Silver Lake Improvement Feasibility Study and 5-Year Management Plan
Oceana County, Michigan

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

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July, 2018

1.0 EXECUTIVE SUMMARY

Physical Characteristics Status:

Silver Lake is located in Sections 19, 20, 29, 30, and 31 of Golden Township, Oceana County, Michigan (T.15N, R.18W). The lake is comprised of 679.2 acres (RLS, 2018 bathymetric data) and is the center of a recreational community as the west shore of the lake is bordered by sand dunes that abut Lake Michigan. The surface area of Silver Lake was around 690 acres in 1950 but has been reduced due to sand dune encroachment. Silver Lake is a natural lake with a dam located at the southwest corner and has three areas of water influx which include a spring located at the northeast corner, Hunter Creek inlet at the west shore, and a small drainage area located on the south shore near the Silver Lake State Park. The lake has a shoreline of approximately 4.3 miles and a mean (average) depth of 14 feet and a maximum depth of 22 feet (RLS, 2018 bathymetric scan data). The lake also has a fetch (longest distance across the lake) of approximately 1.6 miles (MDNR, 2006). Silver Lake has an approximate water volume of 9,379.96 acre-feet (RLS, 2018 bathymetric data). The approximate residence time of water in the lake is around 223 days.

Aquatic Vegetation Status:

Based on the current study, Silver Lake contains approximately 11.6 acres of the exotic submersed macrophyte hybrid Eurasian Watermilfoil (*Myriophyllum sibiricum* var. *spicatum* L.). Other exotics such as the submersed aquatic plants Curly-Leaf Pondweed were found in Hunter Creek but would not require management. All invasives must be managed to prevent further population increases and protect the biodiversity of Silver Lake. Hybrid milfoil should be managed in the spring and as needed during the growing season with systemic aquatic herbicides using granular triclopyr at a high dose due to hybridity and associated tolerance at lower doses.

The native aquatic plant biodiversity is very low in Silver Lake which has negative impacts on the lake health and includes contributing to a weak fishery and resulting in an over-abundance of planktonic algae that reduce water clarity.

The July 23, 2018 whole-lake survey on Silver Lake determined the presence of 4 native aquatic plant species with only two submersed and two emergent aquatic plant species present. There was slightly higher biodiversity of aquatic plants in Hunter Creek but that is also low. RLS recommends transplanting of native strain aquatic plants from Hunter Creek into Silver Lake if the native aquatic plant biodiversity does not improve without intervention. Increasing this biodiversity should be a primary goal for the lake improvement program. Increases in biodiversity would also be expected with continued reduction of invasive milfoil in the lake.

Water Quality/Algae Status:

The overall water quality of Silver Lake was measured as fair to good with much less water column total phosphorus and ortho-phosphorus than total inorganic and total kjeldahl nitrogen. The mean total phosphorus concentration was 0.021 mg L^{-1} and the mean ortho-phosphorus was < 0.010 mg L^{-1} (below detection) for the July 23, 2018 samples in the three basin locations. In fact, the percentage of nitrate (NO_3^-) of the total nitrogen ranged from 17-92% which is quite high since nitrate contributes to algal growth. In addition, the overall mean nitrogen to phosphorus ratio (N:P) was 36 which indicates that there is approximately 36 times more nitrogen in Silver Lake water than phosphorus which means that phosphorus is the limiting growth factor. An additional limiting growth factor for aquatic plants is the reduced water clarity with a mean Secchi disk transparency on July 23, 2018 of 3.9 feet which is quite low. This limits light penetration to the roots of submersed aquatic plants in the majority of the lake littoral zone. Dissolved oxygen concentrations ranged from a low of 3.8 mg L^{-1} in basin #1 (north) to a high of 7.8 mg L^{-1} in basin #3 (south). Although the low dissolved oxygen concentration does not indicate anoxia, these concentrations are not ideal for a lake warm water fishery as the minimum preferred concentration is around 5.5 mg L^{-1}. This parameter should be monitored throughout the growing season to determine if dissolved oxygen supplementation methods are needed in the near future to enhance the health of the lake fishery. Water temperatures ranged from a low of 24.2°C to a high of 24.5°C which indicates a completely mixed lake system (polymictic). The pH of the lake water ranged from 7.5 S.U. to 8.5 S.U. with the lowest and highest values recorded at the bottom and surface of basin #1 (north), respectively. The specific conductivity of the lake water ranged from 333-452 µS cm^{-1} which is moderate for an inland lake and indicates higher values for salt activity near basin #2 (central near dunes). The total dissolved solids ranged from 213-290 mg L^{-1} which is moderately high and indicates the presence of ample dissolved substances in the water column that can contribute to reduced water clarity.

The highest concentrations of nitrate were in Hunter Creek which indicates that this tributary is a significant source of nitrate for Silver Lake. Phosphorus concentrations were lowest in the Creek yet the specific conductivity and total dissolved solids were slightly higher than in the lake. Nitrate concentrations at both the mouth and head of the Creek were around 3x higher than in Silver Lake. As a result of this, a Critical Source Analysis (CSA) evaluation of the Creek is needed to recommend Best Management Practices (BMP's) to successfully reduce nitrate loads to the lake which should improve water quality over time.

Chlorophyll-a concentrations were negative but the pheophytin-a concentrations were around 11.8 µg L^{-1} which is quite high and indicates that the central magnesium (Mg^{+2}) atom that is found in chlorophyll and green algae was lacking. This means that the cyanobacteria (blue-green algae) have the distinct advantage of using nitrate and ammonia in the water (along with N_2 gas from the atmosphere) as food and can out-compete the green algae due to their faster growth rates and ability to be buoyant at the lake surface which reduces light to underlying green algae. This relative lower abundance of green algae relative to blue-green algae can reduce needed food for zooplankton which can also create limitations on food for the lake fishery.

Lake Fishery Status:

The lake fishery spawning habitat is under great threat from the existing milfoil growth, lack of native aquatic vegetation, and lack of woody debris. In addition, the lake fishery is threated by low quantities of favorable green algae and lower dissolved oxygen concentrations with depth. Previous historical fishery surveys by the Michigan Department of Natural Resources (MDNR) indicated the presence of 16 native fish species in the lake but this will need to be revised with a future inventory of species in the near future. A 2017 MDNR fisheries report by O'Neal indicated that the current walleye population is thriving due to intensive fish stocking efforts by the MDNR from 1979-2018. The report also supports the concerns and recommendations in this lake management plan offered by RLS.

Erosion Control Status:

It is also recommended that the Silver Lake community implement Best Management Practices (BMP's) to reduce the nutrient and sediment loads being transported into the lake from areas with high slope (> 6% slope). At the request of the Silver Lake Improvement Board, RLS staff have identified problematic areas with a potential for erosion, or currently experiencing active erosion. While conditions on the western and southern shorelines are good, some eastern and northern shoreline areas are experiencing active erosion and sedimentation that could impact water quality, lake habitat and recreational activities. Shoreline restoration efforts should be focused in these areas.

The use of vegetation alone as a treatment relies solely on using sprigs of emergent aquatic plants, such as water willow, bulrush, spike-rushes, or other grass-like plants, and unrooted cuttings or poles of dormant woody plants, such as willow. Emergent aquatic plants would be placed in a zone lakeward of the shoreline in water depths extending up to 1.5 feet. Woody plants would be planted from the shoreline on up to an elevation that is affected by erosion. More severely eroded areas should focus on using vegetation in combination with some materials such as geotextile fabrics or mats and stakes and wire to anchor plants into the ground. This includes a variety of options such as coco fiber geotextile rolls, erosion control mats, and willow bundles. These techniques are often used with rock rip-rap for extra protection in areas where fetches in combination with wind produce waves greater than 1 foot in height.

In addition to mitigating erosion, restoration work will assist in increasing the abundance and distribution of aquatic vegetation that is scarce in Silver Lake. Repairing eroded slopes can be problematic due to restricted access and difficult working conditions. Such difficulties can result in high costs for slope repair, therefore minimizing the disturbance of natural shoreline areas and implementing effective erosion protection in actively used spaces can prevent or reduce the magnitude of these problems.

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 Silver 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. Silver Lake may be categorized as a drainage lake since it has an inlet at the east shore of the lake (Hunter Creek) and small drainage areas as well as an outlet at the southernmost shore of the lake which enters Silver Creek that eventually drains to Lake Michigan. Additionally, the lake also receives water from wetlands and runoff and spring activity.

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 eco-system, 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 SILVER LAKE PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Silver Lake Basin

Silver Lake is located in Sections 19, 20, 29, 30, and 31 of Golden Township, Oceana County, Michigan (T.15N, R.18W). The lake is comprised of 679.2 acres (RLS, 2018 bathymetric data) and is the center of a recreational community as the west shore of the lake is bordered by sand dunes that abut Lake Michigan (Figure 1). The lake was reported to have a surface area of 690 acres in 1950 but has been reduced in size due to migration of the nearby dunes. Silver Lake is a natural lake with a dam located at the southwest corner and has three areas of water influx which include a spring located at the northeast corner, the Hunter Creek inlet at the east shore, and a small inlet located on the south shore near the Silver Lake State Park. Springs and runoff from wetlands also contribute water sources to the lake.

The lake is classified as a eutrophic (nutrient-enriched) aquatic ecosystem with a distinct central deep basin. The lake contains a moderate-sized littoral (shallow) zone that could support rigorous submersed aquatic plant growth but currently does not.

Silver Lake has a mean depth of 14 feet and a maximum depth of 22 feet (RLS, 2018 bathymetric data). The maximum depth was confirmed by RLS scientists in July of 2018 with the use of a bottom-scanning GPS system that created a modernized depth contour bathymetric map (Figure 2). The lake also has a fetch (longest distance across the lake) of approximately 1.6 miles (MDNR, 2006). Silver Lake has a lake perimeter of approximately 4.3 miles (Restorative Lake Sciences, 2018) and an approximate water volume of 9,379.96 acre-feet (RLS, 2019 bathymetric data). The approximate residence time of water in the lake is around 223 days.

In addition to the depth contour map, a map of soft versus hard bottom was also created (Figure 3). The bottom hardness map shows that there are two regions of fairly consolidated sediment throughout the lake with one small area near the south shore with soft organic bottom. This is not surprising given the amount of sand in the region which contributes to the lake geology. Silver Lake contains an inlet (Hunter Creek) at the east end of the lake. An outlet is located at the southernmost end of the lake. The outlet drains to the Silver Creek River which eventually empties into Lake Michigan.

From a long-term, geological perspective, Lake Michigan was around 80 meters lower in water level than now during the time the glaciers retreated. Fisher and Loope (2005) determined that the higher water levels destabilize coastal bluffs which can contribute to the transport of sand across the lake during ice-on and enter the lake during ice-melt. Further, Fussell et *al*., (2006) found that sedimentary fauna such as the gastropod *Stagnicola* sp., and the bivalve *Pisidium* sp., present in Silver Lake sediment cores indicated previously much lower water levels than today. Thus, as Lake Michigan levels continue to increase, the probability of dune de-stabilization increases and so does the ability of the dunes to contribute sand inputs to Silver Lake and the surrounding land.

Figure 1. Aerial photo of Silver Lake, Golden Township, Oceana County, Michigan.

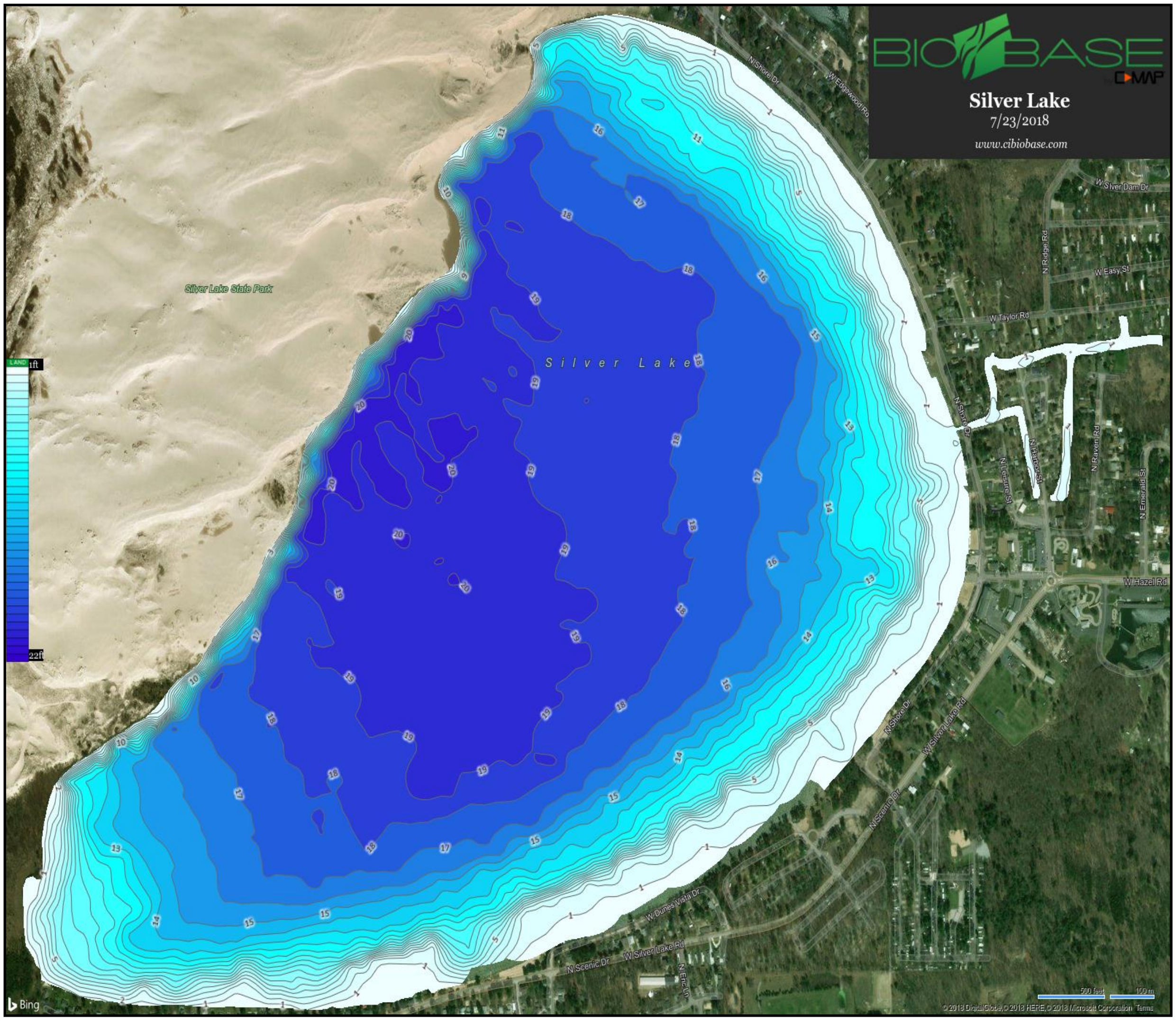

Figure 2. Silver Lake depth contour map (RLS, July 23, 2018).

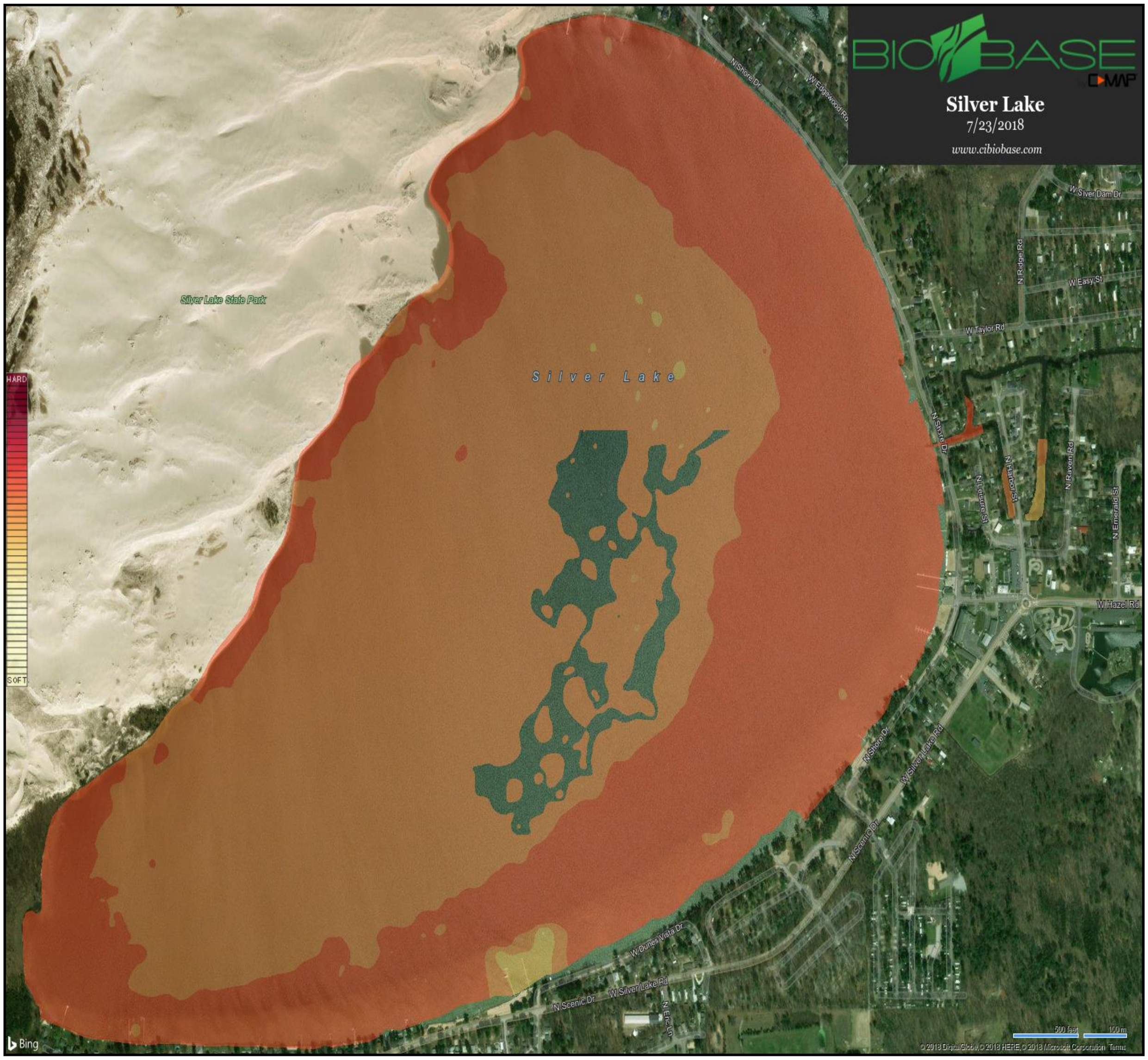

Figure 3. Silver Lake sediment bottom hardness map (RLS, July 23, 2018).

3.2 Silver Lake Extended and Immediate Watershed and Land Use Summary

A watershed is defined as a region surrounding a lake that contributes water and nutrients to a waterbody through drainage sources. Watershed size differs greatly among lakes and also significantly impacts lake water quality.

Large watersheds with high development, numerous impervious or paved surfaces, abundant storm water drain inputs, and surrounding agricultural lands, have the potential to contribute significant nutrient and pollution loads to aquatic ecosystems.

Silver Lake is located within the Pere Marquette-White River extended watershed (HUC 04060101) The watershed is characterized by highly variable terrain, land use, and soil types which means that sustainable land use practices must consider site-specific conditions. 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 Silver Lake community.

Silver Lake's immediate watershed consists of the area around the lake which directly drains to the lake and measures approximately 12,384 acres (19.4 mi^2) in size (Figure 4; RLS, July 23, 2018).

There are however, many areas around the lake with significant slopes (>6%). These areas are prone to erosion especially in areas with non-vegetated sands. The immediate watershed is approximately 18.2 times larger than the size of Silver Lake, which indicates the presence of a large-sized immediate watershed. In general larger watersheds have more opportunities for pollutants, nutrients, and sediments to enter water bodies. Best Management Practices (BMP's) for erosion reduction are offered in the sediment reduction section of this report.

Figure 4. Silver Lake immediate watershed boundary (RLS, July 23, 2018).

3.3 Silver Lake Shoreline Soils

There are 4 major soil types immediately surrounding Silver Lake which may impact the water quality of the lake and may dictate the particular land use activities within the area. Figure 5 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service, 1999) demonstrates the precise soil types and locations around Silver Lake. Major characteristics of the dominant soil types directly surrounding the Silver Lake shoreline are discussed below. The locations of each soil type north (N), south (S), west (W), east (E) are listed in Table 1 below.

Table 1. Silver Lake Shoreline Soil Types (USDA-NRCS soil survey data).

USDA-NRCS Soil Series	*Silver Lake Soil Type Location*
Pipestone fine sand; 0-4% slopes	E, SE, S shores
Covert sand; 0-6% slopes	S shore
Dune land- Quartzipsamments;level to very steep	W shore
Martisco muck	SW shore

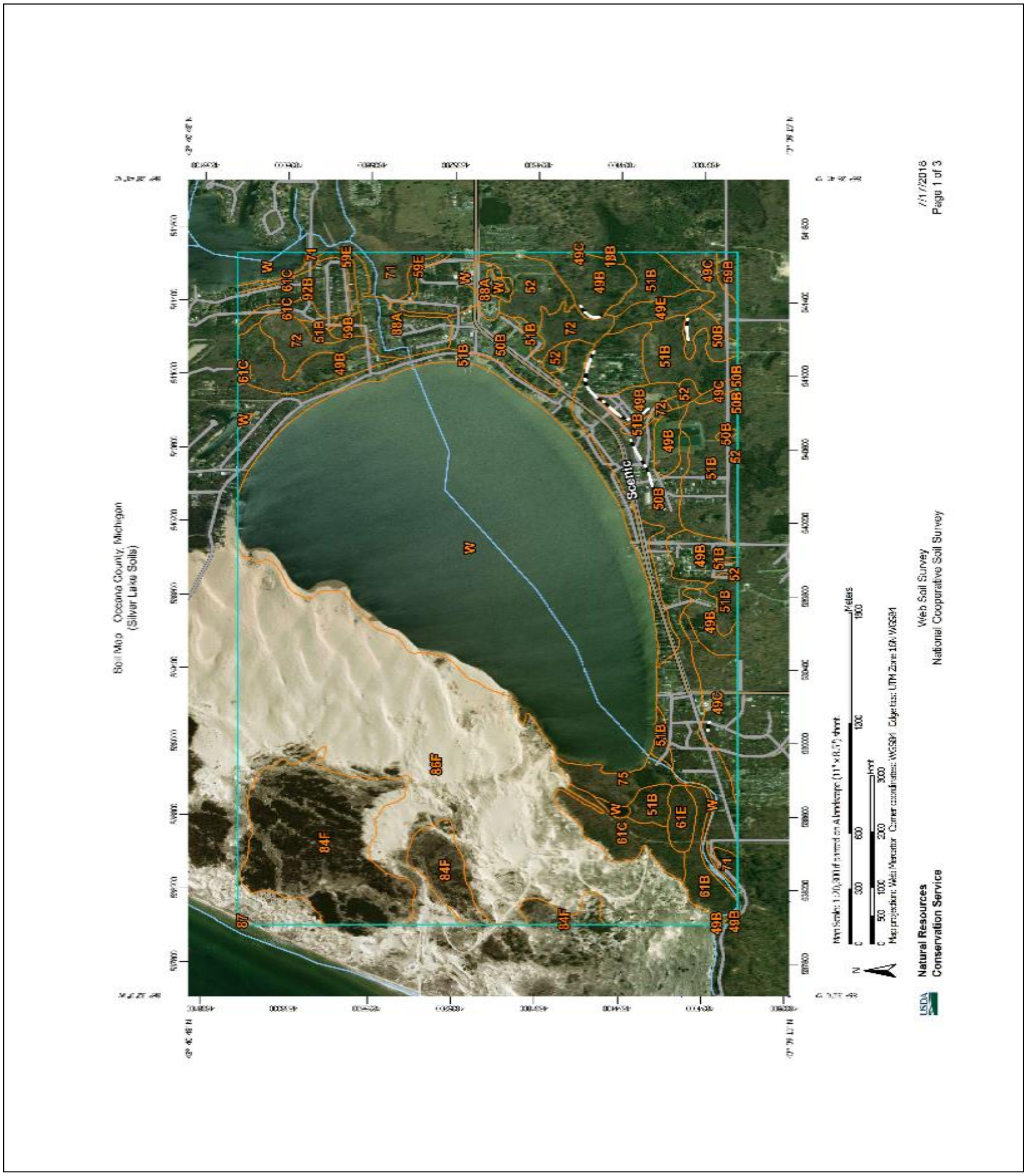

Figure 5. NRCS-USDA soils map for Silver Lake shoreline soils.

The majority of the soils around Silver Lake are somewhat poorly drained soils that are very deep such as Pipestone sands that have a water table depth of 0-4 feet beneath the ground surface. The second most common soil type consists of Covert sands that are very deep, moderately well-drained sands, typically on dunes, with low runoff potential and high permeability.

There are areas around the immediate shoreline at the southwest section where wetlands are present and these soils known as Martisco mucks are prone to ponding and even flooding. Ponding occurs when water cannot permeate the soil and accumulates on the ground surface which then may runoff into nearby waterways such as the lake and carry nutrients and sediments into the water. Excessive ponding of such soils may lead to flooding of some low-lying shoreline areas, resulting in nutrients entering the lake via surface runoff since these soils do not promote adequate drainage or filtration of nutrients**.** The mucks located in the wetlands may become ponded during extended rainfall and the wetlands can serve as a source of nutrients to the lake. When the soils of the wetland are not saturated, the wetland can serve as a sink for nutrients and the nutrients are filtered by wetland plants.

4.0 SILVER LAKE WATER QUALITY

Water quality is highly variable among Michigan's inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by 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 2). Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a*, and low in transparency are classified as eutrophic; whereas those that are low in nutrients and chlorophyll-*a*, and high in transparency are classified as oligotrophic. Lakes that fall in between these two categories are classified as mesotrophic. Silver Lake is classified as eutrophic due to excessive algal growth and low Secchi transparency and some dissolved oxygen depletion with depth during late season, as well as having moderate to high total nitrogen concentrations. The nitrogen concentrations in the lake are much higher than the phosphorus which favors blue-green algae.

Table 2. Lake Trophic Status Classification Table (MDNR)

Lake Trophic Status	*Total Phosphorus ($\mu g\ L^{-1}$)*	*Chlorophyll-a ($\mu g\ L^{-1}$)*	*Secchi Transparency (feet)*
Oligotrophic	< 10.0	< 2.2	> 15.0
Mesotrophic	10.0 – 20.0	2.2 – 6.0	7.5 – 15.0
Eutrophic	> 20.0	> 6.0	< 7.5

4.1 Water Quality Parameters

Parameters such as, but not limited to, dissolved oxygen, water temperature, oxidative reduction potential, conductivity, turbidity, total dissolved solids, pH, total alkalinity, total phosphorus and ortho-phosphorus, total Kjeldahl nitrogen and inorganic nitrogen, chlorophyll-*a*, algal community composition, and Secchi transparency, respond to changes in water quality and consequently serve as indicators of lake health. During this evaluation, RLS collected water samples from within three basins on July 23, 2018 and took all samples to a NELAC-certified laboratory for analysis.

The deep basin results are discussed below and are presented in Tables 3-5. A map showing the sampling locations for all water quality samples is shown below in Figure 6. All water samples were collected with a depth-integrated Van Dorn horizontal water sampler and physical readings were collected with a calibrated Eureka Manta II® multi-meter probe with parameter electrodes, respectively.

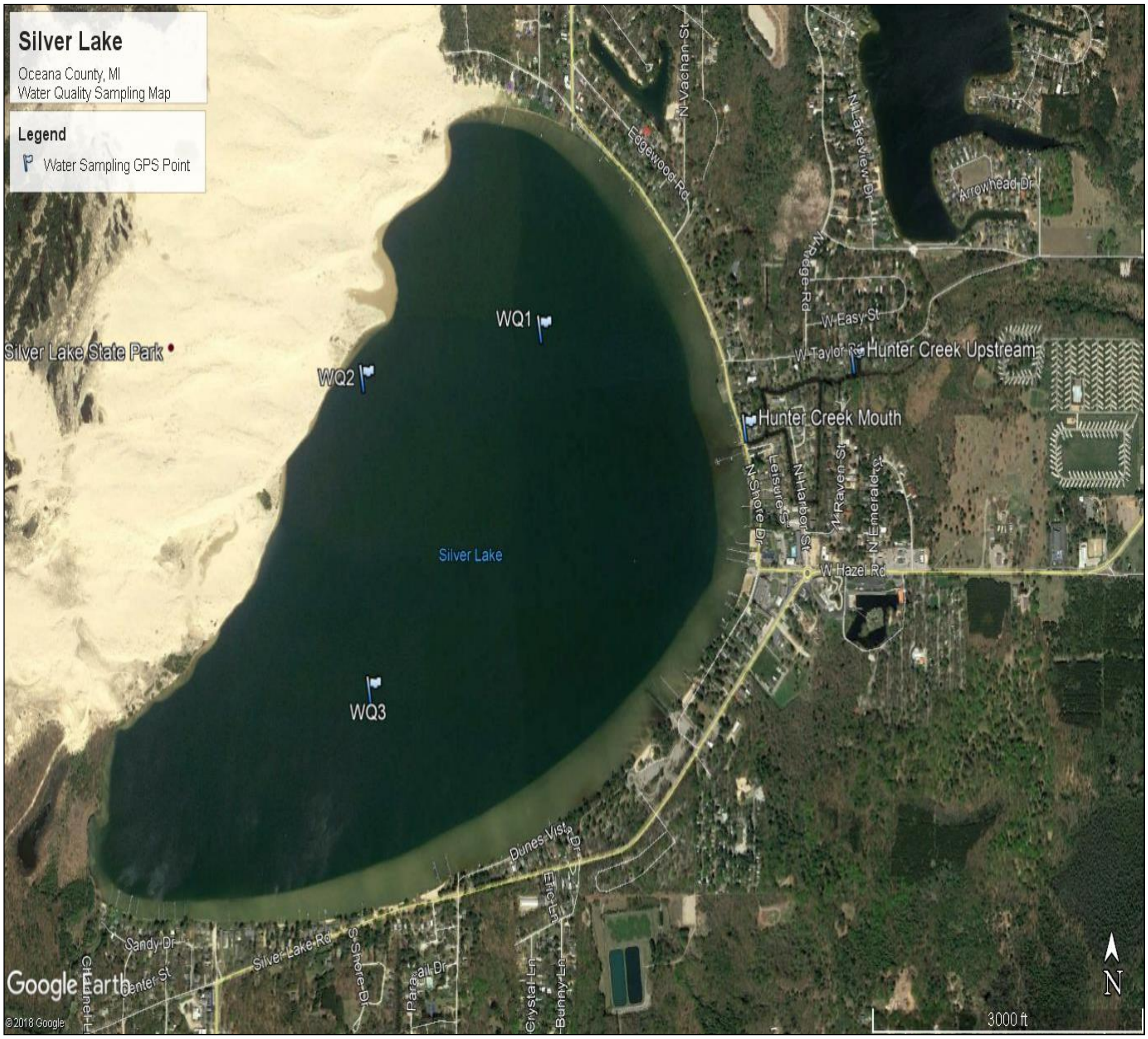

Figure 6. Locations for water quality sampling in Silver Lake (July 23, 2018).

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 5.0 mg L^{-1} to sustain a healthy warm-water fishery. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. Dissolved oxygen was measured in milligrams per liter (mg L^{-1}) with the use of a calibrated Eureka Manta II® dissolved oxygen meter. Dissolved oxygen concentrations ranged between 3.8-7.8 mg L^{-1}, with concentrations of dissolved oxygen higher at the surface and mid-depth and lower at the bottom, especially in basins #1 and #2. The bottom of the lake produces a higher 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. RLS recommends continued monitoring of the dissolved oxygen levels to determine if the lake bottom becomes anoxic in future years which could be problematic.

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". In general, shallow lakes will not stratify and deeper lakes may experience single or multiple turnover cycles. Water temperature was measured in degrees Fahrenheit (ºC) with the use of a calibrated Eureka Manta II® submersible thermometer. The July 23, 2018 water temperatures of Silver Lake demonstrated a lack of a thermocline and is indicative of a well-mixed (polymictic) lake that mixes multiple times per year. On the day of sampling, water temperatures ranged from 24.5ºC (at the surface) to 24.2ºC (at the bottom) of the three basins. The water temperature was essentially uniform throughout the water column at the sampling sites.

4.1.3 Specific Conductivity

Specific cconductivity (abbrev. Conductivity) is a measure of the amount of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Conductivity was measured in micro Siemens per centimeter (µS cm^{-1}) with the use of a calibrated Eureka Manta II® conductivity probe and meter. Conductivity values for Silver Lake were variable among the three basins and ranged from 333-452 mS cm^{-1}.

These values are moderately high for an inland lake and mean that the lake water contains ample dissolved metals and ions such as calcium, potassium, sodium, chlorides, sulfate, and carbonate. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Silver 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^{-1} can negatively impact aquatic life.

4.1.4 Turbidity and Total Dissolved Solids

Turbidity is a measure of the loss of water transparency due to the presence of suspended particles. The turbidity of water increases as the number of total suspended particles increases. Turbidity may be caused by erosion inputs, phytoplankton blooms, storm water discharge, urban runoff, re-suspension of bottom sediments, and by large bottom-feeding fish such as carp (though this usually occurs in small, shallow water bodies). 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® turbidimeter. 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 Silver Lake was moderate and ranged from 3.8-5.2 NTU's during the July 23, 2018 sampling event. On the day of sampling, the winds were calm and turbidity was not likely due to re-suspension of sediments. Spring values would likely be higher due to increased watershed inputs from spring runoff and/or from increased algal blooms in the water column from resultant runoff contributions.

Total Dissolved Solids

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 was measured with the use of a Eureka Manta II® calibrated probe and meter in mg L^{-1}. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The TDS in Silver Lake during the July 23, 2018 event ranged from 213-290 mg L^{-1} for the three basins which is moderately high for an inland lake and correlates with the measured moderate conductivity.

4.1.5 pH

pH is the measure of acidity or basicity of water. pH was measured with a Eureka Manta II® calibrated pH electrode and pH-meter in Standard Units (S.U). The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 6.5 to 9.5.

Acidic lakes (pH < 7) are rare in Michigan and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC). The pH of Silver Lake water ranged from 7.5-8.5 S.U. during the sampling event. This range of pH is neutral to slightly alkaline on the pH scale and is ideal for an inland lake. pH tends to rise when abundant aquatic plants are actively growing (photosynthesis) or when marl deposits are present.

4.1.6 Total Alkalinity

Total alkalinity is the measure of the pH-buffering capacity of lake water. Lakes with high alkalinity (> 130 mg L^{-1} of $CaCO_3$) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of $CaCO_3$ and are categorized as having "hard" water. Total alkalinity was measured in milligrams per liter of $CaCO_3$ through an acid titration method. The total alkalinity of Silver Lake is considered "elevated" (≥ 140 mg L^{-1} of $CaCO_3$) except at the lake bottom, and indicates that the water is slightly alkaline**.** Total alkalinity in the three basins ranged from 140-144 mg L^{-1} of $CaCO_3$ during the July 23, 2018 sampling event. 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

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 that contain greater than 0.020 mg L^{-1} of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to the higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Phosphorus may also be released from sediments as pH increases. Total phosphorus was measured in milligrams per liter (mg L^{-1}) with the use of a chemical auto analyzer with Method EPA 200.7, Rev. 4.4. TP concentrations in the lake ranged from 0.015-0.030 mg L^{-1}. These values are quite low, especially given the elevated nitrogen concentrations discussed below. The TP concentration was lowest in Hunter Creek at 0.013 mg L^{-1}. Given the low concentration of TP in the lake, this means that P is the limiting nutrient for aquatic plant and green algae growth in the lake.

Ortho-phosphorus refers to soluble reactive phosphorus or the most bioavailable form used by aquatic life. All but one sample (bottom of basin #3) had ortho-P concentrations ≤ 0.010 mg L^{-1} which is quite low and favorable.

4.1.8 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of inorganic nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e. burning of fossil fuels), wastewater sources from developed areas (i.e. runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen such as Silver Lake (mean N: P = 36 mg L^{-1}), phosphorus is the limiting nutrient for phytoplankton and aquatic macrophyte growth. Lakes with a mean TKN value of 0.66 mg L^{-1} may be classified as oligotrophic, those with a mean TKN value of 0.75 mg L^{-1} may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg L^{-1} may be classified as eutrophic. Silver Lake contains moderate values for TKN at all depths (0.7-0.9 mg L^{-1}), which is normal for an inland lake of similar size and demonstrates that the lake is phosphorus limited (dominant in nitrogen). Thus, any additional inputs of phosphorus would lead to increased aquatic plant and algae growth. In the absence of dissolved oxygen, nitrogen is usually in the ammonia form and will contribute to rigorous milfoil growth.

The total inorganic nitrogen (TIN) consists of nitrate, nitrite, and ammonia forms without the organic forms of nitrogen. Based on the proportions of TIN and TKN, the samples indicate that between 17-92% of the total nitrogen consists of nitrate and the remainder of each sample was in the ammonia form.

4.1.9 Chlorophyll-a and Algal Community Composition

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-*concentrations* are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg L^{-1} are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg L^{-1} are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* was measured in micrograms per liter (µg L^{-1}) with the use of an acetone extraction method and a spectrometer. The chlorophyll-*a* concentrations in Silver Lake were determined by collecting a composite sample of the algae throughout the water column at each of three basin sites from just above the lake bottom to the lake surface Chlorophyll-a concentrations were negative but the pheophytin-a concentrations were around 11.8 µg L^{-1} which is quite high and indicates that the central magnesium (Mg^{+2}) atom that is found in chlorophyll and green algae was lacking. This means that the cyanobacteria (blue-green algae) have the distinct advantage of using nitrate and ammonia in the water (along with N_2 gas from the atmosphere) as food and can out-compete the green algae due to their faster growth rates and ability to be buoyant at the lake surface which reduces light to underlying green algae. This relative lack of green algae can reduce needed food for zooplankton which can also create limitations on food for the lake fishery.

Algal genera from a composite water sample collected over the deep basins of Silver Lake were analyzed under a compound bright field microscope. Genera are listed here in the order of most abundant to least abundant. The genera present included the Chlorophyta (green algae): *Chlorella* sp., *Haematococcus* sp., Ulothrix sp., *Mougeotia* sp., *Gleotrichia* sp., *Rhizoclonium* sp., *Gleocystis* sp., *Spirogyra* sp., and *Chloromonas* sp. the Cyanophyta (blue-green algae): *Oscillatoria* sp. and *Microcystis* sp.; the Bascillariophyta (diatoms): *Synedra* sp., *Navicula* sp., *Cymbella* sp., and *Fragilaria* sp. The aforementioned species indicate a moderately diverse algal flora but the blue-green algae were the most abundant which is not desirable. If the dissolved oxygen levels of the lake were increased, diatoms may increase and be more beneficial for the zooplankton which form the base of the lake food chain.

4.1.10 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and was measured with the use of an 8-inch diameter standardized Secchi disk (Figure 7). 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. 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 Silver Lake deep basins measured on July 23, 2018 ranged from 3.0-4.7 feet which is quite low. Measurements were collected during calm wind conditions (winds out of the northwest at 5-7 mph). This transparency indicates that an abundance of solids such as suspended particles and algae are present throughout the water column which increases turbidity and reduces 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.

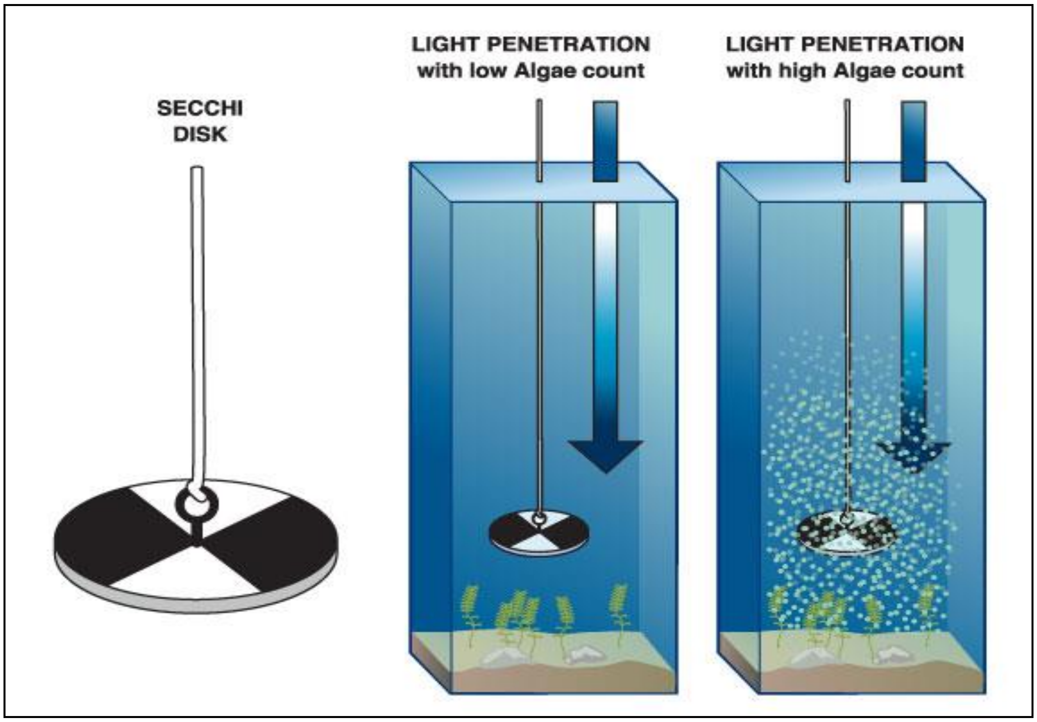

Figure 7. A Secchi dish and the relationship between Secchi transparency and algae in the water column. Photo courtesy of Michigan Sea Grant.

4.1.11 Oxidative Reduction Potential

The oxidation-reduction potential (ORP or E_h) of lake water describes the effectiveness of certain atoms to serve as potential oxidizers and indicates the degree of reductants present within the water. In general, the E_h level (measured in millivolts) decreases in anoxic (low oxygen) waters. Low E_h values are therefore indicative of reducing environments where sulfates (if present in the lake water) may be reduced to hydrogen sulfide (H_2S). ORP values are measured in situ with a calibrated probe and meter. Decomposition by microorganisms in the hypolimnion may also cause the E_h value to decline with depth during periods of thermal stratification. The E_h values for the Silver Lake ranged from 189.6-92.7 mV from the surface to the bottom among the three basins on July 23, 2018. The high variability could be due to numerous factors such as degree of microbial activity near the sediment-water interface, quantity of phytoplankton in the water, or mixing of the lake water.

Table 3. Silver Lake water quality parameter data collected site #1 (July 23, 2018).

Depth (m).	*Water Temp ºC*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Alk. mg L^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*	*TDS mg L^{-1}*	*TIN mg L^{-1}*	*Ortho-P mg L^{-1}*
0	24.5	7.7	8.5	334	4.6	0.7	140	0.016	214	0.14	<0.010
0.5	24.5	7.4	8.5	334	3.8	--	--	--	214	--	--
1.0	24.5	7.4	8.5	334	3.9	--	--	--	214	--	--
1.5	24.5	7.3	8.5	334	4.2	--	--	--	214	--	--
2.0	24.5	7.3	8.5	334	4.2	--	--	--	214	--	--
2.5	24.5	7.3	8.4	334	4.8	--	--	--	214	--	--
3.0	24.4	7.0	8.4	335	4.8	0.9	144	0.030	214	0.15	0.010
3.5	24.5	6.9	8.4	334	4.1	--	--	--	214	--	--
4.0	24.4	6.8	8.4	335	3.9	--	--	--	215	--	--
4.5	24.4	6.6	8.4	336	4.9	--	--	--	215	--	--
5.0	24.4	6.5	8.4	335	4.9	--	--	--	215	--	--
5.5	24.4	6.4	8.4	336	4.8	--	--	--	215	--	--
6.0	24.2	3.8	7.5	441	4.9	0.9	144	0.021	282	0.16	0.010

Table 4. Silver Lake water quality parameter data collected site #2 (July 23, 2018).

Depth (m).	*Water Temp ºC*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Alk. mg L^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*	*TDS mg L^{-1}*	*TIN mg L^{-1}*	*Ortho-P mg L^{-1}*
0	24.5	7.5	8.4	335	4.9	0.8	141	0.018	214	0.15	<0.010
0.5	24.5	7.3	8.4	335	5.2	--	--	--	214	--	--
1.0	24.5	7.2	8.4	335	4.8	--	--	--	214	--	--
1.5	24.5	7.1	8.4	335	4.8	--	--	--	214	--	--
2.0	24.5	7.0	8.4	334	4.8	--	--	--	214	--	--
2.5	24.5	7.0	8.4	335	4.8	--	--	--	214	--	--
3.0	24.5	7.0	8.4	335	4.8	0.8	141	0.030	214	0.18	<0.010
3.5	24.5	7.0	8.4	335	4.8	--	--	--	214	--	--
4.0	24.5	7.0	8.4	334	4.5	--	--	--	214	--	--
4.5	24.5	7.0	8.4	334	5.0	--	--	--	214	--	--
5.0	24.4	7.0	8.5	334	5.0	--	--	--	214	--	--
5.5	24.4	7.0	8.5	334	4.9	--	--	--	214	--	--
6.0	24.4	7.0	8.4	334	4.9	--	--	--	214	--	--
6.5	24.4	5.0	8.3	452	4.9	0.8	142	0.023	290	0.15	<0.010

Table 5. Silver Lake water quality parameter data collected site #3 (July 23, 2018).

Depth (m).	*Water Temp ºC*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Alk. mg L^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*	*TDS mg L^{-1}*	*TIN mg L^{-1}*	*Ortho-P mg L^{-1}*
0	24.4	7.8	8.5	333	4.8	0.8	140	0.018	213	0.14	<0.010
0.5	24.5	7.8	8.5	333	4.5	--	--	--	213	--	--
1.0	24.5	7.8	8.5	333	4.5	--	--	--	213	--	--
1.5	24.5	7.8	8.5	333	4.8	--	--	--	213	--	--
2.0	24.5	7.8	8.5	333	4.8	--	--	--	213	--	--
2.5	24.5	7.8	8.5	333	4.8	--	--	--	213	--	--
3.0	24.5	7.8	8.5	333	4.4	0.9	140	0.016	213	0.19	<0.010
3.5	24.5	7.7	8.5	333	4.6	--	--	--	213	--	--
4.0	24.5	7.7	8.5	333	4.6	--	--	--	213	--	--
4.5	24.4	7.7	8.5	333	4.8	--	--	--	213	--	--
5.0	24.4	7.7	8.5	333	4.8	--	--	--	213	--	--
5.5	24.4	7.7	8.5	333	4.9	--	--	--	213	--	--
6.0	24.3	7.6	8.5	334	4.9	--	--	--	214	--	--
6.5	24.3	7.4	8.4	335	4.9	0.9	144	0.028	214	0.18	0.012

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4.2 Silver 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, 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.

4.2.1 Silver Lake Exotic Aquatic Macrophytes

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

Eurasian Watermilfoil (*Myriophyllum spicatum*; Figure 8) 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. 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), 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).

The Eurasian Watermilfoil in Silver Lake has been previously determined to be the hybrid *Myriophyllum spicatum* x *Myriophyllum sibiricum*. This combination has shown resistance to fluridone (trade name: SONAR®) and other systemic herbicides. This approach is discussed in the aquatic herbicide section under lake management methods. The lake currently contains approximately 11.6 acres of hybrid milfoil. The moderate to low water clarity of Silver Lake limits the distribution of Eurasian Watermilfoil but nutrient concentrations can favor growth over time even with reduced water clarity. Hybrid watermilfoil is a serious problem in Michigan inland lakes.

A similar milfoil species that is considered to be exotic by some scientists (*Myriophyllum heterophyllum*) in New Hampshire was found to have significant impacts on waterfront property values (Halstead et *al*., 2003). Moody and Les (2007) were among the first to determine a means of genotypic and phenotypic identification of the hybrid watermilfoil variant and further warned of the potential difficulties in the management of hybrids relative to the parental genotypes. It is commonly known that hybrid vigor is likely due to increased ecological tolerances relative to parental genotypes (Anderson 1948), which would give hybrid watermilfoil a distinct advantage to earlier growth, faster growth rates, and increased robustness in harsh environmental conditions. Furthermore, the required dose of 2,4-D for successful control of the hybrid watermilfoil is likely to be higher since there is much more water volume at greater depths it can occupy and also due to the fact that hybrid watermilfoil has shown increased tolerance to traditionally used doses of systemic aquatic herbicides. In regards to impacts on native vegetation, hybrid watermilfoil possesses a faster growth rate than Eurasian milfoil or other plants and thus may effectively displace other vegetation (Les and Philbrick 1993; Vilá et *al*. 2000). Management options for the plant are provided in the management recommendations section of the report.

Curly-leaf Pondweed (*Potamogeton crispus*; Figure 9) is an exotic, submersed, rooted aquatic plant that was introduced into the United States in 1807 but was abundant by the early 1900's. It is easily distinguished from other native pondweeds by its wavy leaf margins. It grows early in the spring and as a result may prevent other favorable native aquatic species from germinating. The plant reproduces by the formation of fruiting structures called turions. The plant does not reproduce by fragmentation as milfoil does; however, the turions may be deposited in the lake sediment and germinate in following seasons. Fortunately, the plant naturally declines around mid-July in most lakes and thus is not likely to be prolific throughout an entire growing season. Curly-leaf Pondweed is a pioneering aquatic plant species and specializes in colonizing disturbed habitats. It is highly invasive in aquatic ecosystems with low biodiversity and unique sediment characteristics. It was found to occupy approximately <0.75 acres of the bottom in Hunter Creek, which is a low quantity.

Figure 10 shows the general distribution of the hybrid Eurasian Watermilfoil in Silver Lake on July 23, 2018. Table 6 below shows all exotic aquatic plant species in Silver Lake and the canals such as Hunter Creek as of July 23, 2018.

Figure 8. Photo of Eurasian Watermilfoil ©RLS

Figure 9. Photo of Curly-leaf Pondweed ©RLS

Figure 10. Distribution of Hybrid Eurasian Watermilfoil in Silver Lake, Oceana County, MI. (July 23, 2018).

Table 6. Silver Lake exotic aquatic plant species (July 23, 2018).

Exotic Aquatic Plant Species	*Aquatic Plant Common Name*	*Growth Habit*	*Abundance in or around Silver Lake (Acres or # Sites)*
Myriophyllum spicatum	Eurasian Watermilfoil	Submersed; Rooted	11.6
*Potamogeton crispus**	Curly-leaf Pondweed	Submersed; Rooted	< 0.75

* Curly-leaf Pondweed was found in Hunter Creek.

4.2.2 Silver 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.

On July 23, 2018, Silver Lake contained 2 native submersed, 0 floating-leaved, and 2 emergent aquatic plant species, for a total of 4 native aquatic macrophyte species (Table 7). The majority of the emergent macrophytes may be found along the shoreline of the lake, especially near the wetland located at the southwest shore near the dam. This represents a very low biodiversity of native aquatic vegetation and is an impediment to a robust and healthy lake fishery (O'Neal, 2017). Slightly more diversity was located in Hunter Creek but this too was low overall (Table 8).

The dominant aquatic plant in the main part of the lake included the submersed macro alga, *Chara vulgaris* which has a strong sulfurous odor and feels brittle to the touch. In addition, this alga can carpet the lake bottom and serve to prevent the rooting of milfoil fragments when in abundance. The abundance of this plant in Silver Lake is very low and should be allowed to increase with time as it also reduces sediment re-suspension which leads to reduced water clarity.

The emergent plants, such as *Typha* sp. (Cattails), and *Schoeneoplectus* sp. (Bulrushes) are critical for shoreline stabilization as well as for wildlife and fish spawning habitat and are scarce, except for in the wetland area near the dam.

Figure 11 shows the relative biovolume of all aquatic vegetation in Silver Lake. Biovolume is a measure of the height in the water column that each plant occupies. On this map, blue color represents no vegetation, green color represents low-growing vegetation, and red/orange colors represent tall-growing aquatic vegetation in the water column. As the map demonstrates, Silver Lake contains a very low quantity of aquatic vegetation with low biovolume and thus the need for preservation and proper management of invasives is critical. Photos of all native aquatic plant species are shown in Figures 12-18.

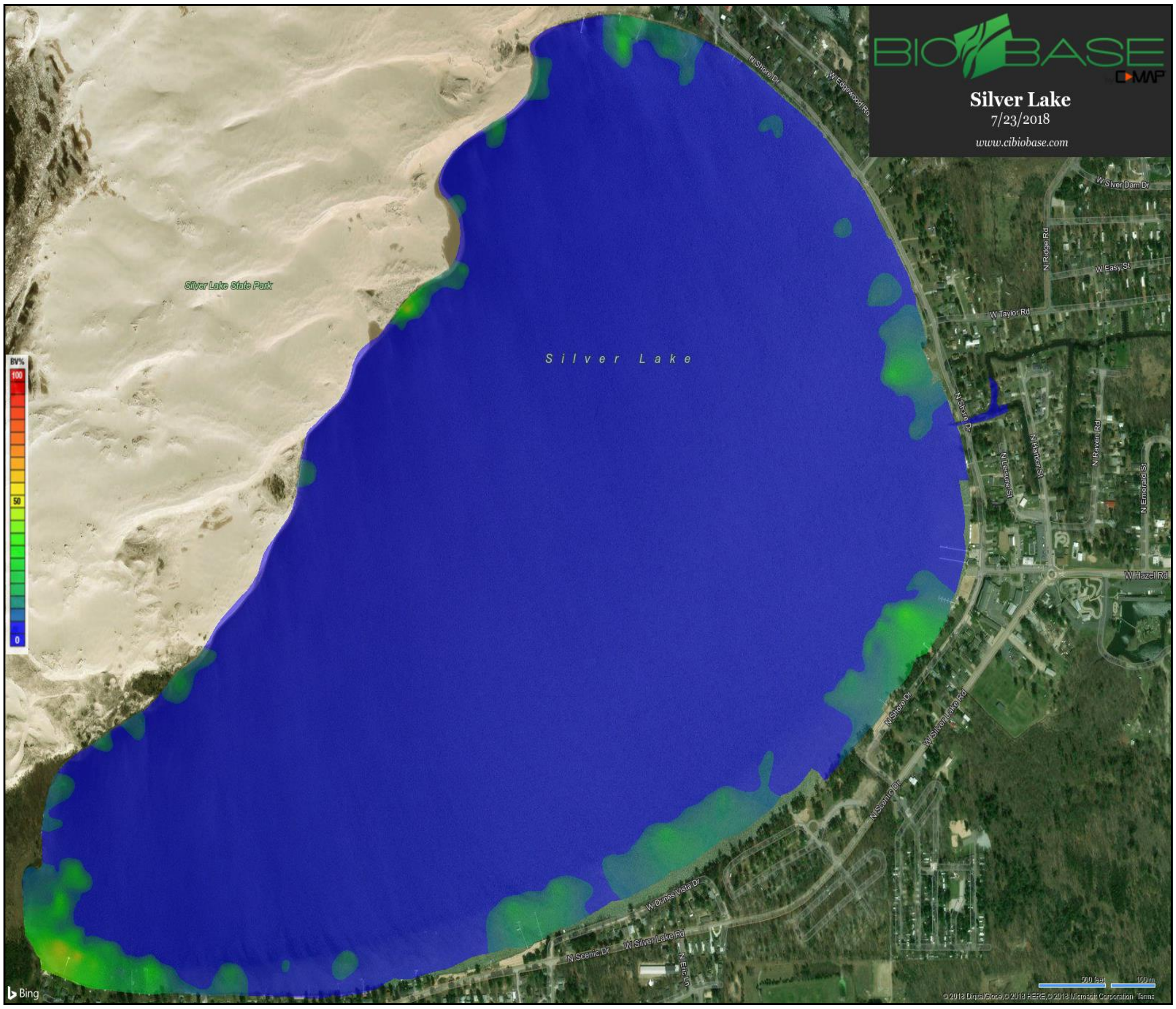

Figure 11. A biovolume map showing relative heights in the water column of all aquatic vegetation in Silver Lake. (July 23, 2018). Note: Dark red and orange colors denote thick vegetation, whereas green and yellow colors show lower-growing plants and blue denotes no vegetation.

Table 7. Silver Lake native aquatic plants (July 23, 2018). Relative abundance displayed as a percentage.

Native Aquatic Plant Species Name	***Aquatic Plant Common Name***	***Abundance in/around Silver Lake (% cover)***	***Aquatic Plant Growth Habit***
Chara vulgaris	Muskgrass	2.0	Submersed, Rooted
Najas guadalupensis	Southern Naiad	0.2	Submersed, Rooted
Typha latifolia	Cattails	0.1	Emergent
Schoenoplectus acutus	Bulrushes	0.1	Emergent

Table 8. Hunter Creek native aquatic plants (July 23, 2018). Relative abundance displayed as a percentage.

Native Aquatic Plant Species Name	***Aquatic Plant Common Name***	***Abundance in/around Hunter Creek (% cover)***	***Aquatic Plant Growth Habit***
Chara vulgaris	Muskgrass	0.2	Submersed, Rooted
Potamogeton pectinatus	Thin-leaf Pondweed	4.0	Submersed, Rooted
Potamogeton zosteriformis	Flat-stem Pondweed	4.0	Submersed, Rooted
Elodea canadensis	Common Waterweed	10.5	Submersed, Rooted
Typha latifolia	Cattails	0.2	Emergent
Schoenoplectus acutus	Bulrushes	0.2	Emergent

Figure 12. Chara (Muskgrass)

Figure 13. Thin-leaf Pondweed ©RLS

Figure 14. Flat-stem Pondweed ©RLS

Figure 15. Elodea ©RLS

Figure 16. Southern Naiad ©RLS

Figure 17. Bulrushes ©RLS

Figure 18. Cattails ©RLS

4.3 Silver Lake Macroinvertebrates and the Lake Fishery

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

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

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

RLS collected aquatic macroinvertebrates two separate locations (North and South Basins) within Silver Lake on July 23, 2018 (Table 9). The study found mayfly larvae (*Hexagenia limbata*, Ephemeridae), midge larvae (Chironomindae), pond snails (*Lymnaea* sp.), wheel snails (Planorbidae) and zebra mussels (Dreisseniidae). Of all the species found, all were native except for the zebra mussels. 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). The mayfly, *Hexagenia limbata*, found within this lake, has been shown to be linked with good water quality but only one specimen was noted.

Native lake macroinvertebrate communities can and have been impacted by exotic and invasive species. A study by Stewart and Haynes (1994) examined changes in benthic macroinvertebrate community in southwestern Lake Ontario following the invasion of zebra and quagga mussels (*Dreissena spp*.). They found that *Dreissena* had replaced a species of freshwater shrimp as the dominant species. However, they also found that additional macroinvertebrates actually increased in the 10-year study, although some species were considered more pollution-tolerant than others. This increase was thought to have been due to an increase in *Dreissena* colonies increasing additional habitat for other macroinvertebrates.

Eurasian water-milfoil (*Myriophyllum spicatum*) has also been shown to negatively influence both fish and macroinvertebrate communities (Lillie and Budd 1992).

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

Table 9. Silver Lake, Oceana County, Macroinvertebrate Samples.

Location	Order	Class, Family, Genera, etc.	Quantity	Common Name
Central Lake	Gastropoda	Planorbidae	4	Wheel snails
	Gastropoda	Lymnaea	11	Pond snails
	Diptera	Chironomidae	5	Midge larvae
		Total	**20**	
South Shore	Gastropoda	Lymnaea	9	Pond snails
	Dreissenidae	*Dreissena polymorpha*	11	Zebra mussels
	Ephemeroptera	Ephemerillidae	1	Mayfly larvae
	Diptera	Chironomidae	7	Midge larvae
		Total	**28**	

The fishery of Silver Lake may be defined as a warm-water fishery due to the shallow depth of the lake and the resultant warm water temperatures during the open-water season. Historical studies by the MDNR of Silver Lake fish communities consisted of 16 species including Yellow Perch (*Perca flavescens*), Bluegill (*Lepomis macrochirus*), Pumpkinseed Sunfish (*Lepomis gibbosus*), Largemouth Bass (*Micropterus salmoides*), Yellow Bullhead Catfish (*Ameiurus* sp.), Black Crappie (*Pomoxis nigromaculatus*), Smallmouth Bass (*Micropterus dolomieu*), Common Carp (*Cyprinus carpio*), Walleye (*Stizostedion vitreum vitreum*), Rock Bass (*Ambloplites rupestris*), White Sucker (*Catostomus commersonii*), Brook Trout (*Salvelinus fontinalis*), Rainbow Trout (*Oncorhynchus mykiss*), Bowfin (*Amia calva*), and Brown Bullhead (*Ameriurus nebulosus*), and the Northern Pike (*Esox lucius*). More species may be in the lake that were not observed during the lake survey. The lake has been stocked with Walleye in from 1979-2018 (MDNR online fish stocking database). A 2017 MDNR report by Rich O'Neal emphasized the lack of aquatic vegetation in Silver Lake as a key contributor to lake health degradation. The lake fishery will benefit from a diverse (yet balanced) native aquatic plant community, ample supply of zooplankton, and abundance of submerged habitats (i.e. wood structures and native macrophyte beds).

4.4 Silver Lake Zooplankton

Zooplankton are microscopic organisms that cannot produce their own food and thus feed on algae (phytoplankton) in the water column. They are thus responsible for keeping algae populations balanced and are the reason that many lakes are not completely covered with algae. Zooplankton are selective feeders, only ingesting green algae and diatoms. They will not consume blue-green algae due to the compounds and toxins often present in that type of algae. Zooplankton includes the rotifers which have over 2,000 freshwater species and cladocerans which are small crustaceans that have a carapace that covers much of their body. Another group, the copepods are active and powerful swimmers and are an excellent fish food source. The last group consists of protozoans which are the smallest and least motile. They tend to reside in lake sediments unless they are planktonic which then they are common in the water column during summer.

Two zooplankton tows using a pelagic plankton net with collection jars were conducted by RLS scientists on July 23, 2018 in the north and south basins. Plankton sub-samples (in 10 ml aliquots) were analyzed under a Zeiss® dissection scope with the use of a Bogorov counting chamber. The most abundant zooplankton genera included copepods such as *Diaptomus* sp. (approximately 2 organisms per 10 ml aliquot), *Mesocyclops* (approximately 2 organisms per 10 ml aliquot). Also present was the cladoceran *Daphnia* (approximately 6 organisms per 10 ml aliquot).

Lakes such as Silver Lake that are eutrophic will select for small zooplankton since these organisms prefer planktonic green algae and diatoms as their primary food source relative to the overabundant blue-green algae that offer less nutrition. This ultimately results in the loss of large zooplankton which could reduce the selection available to the fishery and contribute to a lower biodiversity of the fishery.

5.0 LAKE IMPROVEMENT OPTIONS FOR SILVER LAKE

5.1 Silver Lake Aquatic Plant Management

Improvement strategies, including the management of exotic aquatic plants, control of land and shoreline erosion, and further nutrient loading from external sources, are available for the various problematic issues facing Silver Lake. The lake management components involve both within-lake (basin) and around-lake (watershed) solutions to protect and restore complex aquatic ecosystems. The goals of a Lake Management Plan (LMP) are to increase water quality, favorable wildlife habitat, aquatic plant and animal biodiversity, recreational use, and protect property values. Regardless of the management goals, all management decisions must be site-specific and should consider the socio-economic, scientific, and environmental components of the LMP.

The management of submersed invasive aquatic plants is necessary in Silver Lake due to the threat of 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. In Silver Lake, only exotic aquatic plant species should be managed with solutions that will yield long-term results to reduce the need for future herbicide treatments. Various methods and their applications to the management of invasive aquatic vegetation in Silver Lake are discussed below.

5.1.1 Chemical Aquatic Herbicide Applications

The use of aquatic chemical herbicides is regulated by the MDEQ under Part 33 (Aquatic Nuisance) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, and requires a permit. The permit contains a list of approved herbicides for a particular body of water, as well as dosage rates, treatment areas, and water use restrictions. Contact and systemic aquatic herbicides are the two primary categories used in aquatic systems. All herbicides are applied with either an airboat or skiff boat equipped with pumps, hoses, and even GPS units for geo-location (Figure 19).

Contact herbicides such as diquat (Trade Name: Reward®), hydrothol (Trade Name: Aquathol-K®), glyphosate (Trade Name: Habitat®), and flumioxazin (Trade Name: Clipper®) cause damage to leaf and stem structures; whereas systemic herbicides are assimilated by the plant roots and are lethal to the entire plant. Wherever possible, it is preferred to use a systemic herbicide for longer-lasting aquatic plant control. There are often restrictions with usage of some systemic herbicides around shoreline areas that contain shallow drinking wells. In Silver Lake, the use of contact herbicides is not recommended due to the lack of native aquatic plant biodiversity.

Systemic herbicides such as 2, 4-D and triclopyr are the two primary systemic herbicides used to treat hybrid invasive milfoil that does not cover an entire lake. 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. This method has been used in many previous years of prior Silver Lake improvement programs and is not recommended now or in the near future unless at least 66% of the lake surface area is covered by invasive milfoil.

The use of granular systemic herbicides such as Triclopyr is recommended for the 11.6 acres of milfoil found in Silver Lake during the July 23, 2018 survey. This herbicide has been used very successfully on many inland lakes in Michigan that have hybrid watermilfoil. Triclopyr must be used in near shore areas with shallow well (< 30 feet deep) restrictions. Also, the use of granular 2, 4-D in offshore area may be considered. The objective is to reduce the biomass of milfoil and rely on spot-treatments with significantly less herbicide once the population is under control. Based on review of MDEQ-issued aquatic herbicide permits, herbicides such as copper sulfate, chelated copper algaecides, diquat, endothol, flumioxazin, and triclopyr have been used in Silver Lake to reduce nuisance aquatic vegetation growth. Only systemic herbicides should be used for this program in an effort to re-populate the native aquatic plant population.

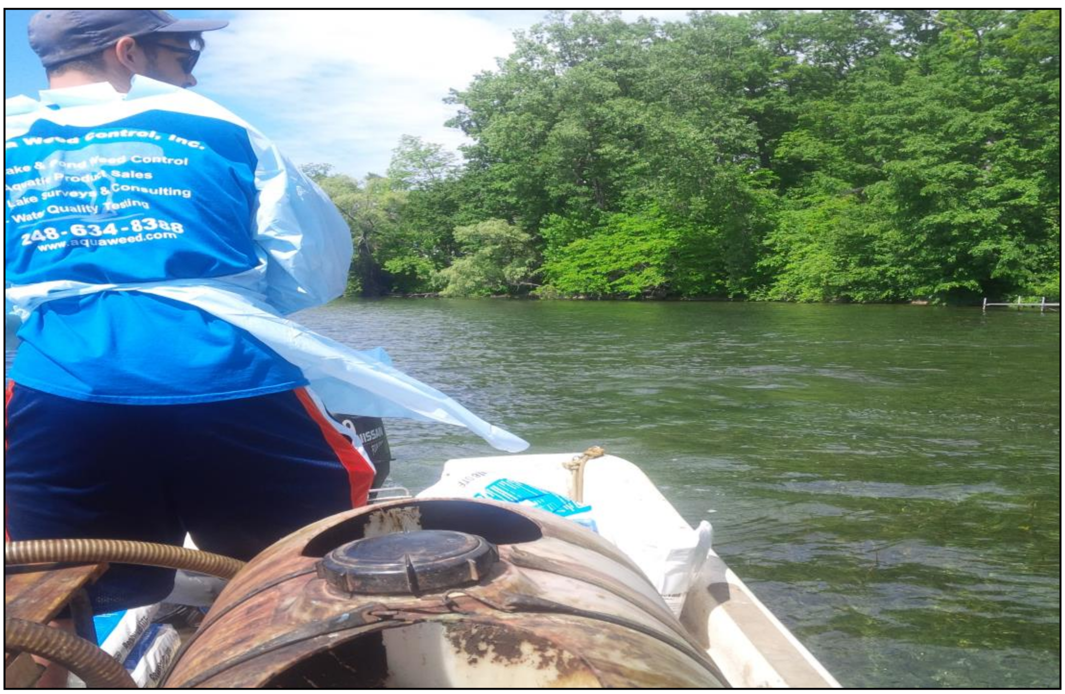

Figure 19. A skiff boat used to apply aquatic herbicides under MDEQ permit on inland lakes.

5.1.2 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 20). 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 plants may fragment when cut and re-grow on the lake bottom. Due to the fact that milfoil is present in Silver Lake and fragmentation is a threat, mechanical removal is not recommended at this time.

Mechanical harvesting does not require a permit from the Michigan Department of Environmental Quality (MDEQ); however, some counties require a launch site use permit from the Michigan Department of Natural Resources (MDNR) if a public access site is present. Costs of mechanical harvesting vary but currently range from $300-$500 per acre for most aquatic vegetation plus $1,000-$3,000 for mobilization of the mechanical harvesting equipment.

Figure 20. A mechanical harvester.

5.1.3 Diver Assisted Suction Harvesting (DASH)

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 21) involves hand removal of individual plants by a SCUBA diver in selected areas of lake bottom with the use of a hand-operated suction hose. Samples are dewatered on land or removed via fabric bags to an offsite location. This method is generally recommended for small (less than 1 acre) spot removal of vegetation since it is costly on a large scale (costs range from $1,000-$5,000 per acre). It may be used in the future to remove small remaining areas of milfoil if a non-chemical method is then preferred. If the DASH method is used on aquatic plants that fragment, then the use of a barrier to prevent movement of the fragments is recommended. Furthermore, this activity may cause re-suspension of sediments (Nayar et *al*., 2007) which may lead to increased turbidity and reduced clarity of the water. This is especially the case when this method is conducted in soft, flocculent sediments. The process requires a permit from the MDEQ and U.S. Army Corps of Engineers.

Figure 21. A DASH boat for hand-removal of milfoil or other nuisance vegetation. ©RLS

5.1.4 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 22) or Weed Rollers (Figure 23) have been used to reduce rooted aquatic weed growth in small areas such as in beach areas and around docks. The mats are not effective on non-rooted aquatic plants since they can rest on top of the mats and move freely throughout the water column. The benthic mats are placed on the lake bottom in early spring prior to the germination of aquatic vegetation. They act to reduce germination of all aquatic plants and lead to a local area free of most aquatic vegetation. Benthic barriers may come in various sizes between 100-400 feet in length. They are anchored to the lake bottom to avoid becoming a navigation hazard. The implementation of a benthic barrier mat requires a minor permit from the MDEQ which can cost around $50-$100. The cost of the barriers varies among vendors but can range from $100-$1,000 per mat. Benthic barrier mats can be purchased online at: www.lakemat.com or www.lakebottomblanket.com. The efficacy of benthic barrier mats has been studied by Laitala et *al*. (2012) who report a minimum of 75% reduction in invasive milfoil in the treatment areas. Lastly, benthic barrier mats should not be placed in areas where fishery spawning habitat is present and/or spawning activity is occurring.

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

Both methods are useful in recreational lakes such as Silver Lake and work best in beach areas and near docks to reduce nuisance rooted aquatic vegetation growth should it occur in future years of the current program.

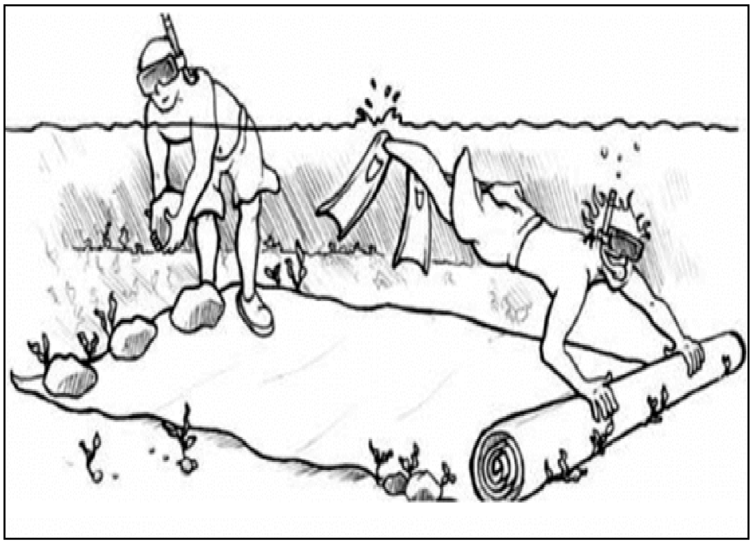

Figure 22. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension

Figure 23. A Weed Roller

5.1.5 Dredging

Dredging is a lake management option used to remove accumulated lake sediments to increase accessibility for navigation and recreational activities (Figure 24). Dredging activities in Silver Lake would remove sediments in shallow areas but is not recommended for aquatic vegetation removal since many of the species re-grow. Due to the non-selective nature of dredging on the lake sediment seed bank, the response by individual species of aquatic vegetation is highly uncertain. Dredging could be used to remove accumulated sediments in Hunter Creek but this would require a separate study and assessment program. Selection of a particular dredging method and CDF should consider the environmental, economical, and technical aspects involved. Dredging is regulated pursuant to provisions of Part 301 (Inland Lakes and Streams) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, and requires a joint permit through both the Michigan Department of Environmental Quality (MDEQ) and the U.S. Army Corps of Engineers (USACE).

The two major types of dredging include hydraulic and mechanical. A mechanical dredge usually utilizes a backhoe and requires that the disposal site be adjacent to the lake. In contrast, a hydraulic dredge removes sediments in an aqueous slurry and the wetted sediments are transported through a hose to a confined disposal facility (CDF). The CDF must be chosen to maximize retention of solids and accommodate large quantities of water from the dewatering of sediments. It is imperative that hydraulic dredges have adequate pumping pressure which can be achieved by dredging in waters greater than 3 foot of depth. Dredge spoils cannot be emptied into wetland habitats; therefore a large upland area is needed for lakes that are surrounded by wetland habitats. In addition, proposed sediment for removal must be tested for metal contaminants before being stored in a CDF.

If the sediment is not contaminated, it could be used for habitat restoration, landfill cover, agriculture, strip mine reclamation, or in other industrial or construction uses (U.S. EPA/USACE 2004). A dredging feasibility study and public hearings would also need to be conducted prior to the start of the project to determine the amount of sediment to be dredged and the associated removal and management oversight costs. The State of Michigan Department of Environmental Quality (MDEQ) has established threshold effects and probable effects concentrations for arsenic levels in sediments. The threshold effects concentration is at 9.79 mg/kg of dry weight and the probable effects concentration is at 33.0 mg/kg of dry weight.

Figure 24. A dredging process (photo courtesy of noaa.gov).

5.1.6 Laminar Flow Aeration and Bioaugmentation

Laminar flow aeration systems (Figure 25) are retrofitted to a particular site and account for variables such as water depth and volume, contours, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute dissolved oxygen throughout the lake sediments for efficient microbial utilization.

A laminar flow aeration system utilizes diffusers which are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help to purge the lake sediment pore water of gases such as hydrogen sulfide (H_2S) and benthic carbon dioxide (CO_2) which are byproducts of microbial metabolism.

The concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment. Beutel (2006) found that lake oxygenation eliminates release of NH_3+ from sediments through oxygenation of the sediment-water interface. Allen (2009) demonstrated that NH_3+ oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry wt. day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt. day^{-1} in controls. Recent case studies have shown promise on the positive impacts of laminar flow aeration systems on aquatic ecosystem management with respect to organic matter degradation and resultant increase in water depth, and rooted aquatic plant management in eutrophic ecosystems with highly organic sediments (Jermalowicz-Jones, 2010-2018). Toetz (1981) found evidence of a decline in *Microcystis* algae (a toxin-producing blue-green algae) in Arbuckle Lake in Oklahoma. Other studies (Weiss and Breedlove, 1973; Malueg et *al.*, 1973) have also shown declines in overall algal biomass.

Benefits and Limitations of Laminar Flow Aeration

In addition to the reduction in toxic blue-green algae (such as *Microcystis* sp.) as described by Toetz (1981), aeration and bioaugmentation in combination have been shown to exhibit other benefits for the improvements of water bodies. Laing (1978) showed that a range of 49-82 cm of organic sediment was removed annually in a study of nine lakes which received aeration and bioaugmentation. It was further concluded that this sediment reduction was not due to re-distribution of sediments since samples were collected outside of the aeration "crater" that is usually formed. A study by Turcotte et *al.* (1988) analyzed the impacts of bioaugmentation on the growth of Eurasian Watermilfoil and found that during two four-month studies, the growth and re-generation of this plant was reduced significantly with little change in external nutrient loading. A reduction of Eurasian Watermilfoil is desirable for protection of native plant biodiversity, recreation, water quality, and reduction of nutrients such as nitrogen and phosphorus upon decay (Ogwada et *al*., 1984). This technology cannot reduce aquatic vegetation on sand and coarse lake sediments since nutrients are not reduced in the sediment pore water as no organic matter is decomposed under those conditions.

Furthermore, bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979) so the concomitant addition of microbes to lake sediments will accelerate that process. A study by Verma and Dixit (2006) evaluated aeration systems in Lower Lake, Bhopal, India, and found that the aeration increased overall dissolved oxygen, and reduced biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total coliform counts.

The laminar flow aeration system has some limitations including the inability to break down mineral sediments, the requirement of a constant Phase I electrical energy source to power the units, and possible unpredictable response by various species of rooted aquatic plants (currently being researched by RLS).

Design of the Laminar Flow Aeration System

A laminar flow system could be retrofitted to Silver Lake if desired; however, much more data (i.e. sediment type and organic matter content) is needed to determine what benefits would be attained by using aeration in Silver Lake. The system has several components which consist of in-water components such as micro-porous ceramic diffusers, self-sinking airline, and bacteria and enzyme treatments which consist of bacteria for sediment nutrient reduction, and enzymes as a catalyst for muck reduction. On-land components consist of locally-sourced sheds and rotary claw compressor(s) along with cooling fans and ventilation. Once the system has been installed, the MDEQ has instituted a required minimum sampling protocol to monitor the efficacy of the system for the intended purposes as determined by stakeholders. The laminar flow aeration design for Silver Lake should include the use of many ceramic diffusers (12" diameter) throughout the entire lake with added bioaugmentation (microbes).

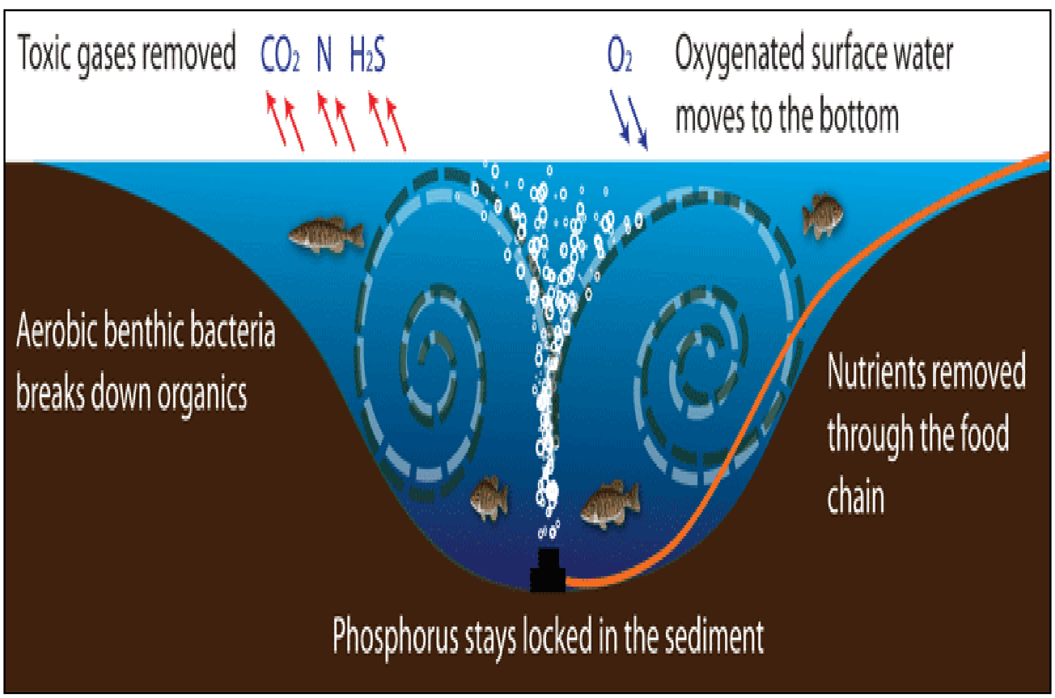

Figure 25. A diagram showing the laminar flow aeration mechanisms. ©RLS

5.2 Silver Lake Watershed Protection

In addition to the proposed treatment of invasives in Silver Lake, it is recommended that Best Management Practices (BMP's) be implemented to improve the lake's water quality. The guidebook, Lakescaping for Wildlife and Water Quality (Henderson et *al.* 1998) provides the following guidelines:

1) Maintenance of brush cover on lands with steep slopes (those > 6%; see above soil table)
2) Development of a vegetation buffer zone 25-30 feet from the land-water interface with approximately 60-80% of the shoreline bordered with vegetation
3) Limiting boat traffic and boat size to reduce wave energy and thus erosion potential
4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion
5) Using only native genotype plants (those native to Silver Lake or the region) around the lake since they are most likely to establish and thrive than those not acclimated to growing in the area soils

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

5.2.1 Silver Lake Erosion and Sediment Control

A soil erosion survey was conducted for Silver Lake, Oceana County, Michigan on July 23, 2018 by certified soil erosion control officers at RLS as part of a comprehensive lake management assessment as a component of this improvement plan. The purpose of this survey is to present data collected in the field by boat, give examples of erosion occurring along the lakes shoreline, and illustrate some possible treatments of erosion using bioengineering methods that incorporate vegetative materials.

Shoreline erosion negatively impacts numerous resources including public use areas with boat launch sites and camping areas; water quality from soils eroding into the lake; fisheries and wildlife habitat being diminished from both turbidity and a lack of suitable vegetative cover.

Shoreline areas may be susceptible to erosion from both natural and human activities, including wind, waves, wakes, ice push and storm water runoff, but this potential for soil movement to surface waters depends on several factors including:

- Soil erodibility
- Rainfall
- Slope
- Vegetative cover
- Fetch
- Bathymetry
- Average depth

RLS evaluated the potential for soil erosion based on the risk of soil mobilization due to the factors listed above. Shoreline exposure and bathymetry play a big part in determining the degree of erosion at a particular shoreline site. Sites with straight shorelines or that are exposed to long wind fetches from prevailing wind directions are particularly vulnerable to more frequent and higher waves (i.e. Silver Lake). Conversely, sites within coves that block the wind are more protected from waves. Lakes with shallow and wide the nearshore underwater benches have more drag and resistance to waves. Waves will subsequently be smaller in these areas in contrast to those where the water deepens abruptly and there is less resistance or bottom roughness to influence the wave. When vegetation is present, erosion is less severe or even minimal. Land use also influences the degree of erosion at a site. If the site is adjacent to a public use area where there are a lot of people going to and from the shoreline, vegetation is often mowed and/or trampled leaving very little, if any vegetation to control erosion.

Silver Lake's proximity to Lake Michigan makes it vulnerable to sustained high winds prevailing from the west. The potential for shoreline erosion is often influenced by fetch, average depth, and wind speed. The fetch, or the distance across a body of water to produce a wind driven wave, ranges from less than ½ mile to 1 mile from west to east across Silver Lake. According to NOAA climatological records, wind speeds can gust at least up to 50 miles per hour on the lake. Using the Wisconsin DNR's erosion energy calculator and assuming there are sustained wind speeds of 35 miles per hour for 5 minutes or more, waves could be produced that are between 1-1.5 ft. high with moderate erosive energy. Once waves are generated, the rate of soil loss is commonly associated with slope, soil type, and vegetative cover. Soils groups (A-D) are classified based on estimates of infiltration rate and runoff potential. Group A soils consist of well drained sands or gravel, while group D soils consist of a clay layer that is nearly impervious and generates significant runoff. The risk for soil erosion for sites with no vegetative cover grows as soil clay content increases from group A to group D.

Eastern Shoreline

Silver Lake's eastern shoreline is the most vulnerable to erosion due to development, in addition to its exposure to Lake Michigan wind-generated waves and soil groups with higher erosive potential. On the contrary, there are no steep bluffs and shallow nearshore benches help to break up waves and lessen the impact to shoreline degradation. A clear majority of shoreline vegetation has been removed and reinforced with seawalls or riprap (Figure 26). Nonetheless, here are some areas with a stable, natural shoreline (Figure 27) and some areas where riprap is failing (Figure 28), possibly due to higher that average water levels. Areas with minimal shoreline protection experiencing active erosion are ideal candidates for bioengineering efforts which could both mitigate erosion and enhance nearshore aquatic habitat (Figures 29 and 30). This effort would have a positive impact on water quality.

Figure 26. Area to the left is an example of seawall with no vegetation present. To the right is an example of a well vegetated shoreline.

Figure 27. Up-close picture of the area in figure 1. This has been planted with native herbaceous vegetation.

Figure 28. Rip-rap failure due to wave action and high-water levels.

Figure 29. Erosion site located at state park campground is an ideal candidate for natural shoreline restoration.

Figure 30. Erosion site located at state park boat launch is an ideal candidate for natural shoreline restoration.

Northern Shoreline

The northern shoreline is semi-protected by its cove-like geometry, sandy group A soils, and low sloping landscape. This area is dominated by manicured lawns (Figure 31 and 32), with small sections of natural vegetation present (Figure 33). There is minimal shoreline degradation occurring in this area except for drainage pipes causing some minor beach gully erosion (Figures 34 and 35). The establishment of emergent shoreline vegetation in these areas will slow the rate of beach loss, filter nutrients and provide aquatic habitat.

Figure 31. Example of manicured lawn in place of natural shoreline vegetation. Drainage discharge causing beach erosion.

Figure 32. Example of manicured lawn in place of natural shoreline vegetation. Drainage discharge causing beach erosion.

Figure 33. Example of naturally vegetated northern shoreline with no signs of active erosion.

Western Shoreline

The western shoreline consists of shifting sand dunes (Figure 34) and some emergent shoreline vegetation in other areas (Figure 35). While there are high slopes and sand particles are free to move due to the lack of vegetation, they often do not become suspended in the water column and thus not a threat to water quality. RLS does not recommend any shoreline erosion controls in this area.

Figure 34. Western shoreline with sand dune area. No signs of active erosion were identified.

Figure 35. Western shoreline with emergent wetland vegetation and no active erosion.

Southern Shoreline

Silver Lake’s southern shoreline is undeveloped with a vigorous, naturally vegetated landscape (Figure 36). This is a great example of an ideal shoreline that includes a favorable swath of emergent aquatic vegetation at the nearshore shallows, such as hard-stem bulrush, backed by wetland species, such as herbaceous plants, shrubs and trees including swamp loosestrife, willow, buttonbush, and other larger tree species (Figure 37). This location is also semi-protected from prevailing westerly winds. No areas of concern with active erosion were found here. This location is part of the Silver Lake State Park and consists of wetlands and bogs, thus likely to be preserved in its current state.

Figure 36. Example of an undisturbed, natural shoreline at the southern end of the lake.

Figure 37. Example of an undisturbed, natural shoreline at the southern end of the lake with shallow water emergent bulrush.

Treatment Types & Next Steps

At the request of the Silver Lake Improvement Board, RLS staff have identified problematic areas with a potential for erosion, or currently experiencing active erosion. While conditions on the western and southern shorelines are good, some eastern and northern shoreline areas are experiencing active erosion and sedimentation that could impact water quality, lake habitat and recreational activities. Shoreline restoration efforts should be focused in these areas.

The use of vegetation alone as a treatment relies solely on using sprigs of emergent aquatic plants, such as water willow, bulrush, spike-rushes, or other grass-like plants, and unrooted cuttings or poles of dormant woody plants, such as willow. Emergent aquatic plants would be placed in a zone lakeward of the shoreline in water depths extending up to 1.5 feet. Woody plants would be planted from the shoreline on up to an elevation that is affected by erosion. More severely eroded areas should focus on using vegetation in combination with some materials such as geotextile fabrics or mats and stakes and wire to anchor plants into the ground. This includes a variety of options such as coco fiber geotextile rolls, erosion control mats, and willow bundles (Figure 38). These techniques are often used with rock rip-rap for extra protection in areas where fetches in combination with wind produce waves greater than 1 foot in height. In addition to mitigating erosion, restoration work would assist in increasing the abundance and distribution of aquatic vegetation that is scarce in Silver Lake. Repairing eroded slopes can be problematic due to restricted access and difficult working conditions. Such difficulties can result in high costs for slope repair, therefore minimizing the disturbance of natural shoreline areas and implementing effective erosion protection in actively used spaces can prevent or reduce the magnitude of these problems.

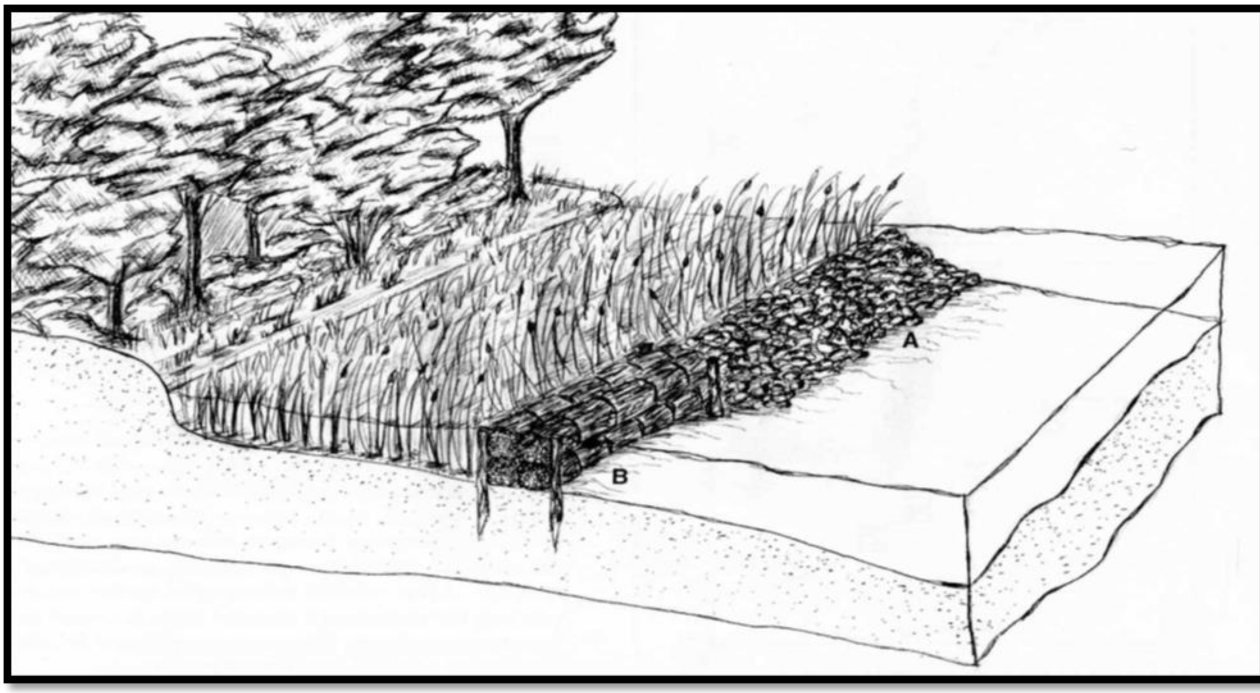

Figure 38. Example of bioengineered shoreline restoration techniques. A) Rock rip-rap in combination with plantings. B) Willow bundles or coco coir logs in combination with plantings.

5.2.2 Silver Lake Nutrient Source Control

Based on the mean high ratio of nitrogen to phosphorus in Silver Lake (i.e. N: P = 36), any additional inputs of phosphorus to the lake are likely to create additional algal and aquatic plant growth. Accordingly, RLS recommends the following procedures to protect the water quality of Silver Lake and reduce nutrient loads:

1) Avoid the use of lawn fertilizers that contain phosphorus (P). P is the main nutrient required for aquatic plant and algae growth, and plants grow in excess when P is abundant. When possible, water lawns with lake water that usually contains adequate P for successful lawn growth. If you must fertilize your lawn, assure that the middle number on the bag of fertilizer reads “0” to denote the absence of P. If possible, also use low nitrogen in the fertilizer or use lake water.

2) Preserve riparian vegetation buffers around lake (such as those that consist of Cattails, Bulrushes, and Swamp Loosestrife), since they act as a filter to catch nutrients and pollutants that occur on land and may run off into the lake. As an additional bonus, Canada geese (*Branta canadensis*) usually do not prefer lakefront lawns with dense riparian vegetation because they are concerned about the potential of hidden predators within the vegetation. RLS has provided shoreline erosion prevention methods and additional information can be found on the Michigan Natural Shoreline Partnership website at: http://www.mishorelinepartnership.org/
3) Do not burn leaves near the lake shoreline since the ash is a high source of P. The ash is lightweight and may become airborne and land in the water eventually becoming dissolved and utilized by aquatic vegetation and algae.
4) Do not dump leaves in the lake as they are also rich in nutrients and break down on the lake bottom very slowly creating a compost pile that is rich in nutrients.
5) Assure that all areas that drain into the lake from the surrounding land are vegetated and that no fertilizers are used in areas adjacent to waters flowing into Silver Lake.

5.3 Silver Lake 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 Silver Lake is awareness and education. The exotic species of concern have been listed in this report. Other exotic species on the move should be introduced to the riparians around Silver Lake through educational workshops and informational meetings.

5.3.1 Zebra Mussels

Zebra mussels (*Dreissena polymorpha*; Figure 39) were first discovered in Lake St. Clair in 1988 (Herbert et *al*. 1989) and likely arrived in ballast water or on shipping vessels from Europe (McMahon 1996). They were noted by Raikow et *al*., (2004) in Silver Lake in 1999 as a component of the benthic fauna. They are easily transferred to other lakes because they inherit a larval (nearly microscopic) stage where they can easily avoid detection. The mussels then grow into the adult (shelled) form and attach to substrates (i.e. boats, rafts, docks, pipes, aquatic plants, and lake bottom sediments) with the use of byssal threads. The fecundity (reproductive rate) of female zebra mussels is high, with as many as 40,000 eggs laid per reproductive cycle and up to 1,000,000 in a single spawning season (Mackie and Schlosser 1996). Although the mussels only live 2-3 years, they are capable of great harm to aquatic environments. In particular, they have shown selective grazing capabilities by feeding on the preferred zooplankton food source (green algae) and expulsion of the non-preferred blue green algae (cyanobacteria). Additionally, they may decrease the abundance of beneficial diatoms in aquatic ecosystems (Holland 1993). Such declines in favorable algae, can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations. Zebra mussels are viewed by some as beneficial to lakes due to their filtration capabilities and subsequent contributions to increased water clarity. However, such water clarity may allow other photosynthetic aquatic plants to grow to nuisance levels (Skubinna et *al*. 1995). The mussels were prevalent in many areas of Silver Lake.

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

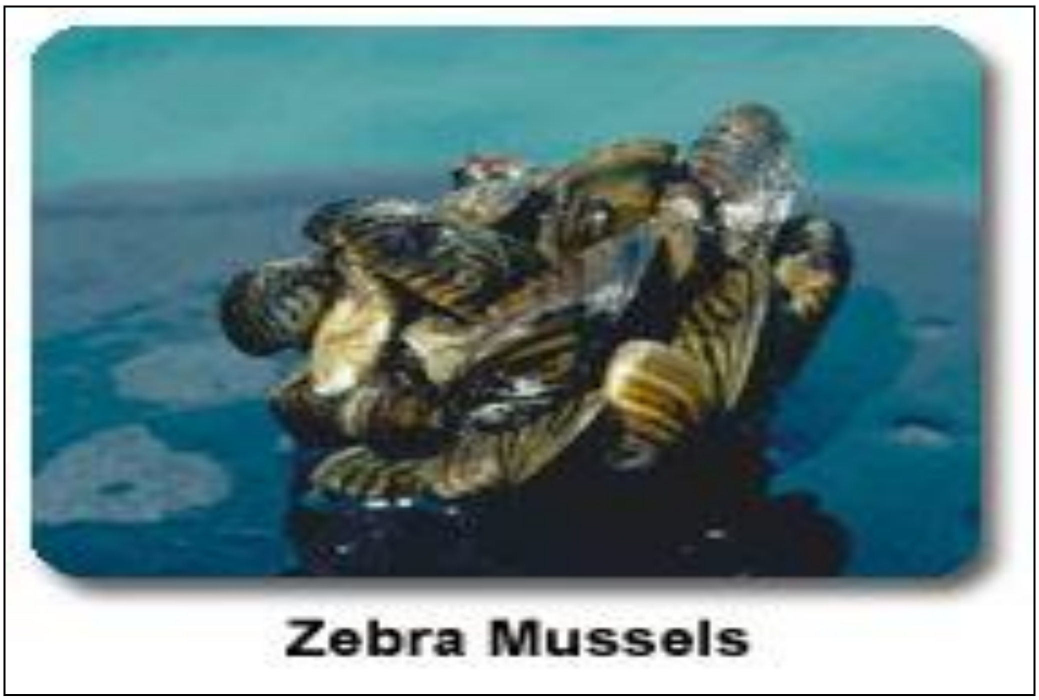

Figure 39. Photo of a zebra mussel colony, USGS.

5.3.2 Invasive Aquatic Plants

In addition to Eurasian watermilfoil (*M. spicatum*), many other invasive aquatic plant species are being introduced into waters of the North Temperate Zone. The majority of exotic aquatic plants do not depend on high water column nutrients for growth, as they are well-adapted to using sunlight and minimal nutrients for successful growth. These species have similar detrimental impacts to lakes in that they decrease the quantity and abundance of native aquatic plants and associated macroinvertebrates and consequently alter the lake fishery. Such species include *Hydrilla verticillata* (Figure 40) and *Trapa natans* (Water Chestnut; Figure 41). *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. Recently, *Hydrilla* was found in Lake Manitou (Indiana, USA) and the lake public access sites were immediately quarantined in an effort to eradicate it. *Hydrilla* retains many physiologically distinct reproductive strategies which allow it to colonize vast areas of water and to considerable depths, including fragmentation, tuber and turion formation, and seed production. Currently, the methods of control for *Hydrilla* include the use of chemical herbicides, rigorous mechanical harvesting, and Grass Carp (*Ctenopharyngodon idella* Val.), with some biological controls currently being researched. However, use of the Grass Carp in Michigan is currently not permitted by the Michigan Department of Natural Resources (MDNR).

Water Chestnut (*Trapa natans*) is a non-native, annual, submersed, rooted aquatic plant that was introduced into the United States in the 1870's yet may be found primarily in the northeastern states. The stems of this aquatic plant can reach lengths of 12-15 feet, while the floating leaves form a rosette on the lake surface. Seeds are produced in May 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 on the lake. Methods of control involve the use of mechanical removal and chemical herbicides. Biological controls are not yet available for the control of this aquatic plant.

Figure 40. Hydrilla, a highly invasive tropical aquatic plant (©RLS).

Figure 41. Water Chestnut, a highly invasive aquatic plant.

5.4 Silver Lake Fishery Habitat Improvement

As mentioned above, the existing fishery spawning habitat in Silver Lake is compromised by the presence of invasive hybrid watermilfoil. Removal of this and other invasive species is recommended to open up new habitat for favorable native aquatic plants that enhance the fishery spawning areas. Additionally, once these species are reduced, the encouragement of emergent native emergent aquatic plants such as Bulrushes and Cattails around the shoreline is recommended. These native emergents will serve as spawning habitat for predator fish which can help regulate the pan fish population. The placement of woody debris or coarse substrate on the lake bottom would also be beneficial in the future for increased fish habitat (if desired and with a proper permit). Aquatic herbicide treatments should be limited to only granular systemic spot-treatments of milfoil as needed.

A detailed fishery survey with age-size distribution and species composition should be pursued by the MDNR to determine the long-term effects of various parameters on the health and viability of the lake fishery.

6.0 SILVER LAKE ECOSYSTEM ASSESSMENT CONCLUSIONS & RECOMMENDATIONS

The primary challenges facing the health of Silver Lake are associated with the invasion of hybrid water milfoil, reduction in native aquatic plant biodiversity, nutrient loading, soil erosion, varying degrees of environmental awareness among visitors to the lake and riparians, and the need for more information regarding nitrate loading from Hunter Creek. Previous studies by GVSU AWRI and the USGS (Brennan et *al*., 2015) have been useful to determine the locations for nutrient loading and the types of nutrient entering Silver Lake; however much more information is needed in regards to the origin of nutrients, especially nitrate, from Hunter Creek.

The urgent spot-control of the invasive hybrid Eurasian Watermilfoil with high-dose systemic Triclopyr in Silver Lake is essential for the long-term preservation of the favorable (non-nuisance) native aquatic plant communities in the lake and to reduce the need for heavy future treatments. The use of aquatic herbicides for species-specific control of these plants is preferred over other methods such as mechanical harvesting or suction harvesting at this time due to a high fragmentation risk and need to urgently decrease the invasive milfoil population in Silver Lake to protect the lake ecosystem. In addition, the biodiversity of native aquatic plants should be enhanced either through natural occurrence or transplanting.

Regular water quality sampling of Silver Lake is continuously recommended to assess the nutrient status of the lake both prior to lake improvements and for years after to reassess water quality improvements from implemented management techniques.

The Association and/or Lake Board should work with RLS to create an educational program for riparians and community members to improve the water quality and health of the lake. This would likely include annual informational meeting and periodic community engagement workshops.

Furthermore, professional limnologists/aquatic botanists should perform regular GPS-guided whole-lake surveys each season to monitor the growth and distribution of all invasives and all aquatic plants continuously monitor the lake for potential influxes of other exotic aquatic plant genera that could also significantly disrupt the ecological stability of Silver Lake. The lake manager should oversee all management activities and would be responsible for the creation of aquatic plant management survey maps, direction of contractors to target-specific areas of aquatic vegetation for removal, implementation of watershed best management practices, administrative duties such as the review and approval of all contractor invoices, and the education of lakefront owners attending SLIB meetings or annual workshops.

Every lake improvement program should offer solutions that are ecologically sound, practical, and economically feasible. Project funds as recommended should come from the existing Special Assessment District structure through a new assessment for the proposed new 5-year program. As in the past, the SAD should include all riparian properties around Silver Lake and back lot properties with deeded or dedicated access. Categories may include lakefront residential (1.0 unit of benefit), lakefront residential with > 200 feet of frontage (2.0 units of benefit), lakefront commercial (2.0 units of benefit), backlot residential (0.5 unit of benefit), and backlot commercial (1.0 unit of benefit).

Table 10 below lists the recommended lake management activities along with their primary and secondary goals that would be executed at different scales around and within the lake basin.

Table 10. Proposed lake restoration methods for Silver Lake's Five-year plan.

Lake Management Activity/Duration	Primary Goal	Secondary Goal	Best Locations to Use
Lake Vegetation Surveys/Scans (Annually)	To determine % cover by invasives and use as data tool	To compare year to year reductions in invasive vegetation areas	Main Lake, Canal
Aquatic herbicide treatment of hybrid milfoil/Invasives with long-lasting systemics (Annually)	To permanently reduce areas where the milfoil is present	To prevent further spread in/around lake	Throughout lake
Sampling of lake water quality for parameters similar to this study (Annually)	To measure changes in lake water quality with time	To determine if BMP implementation is improving water quality	Throughout lake/Hunter Creel
Increase native aquatic plant biodiversity/native transplants	To increase native biodiversity of aquatic plants	To increase fish forage habitat	Throughout lake
Improve lake fishery/work with MDNR on methods	To increase fish population/pan fish	To create more balance to Silver Lake ecosystem	Shorelines and throughout lake
Critical Source Analysis (CSA) of Hunter Creek/tributary BMP recommendations	To target specific areas around Hunter Creek that contribute NO_3 to Silver Lake	To recommend BMP's for reducing NO_3- that are site-specific	Hunter Creek immediate watershed area to mouth of Silver Lake
Community Engagement/riparian education/workshop (summer of 2019 and 2023) Annual informational meetings in 2020, 2021, 2022	To empower local riparians/stakeholders to better understand Silver Lake ecosystem	To educate riparians/stakeholders on lake BMP's for better lake protection	Annual lake meeting w/Report/Workshop and regular BLLB Meetings

6.1 Proposed Cost Estimates for Silver Lake Improvements (2019-2023)

The proposed integrated lake improvement program for Silver Lake would begin during the spring of 2019 and continue through 2023. A breakdown of costs associated with the recommended Silver Lake improvements is presented in Table 11. It should be noted that proposed costs are estimates and may change in response to changes in environmental conditions (i.e. increases in aquatic plant growth or distribution, or changes in herbicide costs).

Table 11. Silver Lake proposed lake improvement program costs (2019-2023).

Silver Lake Improvement Method	Estimated 2019 Cost	Estimated 2020 Cost	Estimated 2021 Cost	Estimated 2022 Cost	Estimated 2023 Cost
Systemic granular herbicides for EWM and annual MDEQ permit (est. $722/acre)[1]	$11,230	$11,230	$11,230	$11,230	$11,230
CSA of Hunter Creek to determine nitrate origin(s) (includes GIS techniques, ground-truthing, additional sampling, map analysis, BMP recommendations/monitoring in future years)	$8,000	$2,000	$2,000	$2,000	$2,000
Native aquatic plant transplants with RLS research divers/future years work with MDNR on fishery habitat improvements	$7,000	$7,000	$6,000	$6,000	$6,000
Community workshops (2019 and 2023) and annual informational meetings (2020-2022)	$5,000	$2,000	$2,000	$2,000	$5,000
Professional consulting services (RLS), water quality sampling/treatment oversight, reporting/data analysis/surveys/tech support[2]	$8,000	$8,000	$8,500	$8,500	$9,000
Contingency (10%)[3]	$3,923	$3,023	$2,973	$2,973	$3,323
TOTAL ANNUAL COST	$43,153	$33,253	$32,703	$32,703	$36,553
EST. COST PER UNIT BENEFIT	$76.38	$58.85	$57.88	$57.88	$64.70
EST. COST PER 0.5 UNIT BENEFIT	$38.19	$29.43	$28.94	$28.94	$32.34

[1] Herbicide treatment scope may change annually due to changes in the distribution and/or abundance of aquatic plants. If a surplus exists, the money can be used for other improvements. If a deficit exists, RLS can recommend use of lower cost product(s).

[2] RLS professional consulting services includes annual GPS-guided, aquatic vegetation surveys, pre and post-treatment surveys for aquatic plant control methods, oversight of applicator treatments and management of the aquatic plant control program, review and approval of all invoices from contractors and others billing for services related to the improvement program, collection of water quality samples, preparation of annual progress report and presentation to the SLIB and attending public, and attendance at up to 5 regularly scheduled board meetings.

[3] Contingency is 10% of the total project cost, to assure that extra funds are available for unexpected expenses. Note: Contingency may be advised and/or needed for future management years. Contingency funds may also be used for other water quality improvements and watershed management.

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