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

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

Dr. Jennifer L. Jermalowicz-Jones, CLP
18406 West Spring Lake Road
Spring Lake, Michigan 49456
www.restorativelakesciences.com

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

March, 2023

1.0 EXECUTIVE SUMMARY

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, 2022 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, 2022 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, 2022 bathymetric data). The approximate residence time of water in the lake is around 223 days.

In past years, the primary focus relative to lake improvement has focused on reduction of the invasive submersed macrophyte hybrid Eurasian Watermilfoil (*Myriophyllum sibiricum* var. *spicatum* L.). In recent years, this aquatic plant, along with most natives, have been very sparse throughout the lake. This has resulted in the lake shifting from an aquatic-plant dominated ecosystem to an algal-dominated ecosystem. At this point, RLS recommends no herbicide treatment of any plants until there is enough suitable cover to shift the lake back to an aquatic plant dominant ecosystem where natives can further thrive. The causes of this reduction in all plants are attributed to many factors including previous intensive herbicide treatments (especially whole lake fluridone treatments), an overabundance of algae and carp which have led to reduced water clarity that is needed for successful aquatic plant germination, and the influx of nutrients from runoff that are further exacerbating nuisance algal blooms. The recommended improvements below should result in increased water clarity over time that will allow for successful germination of native aquatic vegetation in the future.

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. In 2022, RLS conducted a long-term evaluation of runoff entering from Critical Source Areas (CSA's) around Silver Lake. The evaluation demonstrated that runoff contains much higher concentrations of nutrients and solids than are present in the lake. This means that the runoff is a major source of nutrients to the lake and should be mitigated. TP concentrations in the lake have ranged from 0.020-0.149 mg L^{-1} and internal loading of phosphorus is now present as a result of nutrient runoff and septic system effluent.

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. Oceana County lacks a stormwater inventory for the area and a map would be necessary to precisely determine what drains are emptying water from specific sources or locations. RLS recommends that such an inventory and map be created for the future. RLS has recommended grading and stabilization of launch sites with gully erosion and installation of Biochar at the drain locations to adsorb nutrients and pollutants. RLS additionally recommends sampling the Little Silver Lake outflow during heavy rain events in 2023 to determine whether this lake may be the primary source of nutrients to Hunter Creek.

It is estimated that Michigan has over 1.2 million septic systems currently installed with many of them occurring in rural areas around inland lakes. The number of septic systems that are a risk to the aquatic environment is unknown which makes riparian awareness of these systems critical for protection of Silver Lake. RLS recommends an annual summer workshop for the lake community to introduce riparians to nutrient reduction technologies for septic systems among other lake BMP's.

This relative lack of green algae can reduce needed food for zooplankton which can also create limitations on food for the lake fishery along with an over-abundance of Common Carp. RLS recommends an annual carp cull with an electrofishing or similar method to remove carp biomass and allow the favorable fish species to populate.

Thus, this new lake restoration program will focus on addressing the following goals:

1. Increase the water clarity (Secchi transparency)
2. Decrease the blue-green algae
3. Increase the native aquatic vegetation growth
4. Decrease the Common Carp presence
5. Improve the lake fishery
6. Reduce the runoff nutrients and solids to the lake
7. Maintain low/no invasive aquatic vegetation
8. Educate and empower riparians on use of septic system nutrient reduction technologies.

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 and 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 influence from land use 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 which are often impacted by land use activities. In general, larger watersheds possess more opportunities for pollutants to enter the ecosystem, altering the water quality and ecological communities. In addition, watersheds that contain abundant development and industrial sites are more vulnerable to water quality degradation from pollution which may negatively affect both surface and groundwater. 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 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, 2022 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 small to 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, 2022 bathymetric data). The maximum depth was confirmed by RLS scientists in July of 2022 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, 2022) and an approximate water volume of 9,379.96 acre-feet (RLS, 2022 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.

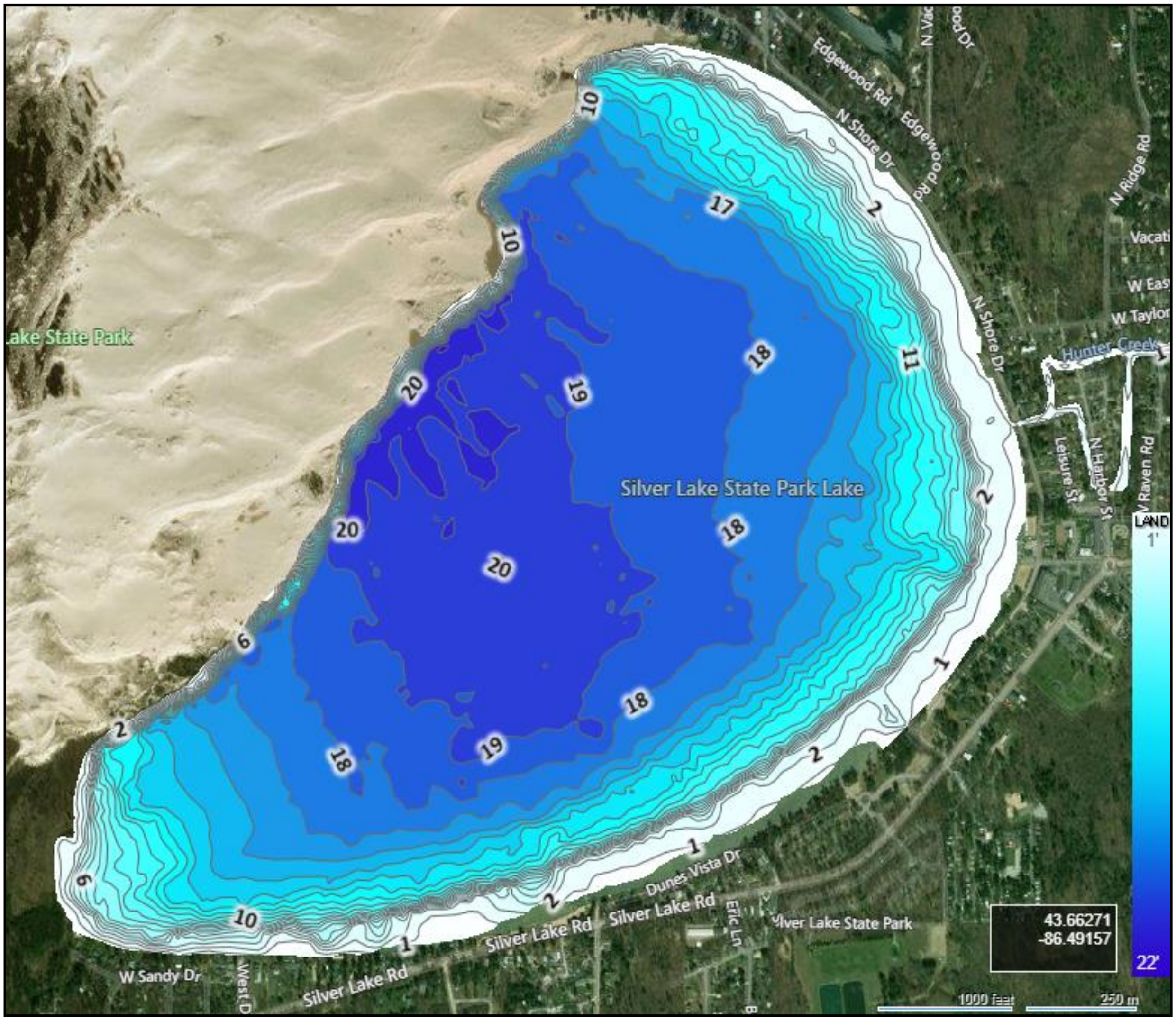

Figure 2. Silver Lake 2022 depth contour map (RLS).

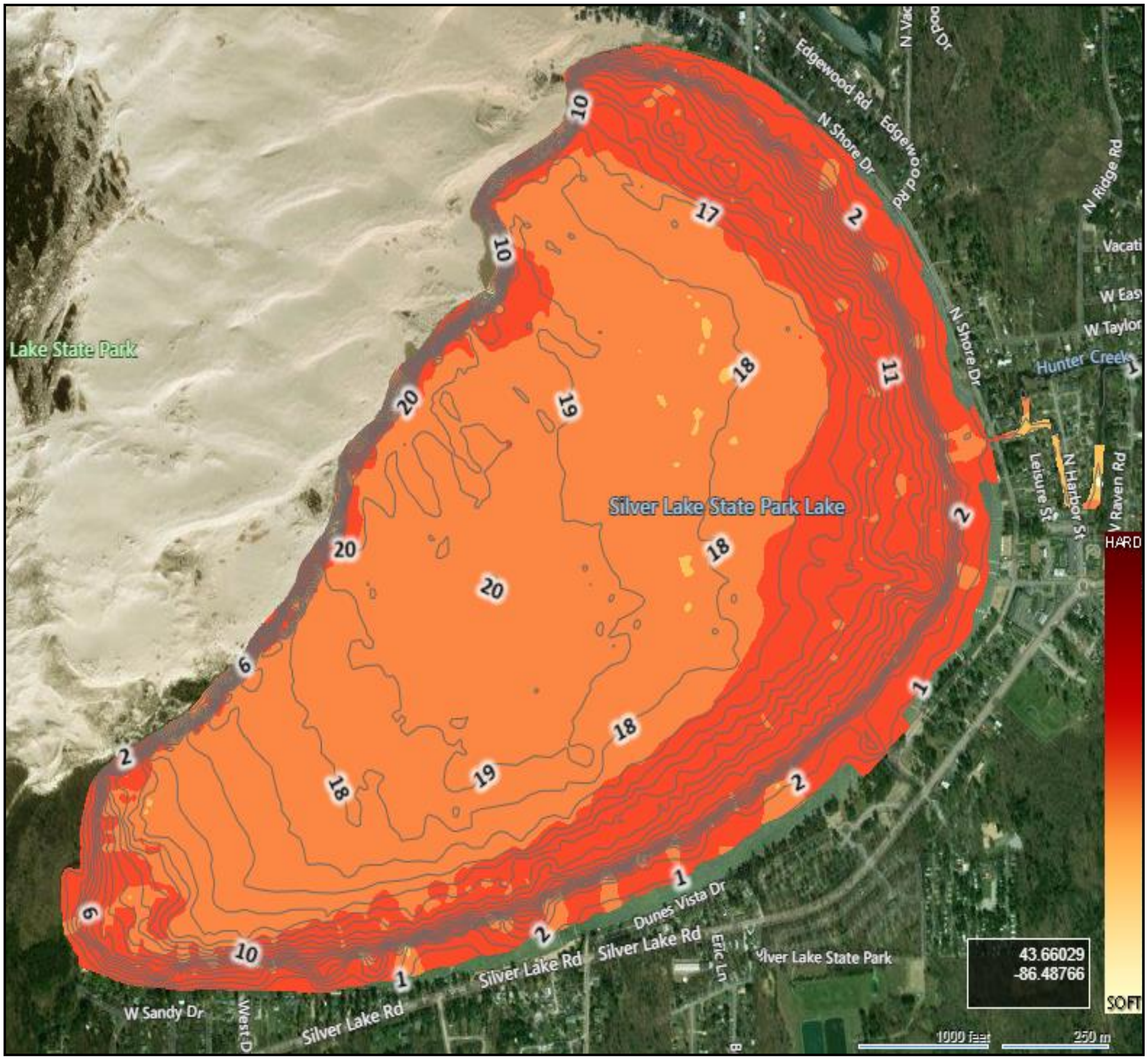

Figure 3. Silver Lake 2022 sediment bottom hardness map (RLS).

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, 2022).

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, 2022).

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

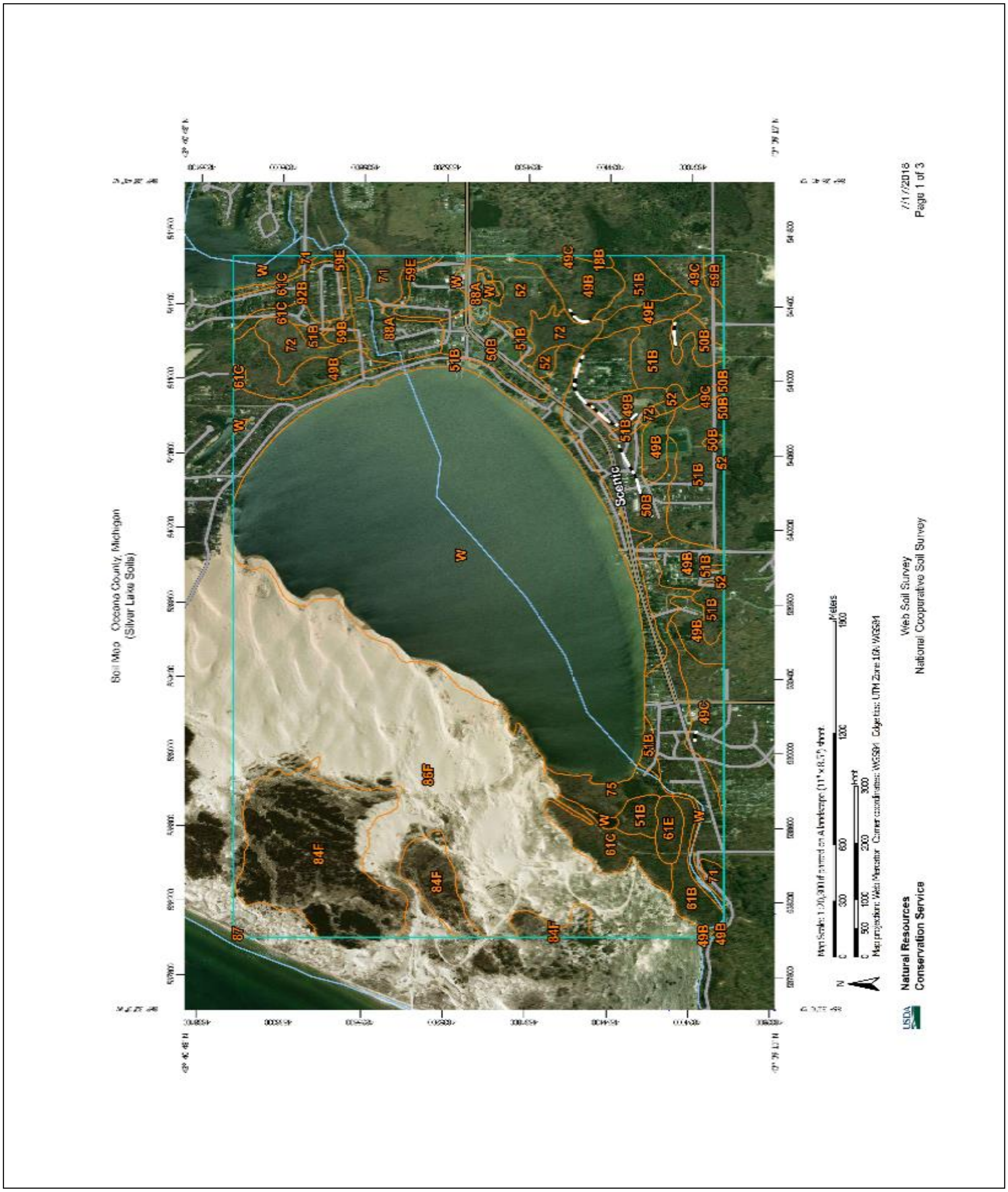

Figure 5. NRCS-USDA soils map for Silver Lake shoreline soils.

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 BASIN 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 periodic 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

There are numerous water quality parameters that can be measured on an inland lake, but several are the most critical indicators of lake health. Water quality parameters were regularly measured in the three deep basins (Figure 6) and overtime and trends in most critical parameters are shown in the sections below. These parameters included: water temperature (measured in °C), dissolved oxygen (measured in mg/L), pH (measured in standard units-SU), conductivity (measured in micro-Siemens per centimeter-µS/cm), total dissolved solids (mg/L), secchi transparency (feet), total phosphorus and total nitrogen (both in mg/L), chlorophyll-*a* (in µg/L), and algal community composition.

All chemical water samples were collected at the surface, mid-depth, and bottom using a 4-liter VanDorn horizontal water sampler with weighted messenger (Wildco® brand). Water quality physical parameters (such as water temperature, dissolved oxygen, conductivity, total dissolved solids and pH) were measured with a calibrated Eureka Manta II® multi-probe meter. Total phosphorus was titrated and analyzed in the laboratory according to method SM 4500-P E. Total nitrogen was titrated and analyzed in the laboratory according to methods EPA 300.0 Rev. 2.1 and EPA 350.1 Rev 2.0.

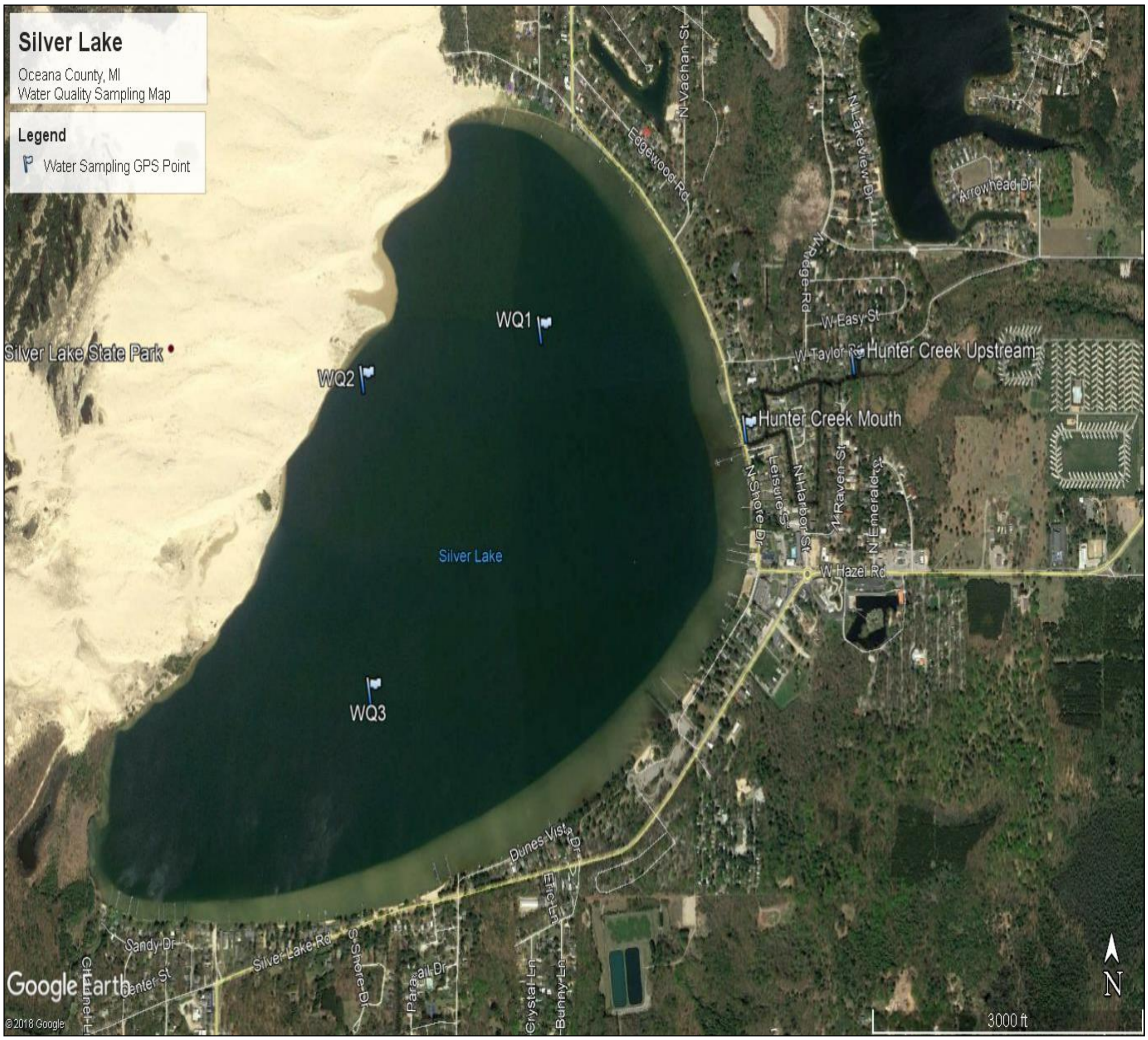

Figure 6. Locations for water quality sampling in Silver Lake (2018-2022).

4.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water column. In general, dissolved oxygen levels should be greater than 5.0 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 7.2-9.9 mg L^{-1} (Figure 7), 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 can periodically reduce 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 and result in increased release of phosphorus from lake sediments.

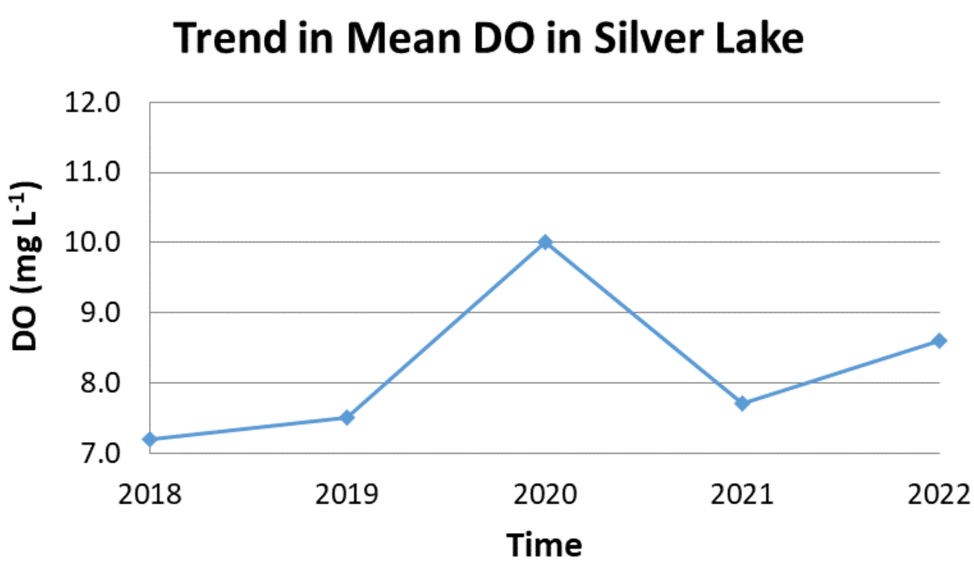

Figure 7. Trend in mean dissolved oxygen (DO) with time in Silver Lake (2018-2022).

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 Celsius (ºC) with the use of a calibrated Eureka Manta II® submersible thermometer. The water temperatures in Silver Lake demonstrate a lack of a thermocline and are indicative of a well-mixed (polymictic) lake that mixes multiple times per year. Mid-summer water temperatures usually range from 23-25ºC at the surface and bottom of the three basins with little temperature variation

4.1.3 Specific Conductivity

Specific conductivity (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 ($\mu S\ cm^{-1}$) with the use of a calibrated Eureka Manta II® conductivity probe and meter. Conductivity values for Silver Lake have been variable among the three basins and have ranged from 300-507 $mS\ cm^{-1}$(Figure 8).

These values are moderate 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. RLS conducted a runoff evaluation in 2022 and determined that the conductivity from runoff was generally higher than ambient mean basin values.

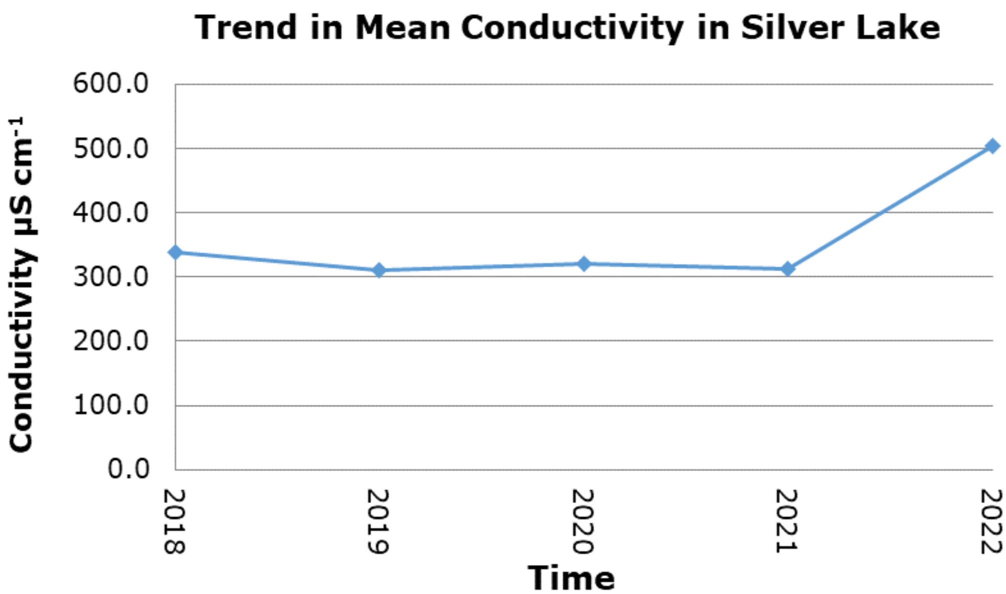

Figure 8. Trend in mean specific conductivity with time in Silver Lake (2018-2022).

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® turbidity meter. The World Health Organization (WHO) requires that drinking water be less than 5 NTU's; however, recreational waters may be significantly higher than that. The turbidity of Silver Lake has been moderately high and ranged from 3.8-5.2 NTU's during the past and recent sampling events. Spring values are usually higher due to increased watershed inputs from spring runoff and/or from increased algal blooms in the water column from resultant runoff contributions. Increased rainfall events during the summer or fall can also result in increased turbidity measurements.

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 multi-meter probe in mg L^{-1}.

Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The TDS in Silver Lake have ranged from 182-325 mg L^{-1} for the three basins which is moderate 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 calibrated Eureka Manta II® pH electrode and pH-meter in Standard Units (S.U). The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 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 has ranged from 8.2-8.5 S.U. during the past and recent sampling events (Figure 9). 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.

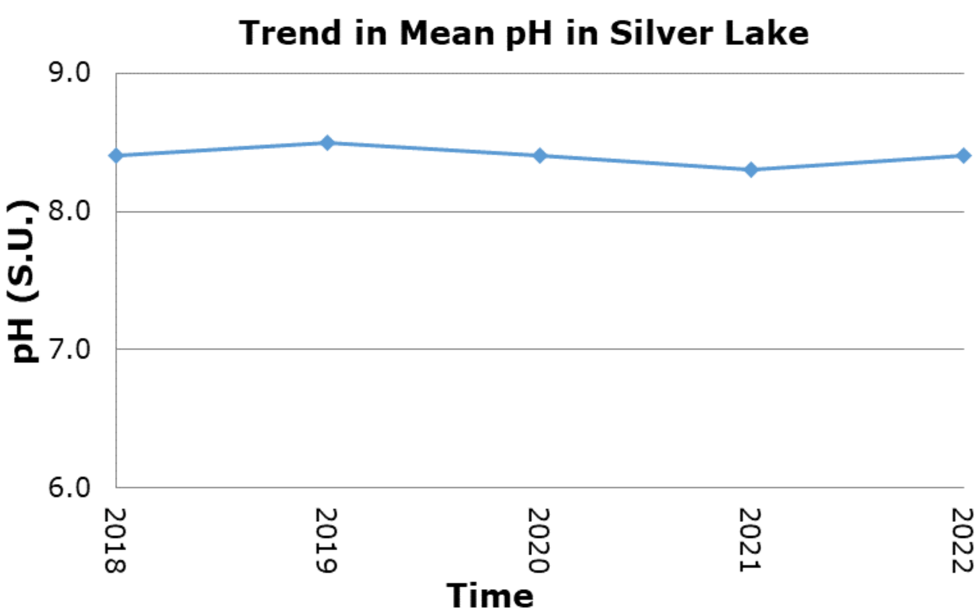

Figure 9. Trend in mean pH with time in Silver Lake (2018-2022).

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 has ranged from 140-144 mg L^{-1} of $CaCO_3$ during the past and recent sampling events. 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 have ranged from 0.020-0.149 mg L^{-1}(Figure 10). These values are quite variable and may increase significantly in periods of heavy rainfall.

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.

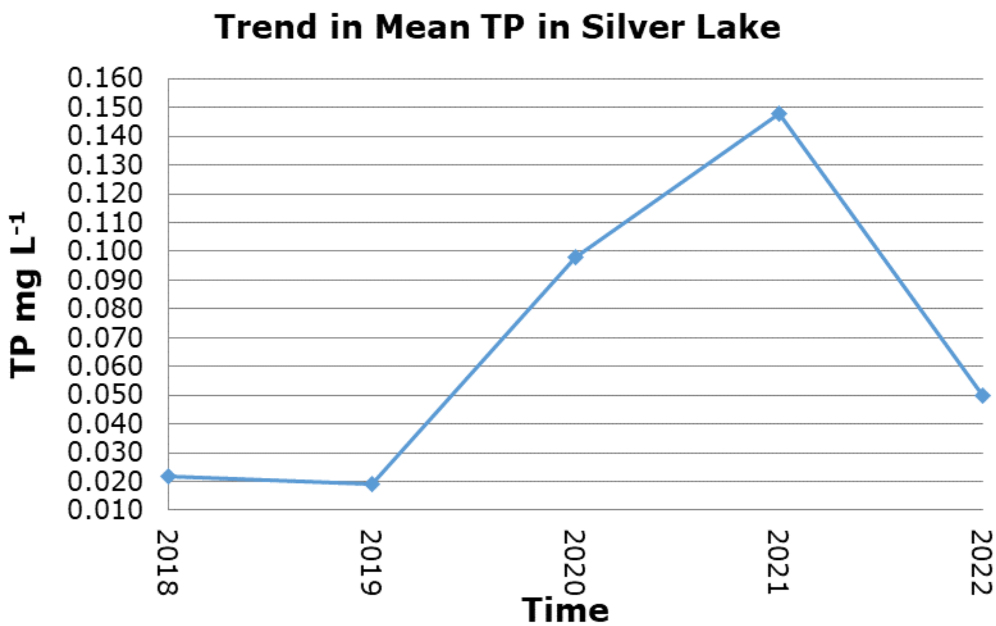

Figure 10. Trend in mean total phosphorus (TP) with time in Silver Lake (2018-2022).

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 (0.8-2.0 mg L^{-1}), which is normal for an inland lake of similar size and demonstrates that the lake is phosphorus limited (dominant in nitrogen; Figure 11). 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.

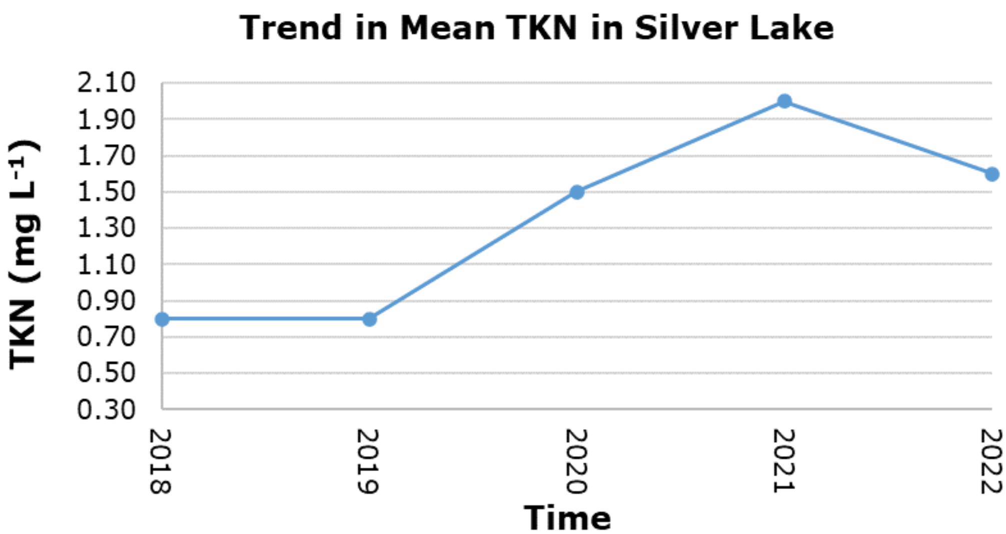

Figure 11. Trend in mean total Kjeldahl nitrogen (TKN) with time in Silver Lake (2018-2022).

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-*a* 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. Concentrations have ranged from 3.8-12 µg L^{-1} (Figure 12) in recent and past years, which is elevated.

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., *Mougeotia* sp., *Cladophora* sp., *Spirogyra* sp., and *Chloromonas* sp. the Cyanophyta (blue-green algae): *Gleotrichia* sp., *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. Cladophora algae (Figure 13) has become problematic in the Great Lakes and is considered a symptom of high nutrient loads processed by Zebra mussels (Higgins et *al*., 2008). *Cladophora* nearshore may become a nuisance because it produces strong sewage-like odors in nearshore areas, especially upon decay and may accumulate harmful bacteria such as *E. coli.* It was found to be present along the east shore of Silver Lake in 2022.

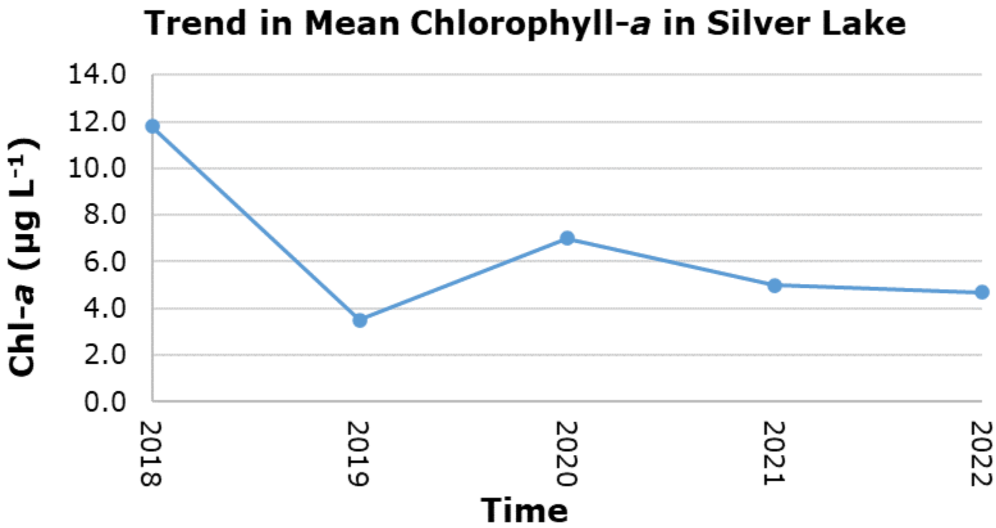

Figure 12. Trend in mean chlorophyll-*a* (Chl-*a*) with time in Silver Lake (2018-2022).

Figure 13. *Cladophora glomerata* growing along the shore in Silver Lake (July, 2022).

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 14). 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 has ranged from 2.6-6.8 feet which is quite variable and overall low (Figure 15). Measurements were collected during calm wind conditions. 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. An overall goal of the new Silver Lake restoration program is to increase Secchi transparency over time.

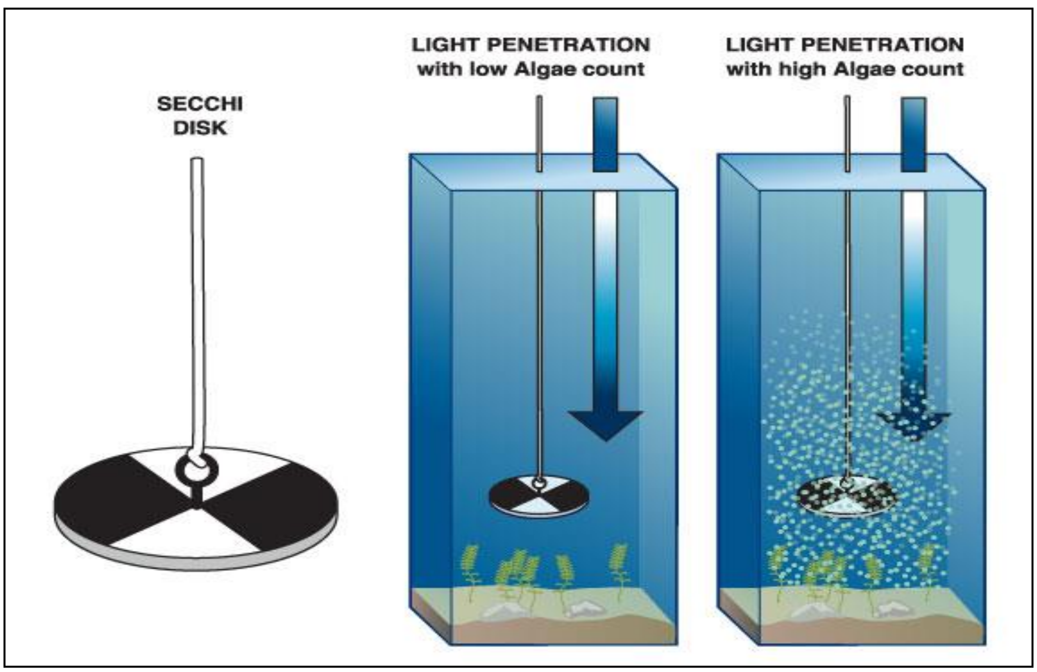

Figure 14. A Secchi dish and the relationship between Secchi transparency and algae in the water column. ***Photo courtesy of Michigan Sea Grant.***

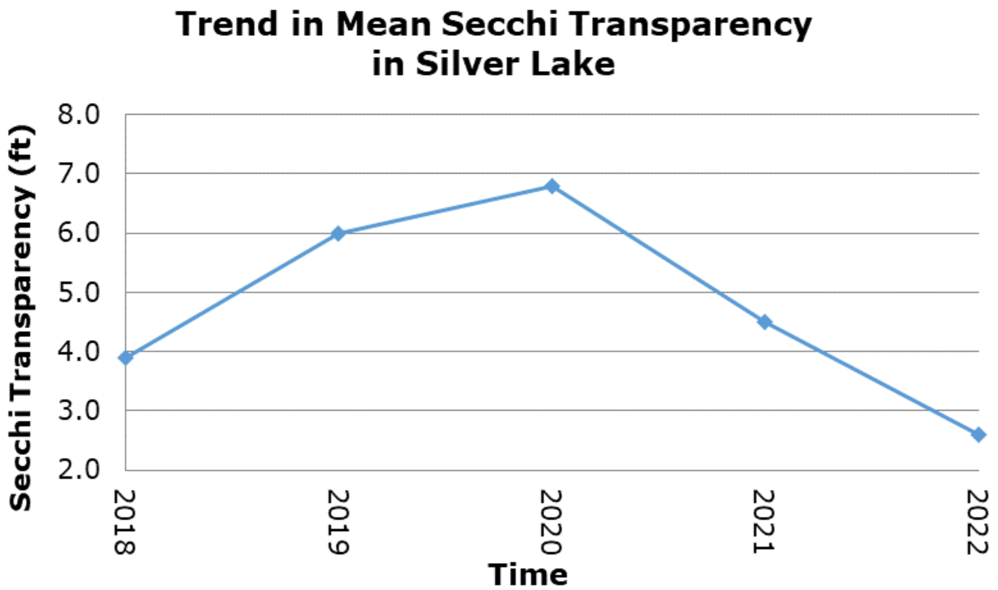

Figure 15. Trend in mean Secchi transparency with time in Silver Lake (2018-2022).

5.0 SILVER LAKE RUNOFF WATER QUALITY

In addition to the lake basin water quality parameters described above, specific water quality parameters were evaluated for N=8 locations around the lake where runoff was considered significant. These areas were sampled from April-September, 2022 during low, moderate, and very heavy rainfall events (Figure 16). The physical water quality parameters measured with a calibrated Eureka Manta II® multi-meter probe with parameter electrodes included the following:

1. Water temperature (°c)
2. Dissolved oxygen (mg L^{-1})
3. pH (S.U.)
4. Specific conductivity (mS cm^{-1})
5. Total dissolved solids (mg L^{-1})

In addition to the physical water quality measurements, chemical water quality parameters such as total phosphorus, total inorganic nitrogen (nitrate, nitrite, and ammonia), total suspended solids, and chlorides were also measured. All samples were taken to TRACE Analytical Laboratory in Muskegon, Michigan (a NELAC-certified laboratory).

TSS was analyzed in the laboratory with Method SM2549-D15. Total phosphorus was analyzed in the laboratory with Method EPA 200.7, Rev. 4.4. TIN was analyzed in the laboratory with Method EPA 300. Rev 2.1 and Method EPA 350.1, Rev 2.0. Chlorides were analyzed in the laboratory with Method SM 400-CL D1. In addition to water quality samples, water flow velocity was measured at each site when flow was present (in cubic feet per second or cfs).

In recent years, the lake has experienced symptoms that include increased turbidity (lower water clarity), increased nutrient loads, increased cyanobacteria (blue-green algae) blooms, and occasional dissolved oxygen depletion. All of these issues are attributed to increased inputs of nutrients and solids from the immediate watershed (runoff, fertilizers, and septic tanks). During the period of April-September, 2022, RLS was commissioned by the Silver Lake Improvement Board (SLIB) to sample eight locations around Silver Lake found to be significant sources of loading to the lake during low to very high rainfall events. These sites were sampled on April 22, July 24, August 3, August 13, and September 11, 2022. Sites were sampled for physical water quality parameters such as water temperature, dissolved oxygen, pH, total dissolved solids, and conductivity. Additionally, the sites were sampled for chemical water quality parameters such as total phosphorus, total inorganic nitrogen, total suspended solids, and total chlorides. Figure 17 shows the flow paths of runoff from the immediate watershed that drains to the lake.

Figure 16. Locations for runoff water quality sampling in Silver Lake (April-September, 2022).

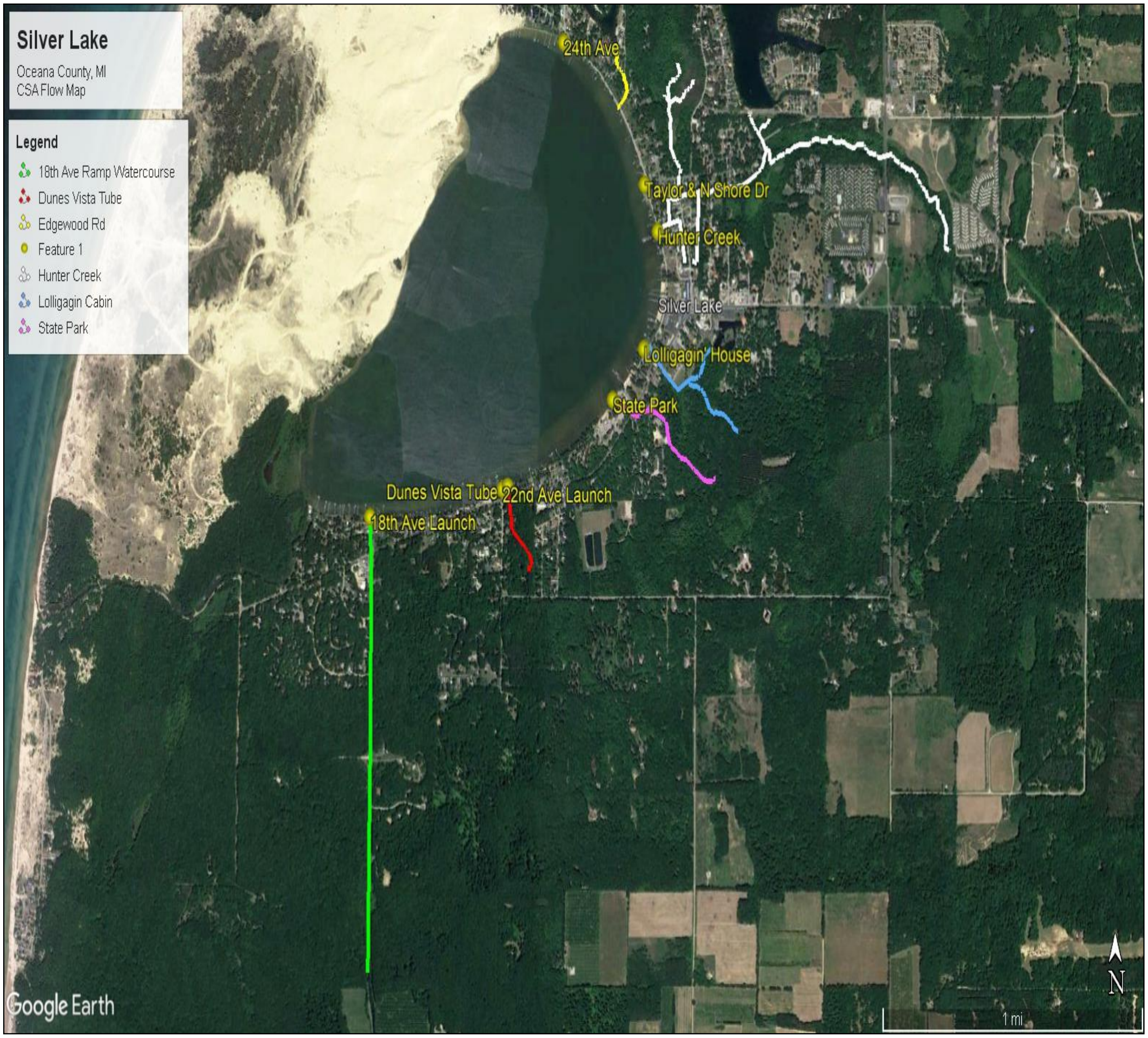

Figure 17. Runoff water quality sampling location flow paths (April-September, 2022).

5.1 Drain Runoff Physical and Chemical Parameters

The physical parameters measured at the runoff sites were similar to those measured in the lake basin, with some additional parameters specific for runoff. Figures 18-25 below display the specific sites where significant runoff and gully erosion were noted.

Figure 18. 18th Ave. Ramp (693 West Drive, Mears, MI).

Figure 19. 22nd Ave. Ramp (9006 Silver Lake Rd, Mears, MI).

Figure 20. Dunes Vista Tube (10 yards east of 22nd Ave Ramp, Mears, MI).

Figure 21. State Park (20 yards west of State Park Ramp, Mears, MI).

Figure 22. Lollygagging Cabin (1114 N. Shore Drive, Mears, MI).

Figure 23. Hunter Creek (1343 N. Shore Drive, Mears, MI).

Figure 24. Taylor Road Ramp (1476 N. Shore Drive, Mears, MI).

Figure 25. 24th Ave Ramp/Tube (1809 N. Shore Drive, Mears, MI).

5.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water. 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 and also in flowing waters. Dissolved oxygen was measured in milligrams per liter (mg L^{-1}) with the use of a calibrated Eureka Manta II® dissolved oxygen meter. Mean dissolved oxygen concentrations ranged from 8.3-9.9 mg L^{-1} at the runoff sampling sites during the evaluation period. These concentrations are favorable and common in flowing waters.

5.1.2 Water Temperature

Water temperature was measured in degrees Celsius (ºC) with the use of a calibrated Eureka Manta II® submersible thermometer. Mean water temperatures ranged from 14.1-18.6ºC at the sampling sites during the evaluation period. Water temperatures were higher later in the season and lower in April. They are typically also lower in areas with abundant shade from tree cover such as near the State Park.

5.1.3 Specific Conductivity

Specific conductivity (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. Mean conductivity values ranged from 105-352 mS cm^{-1} at the sampling sites during the evaluation period. These values are favorable. The highest concentration was noted at the State Park early in the season but was lower the remainder of the season and thus this value was likely an outlier.

5.1.4 Total Dissolved Solids and Total Suspended Solids

There are two primary forms of solids that enter waterways and include total dissolved solids and total suspended solids. Both may increase turbidity and reduce water clarity over time. The concern in Silver Lake is relative to decreased water clarity which reduces germination and growth of submersed aquatic vegetation that are needed to reduce sediment suspension and also compete with algae for nutrients.

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the amount of dissolved organic and inorganic particles in the water. 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}. The mean TDS in the sites during the evaluation period ranged from 37-225 mg L^{-1}. These values were highest at the State Park and are likely elevated due to the presence of tannins from the dense forest near the park. TDS are not a large concern relative to TSS, as TDS are commonly natural in origin and not necessarily a product of poor land use.

Total Suspended Solids

Total suspended solids (TSS) refers to the quantity of solid particles detected in the water that reduce light penetration and create turbidity in the water. TSS was measured in the laboratory with Method SM2549-D15. The mean TSS samples measured at the sampling sites during the evaluation period ranged from 14-245 mg L^{-1} and increased with increased flow rates. The ideal concentration for TSS in waters is ≤ 20 mg L^{-1}. TSS are usually deposited from runoff which may bring soils and dirt into the lake and then are deposited as lake sediments. TSS are often re-suspended in the water column during high wind and storm events in shallow waters which result in increased turbidity or lack of water clarity. The highest concentrations were noted at the 18th Ave Ramp and the Dunes Vista Tube.

5.1.5 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 waters have pH values that range from 6.5 to 9.5. The pH at the sampling sites during the evaluation period ranged from a mean of 7.4-8.1 S.U. This range of pH is neutral to slightly alkaline on the pH scale and is ideal. These values are typical for drains and tributaries as the presence of tannins can lower pH relative to the lake basin. These values are also similar to those present in the lake basin.

5.1.6 Total Phosphorus

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Waters that contain greater than 0.020 mg L^{-1} of TP are defined as eutrophic or nutrient-enriched. Total phosphorus was measured in milligrams per liter (mg L^{-1}) with Method EPA 200.7, Rev. 4.4. Over time, external loads may lead to internal loads as nutrients become bound in lake sediments and released during periods of anoxia (low dissolved oxygen).

The mean TP concentrations from runoff locations ranged from 0.036-0.375 mg L^{-1} and were highest at the 18th Ave Ramp. Additionally, the concentrations of most locations increased with increased flow rates in mid-September.

5.1.7 Total Inorganic Nitrogen

Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e., burning of fossil fuels), wastewater sources from developed areas (i.e., runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen such as Silver Lake (mean N: P = 36 mg L^{-1}), phosphorus is the limiting nutrient for phytoplankton and aquatic macrophyte growth.

The total inorganic nitrogen (TIN) consists of nitrate, nitrite, and ammonia forms without the organic forms of nitrogen. TIN was analyzed in the laboratory with Method EPA 300. Rev 2.1 and Method EPA 350.1, Rev 2.0. The mean TIN concentrations ranged from 0.100-0.950 mg L^{-1} at the sampling sites during the evaluation period. The highest concentration was measured at the 18th Ave Ramp. This value is considered very high but precise sources are difficult to specify in the absence of a storm drain inventory map.

5.1.8 Total Chlorides

Total chlorides are often associated with another element to form a salt. They are usually correlated with conductivity. Additionally, they are usually elevated in urban areas and enter storm drains, often transporting salts to waterways during winter road salting or after ice melt (Haake and Knouft, 2019). Chlorides can also reduce photosynthetic capacity in plants and thus can reduce aquatic plant growth in areas with high levels. Chlorides are typically measured in mg L^{-1} and are analyzed in the laboratory with Method SM 4500-Cl D-11. The mean total chlorides in the runoff samples ranged from 10.0-18.2 mg L^{-1} with the highest concentration measured in April, 2022 at the 24th Ave ramp.

5.1.9 Water Flow Rates

Water flow rates (velocity) are a measure of the volume of water moved over a specific period of time. Silver Lake runoff flow rates were measured with a calibrated Swoffer® digital velocity meter (in cfs) for each runoff event. Flow rates are usually measured in cubic feet per second (cfs) and vary significantly with rainfall quantity and frequency. Flow rates are useful for determine load contributions over time. The flow rates from the runoff locations ranged from 0.2-6.5 cfs with the highest flow rates measured in Hunter Creek and the State Park.

Although many of the other flow rates seemed low, they still contributed high amount of nutrients and solids to the lake during the rain events. For more details on the 2022 runoff evaluation refer to that detailed report.

Oceana County lacks a stormwater inventory for the area and a map would be necessary to precisely determine what drains are emptying water from specific sources or locations. RLS recommends that such an inventory and map be created for the future. Specific examples of these diffuse sites include N. 24th Ave Ramp located at the northern region of Silver Lake. The precise origins of pollutants are unknown. Additionally, the Taylor Rd Tube drains a large area but the sources to this tube are difficult to delineate. RLS has created flow path maps that show the length of water course contribution, but this alone cannot pinpoint storm drain sources.

RLS additionally recommends sampling the Little Silver Lake outflow during heavy rain events in 2023 to determine whether this lake may be the primary source of nutrients to Hunter Creek.

Table 3. Silver Lake runoff mean physical water quality data (April-September, 2022).

Silver Lake Runoff Sampling Site	*Water Temp (°C)*	*DO (mg L^{-1})*	*pH (S.U)*	*TDS (mg L^{-1})*	*Conduct. mS cm^{-1}*
18th Ave Ramp	17.6±3.6	9.4±0.6	8.1±0.1	37.0±30.0	105.0±21.0
22nd Ave Ramp (Dunes Vista)	17.9	9.0	7.8	213.0	290.0
Dunes Vista Tube	15.0±3.7	9.9±1.0	7.9±0.1	198.0±65.0	308±99.0
State Park	14.1±3.1	9.9±1.0	7.9±0.1	225.0±80.0	352.0±125
Lollygagging Cabin	17.8±5.2	9.3±1.4	7.6±0.1	190.0±68.0	299.0±106
Hunter Creek	17.6±5.2	9.2±1.6	7.8±0.4	218.0±77.0	341±120.0
Taylor Road Tube	18.6±6.8	9.1±1.1	7.9±0.2	132.0±73.0	207±115.0
24th Ave Ramp Tube	16.7±4.4	8.3±1.1	7.4±0.2	207±110	324±171

Table 4. Silver Lake mean runoff chemical water quality data (April-September, 2022).

Silver Lake Runoff Sampling Site	*TSS (mg L^{-1})*	*TP (mg L^{-1})*	*TIN (mg L^{-1})*	*Cl- (mg L^{-1})*	*NO3 mg L^{-1}*	*NH3- mg L^{-1}*
18th Ave Ramp	245±35	0.375±0.0	0.950±0.6	13.5±4.9	0.360±0.1	0.550±0.594
22nd Ave Ramp (Dunes Vista)	14	0.046	0.100	10.0	0	0.100
Dunes Vista Tube	83±68	0.239±0.2	0.654±0.2	11.8±4.0	0.596±0.2	0.061±0.0
State Park	69±32	0.085±0.1	0.764±0.3	10.0±0.0	0.726±0.3	0.040±0.0
Lollygagging Cabin	21±15	0.077±0.1	0.184±0.1	10.0±0.0	0.154±0.1	0.036±0.0
Hunter Creek	23±11	0.042±0.0	0.622±0.4	11.4±3.1	0.564±0.4	0.060±0.045
Taylor Road Tube	18±14	0.036±0.0	0.646±0.6	10.0±0.0	0.432±0.5	0.199±0.2
24th Ave Ramp Tube	64±72	0.226±0.2	0.368±0.2	18.2±16	0.210±0.1	0.186±0.2

The overall conclusions of this 2022 runoff evaluation included the following:

1. Dense areas of the filamentous algae *Cladophora* are growing along some areas of the Silver Lake shoreline. This algae has become problematic in the Great Lakes and is considered a symptom of high nutrient loads processed by Zebra mussels (Higgins et *al*., 2008). *Cladophora* nearshore may become a nuisance because it produces strong sewage-like odors in nearshore areas, especially upon decay and may accumulate harmful bacteria such as *E. coli.*
2. Many areas in Silver Lake experienced plumes of dark-colored water from incoming solids during heavy rainfall events.
3. The lake bottom total phosphorus concentration collected on July 20, 2022 exhibited a maximum of 0.160 mg L^{-1} which is indicative of internal loading. External loads such as those measured from the runoff are entering Silver Lake and being released from bottom sediment pore water during low oxygen conditions.
4. The physical water quality parameters of all drains were favorable and not a threat to the lake water quality.
5. The 18th Ave ramp contributed the highest concentrations of total suspended solids, total inorganic nitrogen, and total phosphorus concentrations of all N=8 sampled locations.
6. The Dunes Vista Tube contributed the second highest concentrations of total suspended solids, total phosphorus, and total inorganic nitrogen of all N=8 sampled locations.
7. The 24th Ave Ramp Tube contributed the third highest concentration of total phosphorus of all N=8 sampled locations. It also contributed the highest chloride concentration.
8. The State Park contributed the fourth highest concentration of phosphorus and the third highest concentration of total inorganic nitrogen and total suspended solids of all N=8 sampled locations.
9. The Lollygagging Cabin Tube contributed the fifth highest concentration of phosphorus of all N=8 sampled locations.
10. The majority of the sampled locations contained favorable chloride concentrations (with the 24th Ave Ramp Tube contributing the highest marginal concentrations).
11. Hunter Creek and the Taylor Road Tube contributed the lowest concentration of total phosphorus to the lake.
12. The 18th Ave Ramp Tube, Dunes Vista Tube, and 24th Ave Ramp are the highest priority for mitigation due to measured impairments.

6.0 SILVER LAKE BIOLOGICAL COMMUNITIES

The biotic (living) components of Silver Lake include the aquatic vegetation, the food chain base (algae, zooplankton, and macroinvertebrates, the lake fishery, and associated wildlife. The latter are excluded in this evaluation as they are not currently a focus of the lake improvement program. Improvements to the lake will, however, allow for better wildlife habitat and growth over time.

6.1 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.

6.1.1 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 26) 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 0 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). If the plant regrows, management options for the plant are provided in the management recommendations section of the report.

Curly-leaf Pondweed (*Potamogeton crispus*; Figure 27) 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 into 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 a few small areas on the bottom in Hunter Creek, which is a low quantity. At this time, management is not required due to the low abundance of the plant. A list of invasive aquatic plant species found in Silver Lake can be found in Table 5.

Figure 26. Photo of Eurasian Watermilfoil ©RLS

Figure 27. Photo of Curly-leaf Pondweed ©RLS

Table 5. Silver Lake exotic aquatic plant species (July 20, 2022).

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	0
*Potamogeton crispus**	Curly-leaf Pondweed	Submersed; Rooted	0

* Curly-leaf Pondweed was found only in Hunter Creek.

6.1.2 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.

Previous aquatic vegetation surveys have revealed 7-12 native aquatic plant species present annually (Table 6). 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.

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 *Schoenoplectus* 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 28 shows the relative biovolume of all aquatic vegetation in Silver Lake in 2022. 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 of natives and proper management of invasives is critical. Photos of all native aquatic plant species are shown in Figures 29-39.

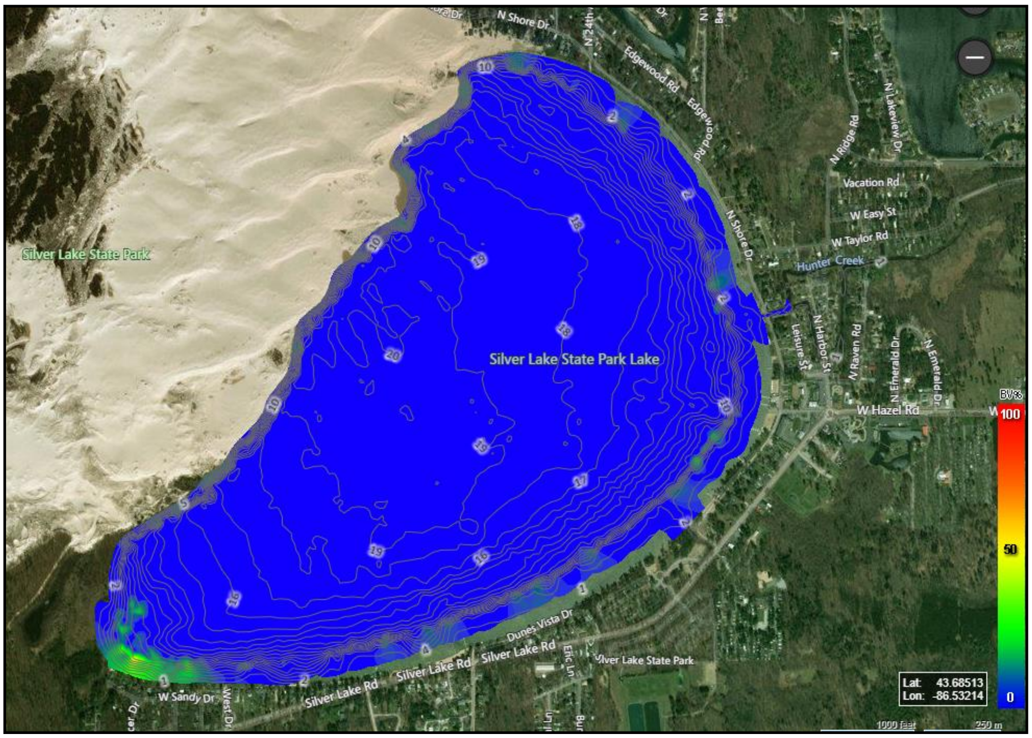

Figure 28. A biovolume map showing relative heights in the water column of all aquatic vegetation in Silver Lake. (July 20, 2022). Note: Dark red and orange colors denote thick vegetation, whereas green and yellow colors show lower-growing plants and blue denotes no vegetation.

Table 6. Silver Lake Native Aquatic Plant Species (July 20, 2022). Note: *Iris pseudacorus* is considered invasive but is not a current threat to the Silver Lake shoreline. Also note the disappearance of 5 species previously noted.

Native Aquatic Plant Species	***Aquatic Plant Common Name***	***% Abundance***	***Aquatic Plant Growth Habit***
Chara vulgaris	Muskgrass	0.2	Submersed; Rooted
Stuckenia pectinata	Sago Pondweed	0	Submersed; Rooted
Potamogeton praelongus	White-stemmed Pondweed	0	Submersed; Rooted
Potamogeton robbinsii	Fern-leaf Pondweed	0	Submersed; Rooted
Najas guadalupensis	Southern Naiad	0	Submersed; Rooted
Elodea canadensis	Common Elodea	0	Submersed; Rooted
Utricularia vulgaris	Common Bladderwort	0.2	Submersed; Non-Rooted
Typha latifolia	Cattails	0.9	Emergent
Schoenoplectus acutus	Bulrushes	2.0	Emergent
Decodon verticillatus	Swamp Loosestrife	0.1	Emergent
Eleocharis acicularis	Spike rush	0.1	Emergent
*Iris pseudacorus**	Yellow Iris	0.6	Emergent

Figure 29. Chara (Muskgrass)

Figure 30. Thin-leaf (Sago) Pondweed ©RLS

Figure 31. Fern-leaf Pondweed ©RLS

Figure 32. Elodea ©RLS

Figure 33. Southern Naiad ©RLS

Figure 34. White-stem Pondweed©RLS

Figure 35. Bladderwort ©RLS

Figure 36. Swamp Loosestrife ©RLS

Figure 37. Spikerush ©RLS

Figure 38. Cattails ©RLS

Figure 39. Yellow Iris ©RLS

6.2 Silver Lake Macroinvertebrates

Freshwater macroinvertebrates are ubiquitous, as even the most impacted lake contains some representatives of this diverse and ecologically important group of organisms. Benthic macroinvertebrates are key components of lake food webs both in terms of total biomass and in the important ecological role that they play in 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 (hydrological, 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 in two separate locations (North and South Basins) within Silver Lake on July 23, 2018 (Table 7). 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 the 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 7. Silver Lake, Oceana County, Macroinvertebrates (2018).

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**	

6.3 The Silver Lake Fishery

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 determined the presence 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*), Brown Bullhead (*Ameriurus nebulosus*), and the Northern Pike (*Esox lucius*). The lake has been stocked with Walleye in from 1979-2022 (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).

6.3.1 Nuisance Common Carp in Silver Lake

Numerous observations have been made in recent years regarding decreased water clarity and a strong presence of nuisance Common Carp (*Cyprinus carpio*). The carp are known to proliferate quickly and occupy shallows, especially during the evening. They are large fish that are capable of relocating the lake sediments to nearshore areas which may lead to sediment burial of fish beds that belong to favorable fish species. Additionally, they may create turbid conditions that prevent low-growing native aquatic plants from germinating. Germination of these plants is critical for the future fishery forage habitat and for ecosystem balance.

Weber and Brown (2011) determined that numerous favorable fish species were reduced in Midwest lakes where carp were dominant. These species included Black Bullhead, Black Crappie, Bluegill, White Bass, and Northern Pike. Badiou and Goldsborough (2015) determined that carp increased ammonia nitrogen concentrations, turbidity, and phytoplankton biomass in wetland mesocosms which are controlled systems but informative on key variables that may be altered with a strong carp presence. Jackson et *al*., (2010) found that carp were most destructive in shallow lakes and may reduce water clarity which can select for blue-green algae that can float on the surface and do not have the light requirements needed by submersed aquatic vegetation. Interestingly, submersed macrophyte biomass was not correlated with carp fish size (Nieoczym and Kloskowski, 2014).

6.4 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 that are small crustaceans which 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 usually 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.

7.0 SILVER LAKE IMPROVEMENT OPTIONS

7.1 Silver Lake Aquatic Plant Management and Water Quality Improvements

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 restoration 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 continual evaluation of submersed invasive aquatic plants is necessary in Silver Lake due to the threat of accelerated growth and distribution. Control 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.

7.1.1 Chemical Aquatic Herbicide Applications

The use of aquatic chemical herbicides is regulated by EGLE 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 40).

Contact herbicides such as diquat, hydrothol, glyphosate, and flumioxazin cause damage to leaf and stem structures; whereas systemic herbicides are assimilated by the plant roots and are lethal to the entire plant. Wherever possible, it is preferred to use a systemic herbicide for longer-lasting aquatic plant control. There are often restrictions with usage of some systemic herbicides around shoreline areas that contain shallow drinking wells. In 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 the granular or liquid systemic herbicides such as triclopyr would be recommended for future infestations of milfoil in Silver Lake. These herbicide has been used very successfully on many inland lakes in Michigan that have hybrid watermilfoil. Triclopyr can be used in near shore areas with shallow well (< 30 feet deep) restrictions. A newer systemic herbicide called ProcellaCOR® showed great efficacy with milfoil control in recent years. 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 EGLE-issued aquatic herbicide permits, herbicides such as copper sulfate, chelated copper algaecides, diquat, endothall, 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.

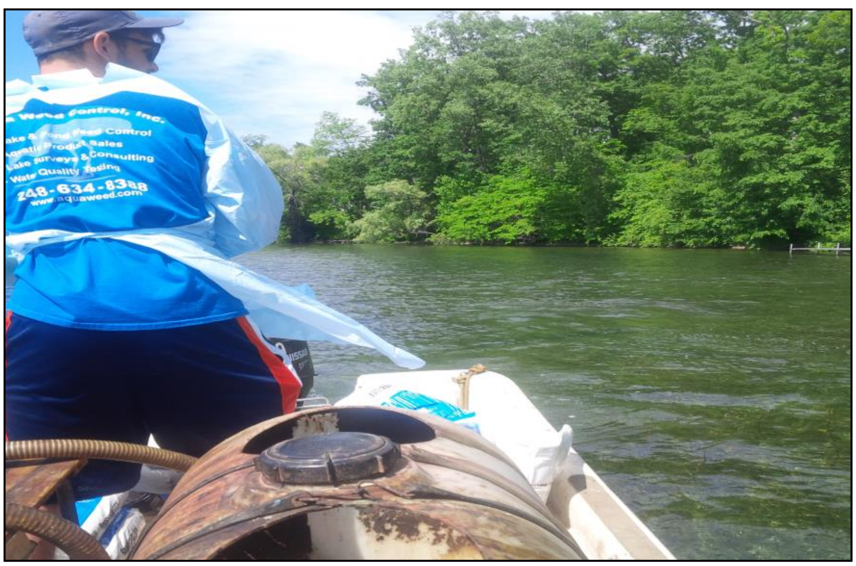

Figure 40. A skiff boat used to apply aquatic herbicides under EGLE permit on inland lakes.

7.1.2 Silver Lake Watershed Runoff Pollutant Reduction

There is a great need for reduction of the nutrients and pollutants previously discussed that negatively impact the water quality of Silver Lake. An innovative and natural product called Biochar (Figure 41) has been used with measurable reductions in nutrients and solids in stormwater and water body improvement programs.

A natural charcoal technology called EarthFood Biochar US® is available for filtration of nutrients and pollutants that may enter inland waters such as Silver Lake. The Biochar is comprised of 87.4% organic carbon based on percentage of total dry mass. Particles range in size from 8-25 mm so there is inherent variability in particle size. This variability allows for the adsorption of nutrients and pollutants due to increased adsorptive surface area. Biochar may be placed in a multi-filament polypropylene sock (such as Silt Sock®) which has a life expectancy of up to 2 years. It is considered an inert product with no chemical effect on the environment. This product allows for the Biochar to be contained in an area and serves to consolidate the particles for optimum filtration efficiency. Previous data collected by RLS on an inland lake inlet that utilized the Biochar showed significant reductions in nutrients such as phosphorus and nitrogen as well as total suspended solids (Jermalowicz-Jones, 2012-2016).

Figure 41. EarthFood Biochar US® product.

In the 2022 runoff evaluation, RLS recommended the following improvements for each of the problematic Critical Source Areas (CSA's):

Mitigation of Gully "Rill" Erosion:

This type of erosion was found at the 18th Ave, 22nd Ave, 24th and 26th Ave Ramps. Neighborhood or unhardened private boat launch areas can contribute significant amounts of sediment to the lake over time. Sheet, rill, and gully erosion occurs on these sites because of the lack of vegetation, compaction due to being driven on, and lack of a properly hardened surface. Often times these areas start with minor amounts of sheet erosion, which concentrates into rill erosion (3 inch or deeper gullies forming a parallel or dendritic pattern) and finally if not addressed into deep gully erosion. All boat launches, by nature, slope to the lake and can be excellent conduits for sediment delivery to the lake.

Private boat launch areas should be hardened to prevent accelerated erosion from happening. A gravel or concrete surface is the best approach to reducing sedimentation into the lake. If the launch area is a fairly long distance from the road, the area should be re-sloped before it reaches the lake to reduce the concentration of storm water. The storm water should be discharged onto a small rock energy dissipator or a well vegetated sod area so as not to cause further erosion.

These efforts may be coordinated with the local Oceana County Road Commission as they may have the equipment and supplies to smooth and stabilize these areas.

State Park:

Analysis of aerial photos of the Silver Lake State Park demonstrate that dark black fine soils are entering the lake at the sampled drain/tributary. In the vicinity of the drain through the park, the following soil types were found:

1. Covert sands; 0-6% slopes
2. Pipestone fine sands; 0-4% slopes
3. Adrian mucks; 0-1% slopes
4. Grattan sands; 0-6% slopes
5. Grattan sands; 18-35% slopes

Of these soil types, the one of most concern are the Adrian mucks. These are very poorly drained soils prone to ponding and contribute dark fines to the tributary. These fines eventually enter Silver Lake and carry nutrients with them.

These soils generally originate from wetland areas and thus little can be done to prevent the source. A recommendation may be to install a sedimentation basin prior to the entry of the tributary into the lake to settle out the fines. An additional method would include installation of EarthFood Biochar US® to reduce nutrients and pollutants prior to entering the lake.

Lollygagging Cabin:

The culvert draining into the lake from across this cabin also drains from the pond at Craig's Cruisers. RLS recommends using a phosphorus reduction method like Phoslock® if that pond tests high for phosphorus. This location was not the largest contributor of P and N relative to other sites but is a contributing source. An additional method would include installation of EarthFood Biochar US® to reduce nutrients and pollutants prior to entering the lake.

18th Ave Ramp (near Mac Woods):

This area was found to contribute the highest total suspended solids, total phosphorus, total inorganic nitrogen to Silver Lake during rain events. Farms located upland are not likely contributors of runoff due to being downslope of a ridge that drains to the lake. Many dirt roads (N. Spencer Rd., W. Wildridge Rd., W. State Park Rd) are along this route. Additionally, West Silver Lake Drive consists of dirt and is especially impaired for a section of approximately 457 feet to the lake.

Diffuse Non-Point Sources:

Pollutants that enter a water body from multiple sources originate upstream and are often transported to the lake via runoff and through large culverts. During this evaluation, the Dunes Vista Tube, Taylor Road Tube, and Hunter Creek all were within this category. Such poor delineation makes corrective actions difficult since precise source locations are unknown at this time. Oceana County lacks a stormwater inventory for the area and a map would be necessary to precisely determine what drains are emptying water from specific sources or locations. RLS recommends that such an inventory and map be created for the future. Specific examples of these diffuse sites include N. 24th Ave Ramp located at the northern region of Silver Lake. The precise origins of pollutants are unknown. Additionally, the Taylor Rd Tube drains a large area but the sources to this tube are difficult to delineate. RLS has created flow path maps that show the length of water course contribution, but this alone cannot pinpoint storm drain sources. Another example is near Edgewood Rd. which drains a waterbody at the north region of Silver Lake. This water body is approximately 5.75 acres. A sub-surface drainage tube was difficult to locate for sampling. There is a ditch that may also flow into the lake during heavy rainfall. RLS recommends lining this ditch with rock for a distance of 1,000 feet to reduce fines if it is determined that this ditch is a possible source.

Hunter Creek:

Previous studies have determined that during periods of no rainfall, Hunter Creek is not a source of nutrients or sediment to the lake. However, during moderate to heavy rainfall, it is a source of these pollutants to Silver Lake. A prominent sediment plume can be seen during rainfall events as it enters the lake and travels out into the open waters. Hunter Creek receives water from Little Silver Lake.

A review of aerial maps of Little Silver Lake revealed many green lawns and thus riparians should not use lawn fertilizer but rather water from the lake as the lake water would likely have sufficient nutrients for a lush lawn. Upper Silver Lake that drains into Little Silver Lake, receives water from the Golden Sands golf course. All of this water may flow into Hunter Creek during heavy rainfall periods. RLS recommends sampling the Little Silver Lake outflow during heavy rain events in 2023 to determine whether this lake may be the primary source of nutrients to Hunter Creek. RLS previously demonstrated that most areas along Hunter Creek are not major contributors of nutrients. Fine sediments are accumulating approximately 0.33 miles upstream in Hunter Creek from the lake entrance (up to the foot bridge). One possible solution would be to reduce fines in the Creek by installation of a sediment basin that would filter out fines prior to washing into the lake. This would reduce the large plumes noted during heavy rainfall events. The combination of fines, algae, carp activity, and suspended sediments in the lake basin are all resulting in increased lake turbidity over time. An additional method would include installation of EarthFood Biochar US® to reduce nutrients and pollutants prior to entering the lake.

Table 8. Silver Lake runoff locations with prioritization based on measured impairments for recommended mitigation methods.

Runoff Location	Priority	Key Recommendations
18th Ave Ramp	VERY HIGH (gully erosion)	Keep free of debris; Sweep; Consider settling basin upland to reduce solids and nutrients
22nd Ave Ramp	LOW	Keep free of debris; Sweep
Dunes Vista Tube	VERY HIGH	Need stormwater inventory map to determine precise sources draining into Tube
State Park	HIGH	Need to settle out dark organic fines prior to lake entry; nutrient reduction
Lollygagging Cabin	HIGH	Nutrient inactivation in upstream ponds; possible settling basin for solids
Hunter Creek	LOW	Upstream BMP/Riparian Education
Taylor Road Tube	LOW	Upstream BMP/Riparian Education
24th Ave Ramp Tube	VERY HIGH (gully erosion)	Re-slope and reduce gully erosion

7.1.3 Silver Lake Carp Reduction and Fishery Habitat Improvement

As mentioned above, the existing fishery spawning habitat in Silver Lake is compromised by the presence of excessive common carp. Removal of these fish is recommended to open up new habitat for favorable fish species since they have been found to be detrimental to native fish species such as Black Bullhead, Black Crappie, Bluegill, White Bass, and Northern Pike (Weber and Brown, 2011). Also recommended is the protection of emergent aquatic vegetation around the lake shoreline (i.e., cattails, reeds, etc.) as these offer reduction of erosion which can contribute to sediment accumulation that may contribute to degradation in fishery spawning habitat. RLS recommends a Carp Cull program occur each year to continually reduce a nuisance species that is capable of high fecundity and will require annual removals to maintain a low population. A cull is a mass-removal effort of carp biomass using a permanent removal method. The use of electrofishing is optimal as it allows for a temporary electrical current which stuns the carp and allows for hands-on removal at that time. Other non-target, favorable fish species will be placed back into the lake so they can reproduce. The carp will be placed in a large container and then hauled away from the lake. Electrofishing is most effective in shallow waters (0-8 feet deep) and thus the effort is conducted at night when the carp are in shallow waters to allow for optimum removal. The removal should be conducted as early in the spawning season as possible and then possibly later if the population remains strong. It may be needed annually for years before populations can be considered favorably “controlled”. During the fish removal procedure(s), the total number of carp, range of carp sizes, and total carp weight are also recorded and will be provided as critical data. Many factors can influence the efficacy of a carp cull such as boat activity, water temperatures, weather, and seasonality and thus timing is often coordinated to maximize efficiency.

7.1.4 Septic Tank and Drain Field Management

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

On ideal soil types, microbes in the soil are able to decompose nutrients and reduce the probability of groundwater contamination. However, many lakes in Michigan contain soils that are not suitable for septic systems. Such soils that are not very permeable, prone to saturation or ponding, and have mucks exist around many lakes and currently have properties with septic systems. In fact, soils that are saturated may be associated with a marked reduction in phosphorus assimilation and adsorption (Gilliom and Patmont, 1983; Shawney and Starr, 1977) which leads to the discharge of phosphorus into the groundwater, especially in areas with a high water table. In the study by Gilliom and Patmont (1983) on Pine Lake in the Puget Sound of the western U.S., they found that it may take 20-30 years for the phosphorus to make its way to the lake and cause negative impacts on water quality.

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

Spence-Cheruvelil and Soranno (2008) studied 54 inland lakes in Michigan and found that total aquatic plant cover (including submersed plants) was most related to secchi depth and mean depth. However, they also determined that man-made land use activities are also predictors of aquatic plant cover since such variables can also influence these patterns of growth. Prior to changes in offshore aquatic plant communities, an additional indicator of land use impacts on lake water quality in oligotrophic lakes (lakes that are low in nutrients) includes changes in periphytic algae associated with development nearshore. Such algae can determine impacts of septic leachate before other more noticeable changes offshore are found (Rosenberger et *al*., 2008). Development in the watershed also may influence the relative species abundance of individual aquatic plant species. Sass et *al*. (2010) found that lakes associated with rigorous development in surrounding watersheds had more invasive species and less native aquatic plant diversity than less developed lakes. Thus, land use activities such as failing septic systems may not only affect aquatic plant biomass and algal biomass, but also the composition and species richness of aquatic plant communities.

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

It is estimated that Michigan has over 1.2 million septic systems currently installed with many of them occurring in rural areas around inland lakes. The number of septic systems that are a risk to the aquatic environment is unknown which makes riparian awareness of these systems critical for protection of lake water. Construction of new septic tanks requires notification and application by the homeowner to the county Department of Public Health and also that soils must be tested to determine suitability of the system for human health and the environment. It is recommended that each septic tank be inspected every 1-2 years and pumped every 1-2 years depending upon usage. The drain field should be inspected as well and only grasses should be planted in the vicinity of the system since tree roots can cause the drain field to malfunction. Additionally, toxins should not be added to the tank since this would kill beneficial microbes needed to digest septic waste. Areas that contain large amounts of peat or muck soils may not be conducive to septic tank placement due to the ability of these soils to retain septic material and cause ponding in the drain field. Other soils that contain excessive sands or gravels may also not be favorable due to excessive transfer of septage into underlying groundwater. Many sandy soils do not have a strong adsorption capacity for phosphorus and thus the nutrients are easily transported to groundwater. Nitrates are especially more mobile and travel quickly with the groundwater and thus are also a threat to water quality. This phenomenon has been noted by many scholars on inland waterways as it contributes sizeable loads of nutrients and pathogens to lake water. Lakebed seepage is highly dependent upon water table characteristics such as slope (Winter 1981).

The higher the rainfall, the more likely seepage will occur and allow groundwater nutrients to enter waterways. Seepage velocities will different greatly among sites and thus failing septic systems will have varying impacts on the water quality of specific lakes. Lee (1977) studied seepage in lake systems and found that seepage occurs as far as 80 meters from the shore. This finding may help explain the observed increases in submersed aquatic plant and algae growth near areas with abundant septic tank systems that may not be adequately maintained. Loeb and Goldman (1978) found that groundwater contributes approximately 44% of the total soluble reactive phosphorus (SRP) and 49% of total nitrates to Lake Tahoe from the Ward Valley watershed. Additionally, Canter and Knox (1985) determined that man-made (anthropogenic) activities such as the use of septic systems can greatly contribute nutrients to groundwater. Septic tank effluent nutrients can be reduced with in situ on-site waste reduction technologies (i.e., Sludge Hammer, Imet, etc.). These systems will be introduced to Silver Lake riparians during future workshops so that individuals can purchase these systems and do their part to remove nutrients entering Silver Lake.

8.0 SILVER LAKE RESTORATION CONCLUSIONS & OVERALL RECOMMENDATIONS

Although the current invasive watermilfoil population in Silver Lake is well-controlled, a re-surgence could occur at any time and thus regular whole-lake surveys are critical. If any future treatments are needed, they should include only systemic herbicides that are used solely on the watermilfoil to allow for much needed germinations of native aquatic plant species. All treatments should be overseen by an RLS scientist and feedback from the MDNR is needed as well. If watermilfoil is the only plant species present, it may be favorable to allow it to remain as some aquatic vegetation cover is better than none. At this time, the lake is unfavorably sparse relative to all aquatic vegetation communities.

In addition, annual water quality sampling of the lake basin is critical for determination of annual trends that demonstrate the changes in specific water quality parameters over time. This will allow for the determination of efficacy relative to implemented lake restoration methods.

Previously, RLS demonstrated that Hunter Creek was a small source of nutrients to the lake relative to septic system inputs and runoff. This new program will focus on maintaining the existing balance of aquatic vegetation and lake health but reducing the nutrients entering the lake from septic systems and runoff. The lake fishery has been declining due to increased blue-green algae which are a result of increased nutrient loads. In addition, the fishery is under threat due to an excessive Common Carp population that must be reduced since they are contributing to sediment re-distribution that is covering spawning beds from other favorable fish. Additionally, the carp have further contributed to low water clarity through sediment resuspension. It is critical to improve water clarity in Silver Lake over time to increase the germination and successful growth of submersed aquatic vegetation. Lakes with high abundance of submersed aquatic vegetation are generally clearer and healthier. RLS recommends an annual carp cull program to accomplish this reduction of the nuisance fish.

RLS recommends that the runoff entering the lake be filtered to reduce the measured high nutrient and solid loads. This can be accomplished with the use of specialized retrofitted Biochar filters that adsorb nutrients such as phosphorus and nitrogen as well as chlorides and solids. These filters should be placed in front of runoff sites to filter the water prior to entering the lake. RLS will compare ongoing water quality parameter data to baseline data collected at these locations during the extensive 2022 evaluation.

RLS also recommends continued education of all riparians on proper septic system and drain field maintenance to reduce nutrients to Silver Lake. There are very affordable on-site technologies available that can effectively reduce phosphorus, ortho-phosphorus, and nitrogen. RLS will be working on a framework for this education to assist riparians through informative lake 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 9 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 9. Proposed lake restoration methods for Silver Lake's new 5-year plan.

Lake Management Activity/Duration	Primary Goal	Secondary Goal	Best Locations to Use/Implement
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, Hunter Creek
Aquatic herbicide treatment of hybrid milfoil/Invasives with long-lasting systemics (annually)	To permanently reduce areas where ONLY milfoil is present	To prevent further spread in/around lake	Throughout lake
Sampling of lake basin and runoff site water quality	To measure changes in lake and runoff water quality with time	To determine if BMP implementation is improving water quality in lake	Throughout lake and at drain/runoff locations
Septic System Maintenance Education/Intro to nutrient reduction technologies	To educate public on proper maintenance of septic systems and drain fields	To allow for riparians to decide on what technologies to use for septic care	Entire lake population
Improve lake fishery/Carp Cull (annually as needed)	To increase favorable fish population	To reduce turbidity in Silver Lake	Entire lake; especially shorelines at evening
Runoff Nutrient Reductions/Biochar and launch grading	To reduce nutrient and solid loads to Silver Lake	To reduce blue-green algae through reduction of nutrients	At all N=8 runoff sites previously studied
Community Engagement/riparian education/workshop (summer of each year)	To empower local riparians/stakeholders to better understand Silver Lake ecosystem	To educate riparians/stakeholders on lake BMP's for better lake protection	Golden Township Park during summer

8.1 Proposed Cost Estimates for Silver Lake Improvements (2023-2027)

The proposed integrated lake improvement program for Silver Lake would begin during the spring of 2023 and continue through 2027. A breakdown of costs associated with the recommended Silver Lake improvements is presented in Table 10. 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). With this proposed SAD, lakefront properties with 1.0 unit of benefit would pay an assessment of $763.89 for 5 years or $152.78 annually. Backlots with deeded or dedicated access with 0.5 units of benefit would pay an assessment of $381.94 for 5 years or $76.39 annually. The commercial properties with 2.0 units of benefit would pay a total of $1,527.77 for 5 years or $305.55 annually. These amounts may change slightly dependent upon assessment roll changes.

NOTE: The SLIB desires to assess the same amount each year. Thus, a mean of $61,492.80 was calculated based on cost estimates as described above in each column for the total annual cost.

Table 10. Silver Lake proposed lake improvement program costs (2023-2027).

Silver Lake Improvement Method	Estimated 2023 Cost	Estimated 2024 Cost	Estimated 2025 Cost	Estimated 2026 Cost	Estimated 2027 Cost
Systemic granular herbicides for EWM and annual EGLE permit (est. $600-$700/acre)[1]	$3,000	$3,000	$3,000	$3,000	$3,000
Installation of Biochar filters at N=8 drain locations, EGLE permit	$47,000	$5,000	$5,000	$5,000	$49,000
Carp Cull (electrofishing and removal), hauling away	$7,660	$7,780	$7,780	$7,820	$7,820
Community workshops 2023-Septic Tank Maintenance 2024-NPS pollution/watershed 2025-Carp cull results 2026-Lake Health 2027-Future needs	$4,000	$4,000	$4,500	$4,500	$4,500
Professional consulting services (RLS), water quality sampling/treatment oversight, reporting/data analysis/surveys/tech support[2]	$15,500	$15,500	$16,000	$16,000	$16,500
Administrative fees (Oceana County)	$500	$250	$250	$250	$250
Contingency (15%)[3]	$11,649	$5,329.50	$5,479.50	$5,485.50	$12,160.50
TOTAL ANNUAL COST	$89,309	$40,859.50	$42,009.50	$42,055.50	$93,230.50
AVG. ANNUAL COST	$61,492.80				

[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). RLS does not foresee any significant treatments until water clarity improves and plants begin to grow.

[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 for the lake basin, upstream, at the outlet and also any possible required samples from EGLE to evaluate the inflow areas, preparation of annual progress reports and presentation to the SLIB and attending public, including the public hearings in 2023 and again at Year 5, and attendance at up to 5 regularly scheduled board meetings and the annual summer workshop.

[3] Contingency is 15% of the total project cost, to assure that extra funds are available for unexpected expenses. Note: Contingency may be advised and/or needed for future management years. Contingency funds may also be used for other water quality improvements and watershed management. **Any additional fees for the SLIB (i.e., treasurer, unpredicted expenses) can come from the contingency.**

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