Midge
	Planorbidae	*Planorbis* sp.	2	Wheel snails
	Dreissenidae	*Dressena bugensis*	1	Quagga mussels
		Total	**6**	

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 on 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 (Figure 43).

Figure 43. *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 2019 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; 1979-2019).

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

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. A detailed Early Detection Rapid Response Protocol is recommended for Higgins Lake for each invasive species. The following sections detail invasive species prevention and community education.

5.1.1 Aquatic Invasive Species Prevention

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 44 and 45). 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 46-47 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 48 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 44. An aquatic invasive prevention sign for public access sites.

Figure 45. An aquatic hitchhiker (milfoil).

Figure 46. A public boat washing station at South Higgins Lake.

Figure 47. A responsible boat owner using the Higgins Lake boat washing station in 2019.

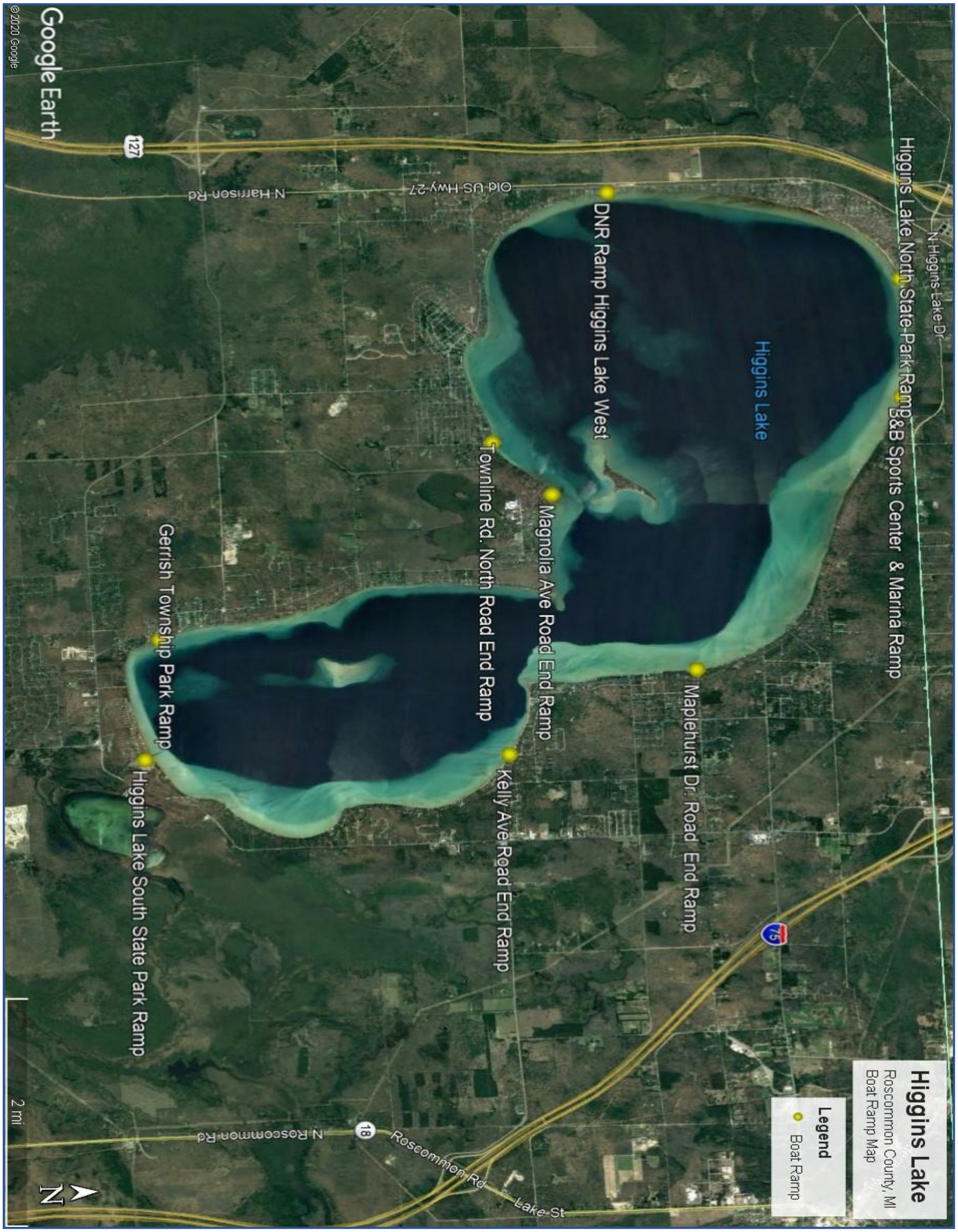


Figure 48. Higgins Lake boat launch access sites (RLS, 2019).

Zebra Mussels and Quagga Mussels

Zebra Mussels (*Dreissena polymorpha*; Figure 49) 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 49) are native 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.

Comparison of quagga (left) and zebra (right) mussel. Michigan Sea Grant.

Figure 49. Zebra Mussels and Quagga Mussels (Photo courtesy of Michigan Sea Grant).

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 50) and *Trapa natans* (Water Chestnut; Figure 51). *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.

Figure 50. Hydrilla from a Florida lake.

Figure 51. Water Chestnut from a northeastern lake.

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 52). 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.

Figure 52. 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 53). 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 53. A mechanical harvester used to remove aquatic plants.

5.1.4 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 54) or Weed Rollers (Figure 55) 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.

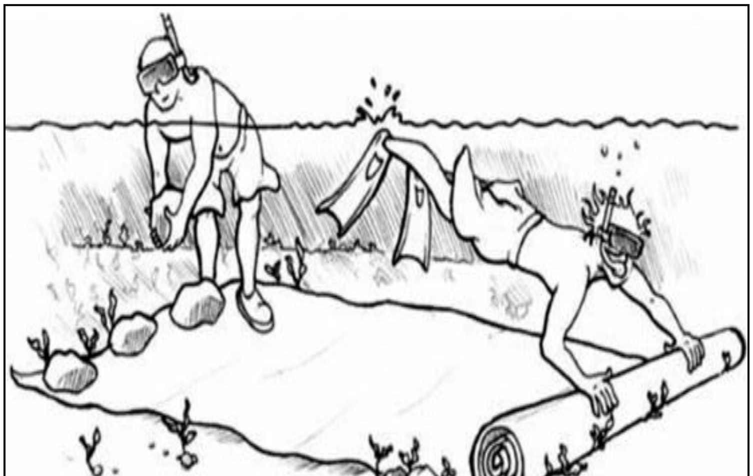


Figure 54. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.

Figure 55. A Weed Roller.

5.1.5 Diver Assisted Suction Harvesting (DASH)

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 56) 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 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 with good success.

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. Figures 57 and 58 below show the conditions of the invasive aquatic vegetation growth in the South State Park Lagoon before and after DASH and the parallel use of systemic herbicides in 2019, respectively.

Figure 56. A DASH boat used in the South State Park Lagoon for aquatic plant removal.

Figure 57. Nuisance aquatic vegetation in the South State Park Lagoon prior to management in 2019.

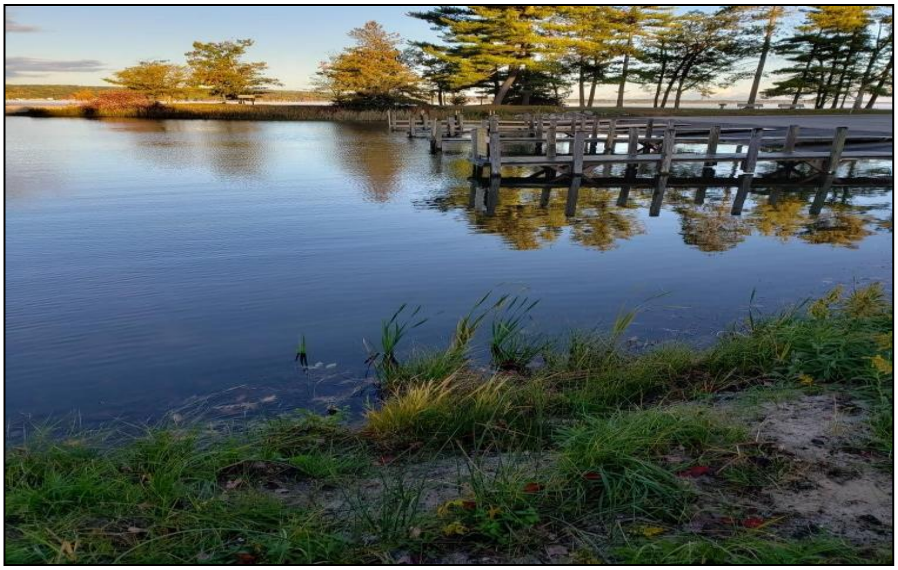


Figure 58. The South State Park Lagoon after DASH improvements in 2019.

5.1.6 Ultraviolet (UV) Light:

Short-wave electromagnetic radiation light (UV-C) damages the DNA and cellular structure of aquatic plants. This method was used in 2017 in Lake Tahoe in California and Nevada, USA. It reduced aquatic plant percent cover, mean aquatic plant height, and aquatic plant density and was used to reduce invasive watermilfoil and curly-leaf pondweed as an alternative to chemical herbicides. Effective control may require multiple UV treatments and eradication may not be possible, but this is the case for most management methods. This technology requires very clear water to be effective, as treatment areas should be closely monitored as the boat moves over individual weed beds. Treatment is also more effective when the plant beds are not yet at mature height and are lower in density. This treatment would require a unique EGLE permit and would also possibly damage other preferred native aquatic plants. Because of these challenges, it should not be considered over DASH for removal of milfoil or Starry Stonewort at this time. An experimental area could be considered in the future if EGLE and MDNR approve of such an experiment.

5.2 Higgins Lake Water Quality Improvements

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. A discussion on septic systems and their impacts on inland waters follows below in Section 5.2.1. 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.

5.2.1 Septic System Maintenance and Sewer Consideration

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 Figure 59).

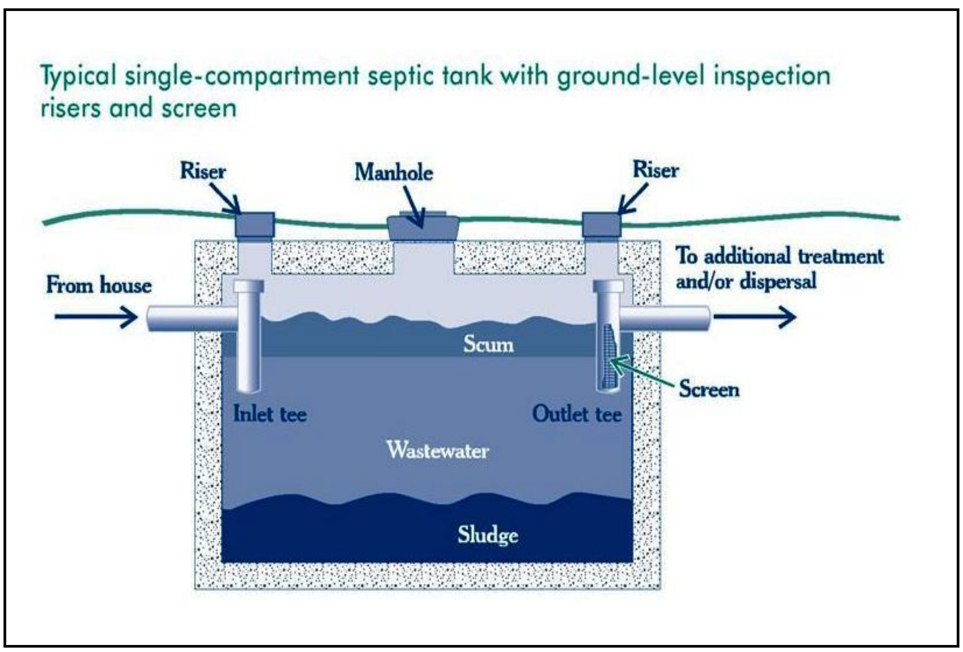


Figure 59. Diagram of essential septic tank components (US EPA).

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. Such 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-Cheruvelil 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 different 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.

5.2.2 Waterfowl Control and Swimmer's Itch

A study by Manny et *al.* (1994) found that the annual contribution of carbon, nitrogen, and phosphorus from migratory waterfowl including Canada geese (*Branta canadensis*) can exceed the external loading contributions on some inland lakes. Thus, an overabundance of geese can lead to increased nutrient loads to Higgins Lake. Fortunately, there are some strategies for reducing geese populations which include but are not limited to the following:

1. Encourage riparians to grow waterfront grass to ≥ 3 inches tall as geese prefer short grass.
2. Plant tall native plants near the shore to encourage a soft shoreline that geese may avoid due to the potential of predators hiding in the tall weeds.
3. Avoid mowing to the water's edge.
4. Do not feed geese or waterfowl as this encourages their presence.
5. Egg replacement, goose round-up, and nest destruction methods are effective to a degree but require an MDNR permit and training as well as knowledge of nesting areas. Some of these methods are currently being used by Swimmer's Itch Solutions® as they are also working with reducing merganser populations.
6. Coyote or other intimidating effigies can scare geese away from lawns.
7. The Audubon Society recommends placement of string 6 inches above the ground followed by another row of string an additional 6 inches above the water.

8. Repellent devices such as the Goosebuster® are effective and can be found at: http://www.bird-x.com
9. Visit the following website for more methods: http://www.icwdm.org/handbook/Birds/CanadadGeese/Default.aspx

In addition to the presence of geese, the abundance of mergansers has previously led to increases in swimmer's itch. Swimmer's itch is caused by a parasite that lives within the gut of waterfowl and snails (such as the *Stagnicola* snail in Higgins Lake). An itchy rash is the result of the parasite entering the skin and can last for a week or more. It is recommended that swimmer's immediately rinse off with freshwater after leaving the lake and also use cortisone creams, baking soda, or colloidal oatmeal if a rash becomes visible. Higgins Lake has had a very successful swimmer's itch parasite reduction program through the removal of resident mergansers. Swimmer's Itch Solutions® and the Higgins Lake Swimmer's Itch Organization (HLSIO) issues an annual report with management activities and data from current and previous years. This has been confirmed through qPCR analyses which detect the number of parasites in the water.

For more information on this parasite visit: www.cdc.gov/parasites/swimmersitch/faqs.html

5.2.3 Fishery Habitat Enhancement

Fish spawning habitat is very important for lakes. In addition to providing suitable habitat for spawning, lakes also benefit from the fish populations by controlling various types of phytoplankton (algae), zooplankton, and other fish species. Fish also add nutrients in the form of waste to the carbon, nitrogen, and phosphorus cycles for other plants and animals in the lake.

Habitat degradation around lakes has harmed fish populations on many lakes. Pesticides, fertilizers, and soil from farm fields drain into lakes and rivers, killing aquatic insects, depleting dissolved oxygen, and smothering fish eggs. Leaves, grass, and fertilizer wash off urban and suburban lawns into sewers, then into lakes, where these excessive nutrients fuel massive algae blooms. The housing boom on fishing lakes is turning native lakeshore and shallow water vegetation into lawns, rocky riprap, and sand beaches. Native plants have been removed in many areas and helped sustain healthy fish populations. Eventually, the water gets murkier from fertilizer runoff, and, lacking bulrushes and other emergent plants in shallows, fish have fewer places to hide and grow. It is important for landowners to realize how important aquatic and emergent lake vegetation can be to the lake ecology.

To restore the natural features of lakeshores that provide fish habitat, a new approach replaces some or all lakeside lawns and beaches with native wildflowers, shrubs, grasses, and aquatic plants. A growing number of lakeshore owners are learning that restoring natural vegetation can cut maintenance costs, prevent unwanted pests such as Canada geese, attract butterflies and songbirds, and improve fish spawning habitat in shallow water.

Preventing erosion and sedimentation around lakes is also important because excess sediment can smother fish eggs. Such a process as the conversion of plowed land along the lake edge into grassy strips can filter runoff and stabilize banks. Vegetative plantings on steep banks can prevent erosion and excess nutrients from reaching the lake. Adding additional natural features such as boulders, can also improve fish spawning habitat in a lake. In Minnesota's Lake Winni, more than 4.5 miles of the lakeshore has been reinforced since 1989 and Walleye are now spawning in the improved habitat. In addition, altering water levels in marshy areas used by northern pike for spawning can create more favorable conditions for reproduction.

A few specific fish species spawning habitat examples:

Numerous fish species utilize different types of habitat and substrate to spawn**.** Gosch et *al*. (2006) examined Bluegill spawning colonies in South Dakota. Habitat characteristics were measured at each nesting site and compared with those measured at 75 randomly selected sites. In Lake Cochrane, mean water depth of spawning colonies was 1.0 m.

Every Bluegill nest site contained gravel substrate, despite the availability of muck, sand, and rock. Additionally, Bluegills selected nesting locations with relatively moderate dissolved oxygen levels. Lake Cochrane Bluegill nest sites consisted of shallow, gravel areas with short, low-density, live submergent *Chara* vegetation. Walleye generally spawn over rock, rubble, gravel and similar substrate in rivers or windswept shallows in water 1 to 6 feet deep, where currents clear away fine sediment and will cleanse and aerate eggs. Male Walleye move into spawning areas in early spring when the water temperature may be only a few degrees above freezing while the larger females arrive later. Spawning culminates when water temperature ranges from 42 to 50 degrees. For Walleye, the success of spawning can vary greatly year to year depending on the weather. Rapidly warming water can cause eggs to hatch prematurely. Prolonged cool weather can delay and impair hatching. A cold snap after the hatch can suppress the production of micro crustaceans that Walleye fry eat.

Largemouth Bass spawning activities begin when water temperatures reach 63° to 68°F. The male moves into shallow bays and flats and sweeps away debris from a circular area on a hard bottom. The male remains to guard the nest while the female heads for deeper water to recover. Northern Pike begin to spawn as soon as the ice begins to break up in the spring and late March or early April. The fish migrate to their spawning areas late at night and the males will congregate there for a few days before spawning actually begins. Marshes with grasses, sedges, rushes or aquatic plants and flooded wetlands are prime spawning habitat for Northern Pike. Mature females move into flooded areas where the water is 12 or less inches deep. Due to predation by insects and other fish including the Northern Pike itself, the number of eggs and fry will be reduced over 99% in the months that follow spawning. The eggs hatch in 12 to 14 days, depending on water temperature, and the fry begin feeding on zooplankton when they are about 10 days old.

Impacts to Fish Spawning from Invasive Species:

Lyons (1989) studied how the assemblage of small littoral-zone fishes that inhabit Lake Mendota, Wisconsin has changed since 1900. A diverse assemblage that included several environmentally sensitive species has been replaced by an assemblage dominated by a single species, the Brook Silverside, whose abundance fluctuates dramatically from year to year. Their decline was associated with the invasion and explosive increase in abundance of an exotic macrophyte, Eurasian Watermilfoil (*Myriophyllum spicatum*), in the mid-1960's. Changes in the assemblage of small littoral-zone fishes in Lake Mendota, indicate environmental degradation in the near shore area, and may have important implications for the entire fish community of the lake including fish spawning habitat availability.

Lillie and Budd (1992) examined the distribution and architecture of Eurasian Watermilfoil in Fish Lake, Wisconsin. They showed that temporal changes in the architecture of milfoil during the growing season and differences in architecture within one macrophyte bed in Fish Lake were substantial and may have influenced spawning habitat use by fish and macroinvertebrates. Eiswerth et *al*. (2000) looked at the potential recreational impacts of increasing populations of Eurasian Watermilfoil. They determined that, unless the weed is controlled, significant alterations of aquatic ecosystems including spawning habitat for native fish, with associated degradation of natural resources and economic damages to human uses of those resources, may occur. In contrast, Valley and Bremigan (2002) studied how changes in aquatic plant abundance or architecture, caused by invasion and/or removal of exotic plants, may affect age-0 Largemouth Bass growth and recruitment. They actually showed that selective removal of Eurasian Watermilfoil did not have a significant positive effect on age-0 Largemouth Bass growth. In this lake, factors influencing age-0 Bluegill availability to age-0 Largemouth Bass appear more related to size structure of Largemouth Bass and Bluegill populations than to plant cover, but plants still are needed to provide habitat and spawning cover.

Impacts from Natural Shoreline Degradation:

Lakeshore development can also play an important role in how vegetation abundance can impact fish spawning habitat. Vegetation abundance along undeveloped and developed shorelines of Minnesota lakes was compared to test the hypothesis that development has not altered the abundance of emergent and floating-leaf vegetation (Radomski and Goeman 2001). They found that vegetative cover in littoral areas adjacent to developed shores was less abundant than along undeveloped shorelines. On average, there was a 66% reduction in vegetation coverage with development. Significant correlations were also detected between occurrence of emergent and floating-leaved plant species and relative biomass and mean size of Northern Pike, Bluegill, and Pumpkinseed. Margenau et *al*. (2008) showed that a loss of near shore habitat has continued at an increased rate as more lake homes are built with shorelines graded, or altered with riprap, sand blankets, or sea walls. Ultimately, suitability for fish spawning habitat had decreased.

Fortunately, the fishery of Higgins Lake is well stocked by intensive efforts from the MDNR and consists primarily of a cold, deep-water fishery with abundant trout and walleye. Preservation of shoreline habitat is still recommended for the reasons mentioned above.

5.3 Higgins Lake Watershed Management

Protection of the lake watershed is imperative for long-term improvement of water quality in Higgins Lake. Such efforts have been executed by the Muskegon River Watershed Assembly (MWRA). There are many practices that individual riparians as well as the local municipalities can adopt to protect the land from erosion and flooding and reduce nutrient loading to the lake. Although the nutrient concentrations in Higgins Lake are so low overall, any reduction in nutrients is beneficial. This is especially important for the nearshore areas as they continue to be vulnerable to nutrient loads. The following sections offer practical Best Management Practices (BMP's) commonly followed to protect water quality.

5.3.1 Higgins Lake Erosion and Sediment Control

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 <u>native</u> 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 looked for areas of erosion around the Higgins Lake shoreline on August 21-23, 2019. 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. A specific whole-lake shoreline inventory of all erosion areas is recommended in the management recommendations table in Section 6.0.

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

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

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

5.3.2 Higgins Lake Nutrient Source Control

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) NEVER dump 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.

Higgins Lake Tributaries

There were three areas of water inflow which drain into Higgins Lake and contribute significant water volume and nutrients to the lake based on continuous flow. A map showing these areas of water influx to the lake is shown below in Figure 63. The major drains include: 1.) Big Creek, 2.) North Creek, and 3.) East Creek. Site-specific aerial photos of each tributary are shown in Figures 64-66 below. Water quality data was collected at each of these tributaries on October 16, 2019 if they were actively flowing. The water quality parameters measured included physical parameters such as water temperature, dissolved oxygen, pH, conductivity, and total dissolved solids. In addition, chemical water quality parameters such as total phosphorus (TP) and ortho-phosphorus (SRP), total Kjeldahl and total inorganic nitrogen (TIN), nitrate, nitrite, ammonia, and total suspended solids (TSS) were also sampled and analyzed in a NELAC-certified laboratory. The methods of analysis and units recorded were the same as for the deep basin samples discussed earlier in this report. All of the tributary water quality data can be seen in Tables 25-26 below.

Overall, the mean TP in all of the tributaries was 0.022 mg/L. This is high when compared to the mean TP in the lake deep basins which was <0.006 mg/L, which means that the tributaries are contributing significant nutrients to the lake. The mean TKN in the drains was 0.8 mg/L relative to a mean of <0.5 mg/L in the lake which indicates that TKN is higher in the tributaries. These values mean that the drains are a constant stable source of nitrogen and phosphorus to the lake and will enrich the lake with time. The mean TIN in the drains was 0.031 mg/L relative to a mean TIN concentration of <0.010 mg/L in the lake. The majority of this TIN was present in the ammonia form which exacerbates algae growth and nitrate and nitrate were below detection levels which is common in healthy lakes.

The mean TSS in the drains was 11 mg/L which is actually lower than values measured in the lake. This is likely due to re-suspension of marl and sand from the lake bottom with boat and wave activity. Big Creek contributed more phosphorus and total inorganic nitrogen, whereas North Creek contributed more total Kjeldahl (organic) nitrogen. A closer inspection of Big Creek revealed the presence of leaves and debris both at the confluence near the lake and further upstream. Proper maintenance of these tributaries is important for reducing future nutrient loads and debris to the lake.

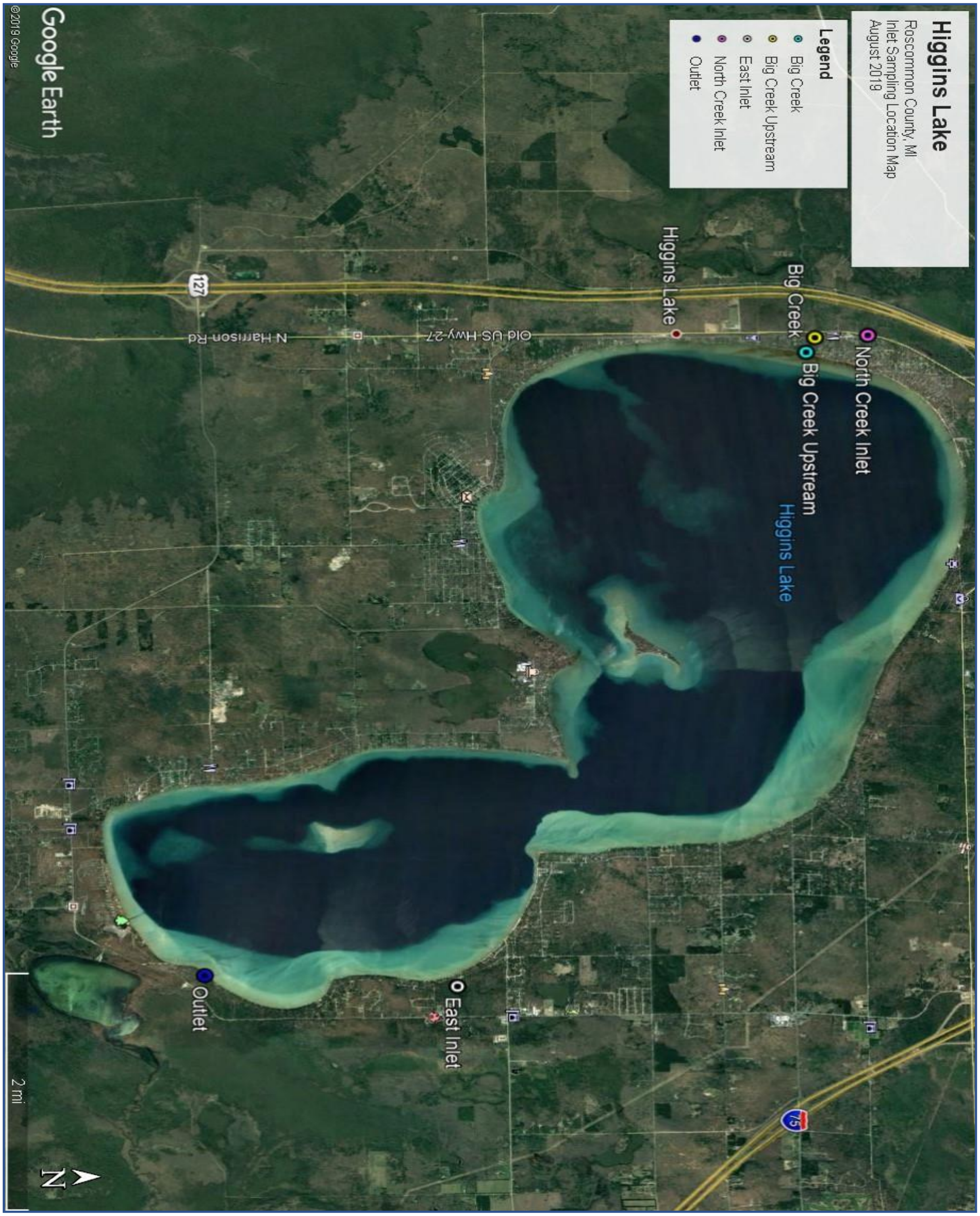


Figure 63. Areas of drainage into Higgins Lake measured on October 16, 2019.

Figure 64. The North Creek on Higgins Lake measured on October 16, 2019. Note the high amount of tannins leaching into the lake.

Figure 65. The East Creek on Higgins Lake measured on October 16, 2019.

Figure 66. The Big Creek on Higgins Lake measured on October 16, 2019. Note the high amount of tannins leaching into the lake.

Table 25. Physical water quality parameters for the major tribs flowing into Higgins Lake (October 16, 2019).

Tributary	Water Temp (°C)	pH (S.U.)	Conduct (mS/cm)	DO (mg/L)	TDS (mg/L)
North Creek	7.5	8.5	282	9.1	180
East Creek	--	--	--	--	--
Big Creek	8.1	8.4	202	8.5	129

***East Creek samples could not be collected due to lack of flow.**

Table 26. Chemical water quality parameters for the major tribs flowing into Higgins Lake (October 16, 2019).

Tributary	TP (mg/L)	TKN (mg/L)	TIN (mg/L)	NO3- (mg/L)	NO2- (mg/L)	NH3 (mg/L)	TSS (mg/L)
North Creek	0.016	0.9	0.029	<0.10	<0.10	0.029	<10
East Creek	--	--	--	--	--	--	--
Big Creek	0.027	0.8	0.033	<0.10	<0.10	0.033	12

***East Creek samples could not be collected due to lack of flow.**

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. Additionally, invasive species such as Eurasian Watermilfoil and Starry Stonewort are scattered throughout the lake and pose a serious risk to the native aquatic plant biodiversity and recreational activities in the lake. Protection of native aquatic plants is essential for lake health. 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. Systemic herbicides such as 2,4-D were used in the South State Park Lagoon in 2019 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. A detailed, Early Detection-Rapid Response Protocol for future invasives that may enter the lake is recommended to be compiled ASAP for the lake community. 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 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. 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. A lake-wide sewer is recommended to reduce these 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 and these areas should be stabilized with rip-rap or soft shoreline emergent vegetation. Guidance for these procedures was offered in Section 5.0 of this report.

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.

A complete list of recommended lake improvement options for this proposed lake management plan can be found in Table 27 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 27. 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
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 28. 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 28. 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	~$20,000 per site
DASH boat removal of current invasive EWM and SS	~$50,000
Early Detection Rapid Response Protocol Guide	~$7,000
Continued water quality sampling of lake deep basins and 3 major tributaries	~$15,000
Continued Swimmer's Itch Control	~$10,000
Contingency[5]	$13,500
Total Annual Estimated Cost	$148,500

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