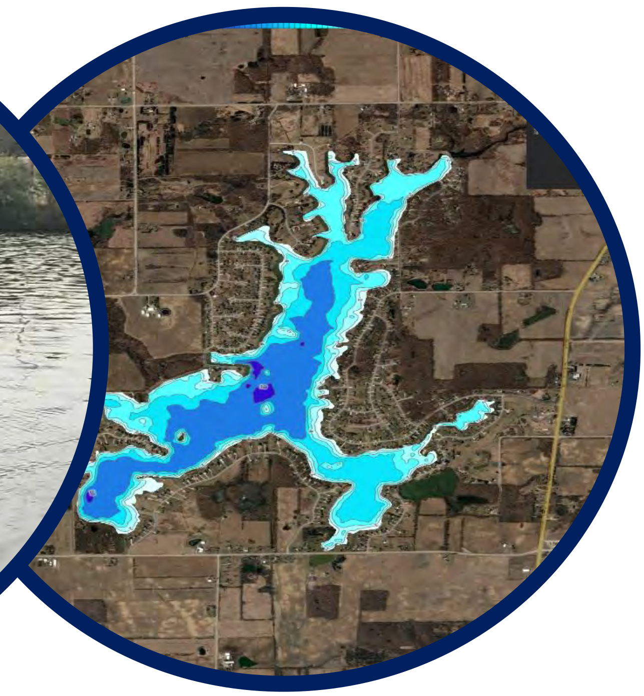
PART I. Loch Erin Improvement Study and Management Plan
Lenawee County, Michigan



Provided for: Loch Erin Property Owners Association (LEPOA) Board

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1.0 EXECUTIVE SUMMARY

Loch Erin is located in Cambridge Township in Lenawee County, Michigan (T.5S, R.2E, Figure 1). The lake is comprised of 581.7 acres (RLS, 2019) excluding the area to the northeast of the lake which when included allows for the lake to consist of 602 acres. The lake is a man-made impoundment with a dam located at the south region of the lake. The lake basin has nearly 15.4 miles of shoreline and is located at an altitude of 922 feet above sea level. The mean depth of the lake basin is approximately 6.5 feet. The maximum depth of the lake basin is approximately 12.1 feet (RLS, 2019 bathymetric scan data; Figure 2). The lake basin also has a fetch (longest distance across the lake) of around 1.9 miles (RLS, 2019). The basin of Loch Erin has an approximate water volume of 3,539.1 acre-feet (RLS, 2019 bathymetric data). The immediate watershed (which is the area directly draining into the lake) is approximately 19,850 acres (based on LiDAR data) and 11,315 acres (based on topographic modeling data). This is about 34 times the size of the lake, which is very large. Legal lake levels have been established for the lake on May 12, 2005 in Circuit Court with the summer and winter levels for the elevations of 925.36' and 924.36', respectively. Wastewater from the Loch Erin community is treated at the Wastewater Treatment Plant (WWTP) via a surface water discharge permit from EGLE to discharge treated water into Wolf Creek which flows through Loch Erin and eventually into Lake Adrian. Wolf Creek is a sub-watershed of the larger River Raisin watershed. The River Raisin flows east to Lake Erie at Monroe and is recognized as the most crooked river in the world.

Based on the current study, Loch Erin contains 3 invasive aquatic plant species which includes the submersed hybrid Eurasian Watermilfoil (EWM), Curly-leaf Pondweed (CLP), and the emergent Phragmites. Continued surveys and vigilance are needed to assure that additional invasives do not enter Loch Erin. Recommendations for prevention of invasives are offered later in this management plan report. There are a total of 3 submersed, 1 floating-leaved, and 3 emergent native aquatic plant species in Loch Erin that were present during the lake survey on July 11, 2019. This represents a fair biodiversity that could be enhanced with proper control of the submersed invasives. Aquatic herbicide treatments are recommended on a spot-treatment basis to effectively reduce the invasives over time.

Algaecides should only be used on green algal blooms since many treatments can exacerbate blue-green algae blooms. The blue-green algae, *Microcystis* sp. was the most prevalent algae in the lake which is an indicator of poor water quality.

A total of 4 water quality sampling locations were sampled within the lake basin on August 15, 2019. These basins were monitored for physical water quality parameters such as water temperature, dissolved oxygen, pH, specific conductivity, total dissolved solids (TDS), turbidity, and Secchi transparency. Additional chemical water quality parameters were also measured at each site and included total Kjeldahl nitrogen (TKN), total inorganic nitrogen (TIN; which consists of ammonia, nitrate, and nitrite), chlorophyll-a, total phosphorus (TP), and ortho (ORP; soluble reactive) phosphorus, and total suspended solids (TSS). The overall water quality of Loch Erin was measured as fair with high nutrients such as phosphorus (TP) and nitrogen (TKN) and low water clarity. The pH of the lake indicates that it is a neutral lake with moderate alkalinity.

The mean TP concentration in the lake basin ranged from was 0.050-0.069 mg/L which is over twice the eutrophic threshold. Additionally, the bioavailable TP (SRP) mean concentration ranged from 0.010-0.014 mg/L in the lake basin, which was favorable. This means that very little of the TP is usable for aquatic biota including the algae. The mean TKN concentration in the lake basin ranged from 1.1-1.3 mg/L which is moderate, and the total inorganic nitrogen (TIN) mean concentration ranged from 0.010-0.051 mg/L, which are favorable values. Total suspended solids (TSS) in the lake ranged from 27-51 mg/L which is well above the detection limit and contributes to low water quality. The mean conductivity of the lake ranged from 466-473 mS/cm which is moderately high and indicative of a large watershed. The mean water clarity (secchi transparency) ranged from 1.2-1.5 feet which are very low values and indicate turbid waters. Mean chlorophyll-a, which is a measure of algal pigment, was low at 10.3-11.0 µg/L, which is very high and attributed to blue-green blooms. Dissolved oxygen depletion was prevalent in deep basins #2 and #4.

Three critical source areas (CSA's) that flow into the lake were sampled on September 12, 2019 and October 21, 2019. CSA#1 was located at the east end of the lake and the remaining two were located along the north region. All of the CSA's had favorable water temperatures, pH, and dissolved oxygen concentrations. The mean conductivity was high in all of them with a range from 617-726 mS/cm which is much higher than the lake basin means. The corresponding total dissolved solids were also high with a mean range of 399-471 mg/L which is higher than the lake mean values. The TKN in the CSA's was favorable; however, the total inorganic nitrogen means ranged from 0.046-0.930 mg/L with the two highest concentrations in CSA #1 and CSA #4. Of particular concern was the high mean nitrate concentrations in CSA #1 and CSA #4. All CSA's had levels of nitrite below detection. The TP mean concentrations ranged from 0.018-0.039-0.051 mg/L which is similar to the lake basins. All of the ortho-phosphorus concentrations were favorable at <0.010 mg/L. The TSS mean concentrations ranged from <10-20 mg/L with the highest values noted in CSA #3. Lastly, E. coli bacteria and total coliform was measured on September 12, 2019 and determined that all CSA's had total coliform counts that were "TNTC" or too numerous too count. CSA #1 and CSA#3 had E. coli counts of 600 CFU's/100 ml and 1,600 CFU's/100 ml, respetovely. CSA#4 also had a measurable E. coli count at 300 CFU's/100 ml. Top priority should be given to all CSA's for implementation of BMP'S which are likely to include drain filters and agricultural BMP's to reduce nutrients before they enter the lake basins. Additional water quality data was collected during May, July, and Agust by the LEPOA along areas on the larger tributaries and drains. This montoring also showed elevated nutrients such as phosphours and bacteria. E. coli is of major concern to public health and it is likely that Loch Erin is not meeting state-recommended designated uses for recreation and body contact. This should allow for prioritization of Loch Erin for development of an enhanced watershed managenet plan for Wolf Creek and its drains.

Loch Erin has multiple land uses such as wetlands, beaches, and riparian properties. Lake improvement strategies to reduce external loading of P to the lake, increase dissolved oxygen with depth, reduce cyanobacteria blooms, and improve water clarity and quality are urgently needed. RLS therefore recommends that a whole-lake laminar flow aeration system be installed and that periodic bioaugmentation treatments be conducted to reduce the algae in the lake and increase water clarity and dissolved oxygen.

In addition, it is recommended that the Loch Erin community implement Best Management Practices (BMP's) discussed in the immediate watershed management report to reduce the nutrient and sediment loads being transported into the lake from areas with high erosion and drains that contribute high sediment and nutrient loads.

It would be beneficial to include the riparian community in the improvement program which could be initiated by holding a community-wide lake education and improvement workshop to introduce residents to the key lake impairments and garner support for continued lake protection.

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 Loch Erin.

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. Loch Erin may be categorized as a drainage lake since it has numerous drainage areas as well as an outlet at the south region of the lake (via a dam) that enters Wolf Creek. Wastewater from the Loch Erin community is treated at the Wastewater Treatment Plant (WWTP) via a surface water discharge permit from EGLE to discharge treated water into Wolf

Creek which flows through Loch Erin and eventually into Lake Adrian. Wolf Creek is a sub-watershed of the larger River Raisin watershed. The River Raisin flows east to Lake Erie at Monroe and is recognized as the most crooked river in the world.

2.1.2 Biodiversity and Habitat Health

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

2.1.3 Watersheds and Land Use

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

In addition, the topography of the land surrounding a lake may make it vulnerable to nutrient inputs and consequential loading over time. Topography and the morphometry of a lake dictate the ultimate fate and transport of pollutants and nutrients entering the lake. Surface runoff from the steep slopes surrounding a lake will enter a lake more readily than runoff from land surfaces at or near the same grade as the lake. In addition, lakes with steep drop-offs may act as collection basins for the substances that are transported to the lake from the land. Land use activities, such as residential land use, industrial land use, agricultural land use, water supply land use, wastewater treatment land use, and storm water management, can influence the watershed of a particular lake. All land uses contribute to the water quality of the lake through the influx of pollutants from non-point sources (NPS) 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. A practical immediate watershed management plan is offered as a second portion to this comprehensive lake evaluation report (see page 72). This immediate watershed plan component is meant to serve within a greater watershed plan such as a Wolf Creek watershed plan which would fall within the larger River Raisin watershed improvement plan.

3.0 LOCH ERIN PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Loch Erin Basin

Loch Erin is located in Cambridge Township in Lenawee County, Michigan (T.5S, R.2E, Figure 1). The lake is comprised of 581.7 acres (RLS, 2019) excluding the area to the northeast of the lake which when included allows for the lake to consist of 602 acres. The lake is a man-made impoundment with a dam located at the south region of the lake. The lake basin has nearly 15.4 miles of shoreline is located at an altitude of 922 feet above sea level. The mean depth of the lake basin is approximately 6.5 feet. The maximum depth of the lake basin is approximately 12.1 feet (RLS, 2019 bathymetric scan data; Figure 2). The lake basin also has a fetch (longest distance across the lake) of around 1.9 miles (RLS, 2019). The basin of Loch Erin has an approximate water volume of 3,539.1 acre-feet (RLS, 2019 bathymetric data). The immediate watershed (which is the area directly draining into the lake) is approximately 19,850 acres (based on LiDAR data) and 11,315 acres (based on topographic modeling data). This is about 34 times the size of the lake, which is very large. Legal lake levels were established for the lake in Circuit Court on May 12, 2005 with the summer and winter levels for the elevations of 925.36’ and 924.36’, respectively.

A bottom sediment hardness scan was conducted of the entire lake bottom on July 11, 2019. The bottom hardness map shows (Figure 3) that most of the lake bottom consists of fairly consolidated sediment throughout the lake with a few areas with soft organic bottom. This is not surprising given the amount of sandy loams in the region which contribute to lake geology. Table 1 below shows the categories of relative bottom hardness with 0.0-0.1 referring to the softest and least consolidated bottom and >0.4 referring to the hardest, most consolidated bottom for the lake basin.

This scale does not mean that any of the lake contains a truly “hard” bottom but rather a bottom that is more cohesive and not flocculent.

Table 1. Loch Erin basin relative hardness of the lake bottom by category or hardness and percent cover of each category (relative cover) on July 11, 2019.

Lake Bottom Relative Hardness Category	# GPS Points in Each Category (Total =18,387)	% Relative Cover of Bottom by Category
0.0-0.1	3	0.02
0.1-0.2	5	0.03
0.2-0.3	721	3.80
0.3-0.4	8377	44.2
>0.4	9850	52.0

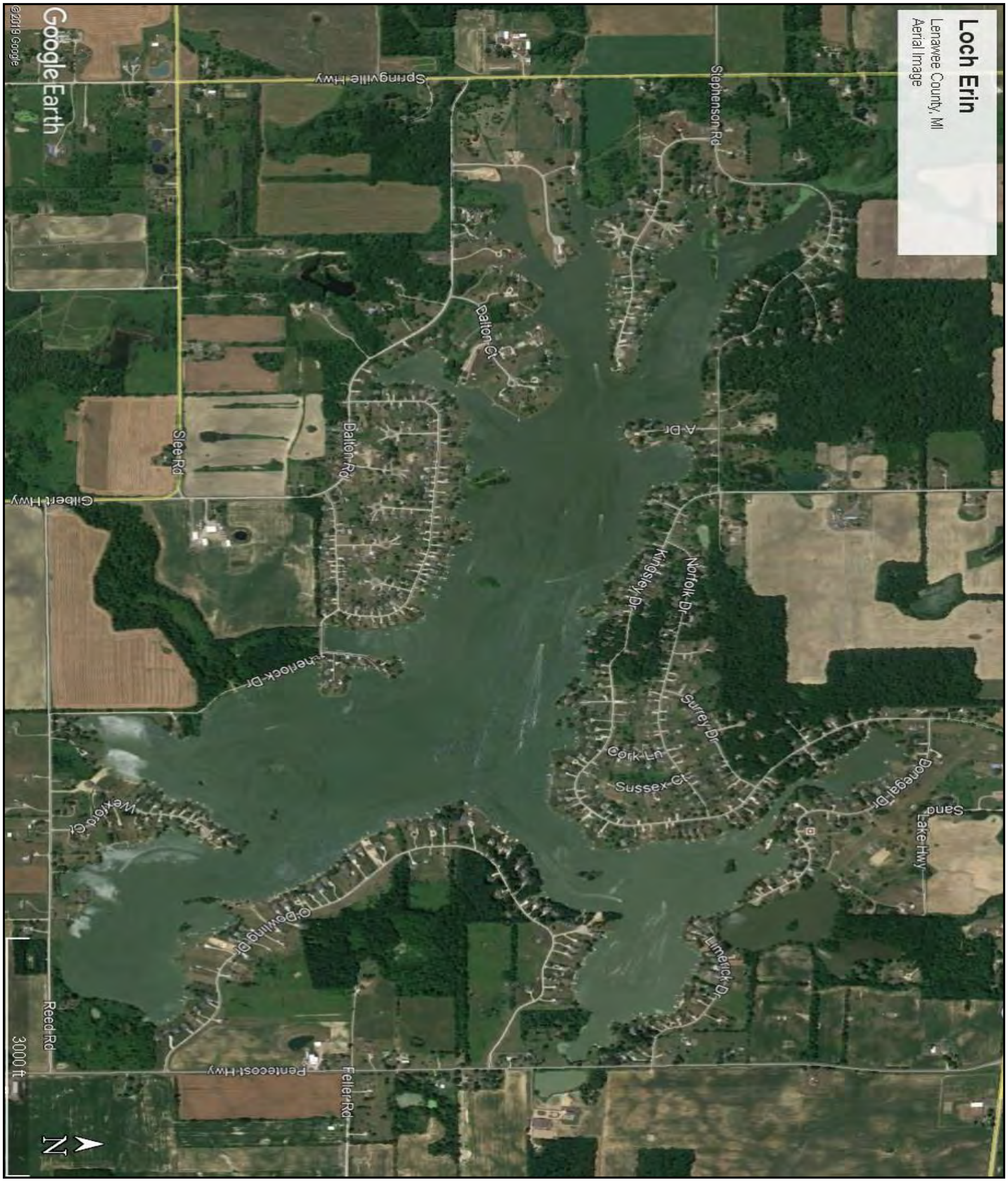


Figure 1. Loch Erin Aerial Photo, Lenawee County, Michigan.

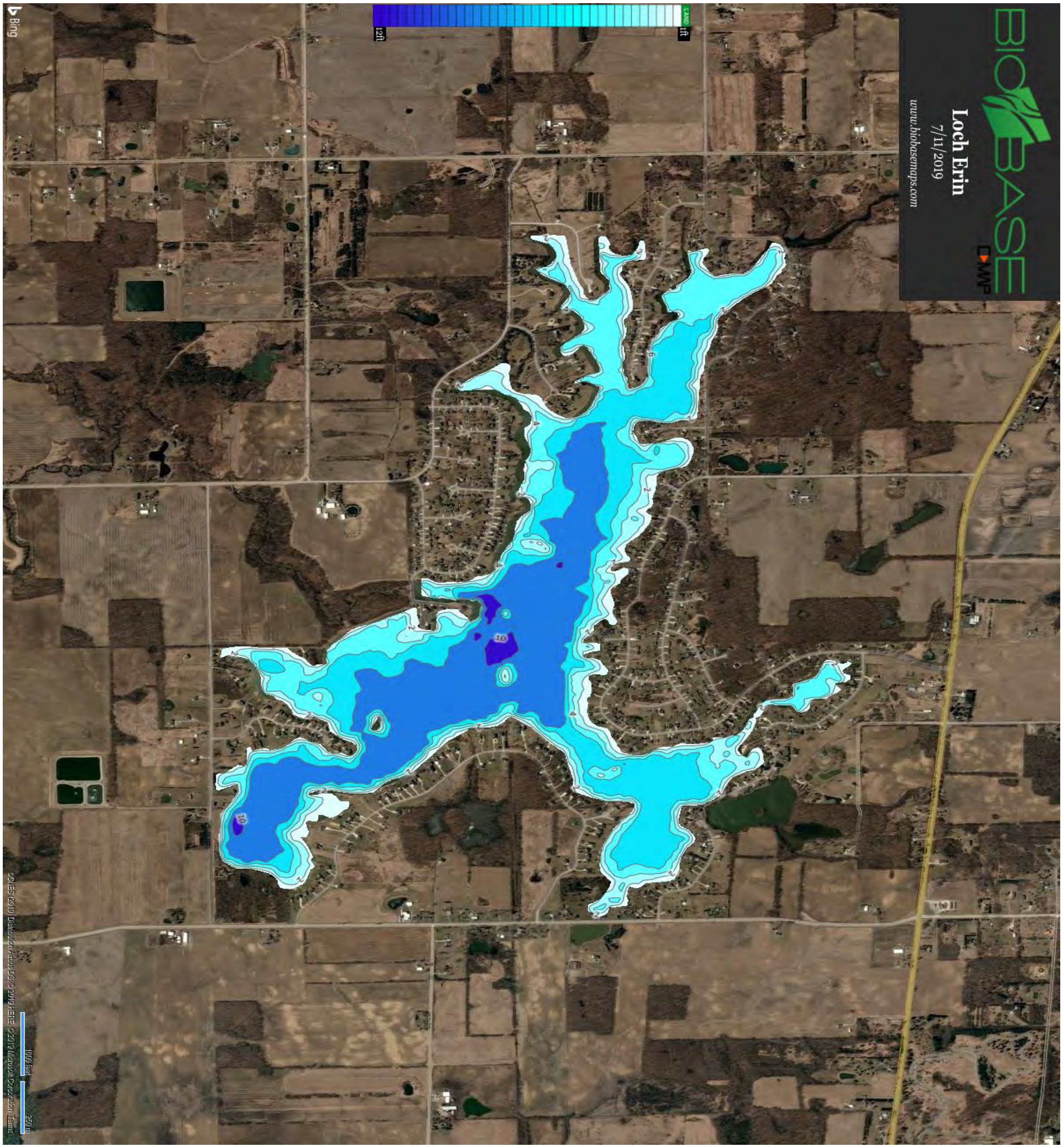


Figure 2. Loch Erin basin depth contour map (July 11, 2019).

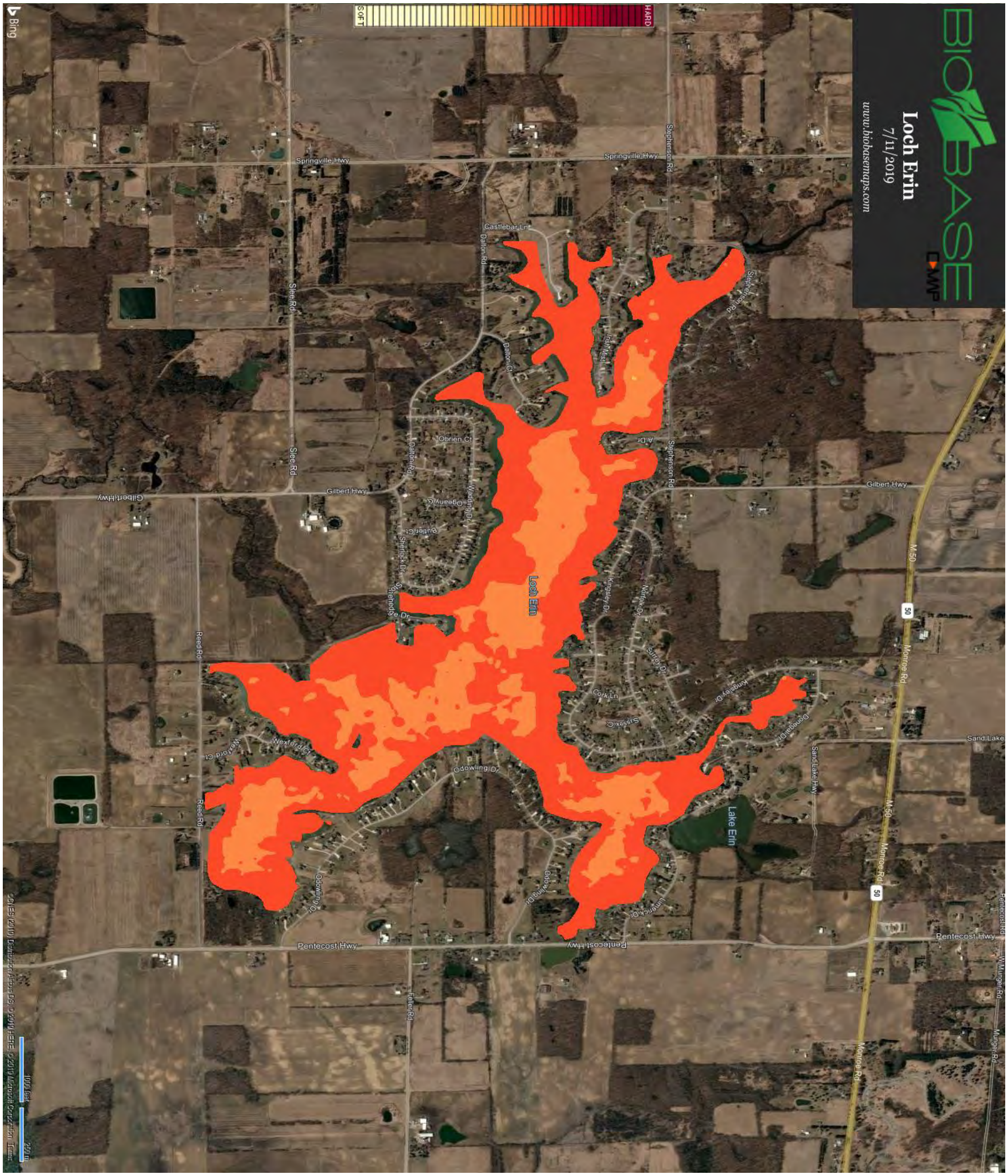


Figure 3. Loch Erin basin sediment relative hardness map (July 11, 2019).

4.0 LOCH ERIN 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. The basin of Loch Erin is classified as hyper-eutrophic (nutrient-enriched) due to the high nutrients and low Secchi transparency and marked dissolved oxygen depletion with depth in some areas (Figure 4).

Table 2. General Lake Trophic Status Classification Table.

Lake Trophic Status	*Total Phosphorus ($mg\ L^{-1}$)*	*Chlorophyll-a ($\mu g\ L^{-1}$)*	*Secchi Transparency (feet)*
Oligotrophic	< 0.010	< 2.2	> 15.0
Mesotrophic	0.010-0.025	2.2 – 6.0	7.5 – 15.0
Eutrophic	> 0.025	> 6.0	< 7.5

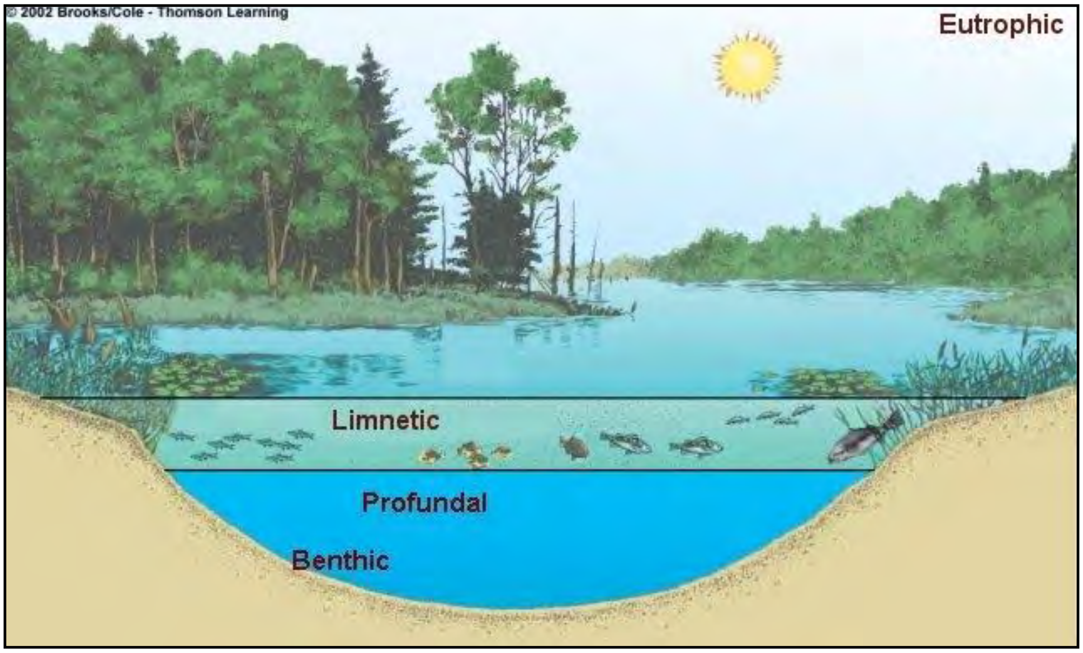


Figure 4. Diagram showing a eutrophic or nutrient-enriched lake ecosystem (photo adapted from Brooks/Cole Thomson learning online).

4.1 Water Quality Parameters

Parameters such as dissolved oxygen (in mg/L), water temperature (in °C), specific conductivity (mS/cm), turbidity (NTU's), total dissolved solids (mg/L), total suspended solids (mg/L), pH (S.U.), total phosphorus and ortho-phosphorus (also known as soluble reactive phosphorus or SRP measured in mg/L), total Kjeldahl nitrogen and total inorganic nitrogen (in mg/L), chlorophyll-a (in µg/L), and Secchi transparency (in feet) are parameters that respond to changes in water quality and consequently serve as indicators of change. The deep basin results for all abiotic and biotic water quality parameters are discussed below and are presented in Tables 4-12. A map showing the sampling locations for all water quality samples is shown below in Figure 5. All water samples and readings were collected at the 4 deepest basins on August 15, 2019 with the use of a 3.2-Liter Van Dorn horizontal water sampler and calibrated Eureka Manta II® multi-meter probe with parameter electrodes, respectively. All samples with the exception of chlorophyll-a were taken to a NELAC-certified laboratory for analysis.

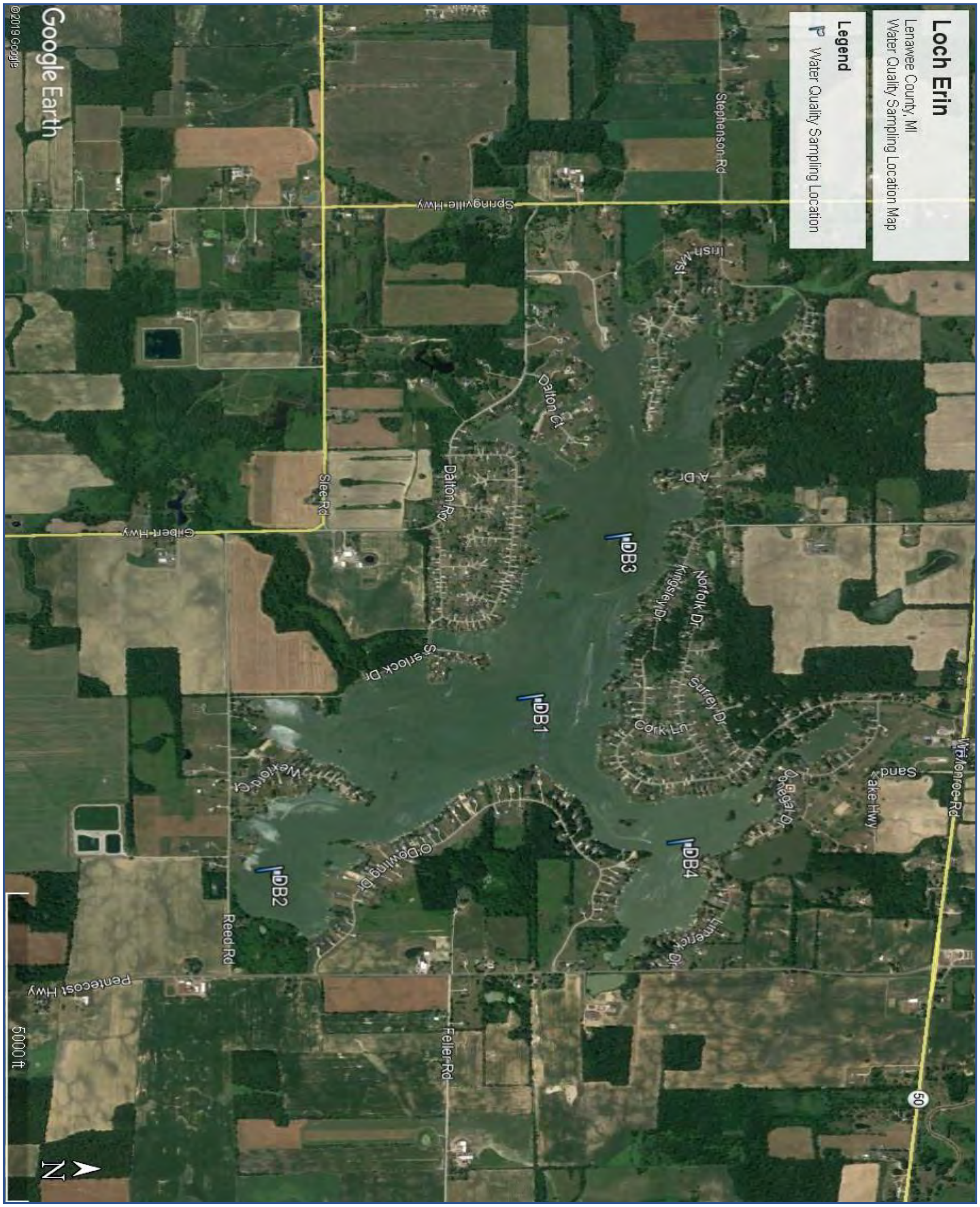
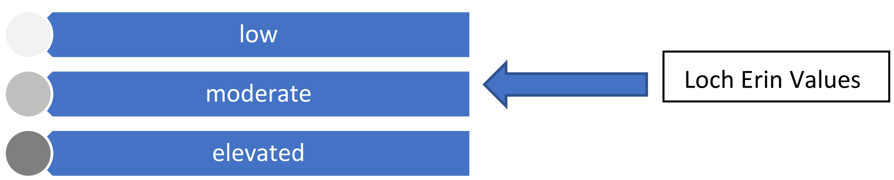


Figure 5. Locations for water quality sampling of the deep basins in Loch Erin (August 15, 2019).

4.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water column. In general, dissolved oxygen levels should be greater than 5 mg/L to sustain a healthy warm-water fishery. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. Dissolved oxygen was measured in milligrams per liter (mg/L) with the use of a calibrated Eureka Manta II® dissolved oxygen meter. The mean dissolved oxygen concentrations in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 5.3-9.3 mg/L, with the lowest concentrations found in deep basins #2 and #4.

The bottom of the lake produces a biochemical oxygen demand (BOD) due to microbial activity attempting to break down high quantities of organic plant matter, which reduces dissolved oxygen in the water column at depth. Furthermore, the lake bottom is distant from the atmosphere where the exchange of oxygen occurs. A decline in the dissolved oxygen concentrations to near zero may result in an increase in the release rates of phosphorus (P) from lake bottom sediments.



4.1.2 Water Temperature

A lake's water temperature varies within and among seasons, and is nearly uniform with depth under the winter ice cover because lake mixing is reduced when waters are not exposed to the wind. When the upper layers of water begin to warm in the spring after ice-off, the colder, dense layers remain at the bottom. This process results in a "thermocline" that acts as a transition layer between warmer and colder water layers. During the fall season, the upper layers begin to cool and become denser than the warmer layers, causing an inversion known as "fall turnover" (Figure 6). 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 mean water temperature measurements in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 24.9-25.7°C which demonstrated a lack of thermocline in all basins and nearly isothermic conditions. Cooler water temperatures generally also hold more dissolved oxygen.

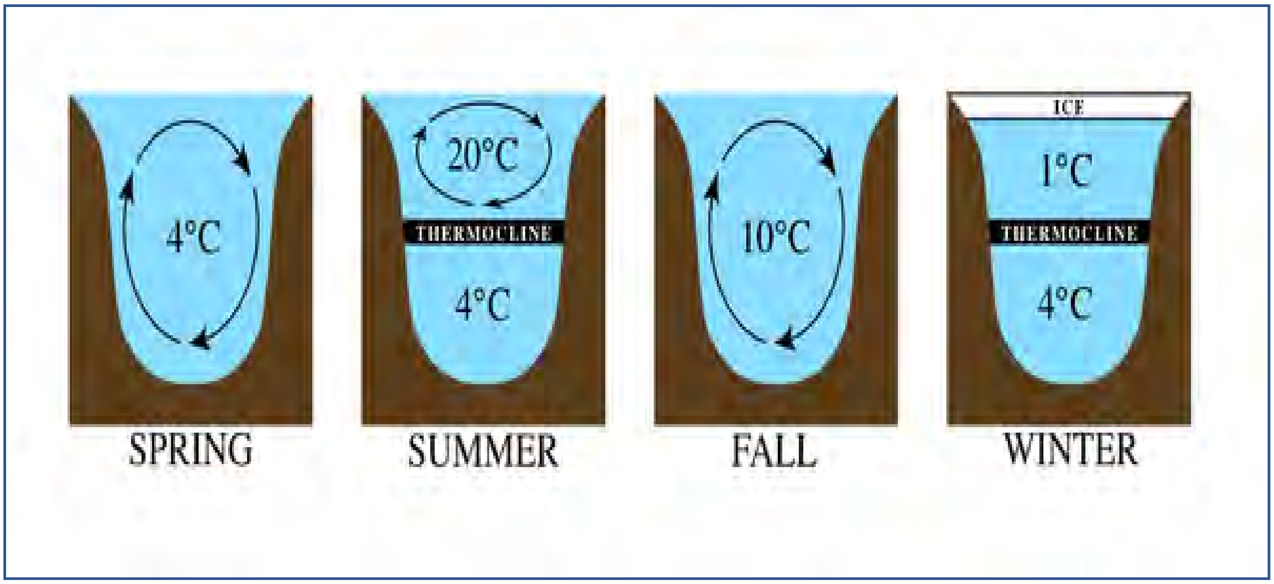
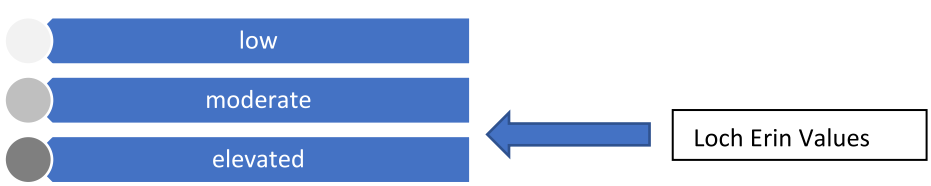


Figure 6. The lake thermal stratification process.

4.1.3 Specific Conductivity

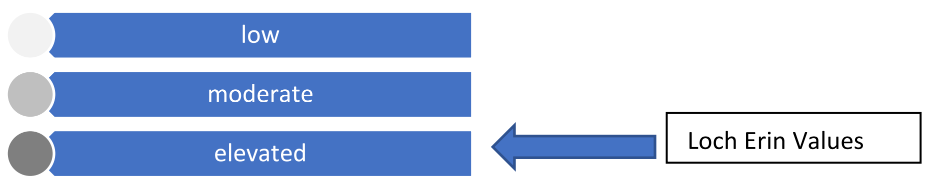
Specific conductivity is a measure of the number of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Specific conductivity was measured in micro Siemens per centimeter (µS/cm) with the use of a calibrated Eureka Manta II® conductivity probe and meter. The mean conductivity values in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 466-473 mS/cm, which are moderately high values. Since these values are moderately high for an inland lake, the lake water contains ample dissolved metals and ions such as calcium, potassium, sodium, chlorides, sulfates, and carbonates. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Loch Erin over a long period of time, or to trace the origin of a substance to the lake in an effort to reduce pollutant loading. Elevated conductivity values over 800 mS/cm can negatively impact aquatic life.



4.1.4 Turbidity, Total Dissolved Solids, and Total Suspended Solids

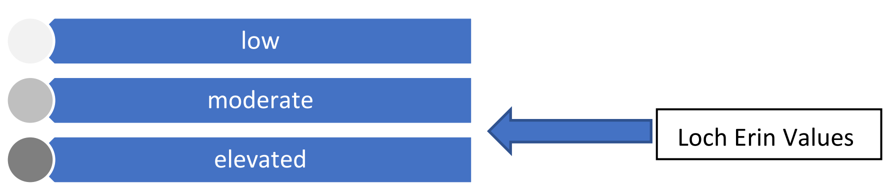
Turbidity

Turbidity is a measure of the loss of water transparency due to the presence of suspended particles. The turbidity of water increases as the number of total suspended particles increases. Turbidity may be caused by erosion inputs, phytoplankton blooms, storm water discharge, urban runoff, re-suspension of bottom sediments, and by large bottom-feeding fish such as carp. Particles suspended in the water column absorb heat from the sun and raise water temperatures. Since higher water temperatures generally hold less oxygen, shallow turbid waters are usually lower in dissolved oxygen. Turbidity was measured in Nephelometric Turbidity Units (NTU's) with the use of a calibrated Lutron® turbidity meter. The World Health Organization (WHO) requires that drinking water be less than 5 NTU's; however, recreational waters may be significantly higher than that. The mean turbidity values in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 4.1-6.2 NTU's, which are elevated values. Spring values are sometimes higher due to increased watershed inputs from spring runoff and/or from increased algal blooms in the water column from resultant runoff contributions. These numbers also correlate with the measured low transparency and elevated chlorophyll-a concentrations.



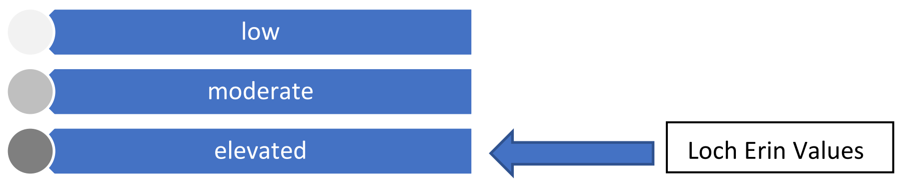
Total Dissolved Solids

Total dissolved solids (TDS) are the measure of the amount of dissolved organic and inorganic particles in the water column. Particles dissolved in the water column absorb heat from the sun and raise the water temperature and increase conductivity. Total dissolved solids were measured with the use of a calibrated Eureka Manta II® meter in mg/L. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The mean TDS concentrations in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 210-257 mg/L. These values are moderately high for an inland lake and correlates with the measured moderately high conductivity.



Total Suspended Solids (TSS)

Total suspended solids are the measure of the number of suspended particles in the water column. Particles suspended in the water column absorb heat from the sun and raise the water temperature. Total suspended solids were measured in mg/L and analyzed in the laboratory with Method SM 2540 D-11. The lake bottom contains many fine sediment particles that are easily perturbed from winds and wave turbulence. Spring values would likely be higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The mean TSS concentrations in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 27-51 mg/L, which are elevated values. Ideally values should be < 10 mg/L.



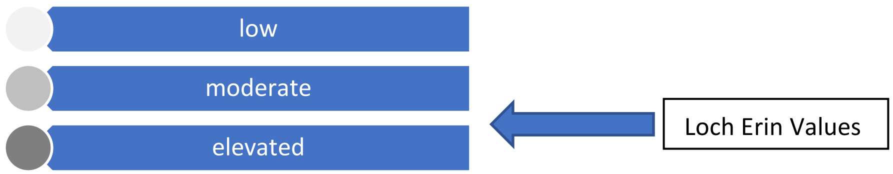
4.1.5 pH

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 7.0 to 9.5 S.U. Acidic lakes (pH < 7) are rare in Michigan and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC). The mean pH values in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 7.9-8.3 S.U. This range of pH is neutral to alkaline on the pH scale and is ideal for an inland lake. pH tends to rise when abundant aquatic plants are actively growing through photosynthesis or when abundant marl deposits are present.

4.1.6 Total Phosphorus and Ortho-Phosphorus (SRP)

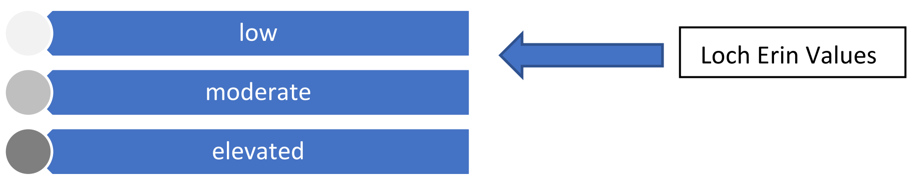
Total Phosphorus

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Lakes which contain greater than 0.020 mg/L of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to the higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Phosphorus may also be released from sediments as pH increases. Total phosphorus was measured in milligrams per liter (mg/L) with the use of Method EPA 200.7 (Rev. 4.4). The mean TP concentrations in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 0.050-0.069 mg/L which are more than twice the eutrophic threshold. These concentrations tend to be higher at the bottom depths and are indicative of internal loading of TP which means that the TP is accumulating in the lake bottom and is released when the dissolved oxygen level is low. This in turn re-circulates the TP throughout the lake and makes it constantly available for algae and aquatic plants to use for growth. Some of the highest TP concentrations in the lake occurred at the surface, which could be indicative of surface runoff contributions from tributaries.



Ortho-Phosphorus

Ortho-Phosphorus (also known as soluble reactive phosphorus or SRP) was measured with Method SM 4500-P (E-11). SRP refers to the most bioavailable from of P used by all aquatic life. The mean SRP concentrations in the basin of Loch Erin during August 15, 2019 sampling event ranged from <0.010-0.014 mg/L, which are low and favorable.

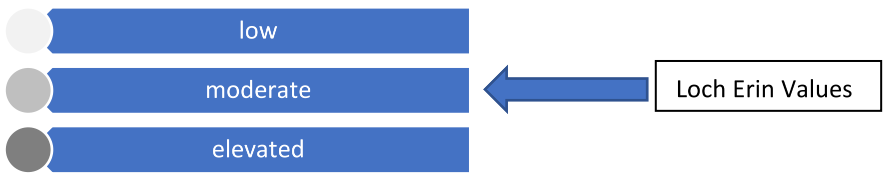


4.1.7 Total Kjeldahl Nitrogen and Total Inorganic Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. TKN was measured with Method EPA 351.2 (Rev. 2.0) and Total Inorganic Nitrogen (TIN) was calculated based on the aforementioned three different forms of nitrogen at Trace Analytical Laboratories, Inc. (a NELAC-certified laboratory). Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e. burning of fossil fuels), wastewater sources from developed areas (i.e. runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen (N:P > 15), phosphorus may be the limiting nutrient for phytoplankton and aquatic macrophyte growth. Alternatively, in lakes with low nitrogen concentrations (and relatively high phosphorus), the blue-green algae populations may increase due to the ability to fix nitrogen gas from atmospheric inputs. Lakes with a mean TKN value of 0.66 mg/L may be classified as oligotrophic, those with a mean TKN value of 0.75 mg /L may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg/L may be classified as eutrophic. The mean TKN concentrations in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 1.1-1.3 mg/L. These values are normal for an inland lake of similar size.

In the absence of dissolved oxygen, nitrogen is usually in the ammonia form which is the most abundant form of nitrogen in the lake.

The total inorganic nitrogen (TIN) consists of nitrate (NO3), nitrite (NO2), and ammonia (NH3) forms of nitrogen without the organic forms of nitrogen. The mean TIN concentrations in the basin of Loch Erin during the August 15, 2019 sampling event ranged from 0.010-0.051 mg/L, which are favorable values. Two major reasons why submersed rooted aquatic plant growth is not more prevalent given these concentrations are due to depth limitations and the lack of water clarity which is critical for higher aquatic plant growth. The nitrite and nitrate concentrations are still below detection. Overall, the nitrogen in Loch Erin is mostly in the ammonia form.



4.1.8 Chlorophyll-a and Algae

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. Chlorophyll-a water samples were collected with an integrated tube sampler and transferred to amber bottles preserved with Lugols solution. Chlorophyll-a samples were collected at the 4 sampling locations during the August 15, 2019 sampling date. High chlorophyll-a concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg/L are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg/L are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* was measured in micrograms per liter (µg/L) with a Turner Designs® *in situ* fluorimeter. The chlorophyll-*a* concentrations in Loch Erin were determined by collecting composite (depth-integrated) samples of the algae throughout the water column (photic zone) at the deep basin sites from just above the lake bottom to the lake surface. The mean chlorophyll-*a* concentrations in the basins during the August 15, 2019 sampling event ranged from 10-11 µg/L, respectively. These concentrations are highly elevated due to the presence of abundant blue-green algae such as *Microcystis*.

The dominant algae in the lake (blue green) tends to be buoyant and float on the surface which reduces light to other favorable algae below. 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 algae.

To determine the presence of algal genera from the composite water samples collected from the deep basins of Loch Erin, 500 ml of preserved sample were collected, and a 1-mL subsample was placed to settle onto a Sedgewick-Rafter counting chamber (Woelkerling et *al*., 1076). The ocular micrometer scale was calibrated. The samples were observed under a

Zeiss® compound microscope at 400X magnification and scanned at 100X magnification to allow for the detection of a broad range of taxa present. All taxa were identified to Genus level. Phytoplankton samples were enumerated for the August 15, 2019 sampling event and are shown below in Table 3. In the lake basin, the blue-green algae were more dominant than both green algae and diatoms (Figures 10-11). Diatoms and green algae are the more favorable algal genera.

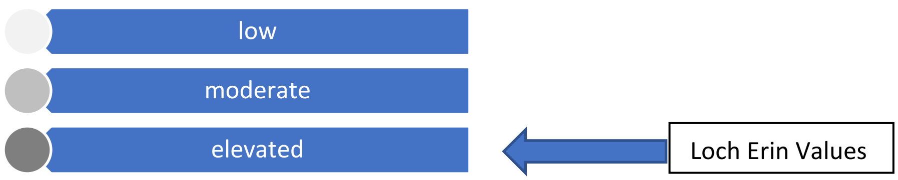


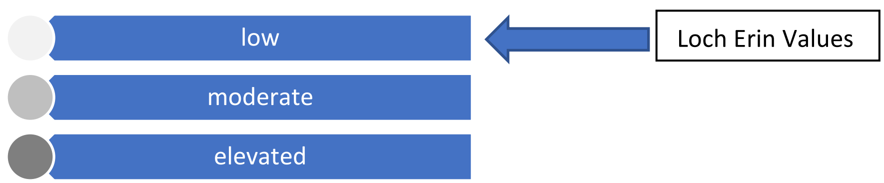
Table 3. Counts (# cells per 1 mL sub-sample) for each genera of algae found at each sampling location (n=4) in the lake basin of Loch Erin (August 15, 2019).

Taxa Present	Type	DB#1	DB#2	DB#3	DB#4
Chlorella sp.	G	2	5	1	0
Scenedesmus sp.	G	7	4	2	0
Mougeotia sp.	G	11	2	6	1
Ulothrix sp.	G	5	2	0	0
Closterium sp.	G	0	0	1	1
Cladophora sp.	G	5	1	0	8
Rhizoclonium sp.	G	2	6	1	0
Gleocapsa sp.	BG	4	15	7	2
Microcystis sp.	BG	1000	3000	2000	150
Anabaena sp.	BG	26	55	10	2
Oscillatoria sp.	BG	2	10	4	1
Navicula sp.	D	1	1	0	1
Synedra sp.	D	2	1	0	1
Rhoicosphenia sp.	D	0	0	1	1

Note: G = green algae (Chlorophyta); BG = blue-green algae (Cyanophyta); D = diatoms (Bacillariophyta). Microcystis algal count data were rounded to the closest whole number.

4.1.9 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and is measured with the use of an 8-inch diameter standardized Secchi disk during calm to light wind conditions. Secchi disk transparency is measured in feet (ft.) or meters (m) by lowering the disk over the shaded side of a boat around noon and taking the mean of the measurements of disappearance and reappearance of the disk (Figure 7). 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 mean Secchi transparency of the basin of Loch Erin on August 15, 2019 ranged from 1.2-1.3 feet which is very low. It is clear that the Secchi transparency declined throughout the season which was largely due to the growth of blue-green algal blooms. This transparency indicates that an abundance of solids such as suspended particles and algae are present throughout the water column which increases turbidity and reduces water clarity. Secchi transparency is variable and depends on the amount of suspended particles in the water (often due to windy conditions of lake water mixing) and the amount of sunlight present at the time of measurement.



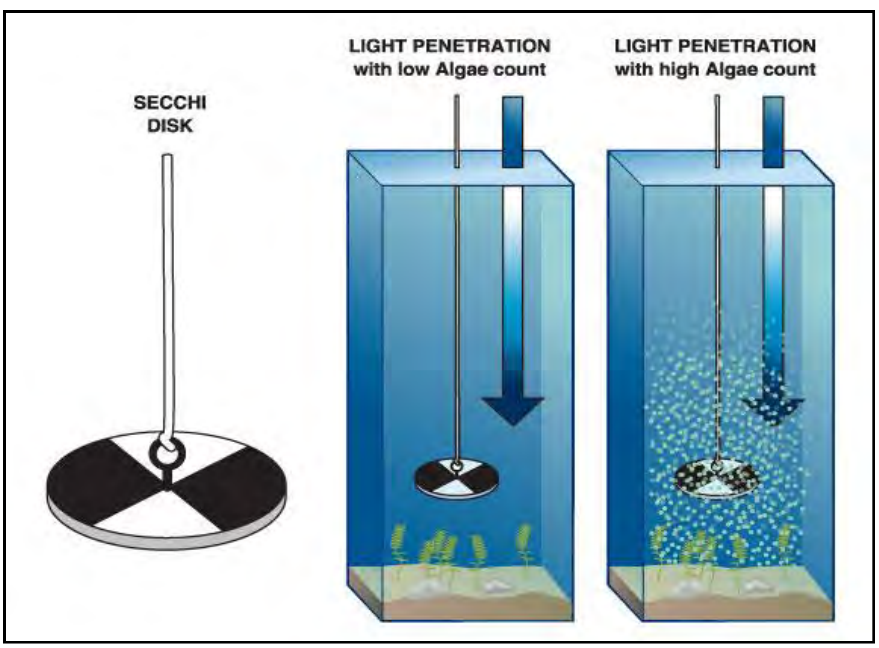


Figure 7. Measurement of water transparency with a Secchi disk.

Table 4. Loch Erin physical water quality parameter data collected at deep basin #1 (August 15, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	26.3	10.6	8.4	468	5.5	231	1.3
0.5	25.8	10.2	8.4	468	6.0	225	
1.0	25.5	8.8	8.3	470	5.0	224	
1.5	25.4	8.0	8.1	470	6.0	220	
2.0	25.3	7.8	8.1	469	5.0	218	
2.5	25.3	7.8	8.0	469	6.0	217	
3.0	25.1	7.3	8.0	470	5.5	218	

Table 5. Loch Erin chemical water quality parameter data collected at deep basin #1 (August 15, 2019).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	1.5	0.073	0.073	<0.10	<0.10	23	0.064	<0.010	10.0
1.5	1.1	0.071	0.071	<0.10	<0.10	19	0.041	<0.010	10.0
3.0	0.9	<0.010	<0.010	<0.10	<0.10	39	0.044	<0.010	11.0

Table 6. Loch Erin physical water quality parameter data collected at deep basin #2 (August 15, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	25.5	7.8	8.4	470	4.0	209	1.2
0.5	25.0	7.0	8.2	472	4.0	210	
1.0	25.0	6.0	8.2	473	4.0	210	
1.5	24.8	5.4	7.9	473	4.0	211	
2.0	24.7	4.7	7.8	473	4.0	211	
2.5	24.7	4.2	7.7	474	5.0	210	
3.0	24.7	3.9	7.4	474	4.0	209	
3.5	24.7	3.5	7.4	475	4.0	209	

Table 7. Loch Erin chemical water quality parameter data collected at deep basin #2 (August 15, 2019).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	1.3	<0.010	<0.010	<0.10	<0.10	18	0.043	<0.010	10.0
2.0	0.9	0.016	0.016	<0.10	<0.10	40	0.053	<0.010	10.0
3.5	1.2	0.110	0.110	<0.10	<0.10	96	0.110	<0.010	11.0

Table 8. Loch Erin physical water quality parameter data collected at deep basin #3 (August 15, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	26.0	9.9	8.5	464	6.0	251	1.3
0.5	25.9	10.1	8.5	464	6.0	251	
1.0	25.7	10.2	8.2	464	7.0	251	
1.5	25.6	9.6	8.2	466	6.0	252	
2.0	25.5	8.9	8.1	467	6.0	254	
2.5	25.4	6.9	8.0	468	6.0	256	

Table 9. Loch Erin chemical water quality parameter data collected at deep basin #3 (August 15, 2019).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	1.0	<0.010	<0.010	<0.10	<0.10	20	0.075	<0.010	10.0
1.5	1.4	<0.010	<0.010	<0.10	<0.10	38	0.047	0.021	10.0
2.5	1.4	<0.010	<0.010	<0.10	<0.10	82	0.066	<0.010	11.0

Table 10. Loch Erin physical water quality parameter data collected at deep basin #4 (August 15, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	26.6	7.8	8.3	472	5.0	251	1.2
0.5	26.0	7.4	8.2	472	5.0	255	
1.0	25.2	6.2	8.2	472	6.0	259	
1.5	25.2	5.5	8.1	472	6.0	259	
2.0	25.1	5.4	8.1	472	6.0	259	

Table 11. Loch Erin chemical water quality parameter data collected at deep basin #4 (August 15, 2019).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3- (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	0.9	<0.010	<0.010	<0.10	<0.10	15	0.069	<0.010	11.0
1.0	1.2	<0.010	<0.010	<0.10	<0.10	48	0.047	<0.010	11.0
2.0	1.3	<0.010	<0.010	<0.10	<0.10	54	0.049	<0.010	11.0

Table 12. Descriptive statistics of all water quality parameters in the deep basins of Loch Erin for water quality parameters collected on August 15, 2019.

Water Quality Parameter	Deep Basin #1 Means ± SD	Deep Basin #2 Means ± SD	Deep Basin #3 Means ± SD	Deep Basin #4 Means ± SD
Water temp (°C)	25.5±0.4	24.9±0.3	25.7±0.2	25.6±0.7
pH (S.U.)	8.2±0.2	7.9±0.4	8.3±0.2	8.2±0.1
Dissolved oxygen (mg/L)	8.6±1.3	5.3±1.5	9.3±1.3	6.5±1.1
Conductivity (mS/cm)	469±0.9	473±1.5	466±1.8	472±0.0
Total dissolved solids (mg/L)	222±5.1	210±0.8	253±2.1	257±3.6
Turbidity (NTU)	5.6±0.4	4.1±0.4	6.2±0.4	5.6±0.5
Secchi transparency (ft.)	1.5	1.2	1.3	1.2
Chlorophyll-a (µg/L)	10.3±0.6	10.3±0.6	10.3±0.6	11.0±0.0
Total Kjeldahl nitrogen (mg/L)	1.2±0.3	1.1±0.2	1.3±0.2	1.1±0.2
Total inorganic nitrogen (mg/L)	0.051±0.0	0.045±0.1	0.010±0.0	0.010±0.0
Ammonia nitrogen (mg/L)	0.051±0.0	0.045±0.1	0.010±0.0	0.010±0.0
Nitrate nitrogen (mg/L)	<0.10±0.0	<0.10±0.0	<0.10±0.0	<0.10±0.0
Nitrite nitrogen (mg/L)	<0.10±0.0	<0.10±0.0	<0.10±0.0	<0.10±0.0
Total phosphorus (mg/L)	0.050±0.0	0.069±0.0	0.063±0.0	0.055±0.0
Ortho-Phosphorus (mg/L)	0.010±0.0	0.010±0.0	0.014±0.0	0.010±0.0
Total suspended solids (mg/L)	27.0±10.6	51.0±40	46.7±32	39.0±21

4.2 Loch Erin Aquatic Vegetation Communities

Aquatic plants (macrophytes) are an essential component in the littoral zones of most lakes in that they serve as suitable habitat and food for macroinvertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (if in the rooted growth form), and contribute to the cycling of nutrients such as phosphorus and nitrogen upon decay. In addition, decaying aquatic plants contribute organic matter to lake sediments which further supports healthy growth of successive aquatic plant communities that are necessary for a balanced aquatic ecosystem. An overabundance of aquatic vegetation may cause organic matter to accumulate on the lake bottom faster than it can break down. Aquatic plants generally consist of rooted submersed, free-floating submersed, floating-leaved, and emergent growth forms. The emergent growth form (i.e. Cattails, Native Loosestrife) is critical for the diversity of insects onshore and for the health of nearby wetlands. Submersed aquatic plants can be rooted in the lake sediment (i.e. Milfoils, Pondweeds), or free-floating in the water column (i.e. Coontail). Nonetheless, there is evidence that the diversity of submersed aquatic macrophytes can greatly influence the diversity of macroinvertebrates associated with aquatic plants of different structural morphologies (Parsons and Matthews, 1995). Therefore, it is possible that declines in the biodiversity and abundance of submersed aquatic plant species and associated macroinvertebrates, could negatively impact the fisheries of inland lakes. Alternatively, the overabundance of aquatic vegetation can compromise recreational activities, aesthetics, and property values. Loch Erin currently has a moderately high quantity of submersed aquatic vegetation which can lead to recreational and navigational issues. Over-management of the native aquatic vegetation is not advised, however, as it will only encourage excess growth by algae since the latter competes with the vegetation for vital water column nutrients.

A whole-lake scan of the aquatic vegetation in Loch Erin was conducted on July 11, 2019 with a WAAS-enabled Lowrance HDS 9® GPS with variable frequency transducer. This data included 18,956 data points in the lake basin. Points were then uploaded into a cloud software program to reveal maps that displayed depth contours, sediment hardness, and aquatic vegetation biovolume (Figure 8). On these maps, the color blue refers to areas that lack vegetation. The color green refers to low-lying vegetation. The colors red/orange refer to tall-growing vegetation. There are many areas around the littoral (shallow) zone of the lake that contain low-growing plants like Chara. In addition, any emergent canopies or lily pads will show as red or yellow color on the map. For this reason, the scans are conducted in conjunction with a whole lake GPS survey to account for individual species identification of all aquatic plants in the lake. Table 13 shows the biovolume categories by plant cover during the July 11, 2019 scan and survey.

The Point-Intercept Survey method is used to assess the presence and percent cumulative cover of submersed, floating-leaved, and emergent aquatic vegetation within and around the littoral zones of inland lakes.

With this survey method, sampling locations are geo-referenced (via GPS waypoints) and assessed throughout the entire lake to determine the species of aquatic macrophytes present and density of each macrophyte which are recorded onto a data sheet. Each separate plant species found in each sampling location is recorded along with an estimate of each plant density. Each macrophyte species corresponds to an assigned number. There are designated density codes for the aquatic vegetation surveys, where a = found (occupying < 2% of the surface area of the lake), b = sparse (occupying 2-20% of the surface area of the lake), c = common, (occupying 21-60% of the surface area of the lake), and d = dense (occupying > 60% of the surface area of the lake). The survey of the lake basin of Loch Erin consisted of 450 sampling locations around the littoral zone and was conducted on July 11, 2019. Data were placed in a table showing the relative abundance of each aquatic plant species found and the total cover.

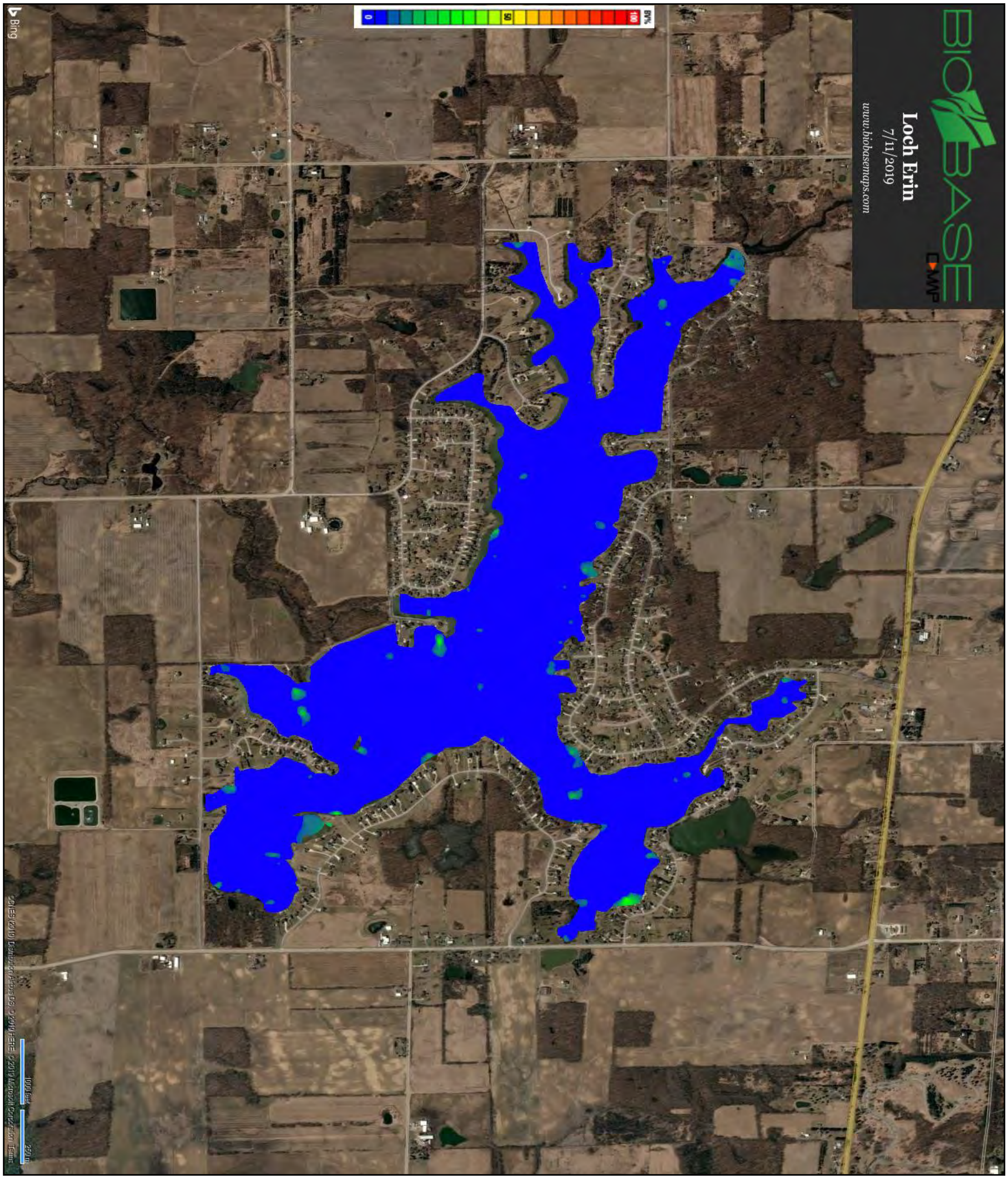


Figure 8. Aquatic plant biovolume of all aquatic plants in north Loch Erin, Lenawee County, Michigan (July 11, 2019). Note: Red color denotes high-growing aquatic plants, green color denoted low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

Table 13. Loch Erin basin aquatic vegetation biovolume by category percent over of each category (relative cover on July 11, 2019).

Biovolume Cover Category	% Relative Cover of Bottom by Category
<5%	96.8
5-20%	2.0
20-40%	0.4
40-60%	0.3
60-80%	0.2
>80%	0.3

4.2.1 Loch Erin 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.

The basin of Loch Erin contained 3 native submersed, 1 floating-leaved, and 3 emergent aquatic plant species, for a total of 7 native aquatic macrophyte species (Table 14). The majority of the emergent macrophytes may be found along the shoreline of the lake. Additionally, the majority of the floating-leaved macrophyte species can be found near the shoreline, shallows, and wetland areas. This is likely due to enriched sediments and shallower water depth with reduced wave energy, which facilitates the growth of aquatic plants with various morphological forms.

The dominant native aquatic plants in the lake basin of the lake included the Chara and White waterlily (Figure 9). The lily pads cover many shallow areas in the lake but are essential for fish cover given the low abundance of rooted submersed aquatic plant species. The relative abundance of rooted aquatic plants (relative to non-rooted plants) in the lake suggests that the sediments are the primary source of nutrients (relative to the water column), since these plants obtain most of their nutrition from the sediments. The emergent plants, such as Arrowhead (Figure 10) are critical for shoreline stabilization as well as for wildlife and fish spawning habitat. Photos of all native aquatic plants are shown below in Figures 11-17.

Table 14. Loch Erin basin and shoreline native aquatic plants (July 11, 2019).

Aquatic Plant Common Name	Aquatic Plant Latin Name	A level	B level	C level	D level	# Sites Found
Muskgrass	*Chara vulgaris*	48	4	0	0	52
Thin-leaf Pondweed	*Stuckenia pectinatus*	9	4	2	0	15
Illinois Pondweed	*Illinoensis*	10	2	4	0	16
White Waterlily	*Nymphaea odorata*	11	8	29	10	58
Pickerelweed	*Potendaria cordata*	2	11	3	1	17
Cattails	*Typha latifolia*	4	4	0	0	8
Arrowhead	*Sagittaria* sp.	2	9	4	4	19

Figure 9. Abundant lily pads near the northwest region of the lake.

Figure 10. Abundant emergent Arrowhead near the northwest of the lake.

Figure 11. Chara (Muskgrass) ©RLS

Figure 12. Thin-leaf Pondweed ©RLS

Figure 13. Illinois Pondweed ©RLS

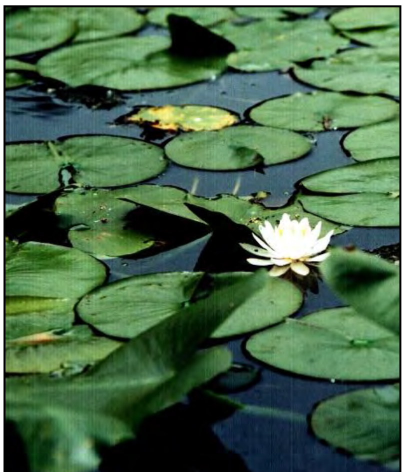


Figure 14. White waterlily ©RLS

Figure 15. Pickerelweed ©RLS

Figure 16. Arrowhead ©RLS

Figure 17. Cattails ©RLS

4.2.2 Loch Erin 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 18) is an exotic aquatic macrophyte first documented in the United States in the 1880's (Reed 1997), although other reports (Couch and Nelson 1985) suggest it was first found in the 1940's. In recent years, this species has hybridized with native milfoil species to form hybrid species. Eurasian Watermilfoil has since spread to thousands of inland lakes in various states through the use of boats and trailers, waterfowl, seed dispersal, and intentional introduction for fish habitat. Eurasian Watermilfoil is a major threat to the ecological balance of an aquatic ecosystem through causation of significant declines in favorable native vegetation within lakes (Madsen et *al*. 1991), in that it forms dense canopies (Figure 19) 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).

Eurasian Watermilfoil was found in a few locations throughout the lake and this distribution likely varies among years and seasons. Table 15 shows the various invasives found and their relative abundance in the lake and Figure 22 shows the distribution of invasive aquatic plants found in and around Loch Erin on July 11, 2019.

Figure 18. Hybrid Eurasian Watermilfoil plant with seed head and fragments (©RLS).

Figure 19. Hybrid Eurasian Watermilfoil Canopy on an inland lake (©RLS).

Curly-leaf Pondweed (*Potamogeton crispus*; Figure 20) 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. It does not reproduce by fragmentation as invasive watermilfoil does; however, the turions may be deposited in the lake sediment and germinate in following seasons. 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. Curly-leaf pondweed was found in a few locations of the lake.

Figure 20. Curly-leaf Pondweed (©RLS).

The Giant Common Reed (*Phragmites australis*; Figure 21) is an imminent threat to the surface area and shallows of the lake since it may grow submersed in water depths of ≥ 2 meters (Herrick and Wolf, 2005), thereby drying up wetland habitat and reducing lake surface area. In addition, large, dense stands of *Phragmites* accumulate sediments, reduce habitat variability, and impede natural water flow (Wang et *al*., 2006). This plant was found in four locations within the lake basin.

Figure 21. The invasive emergent Phragmites (©RLS).

Table 15. Loch Erin basin and shoreline invasive aquatic plants (July 11, 2019).

Aquatic Plant Common Name	Aquatic Plant Latin Name	A level	B level	C level	D level	# Sites Found (% of total)
Hybrid Eurasian Watermilfoil	*Myriophyllum spicatum* var. *sibiricum*	4	0	0	0	4
Curly-leaf Pondweed	*Potamogeton crispus*	0	4	0	0	4
Giant Common Reed	*Phragmites australis*	0	2	0	0	2

Figure 22. Distribution of invasive aquatic plant species found in and around Loch Erin (July 11, 2019).

4.3 Loch Erin Zooplankton and Macroinvertebrates

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

Lake Zooplankton

A zooplankton tow using a Wildco® pelagic plankton net (63 micrometer) with collection jar (Figure 23) was conducted by RLS scientists on August 15, 2019 over the 4 deep basins of Loch Erin. The plankton net was left at depth for 30 seconds and then raised slowly to the surface at an approximate rate of 4 feet/second. The net was then raised above the lake surface and water was splashed on the outside of the net to dislodge any zooplankton from the net into the jar. The jar was then drained into a 125-mL bottle with a CO2 tablet to anesthetize the zooplankton. The sample was then preserved with a 70% ethyl alcohol solution. Plankton sub-samples (in 1 ml aliquots) were analyzed under a Zeiss® dissection scope with the use of a Bogorov counting chamber. Taxa were keyed to species when possible and are shown in Table 16 below.

Table 16. Zooplankton taxa and count data from the basin of Loch Erin (August 15, 2019).

Zooplankton Taxa	DB#1	DB#2	DB#3	DB#4
Cladocerans				
Daphnia parvula	4	11	2	9
D. retrocurva	2	1	0	0
Copepods/Cyclopods				
Diaptomus sp.	2	1	1	1
Mesocyclops sp.	4	2	2	0
Rotifers				
Keratella	6	2	1	1

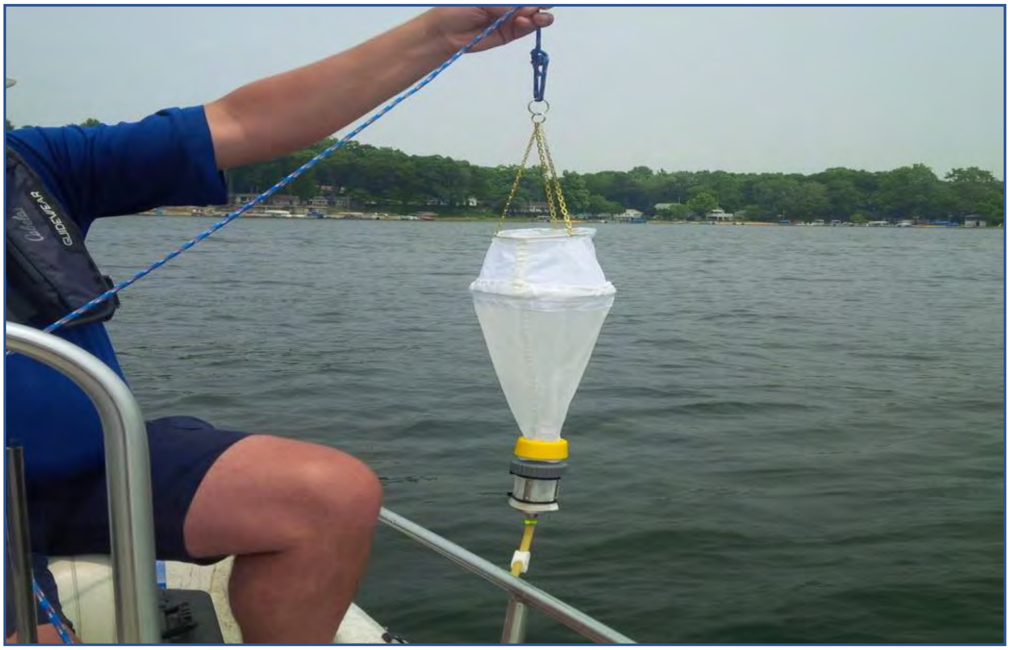


Figure 23. A zooplankton collection tow net (RLS, 2018).

Benthic Macroinvertebrates

Freshwater macroinvertebrates are ubiquitous, as even the most impacted lake contains some representatives of this diverse and ecologically important group of organisms. Benthic macroinvertebrates are key components of lake food webs both in terms of total biomass and in the important ecological role that they play in the processing of energy. Others are important predators, graze 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 (fish) on the other side. Hence, they play an essential role in key ecosystem processes (food chain dynamics, productivity, nutrient cycling, and decomposition).

Restorative Lake Sciences collected benthic (bottom) aquatic macroinvertebrate samples at the same locations as the water quality samples with the use of an Ekman hand dredge (Figure 24). Macroinvertebrate samples were placed in small plastic buckets and analyzed in the RLS wet laboratory within 24 hours after collection using a hard-plastic sorting tray, tweezers, and a Zeiss® dissection microscope under 1X, 3X, and 10X magnification power. Macroinvertebrates were taxonomically identified using a key from: “The Introduction to the Aquatic Insects of North America”, by Merritt, Cummings, and Berg (2008) to at least the family level and genus level whenever possible. All macroinvertebrates were recorded including larval or nymph forms, mussels, snails, worms, or other “macro” life forms.

Genera found in the Loch Erin sediment samples included midges (Chironomindae), Wheel snails (Planorbidae), Blood worms (Glyceridae), and Glass worms (Chaoboridae). 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). Table 17 displays the taxa and abundance found at the 4 sites.

Figure 24. An Ekman hand dredge for sampling lake sediments (RLS, 2018).

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

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

Table 17. Macroinvertebrates found in the basin of Loch Erin, Lenawee County, MI (August 15, 2019).

Site DB#1	**Family**	**Genus**	**Number**	**Common name**
	Chironimidae	*Chironomus* spp.	5	Midges
	Planorbidae	*Gyraulus* spp.	6	Wheel snails
	Chaoboridea	*Chaoborus* spp.	9	Glass worms
		Total	**20**	
Site DB#2	**Family**	**Genus**	**Number**	**Common name**
	Planorbidae	*Gyraulus* spp.	9	Wheel snails
	Chironomidae	*Chironomus* spp.	16	Midges
		Total	**25**	
Site DB#3	**Family**	**Genus**	**Number**	**Common name**
	Chironomidae	*Chironomus* spp.	8	Midges
	Chaoboridae	*Chaoborus* spp.	2	Glass worms
	Planorbidae	*Gyraulus* spp.	7	Wheel snails
		Total	**17**	
Site DB#4	**Family**	**Genus**	**Number**	**Common name**
	Chaoboridae	*Chaoborus* spp.	8	Glass worms
	Chironmidae	*Chironomus* spp.	6	Midges
	Glyceridae	*Glycera* spp.	5	Blood worms
		Total	**19**	

4.4 Loch Erin Fishery

Currently, Loch Erin has healthy populations of bass and pike and larger predatory fish but seems to be lacking an abundant population of smaller panfish. During the lake vegetation surveys in 2019, RLS noted a lack of submersed aquatic vegetation which serves as fish forage habitat and cover and also a lack woody debris for fish spawning habitat.

The fishery habitat is more plentiful along the undeveloped shorelines of the lake and fish beds were located near the shoreline areas in both the developed and undeveloped areas of the lake. There is some erosion around the lake and sediment burial of fish beds may be problematic unless it is being reduced from incoming total suspended solids that may settle on the lake bottom. Further improvements for fish habitat are provided in Section 6.0 below.

5.0 LOCH ERIN AQUATIC VEGETATION AND WATER QUALITY IMPROVEMENT METHODS

Lake improvement methods consist of strategies to reduce invasive aquatic plants, reduce the transport of invasive species, reduce nuisance algae, improve water quality, reduce lake sedimentation and nutrient transport, and facilitate proper immediate watershed management. The following sections offer useful and effective methods for improving the overall condition of Loch Erin. Watershed improvements are discussed in the second section of this report for immediate watershed management.

5.1 Loch Erin Aquatic Plant Management

Improvement strategies, including the management of exotic aquatic plants, control of land and shoreline erosion, and further nutrient loading from external sources, are available for the various problematic issues facing Loch Erin. The lake management components involve both within-lake (basin) and around-lake (watershed) solutions to protect and restore complex aquatic ecosystems such as Loch Erin. The goals of a Lake Management Plan (LMP) such as this are to increase water quality, increase favorable wildlife habitat and aquatic plant and animal biodiversity, optimize 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 such as within this LMP.

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

5.1.1 Aquatic Invasive Species Prevention

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

The first ingredient to successful prevention of unwanted transfers of exotic species to Loch Erin is awareness and education (Figures 25 and 26). The majority of the exotic species of concern have been listed in this report. Other exotic species on the move could be introduced to the riparians around Loch Erin through the use of a professionally developed educational newsletter such as the one distributed by the LEPOA.

Public boat launches are a primary area of vector transport for all invasive species and thus boat washing stations have become more common. With over 13 million registered boaters in the U.S. alone, the need for reducing transfer of aquatic invasive species (AIS) has never been greater. The Minnesota Sea Grant program identifies five major boat wash scenarios which include: 1) Permanent washing stations at launch sites, 2) Portable drive-thru or transient systems, 3) Commercial car washes, 4) Home washing, and 5) Mandatory vs. volunteer washing. Boat washing stations promote the Clean Waters Clean Boats volunteer education program by educating boaters to wash boating equipment (including trailers and bait buckets) before entry into every lake. Critical elements of this education include: 1) How to approach boaters, 2) Demonstration of effective boat and trailer inspections and cleaning techniques, 3) The recording of important information, 4) Identification of high-priority invasive species, and 5) Sharing findings with others. If a boat washing station is placed on Loch Erin, the LEPOA should work together to educate the public and lake users on proper cleaning techniques and other invasive species information. A "Landing Blitz" can be held once the station is in place and the public can be invited to a field demonstration of how to use the washing station. A typical boat washing station typically costs around \$15,000-\$20,000 but lower cost ones are available for private lakes with restricted access (e.g. hand-held sprayer units; Figure 27).

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

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

Figure 25. An aquatic invasive prevention sign for public access sites.

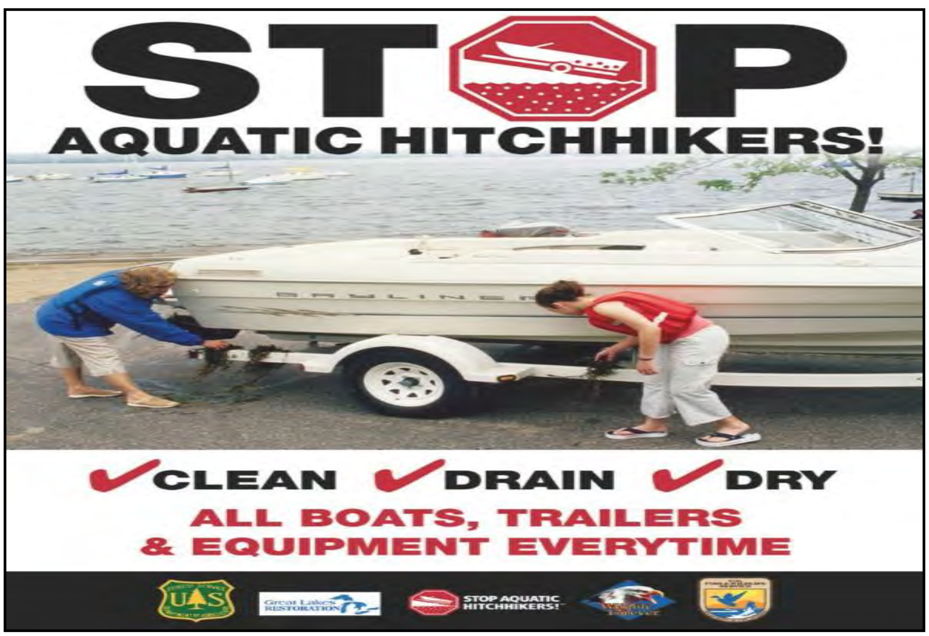


Figure 26. An aquatic invasive prevention sign for public access sites.

Figure 27. A public boat washing station for boat access sites.

Zebra Mussels

Zebra Mussels (*Dreissena polymorpha*; Figure 28) were first discovered in Lake St. Clair in 1988 and likely arrived in ballast water or on shipping vessels from Europe (McMahon 1996). They are easily transferred to other lakes because they inherit a larval (nearly microscopic) stage where they can easily avoid detection. The mussels then grow into the adult (shelled) form and attach to substrates (i.e. boats, rafts, docks, pipes, aquatic plants, and lake bottom sediments) with the use of byssal threads. The fecundity (reproductive rate) of female Zebra Mussels is high, with as many as 40,000 eggs laid per reproductive cycle and up to 1,000,000 in a single spawning season (Mackie and Schlosser 1996). Although the mussels only live 2-3 years, they are capable of great harm to aquatic environments. In particular, they have shown selective grazing capabilities by feeding on the preferred zooplankton food source (green algae) and expulsion of the non-preferred blue green algae (cyanobacteria). Additionally, they may decrease the abundance of beneficial diatoms in aquatic ecosystems (Holland 1993). Such declines in favorable algae, can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations. Zebra Mussels are viewed by some as beneficial to lakes due to their filtration capabilities and subsequent contributions to increased water clarity. However, such water clarity may allow other photosynthetic aquatic plants to grow to nuisance levels (Skubinna et *al*. 1995).

The recommended prevention protocols for introduction of zebra mussels includes steam-washing all boats, boat trailers, jet-skis, and floaters prior to placing them into Loch Erin. Fishing poles, lures, and other equipment used in other lakes (and especially the Great Lakes) should also be thoroughly steam-washed before use in Loch Erin. Additionally, all solid

construction materials (if recycled from other lakes) must also be steam-washed. Boat transom wells must always be steam-washed and emptied prior to entry into the lake.
Excessive waterfowl should also be discouraged from the lake since they are a natural transportation vector of the microscopic zebra mussel larvae or mature adults.

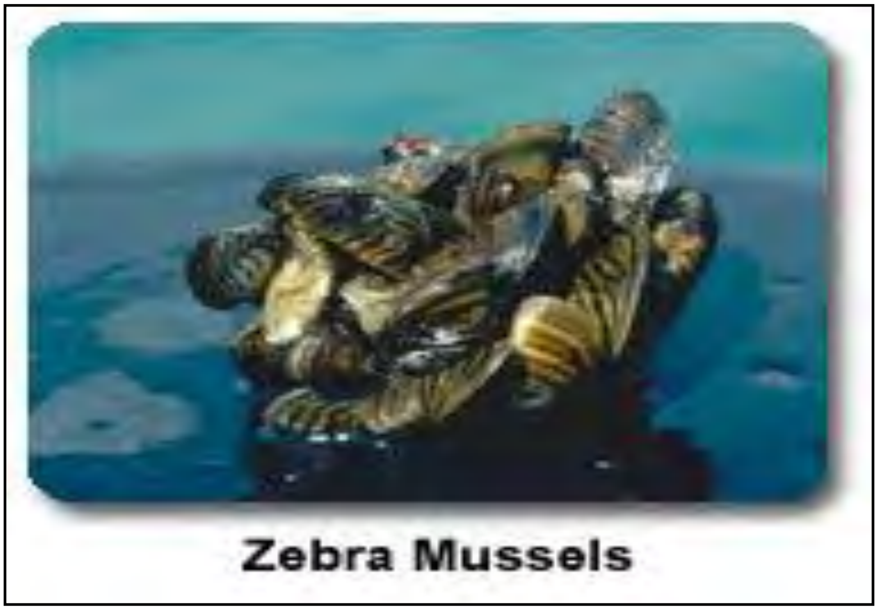


Figure 28. Zebra Mussels (Photo courtesy of USGS).

Invasive Aquatic Plants

In addition to Eurasian Watermilfoil (*M. spicatum*), many other invasive aquatic plant species have been introduced into waters of the North Temperate Zone. The majority of exotic aquatic plants do not depend on high water column nutrients for growth, as they are well-adapted to using sunlight and minimal nutrients for successful growth but excess nutrients often result in exacerbated growth. These species have similar detrimental impacts to lakes in that they decrease the quantity and abundance of native aquatic plants and associated macroinvertebrates and consequently alter the lake fishery. Such species include *Hydrilla verticillata* (Figure 29) and *Trapa natans* (Water Chestnut; Figure 30). *Hydrilla* was introduced to waters of the United States from Asia in 1960 (Blackburn et *al*. 1969) and is a highly problematic submersed, rooted, aquatic plant in tropical waters. Many years ago, *Hydrilla* was found in Lake Manitou (Indiana, USA) and the lake public access sites were immediately quarantined in an effort to eradicate it. *Hydrilla* retains many physiologically distinct reproductive strategies which allow it to colonize vast areas of water and to considerable depths, including fragmentation, tuber and turion formation, and seed production. Currently, the methods of control for *Hydrilla* include the use of chemical herbicides, rigorous mechanical harvesting, and Grass Carp (*Ctenopharyngodon idella* Val.), with some biological controls currently being researched.

Water Chestnut (*Trapa natans*) is a non-native, annual, submersed, rooted aquatic plant that was introduced into the United States in the 1870's yet may be found primarily in the northeastern states. The stems of this aquatic plant can reach lengths of 12-15 feet, while the floating leaves form a rosette on the lake surface. Seeds are produced in July and are extremely thick and hardy and may last for up to 12 years in the lake sediment. If stepped on, the seed pods may even cause deep puncture wounds to those who recreate on the lakes. Methods of control involve the use of mechanical removal and chemical herbicides. Biological controls are not yet available for the control of this aquatic plant.

Figure 29. Hydrilla from a Florida lake (RLS, 2012).

Figure 30. Water Chestnut from a northeastern lake (RLS, 2008).

5.1.2 Aquatic Herbicides and Applications

The use of aquatic chemical herbicides is regulated by the Michigan Department of Natural Resources and requires a permit. Aquatic herbicides are generally applied via an airboat or skiff equipped with mixing tanks and drop hoses (Figure 31). 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.

Figure 31. A boat used to apply aquatic herbicides in inland lakes (RLS, 2018).

Contact herbicides such as diquat, flumioxazin, and hydrothol cause damage to leaf and stem structures; whereas systemic herbicides are assimilated by the plant roots and are lethal to the entire plant. Wherever possible, it is preferred to use a systemic herbicide for longer-lasting aquatic plant control of invasives. In Loch Erin, the use of contact herbicides (such as diquat and flumioxazin) would not be recommended as the lake needs much more aquatic vegetation. Lily pads are the most abundant aquatic plant; however, they are serving as forage cover for the lake fishery and are critical for fishery protection and therefore should not be removed.

Algaecides should only be used on green algal blooms since many treatments can exacerbate blue-green algae blooms. The blue-green algae, *Microcystis* sp. was the most prevalent algae in the lake, which is an indicator of poor water quality (Figure 32). *Microcystis* colonies are a few micrometers in diameter and are evenly distributed throughout a gelatinous matrix. Younger colonies are spherical and older ones are more irregularly shaped. There are numerous gas vesicles and the algae can thrive at the surface with minimal photo-degradation (breaking down) by the sun. When the sunlight is excessive, the algae can break down and release toxins and lower the dissolved oxygen in the water column. The algae are the only type known to fix nitrogen gas into ammonia for growth. *Microcystis* has also been shown to overwinter in lake sediments (Fallon et *al.*, 1981). In addition, it may thrive in a mucilage layer with sediment bacteria that can release phosphorus under anaerobic conditions (Brunberg, 1995). They assume a high volume in the water column (Reynolds, 1984) compared to diatoms and other single-celled green algae. The blue-green algae have been on the planet nearly 2.15 billion years and have assumed strong adaptation mechanisms for survival. In general, calm surface conditions will facilitate enhanced growth of this type of algae since downward transport is reduced. *Microcystis* may also be toxic to zooplankton such as *Daphnia* which was a zooplankton present in Loch Erin and in most lakes (Nizan et *al.*, 1986). Without adequate grazers to reduce algae, especially blue greens, the blue-green population will continue to increase and create negative impacts to water bodies. Filamentous algae will also continue to increase in stagnant areas due to high nutrient levels in the lake. Algaecides are not recommended for algal control in Loch Erin as they often exacerbate growth of blue-green algae.

Figure 32. A late season algal bloom on a Michigan inland lake (©RLS).

Systemic herbicides such as 2, 4-D and triclopyr are the two primary systemic herbicides used to treat milfoil that occurs in a scattered distribution. Fluridone (trade name, SONAR®) is a systemic whole-lake herbicide treatment that is applied to the entire lake volume in the spring and is used for extensive infestations. The objective of a fluridone treatment is to selectively control the growth of milfoil in order to allow other native aquatic plants to germinate and create a more diverse aquatic plant community but this product is not needed in Loch Erin at this time due to the scarcity of milfoil, which at this time, is serving as some submersed aquatic vegetation cover. Milfoil should only be treated with granular triclopyr in nearshore areas and granular 2,4-D in offshore areas where the milfoil is present.

5.1.3 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 33). The mechanical harvester collects numerous loads of aquatic plants as they are cut near the lake bottom. The plants are off-loaded onto a conveyor and then into a dump truck. Harvested plants are then taken to an offsite landfill or farm where they can be used as fertilizer. Mechanical harvesting is preferred over chemical herbicides when primarily native aquatic plants exist, or when excessive amounts of plant biomass need to be removed.

Mechanical harvesting is usually not recommended for the removal of Eurasian Watermilfoil since the plant may fragment when cut and re-grow on the lake bottom. It may be considered in future years for removal of only dense lily pads in Loch Erin. However, those lily pads are urgently needed for fish cover.

Figure 33. A mechanical harvester used to remove aquatic plants (RLS, 2018).

5.1.4 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 34) or Weed Rollers (Figure 35) have been used to reduce weed growth in small areas such as in beach areas and around docks. The benthic mats are placed on the lake bottom in early spring prior to the germination of aquatic vegetation. They act to reduce germination of all aquatic plants and lead to a local area free of most aquatic vegetation. Benthic barriers may come in various sizes between 100-400 feet in length. They are anchored to the lake bottom to avoid becoming a navigation hazard. The cost of the barriers varies among vendors but can range from $100-$1,000 per mat. Benthic barrier mats can be purchased online at: www.lakemat.com or www.lakebottomblanket.com. The efficacy of benthic barrier mats has been studied by Laitala et *al.* (2012) who report a minimum of 75% reduction in invasive milfoil in the treatment areas. Lastly, benthic barrier mats should not be placed in areas where fishery spawning habitat is present and/or spawning activity is occurring.

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

Both methods are useful in recreational lakes such as Loch Erin and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth if it becomes prevalent in future years in beach areas only.

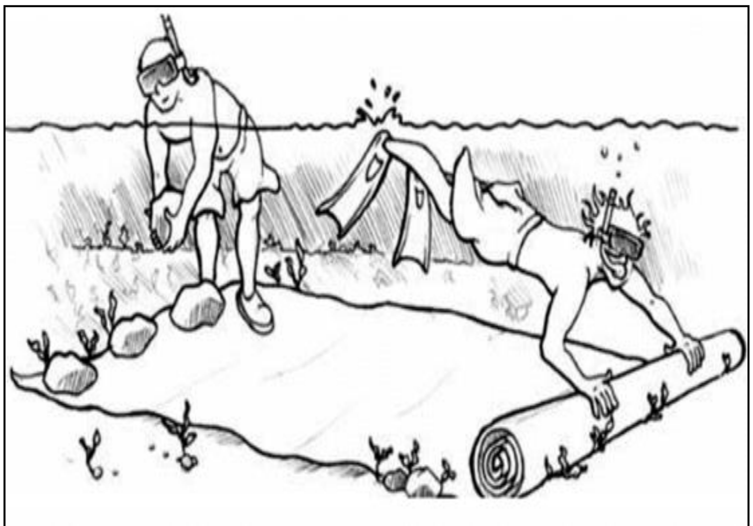


Figure 34. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.

Figure 35. A Weed Roller.

5.1.5 Diver Assisted Suction Harvesting (DASH)

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 36) involves hand removal of individual plants by a SCUBA diver in selected areas of lake bottom with the use of a hand-operated suction hose. Samples are dewatered on land or removed via fabric bags to an offsite location. This method is generally recommended for small (less than 1 acre) spot removal of vegetation since it is costly on a large scale. It may be used in the future to remove small areas of dense growth in shallow areas but is not recommended at this time due to a lack of cover. Furthermore, this activity may cause re-suspension of sediments (Nayar et *al*., 2007) which may lead to increased turbidity and reduced clarity of the water. This method is a sustainable option for removal of plant beds in beach areas and areas where herbicide treatments may be restricted or are not recommended.

Figure 36. A DASH boat used for aquatic plant removal (RLS, 2018).

5.2 Loch Erin Water Quality Improvements

In addition to lake improvement methods that improve the aquatic plant communities (both invasive and native), there are methods to improve the water quality within the lake basin. These methods are often large in scale and costly but are highly effective at increasing water clarity, reducing algae, increasing dissolved oxygen, reducing solids, and allowing for enhanced recreational activities.

5.2.1 Laminar Flow Aeration (LFA) and Bioaugmentation

Laminar flow aeration systems (Figure 37) are retrofitted to a particular site and account for variables such as water depth and volume, contours, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute dissolved oxygen throughout the lake sediments for efficient microbial utilization.

A laminar flow aeration (LFA) system utilizes diffusers which are powered by onshore air compressors.

The diffusers are connected via extensive self-sinking airlines which help to purge the lake sediment pore water of gases such as benthic carbon dioxide (CO_2) and hydrogen sulfide (H_2S). In addition to the placement of the diffuser units, the concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment. Beutel (2006) found that lake oxygenation eliminates release of NH_3+ from sediments through oxygenation of the sediment-water interface. Allen (2009) demonstrated that NH_3+ oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry wt day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt day^{-1} in controls. Although this is a relatively new area of research, recent case studies have shown promise on the positive impacts of laminar flow aeration systems on aquatic ecosystem management with respect to organic matter degradation and resultant increase in water depth, and rooted aquatic plant management in eutrophic ecosystems (Jermalowicz-Jones, 2010; 2011). Toetz (1981) found evidence of a decline in *Microcystis* algae (a toxin-producing blue-green algae) in Arbuckle Lake in Oklahoma. Other studies (Weiss and Breedlove, 1973; Malueg et *al.*, 1973) have also shown declines in overall algal biomass.

Conversely, a study by Engstrom and Wright (2002) found no significant differences between aerated and non-aerated lakes with respect to reduction in organic sediments. This study was however limited to one sediment core per lake and given the high degree of heterogeneous sediments in inland lakes may not have accurately represented the conditions present throughout much of the lake bottom. The philosophy and science behind the laminar flow aeration system is to reduce the organic matter layer in the sediment so that a significant amount of nutrient is removed from the sediments and excessive sediments are reduced to yield a greater water depth.

Benefits and Limitations of Laminar Flow Aeration

In addition to the reduction in toxic blue-green algae (such as *Microcystis* sp.) as described by Toetz (1981), aeration and bioaugmentation in combination have been shown to exhibit other benefits for the improvements of water bodies. Laing (1978) showed that a range of 49-82 cm of organic sediment was removed annually in a study of nine lakes which received aeration and bioaugmentation. It was further concluded that this sediment reduction was not due to re-distribution of sediments since samples were collected outside of the aeration "crater" that is usually formed. A study by Turcotte et *al*. (1988) analyzed the impacts of bioaugmentation on the growth of Eurasian Watermilfoil and found that during two four-month studies, the growth and re-generation of this plant was reduced significantly with little change in external nutrient loading. Currently, it is unknown whether the reduction of organic matter for rooting medium or the availability of nutrients for sustained growth is the critical growth limitation factor and these possibilities are being researched. A reduction of Eurasian Watermilfoil is desirable for protection of native plant biodiversity, recreation, water quality, and reduction of nutrients such as nitrogen and phosphorus upon decay (Ogwada et *al*., 1984).

Furthermore, bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979) so the concomitant addition of microbes to lake sediments will accelerate that process. A reduction in sediment organic matter would likely decrease Eurasian Watermilfoil growth as well as increase water depth and reduce the toxicity of ammonia nitrogen to overlying waters. A study by Verma and Dixit (2006) evaluated aeration systems in Lower Lake, Bhopal, India, and found that the aeration increased overall dissolved oxygen, and reduced biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total coliform counts.

The LFA system has some limitations including the inability to break down mineral sediments, the requirement of a constant Phase I electrical energy source to power the units, and possible unpredictable response by various species of rooted aquatic plants (currently being researched by RLS). Most of the sediments in Loch Erin are consolidated so muck reduction may be minimal. The largest benefit of LFA for Loch Erin would be the increase in water column dissolved oxygen which would reduce the release of phosphorus and also the reduction in blue-green algae which is critical. Aeration and bio augmentation have also been successfully used to reduce nuisance algal blooms, increase water clarity, and reduce water column nutrients and sedimentary ammonia nitrogen (RLS, 2009-2019, among others).

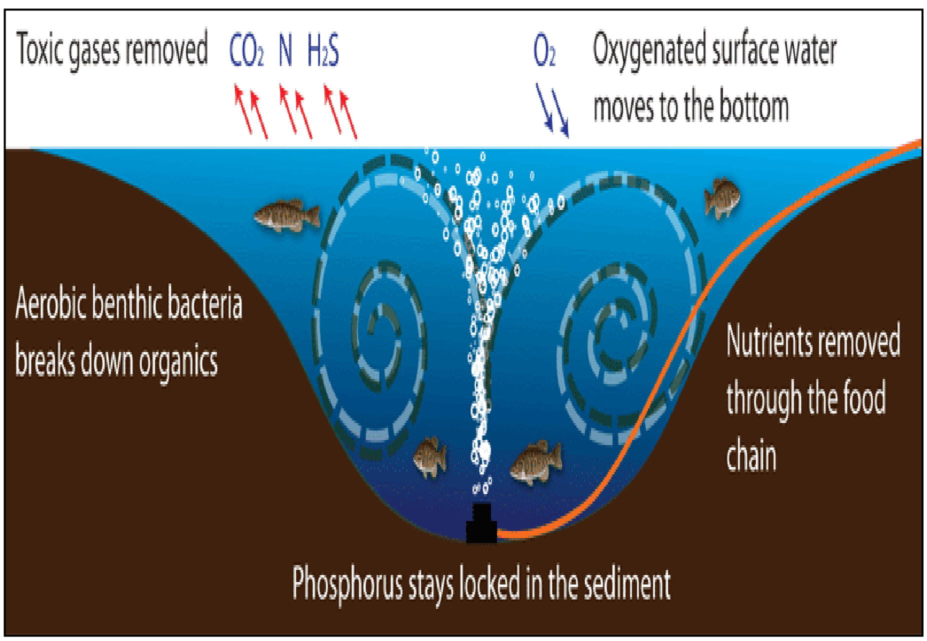


Figure 37. Diagram of laminar flow aeration. ©RLS

5.2.2 Nutrient Inactivation

There are a few products on the lake improvement market that aim to reduce phosphorus in the water column and the release of phosphorus from a lake bottom. Such products are usually applied as a slurry by a special dose-metered vessel to the water column or just above the lake bottom. Most of these formulas can be applied in aerobic (oxygenated) or anaerobic (oxygen-deficient) conditions. In lakes that lack ample dissolved oxygen at depth, this product may help prevent phosphorus release from the sediments. A few disadvantages include cost, inability to bind high concentrations of phosphorus especially in lakes that receive high external loads of phosphorus (i.e. lakes such as Loch Erin with a large catchment or watershed), and the addition of an aluminum floc to the lake sediments which may impact benthic macroinvertebrate diversity and relative abundance (Pilgrim and Brezonik, 2005). Some formulas utilize a clay base with the P-inactivating lanthanum (Phoslock®) which may reduce sediment toxicity of alum.

If this method is implemented, it is highly recommended that sampling the lake sediments for sediment pore water phosphorus concentrations be conducted to determine internal releases of phosphorus pre-alum and then monitoring post-alum implementation. Additionally, external phosphorus loads must be significantly reduced since these inputs would compromise phosphorus-inactivation formulas (Nürnberg, 2017).

Some recent case studies (Brattebo et *al*., 2017) are demonstrating favorable results with alum application in hypereutrophic waters that are also experiencing high external nutrient loads. At this time, a lake mixing technology would be preferred over application of alum since a higher dissolved oxygen concentration is desired throughout the water column and on the lake bottom to reduce internal release of phosphorus and also decrease blue-green algal blooms and increase water clarity while improving the zooplankton and benthic macroinvertebrate biodiversity.

5.2.3 Dredging

Dredging is a lake management option used to remove accumulated lake sediments to increase accessibility for navigation and recreational activities. Dredging is subject to permitting by the U.S. Army Corps of Engineers (USACE), and Michigan Department of Environment, Great Lakes, and Energy (EGLE). The two major types of dredging include hydraulic and mechanical. A mechanical dredge usually utilizes a backhoe and requires that the disposal site be adjacent to the lake (Figure 38). In contrast, a hydraulic dredge removes sediments in an aqueous slurry and the wetted sediments are transported through a hose to a confined disposal facility (CDF).

Selection of a particular dredging method and CDF should consider the environmental, economic, and technical aspects involved. The CDF must be chosen to maximize retention of solids and accommodate large quantities of water from the dewatering of sediments. It is imperative that hydraulic dredges have adequate pumping pressure which can be achieved by dredging in waters greater than 3 foot of depth.

Dredge spoils cannot usually be emptied into wetland habitats; therefore, a large upland area is needed for lakes that are surrounded by wetland habitats. Furthermore, this activity may cause re-suspension of sediments (Nayar et *al*., 2007) which may lead to increased turbidity and reduced clarity of the water. In addition, proposed sediment for removal must be tested for metal contaminants before being stored in a CDF. Dredging is a very costly operation with an average dredging cost of $28-40 per cubic yard. Dredging is not recommended for any areas in Loch Erin at this time but could be used in shallow bays (such as the northeast section of the lake) in the future if the water level becomes too low.

Figure 38. A mechanical dredge for sediment removal in inland waters.

5.2.4 Fishery Habitat Enhancement

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

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

To restore the natural features of lakeshores that provide fish habitat, a new approach replaces some or all lakeside lawns and beaches with native wildflowers, shrubs, grasses, and aquatic plants. A growing number of lakeshore owners are learning that restoring natural vegetation can cut maintenance costs, prevent unwanted pests such as Canada geese, attract butterflies and songbirds, and improve fish spawning habitat in shallow water. Preventing erosion and sedimentation around lakes is also important because excess sediment can smother fish eggs. Such a process as converting plowed land along the lake edge into grassy strips can filter runoff and stabilize banks. Vegetative plantings on steep banks can prevent erosion and excess nutrients from reaching the lake. Adding additional natural features such as boulders can also improve fish spawning habitat in a lake. In Minnesota's Lake Winni, more than 4.5 miles of the lakeshore has been reinforced since 1989 and Walleye are now spawning in the improved habitat. In addition, altering water levels in marshy areas used by northern pike for spawning can create more favorable conditions for reproduction.

Lake aeration can also improve fish populations. Every few winters, most or all fish in many shallow lakes die due to lack of oxygen. When plants die, they decompose and use up dissolved oxygen needed by fish. Adding oxygen to the lake using an aeration system can help prevent winterkill. Fish spawning habitat in many shallow lakes has been destroyed by Carp and Black Bullhead. These fish dig into the silty lake bottoms and stir up nutrient-laden sediment. The murky water blocks sunlight from reaching aquatic plants that stabilize the lake bottom and provide oxygen and habitat for game fish. Bluegill and Bass numbers have been shown to plummet while these fish species thrive. The sediment that carp and bullheads stir up is loaded with nutrients from surrounding farm fields. Nutrients and other contaminated runoff flow into lakes from distant farms, parking lots, streets, and lawns. The nutrients fuel blooms of algae, which, when they die, consume oxygen needed by fish and underwater insects.

A few specific fish species spawning habitat examples:

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

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

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

Impacts to Fish Spawning from Invasive Species:

Lyons (1989) studied how the assemblage of small littoral-zone fishes that inhabits Lake Mendota, Wisconsin has changed since 1900. A diverse assemblage that included several environmentally sensitive species has been replaced by an assemblage dominated by a single species, the Brook Silverside, whose abundance fluctuates dramatically from year to year.

Their decline was associated with the invasion and explosive increase in abundance of an exotic macrophyte, the Eurasian Watermilfoil (*Myriophyllum spicatum*), in the mid-1960's. Changes in the assemblage of small littoral-zone fishes in Lake Mendota indicate environmental degradation in the near shore area, and may have important implications for the entire fish community of the lake including fish spawning habitat availability.

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

Impacts from Natural Shoreline Degradation:

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

6.0 LOCH ERIN IMPROVEMENT PROJECT CONCLUSIONS & RECOMMENDATIONS

Loch Erin is facing significant issues that degrade water quality over time, including inputs of nutrients and solids from surrounding drains and tributaries. Fishery spawning habitat is becoming impaired by the addition of sediments to the lake and the increased BOD is resulting in a decline in dissolved oxygen with depth throughout the lake in some areas. The high nutrients have also led to increased blue-green algal blooms that may secrete toxins such as microcystins that are a public and pet health hazard and result in lake advisories. These algae also reduce light to aquatic plants and favor an algal-dominated state. The result of the overabundance of algae is higher turbidity, lower water clarity, and fewer aquatic plants (especially the native submersed types that cannot tolerate low light conditions). The quantities of nutrients and solids entering the lake are greater than the residual concentrations in the lake basins. Thus, the lake basin will continue to deteriorate unless drain/inlet improvements are made.

Improvements would include the assurance that all areas around the lake are vegetated at all times and with proper erosion stabilization techniques. RLS has recommended intensive BMP's for all three critical source areas (CSA's) that drain to the lake. This will allow for increased recreational use and navigational use of those areas and also lead to reduced sediment and nutrient loading to the lake over time. Some of these areas may require specialized drain filters and agribultural BMP's to slow the velocity of sediment particles before entering the lake.

Whole lake laminar flow aeration is recommended for the lake basin to continuously mix the water and result in increased clarity, dissolved oxygen, and reduced algal blooms. It may also help to improve the lake fishery and provide better algal food choices for the zooplankton and which are at the base of the lake food chain. In addition, regular additions of beneficial bacteria and enzymes (bioaugmentation) are recommended to increase breakdown of organic muck and help to clarify the lake water.

Furthermore, a professional limnologist/aquatic botanist should perform regular GPS-guided whole-lake surveys each spring and late summer/early fall to monitor the growth and distribution of all invasives and nuisance aquatic vegetation growth and recommend any possible treatmetns that may be needed. Continuous monitoring of the lake for potential influxes of other exotic aquatic plant genera (i.e. *Hydrilla*) that could also significantly disrupt the ecological stability of Loch Erin is critical. The lake manager should oversee all management activities and would be responsible for the creation of aquatic plant management survey maps, direction of the herbicide applicator to only target-specific areas of aquatic vegetation for removal, recommendations for implementation of watershed best management practices, administrative duties such as the processing of contractor invoices, and lake management education.

A complete list of recommended lake improvement options for this proposed lake management plan can be found in Table 18 below. It is important to coordinate these methods with objectives so that baseline conditions can be compared to post-treatment/management conditions once the methods have been implemented.

Table 18. List of Loch Erin proposed improvement methods with primary and secondary goals and locations for implementation.

Proposed Improvement Method	**Primary Goal**	**Secondary Goal**	**Where to Implement**
Systemic herbicide spot-treatments for ONLY invasives	Reduce only invasives in lake	Reduce long-term use of herbicides in lake and encourage balanced lake plant communities	Entire lake basin only where invasives present
Laminar flow aeration system/bioaug	Increase DO, reduce blue-green algae, increase water clarity	Reduce nutrients in the water column and sediment nutrient release	Entire lake
Bi-annual water quality monitoring of lake and drains (CSA's)	Monitor efficacy of BMP's implemented, including any aeration, drain filters, etc.	Compare baseline water quality and drain data to modern data to view trends for data-driven management	Entire Lake basin and all major drains (3 CSA's)
Annual lake surveys pre and post-treatment	To determine efficacy of herbicide treatments on invasives (only if needed)	To determine ability of native aquatic vegetation biodiversity to recover post-management implementation	Entire lake in areas where needed
Riparian/Community Education	To raise awareness of lake/drain issues and empower all to participate in lake protection	Long-term sustainability requires ongoing awareness and action	Entire lake community and those who frequent the lake; may also include relevant stakeholders

6.1 Cost Estimates for Loch Erin Improvements

The proposed lake improvement and management program for Loch Erin is recommended to begin as soon as possible. Since laminar flow aeration and bioaugmentation are likely to be the costliest improvements, it may be conducted over a period of five years or more to reduce annual cost. A breakdown of estimated costs associated with the various proposed treatments in Loch Erin is presented in Table 19. It should be noted that proposed costs are estimates and may change in response to changes in environmental conditions (i.e. increases in aquatic plant growth or distribution, or changes in herbicide costs). Note that this table is adaptive and is likely to change.

Table 19. Loch Erin proposed lake improvement program costs. NOTE: Items with asterisks are estimates only and are likely to change based on acquisition of formal quotes from qualified vendors.

Proposed Loch Erin Improvement Item	Year 1 Costs	Years 2-5 (Annual) Costs[4]
Systemic herbicides [1] for invasives; CLP treatment; Nuisance treatments	$2,000	$2,000
LFA System[2] (includes installation for first year; annual lease cost and electrical for each year as well as bioaugmentation and maintenance)	$TBD	$TBD
Drain filters[3] for drains Note: maintenance for future years	$10,000	$10,000
Professional services (limnologist management of lake, oversight, processing, education)[4]	$25,000	$25,000
Contingency[5]	$TBD	$TBD
Total Annual Estimated Cost	$TBD	$TBD

[1] Herbicide treatment scope may change annually due to changes in the distribution and/or abundance of aquatic plants.
[2] Aeration system is an estimate and will likely change with vendor proposals/costs. This is a rough number based on experiences with similar lakes.
[3]Drain filters include individual, retrofitted biologically activated filters for nutrient and solid reductions. In future years, maintenance of the filters will be required.
[4] Professional services includes comprehensive management of the lake with two annual GPS-guided, aquatic vegetation surveys, pre and post-treatment surveys for aquatic plant control methods, oversight and management of the aquatic plant control program and all management activities, all water quality monitoring and evaluation of all improvement methods, processing of all invoices from contractors and others billing for services related to the improvement program, education of local riparians through the development of a high-quality, scientific newsletter (can be coordinated with existing lake newsletter), and attendance at up to three regularly scheduled annual board meetings.
[5] Contingency is 10% of the total project cost, to assure that extra funds are available for unexpected expenses. Note: Contingency may be advised and/or needed for future treatment years. Contingency funds may also be used for other water quality improvements and watershed management.

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Part II. A Practical Immediate Watershed Management Plan for Loch Erin, Lenawee County, Michigan

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1.0 EXECUTIVE SUMMARY

There were a total of 4 Critical Source Areas (CSA's) around Loch Erin that could contribute nutrient and sediment loading to Loch Erin and impair water quality. These CSA's consist of: 1) CSA#1, 2) CSA#3, and 3) CSA#4. During sampling, the CSA's had measurable flow rates that ranged from 0.1-0.2 cubic feet per second (cfs) but this likely varies with time and precipitation events and further sampling of flow rates is encouraged.

Prioritization of improvement mitigation for problematic CSA's is possible through consideration of each site and the impaired water quality parameters. Water quality parameters such as water temperature and pH are less variable among CSA's; however, total phosphorus (TP), and total inorganic nitrogen (TIN), total suspended solids (TSS), and specific conductivity were highly variable among CSA's. The highest TP concentrations were measured in CSA #4. The highest TSS concentrations were measured in CSA #3. The highest TIN, nitrate, and ammonia concentrations were measured in CSA #1 and CSA #4. Additional ongoing data is recommended to determine trends over time, especially once these BMP's have been implemented. Site-specific Best Management Practices (BMP's) are offered in Section 6.0 of this report. Implementation of these BMP's with the CSA's should result in improved water quality in the CSA's and ultimately in Loch Erin.

2.0 WATERSHEDS AND LAKE HEALTH

A watershed may be defined as an area of land that drains to a common point and is influenced by surface water and groundwater resources that are impacted from land use activities. In general, a large watershed of a particular lake possesses more opportunities for pollutants to enter the system and alter water quality and ecological communities. In addition, watersheds that contain abundant development and industrial sites are more vulnerable to water quality degradation since the fate of pollutant transport may be increased and negatively affect surface waters and groundwater. Thus, land use activities have a dramatic impact on the quality of surface waters and groundwater. Engstrom and Wright (2002) cite the significant reduction in sediment flux of a lake which was attributed to substantial reduction of sediment loading from the surrounding catchment (immediate watershed). It is therefore important to practice sound watershed management to reduce sediment loads to lakes.

The topography of the land surrounding a lake may make it vulnerable to nutrient inputs and consequential loading over time. Steep slopes on the land surrounding a lake may cause surface runoff to enter the lake more readily than if the land surface was at grade relative to the lake. In addition, lakes with a steep drop-off may act as collection basins for the substances that are transported to the lake from the land. Many types of land use activities can influence the watershed of a particular lake. Such activities include residential, industrial, agricultural, water supply, wastewater treatment, and storm water management land uses.

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 (Figure 1), 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 land practices by vegetable crop and cattle farmers may contribute nutrient loads to lakes and streams through erosion or runoff. All land uses may contribute to the water quality of the lake through the influx of pollutants from non-point sources (NPS) 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 exit from pipes or input devices and empty directly into a lake or watercourse (Figure 2).

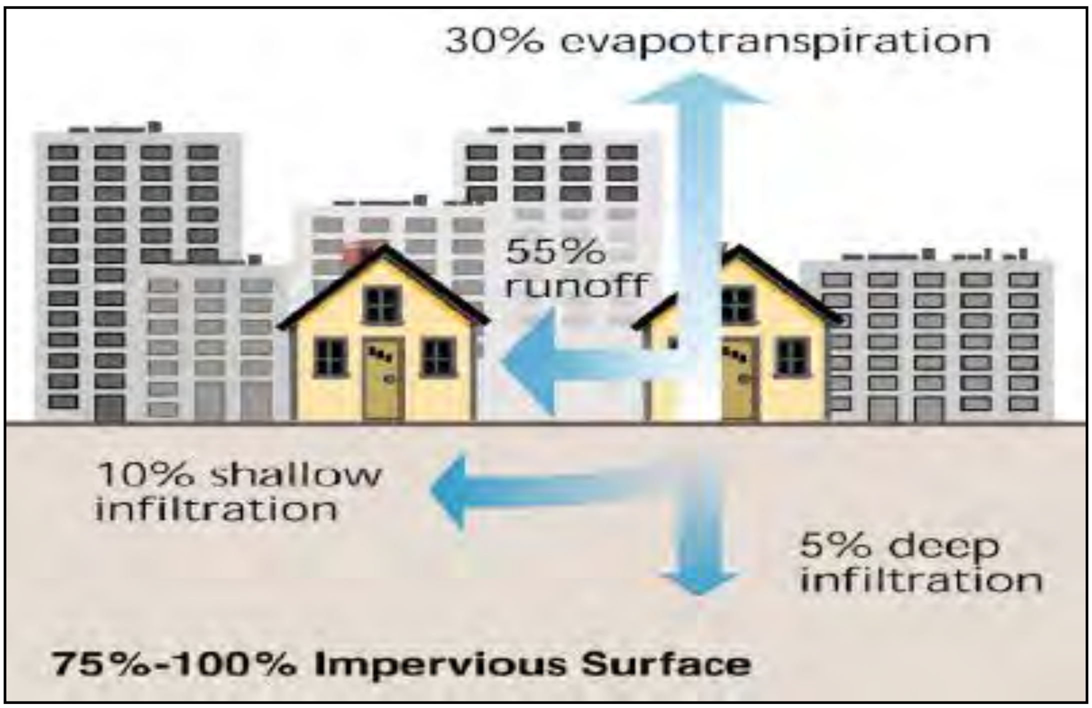

Figure 1. Impervious surfaces in a watershed.

Figure 2. A storm drain emptying a residential street that leads to a lake.

2.1 Maintaining a Healthy Lake Ecosystem:

A healthy aquatic ecosystem will possess a variety and abundance of niches (environmental habitats) available for all of its inhabitants. The distribution and abundance of preferable habitat will depend on limited influence from humans and development, and preservation of sensitive or rare habitats. As a result of this, undisturbed or protected areas generally contain a greater number of biological species and are thus more diverse. A highly diverse aquatic ecosystem is preferred over one with less diversity because it will allow a particular ecosystem to possess a greater number of functions and contribute to both the intrinsic and socio-economic values of the lake. A healthy lake will have a greater biodiversity of aquatic macroinvertebrates, aquatic macrophytes (plants), fishes, phytoplankton, and may possess a plentiful yet beneficial benthic microbial community (Wetzel, 2001). The benthos present on a lake bottom are critical components to the lake metabolism which also reduces the accumulation of organic muck. Loch Erin is subject to transport of sediment and nutrients that originate from the land and are carried into the lake after rain events as runoff. Furthermore, the lake is surrounding by plentiful agricultural lands that have been associated with increased nutrient loads to lakes (Detenbeck et *al.*, 1993). An immediate watershed evaluation allows for determination of significant pollutant sources and considers solutions that should result in water quality improvements (BMP's). It has been proven that lakes with a healthy biodiversity are more resilient, which means that they can bounce back after disturbances such as extreme climatic or pollution events (Walker, 1995). BMP's to increase this resilience are offered later in this report.

3.0 THE LOCH ERIN IMMEDIATE WATERSHED

A watershed (Figure 3) is defined as a region surrounding a lake that contributes water and nutrients to a waterbody through drainage sources. Watershed size differs greatly among lakes and also significantly impacts lake water quality. Large watersheds with much development, numerous impervious or paved surfaces, abundant storm water drain inputs, and surrounding agricultural lands, have the potential to contribute significant nutrient and pollution loads to aquatic ecosystems.

Figure 3. Example of a lake watershed (US EPA).

Loch Erin is located within the extended River Raisin watershed which includes the 135-mile long River Raisin and covers approximately 1, 072 square miles. The River Raisin originates in the Irish Hills area and flows east to Lake Erie at the town of Monroe. Many areas within this watershed demonstrate elevated E. coli bacteria, ammonia, and ortho-phosphorus (ECCSCM data; 2001-2018).

Major land uses in the extended watershed include agriculture, residential lands, forested lands, and wetlands. 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 Loch Erin community.

The immediate watershed (which is the area directly draining into the lake) is approximately 19,850 acres (based on LiDAR data) and 11,315 acres (based on topographic modeling data). This is about 34 times the size of the lake, which is very large. Thus, management options should also consider all of these land uses and preserve their unique functions. Erosion and drain influxes of soils and nutrients are the largest threat to the water quality of Loch Erin.

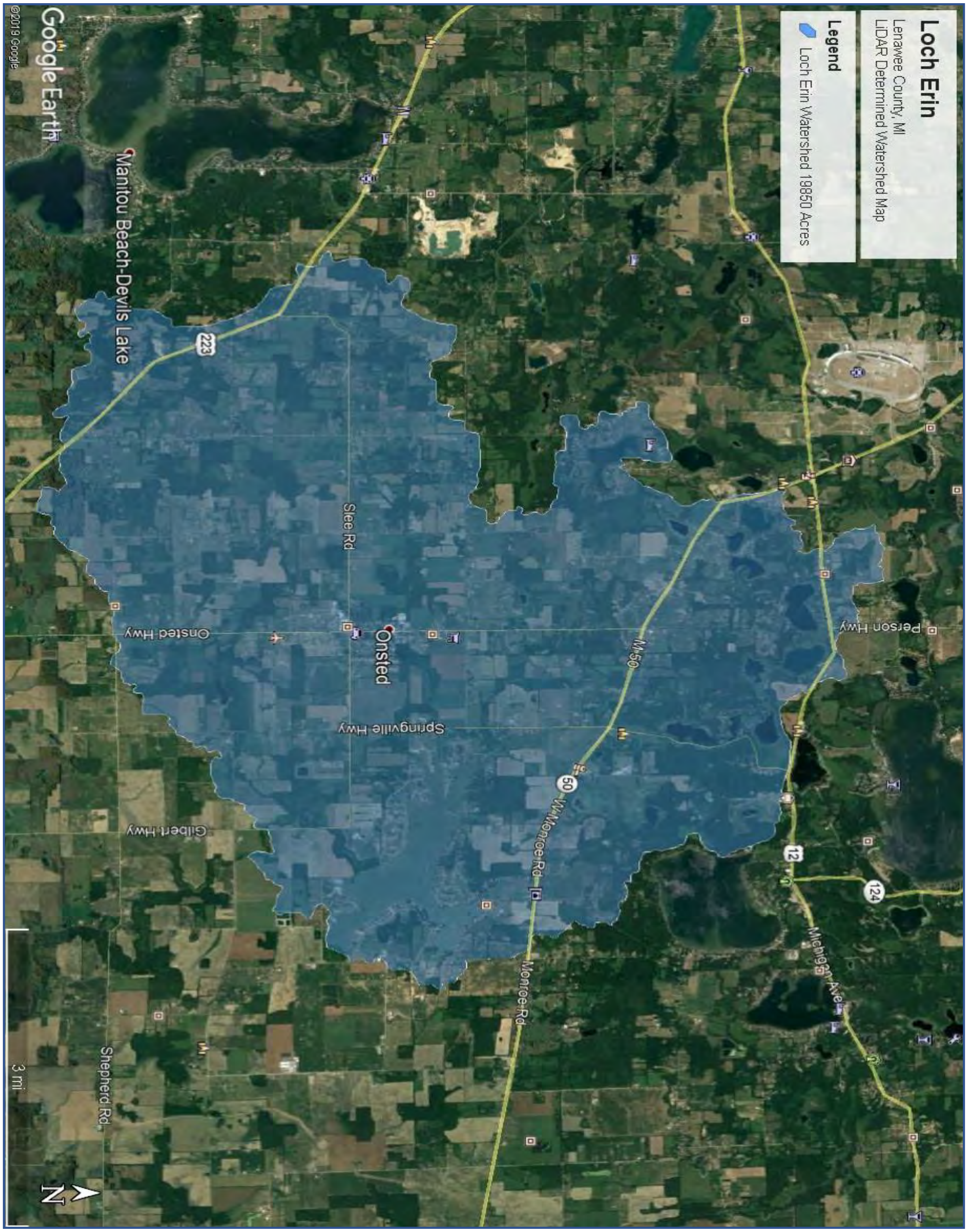

Figure 4. Loch Erin basin immediate watershed (RLS, 2019 with LiDAR data from EGLE).

Some of the areas around the lake are of high slope and are prone to erosion. Best Management Practices (BMP's) for water quality protection are offered in the watershed improvement section of this report.

There are 15 major soil types immediately surrounding the Basin of Loch Erin (Table 1) 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 Loch Erin. Major characteristics of the dominant soil types directly surrounding the Loch Erin shoreline are discussed below. The locations of each soil type are listed in Table 2 below.

Table 1. Loch Erin north basin shoreline soil types (USDA-NRCS data).

USDA-NRCS Soil Series	***Loch Erin North Basin Soil Type Location***
Blount loam; 0-2%	W shore
Blount loam; 2-6%	NE, SE shores
Brookston loam, overwashed; 0-3% slopes	NE, NW, S shores
Cadmus loam; 3-7% slopes	NW shore
Edwards muck; 0-3% slopes	N, NW shores
Griffin & Sloan sandy loams; 0-3% slopes	W shore
Houghton muck, disintegration moraine; 0-2% slopes	NW shore
Kokomo & Barry loams; 0-3% slopes	N, NW shores
Kokomo, Barry, & Wallkill loams, overwashed; 0-3% slopes	NE shore
Glynwood loam; 2-6% slopes	N, S, E shores
Glynwood loam; 2-6% slopes, eroded	NE, E, SE, W, NW shores
Morley loam; 12-25% slopes, moderately eroded	N shore
Morley soils; 7-15% slopes, severely eroded	E, SE, NE, N shores
Morley clay loam; 12-18% slopes, severely eroded	NE shore
Pewamo clay loam; 0-3% slopes	SE, S, W, N shores

The most common soils around the lake include the Glynwood loams, Morley soils, and Pewamo clay loams which are all capable of erosion given their higher slopes and ponding given the clay content.

The only saturated soils present included the Houghton mucks and the Edwards mucks located at the north and northwest regions of the lake. These soils are very deep, poorly drained soils with the potential for ponding. 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.

Figure 5. Loch Erin soil types around the lake shorelines (NRCS-USDA data).

Erosion Control/Shoreline Survey:

RLS conducted an initial survey of erosion around the Loch Erin shoreline on July 11, 2019. Although erosion was well controlled in most locations, the following section offers protection tips for riparians to implement as a few areas along the shoreline were noted where soils are not adequately stabilized. Man-made impoundments where water levels have been manipulated over time are especially prone to erosion. Erosion negatively impacts numerous resources including public use areas; water quality from the soils eroding into the lake; fisheries and wildlife habitat being diminished from both turbidity and a lack of suitable vegetative cover.

Fetch, the distance across a body of water to produce a wind-driven wave, ranges from less than ½ mile to nearly 2 miles in some cases, primarily from the south. Sustained westerly wind speeds could produce waves that are between 1.0-2.0-ft high. Shoreline bathymetry also plays a big part in determining the degree of erosion at a particular shoreline site. Sites with straight shorelines and exposed points that are exposed to long wind fetches from prevailing wind directions are vulnerable to more frequent and higher waves. Additionally, where the water deepens abruptly and there is less resistance or bottom roughness to influence the wave, exposed shorelines are susceptible to larger waves. Lastly, heavy human foot traffic and mowed areas, all contribute to substantial shoreline erosion in certain reaches of the lake. A loss of vegetative cover in these locations accelerates erosion and sedimentation.

These findings suggest that a combination of the above factors such as long fetches and high winds produce significant wave heights. Water manipulation and exposed shorelines with abrupt and deep lake depths adjacent to them contribute to substantial shoreline erosion. There is a wide range of erosion control methods that can be used in a cost-effective manner to address the shoreline erosion problems. Higher priority should go to sites where structures or amenities are threatened.

Figures 6-7 demonstrates how a shoreline without riprap or a seawall may appear with destabilized soils that can easily erode into the lake. This leads to increases turbidity of Loch Erin along with solids from the drains.

Figure 6. A photograph of a weakly stabilized shoreline on Loch Erin (RLS, 2019).

Figure 7. A photograph of a weakly stabilized shoreline on Loch Erin (RLS, 2019).

A larger watershed will generally allow for increased transport of pollutants, nutrients, or soils to a lake and is a major reason for the observed lower water clarity of Loch Erin. Responsible management of Loch Erin water quality is dependent upon within-lake (i.e. aquatic plant surveys and any needed aquatic herbicide treatments, etc.), and external (i.e. watershed BMP's) improvement methods. To address the sources of nutrient and sediment inputs to Loch Erin, recommendations for the minimization of non-point source pollutants to the lake are discussed later in this report in Section 4.0. These inputs have led to water quality degradation of Loch Erin and necessitated a thorough evaluation to determine the most likely Critical Source Areas (CSA's).

Critical Source Areas (CSA's) are defined as the most probable pollutant source(s) and were determined from within the immediate watershed and sampled or marked for future evaluation. Future mitigation efforts at the CSA sites will likely require cooperative relationships between lakefront owners, backlots, and farm and other property owners, and the Natural Resources Conservation Services (NRCS), or other relevant stakeholders (such as Watershed Conservation groups and the Lenawee County Health Department). These were identified through the use of multiple tools such as aerial maps, drain monitoring, and studying the flow of water from the land to the lake using LiDAR-based flow path models (Figure 8).

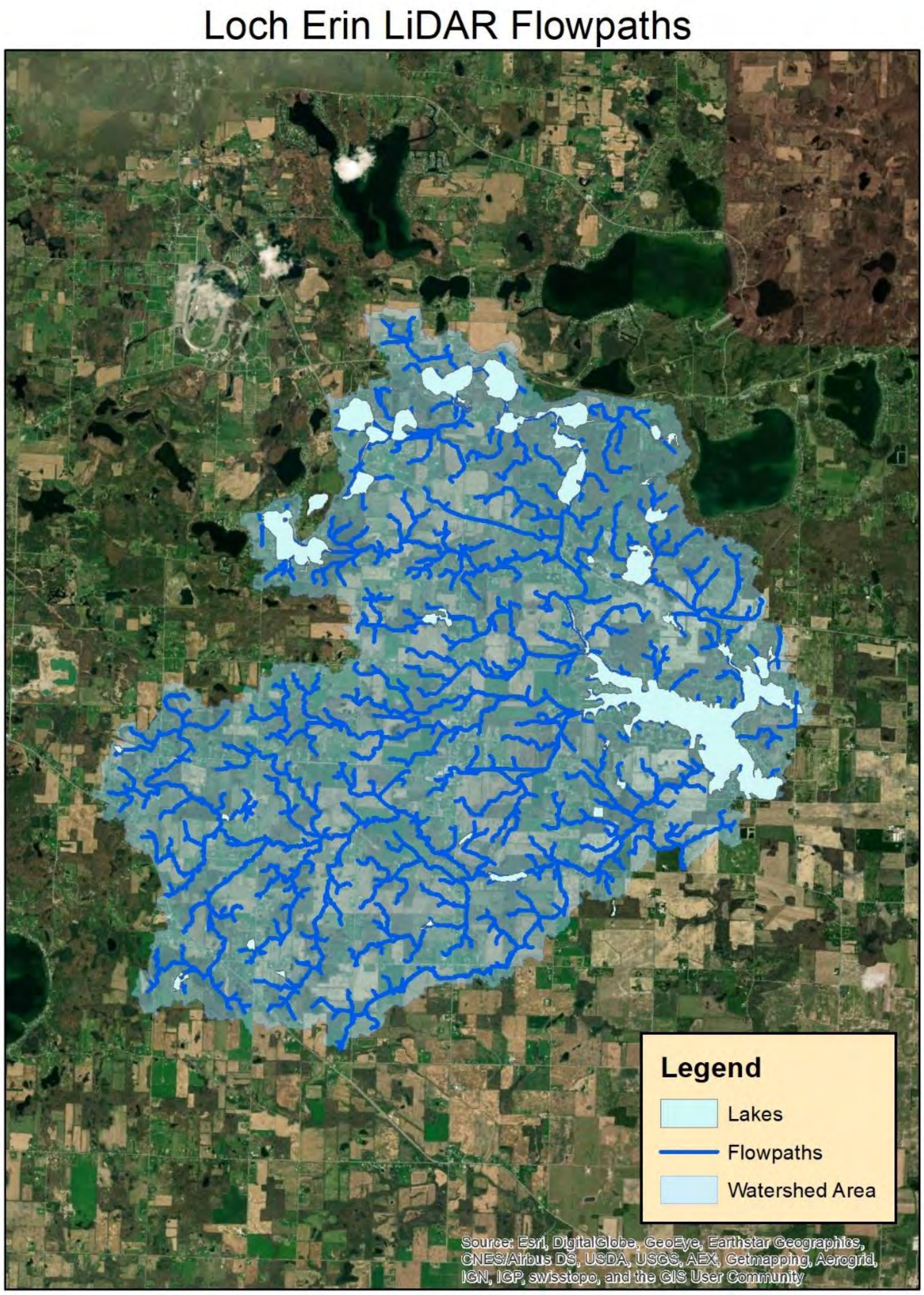

Figure 8. Loch Erin LiDAR-based flow map of the immediate watershed (RLS and EGLE, 2019).

4.0 LOCH ERIN CSA'S AND CSA WATER QUALITY DATA

Inland waters such as lakes provide multiple benefits to riparian communities and local municipalities through a variety of ecosystem services. Stynes (2002) estimated that Michigan's 11,000 inland lakes support a recreational industry that is valued at approximately 15 billion dollars per year. Inland lakes also provide economic and aesthetic values to riparian waterfront property owners with increased residential lot property values and scenic views. A survey of approximately 485 riparians that represented five lakes in Kalamazoo County, Michigan, USA, was conducted in 2002 by Lemberg et *al*. (2002) and revealed that the most important benefit of lakefront ownership was the vista. Thus, lakes clearly provide aesthetic as well as recreational benefits to riparians and those that use them.

For some time, lakes have been under continuous stress from surrounding development and land use activities. A major source of this stress includes the anthropogenic contributions of nutrients, sediments, and pathogens to the lake water from the surrounding landscape (Carpenter et *al*., 1998). Nutrients have caused critical water quality issues such as the inundation of lakes with dense, filamentous green algae, or worse, toxic blue-green algae (Figure 9). Submersed aquatic vegetation also increases with high levels of phosphorus (Figure 10) and leads to impedance of navigation and recreational activities, as well as decreases in water clarity and dissolved oxygen that lead to widespread fish kills. The existence of excess phosphorus in inland waterways has been well established by many scholars (Carpenter et *al*., 1998; Millennium Ecosystem Assessment, 2005, among numerous others). Major sources of phosphorus for inland waterways include fertilizers from riparian lawns, septic drain fields, and non-point source transport from agricultural activities in the vicinity of a water body. Non-point source effluents such as phosphorus are difficult to intercept due to the diffuse geographical dispersion across a large area of land. Additionally, watersheds generally export more non-point source loads relative to point source loads as a result of the reductions of point source pollution required by the Clean Water Act of 1972 (Nizeyimana et *al*., 1997; Morgan and Owens, 2001).

Figure 9. Toxic *Microcystis* blue-green algae on Spring Lake, Ottawa County, MI. Photo: Restorative Lake Sciences, 2009.

Figure 10. Nuisance aquatic plant growth in an inland Michigan lake. ©RLS

4.1 Regulation of Nutrient Pollution in Inland Lakes

The Michigan Department of Environmental Quality (MDEQ) regulates some activities through the Inland Lakes and Streams Program, pursuant to Part 301 of the Natural Resources Environmental Protection Act, P.A. 451 of 1994, as amended. Currently regulated activities include permits for shoreline improvements and beach alterations, wetland mitigation, and dredging. Non-point source pollutants from adjacent lands are loosely regulated, generally through the derivation of Total Maximum Daily Loads (TMDL's) pursuant to the federal Clean Water Act of 1972 (CWA) for water bodies that do not meet state Water Quality Standards (WQS). An initial goal of the CWA was to reduce the discharge of all pollutants into navigable waters by 1985. This goal was clearly not achieved and thus the policy was not as effective as previously assumed. A TMDL is the maximum amount of a specific pollutant a water body can absorb and still maintain good water quality. In Michigan, waters that do not meet WQS must be studied to determine the TMDL's for specific pollutants. Once the TMDL's are established for the water body by the MDEQ, they are submitted to the United States Environmental Protection Agency (EPA) for approval. Once approved, the TMDL's are implemented through the regulation of National Pollutant Discharge Elimination System (NPDES) permits for point source pollutants or through improvement programs for non-point source pollution. The WQS strive to maintain waters with acceptable dissolved oxygen concentrations for the fishery, suitable conditions for recreation, and the protection of high-quality waters. A primary problem with the current TMDL system is that sites need to be monitored frequently to determine what the TMDL should be and once determined, if the system is showing signs of improvement. Although the MDEQ maintains a current list of waters with TMDL's throughout the state, the impairments still exist on many water bodies (Jermalowicz-Jones, *unpublished data*). The monitoring frequency needed to obtain accurate information is often not executed and the runoff of phosphorus from farmland is often unmeasured and unknown. Furthermore, intense monitoring of agricultural non-point pollutant loads would be expensive and transaction costs associated with regulation policies would likely be high (Dosi and Zeitouni, 2001).

4.2 Measured Sources of Non-Point Source (NPS) Pollution to Loch Erin

RLS conducted an initial inventory of potential nutrient and pollutant sources to Loch Erin during the 2019 season. Areas that were identified are described below along with the specific detriments that may be contributed by each source.

4.2.1 Loch Erin Critical Source Areas (CSA's):

Non-point source (NPS) pollutants are diffuse and have many potential sources to inland lakes such as large agricultural land use activities that abut waterways and drain into Loch Erin. Once identified, these are referred to as critical source areas (CSA's) which are areas that contribute directly to the detriment of receiving waters. CSA's often generate substantially more nutrient and sediment loads than most of the immediate watershed area (White et *al*., 2009) and thus are a critical component for the discovery of target areas with highest impact on water quality. CSA's can contribute high loads of nutrients and sediments to inland waterways and often escape detection during lake management programs. In vulnerable areas, these pollutants enter lakes after a climatic event such as heavy rainfall or snowmelt. The surrounding landscape is critical for the determination of CSA's as some areas contain high slopes which increase the probability of erosion, while others contain soils that pond and contribute pollutants to the lake via runoff from the land. This information is critical to include in a watershed management program since Best Management Practices (BMP's) should be site-specific and address the pollutant loads at the site scale. Many BMP's will follow recommendations from Low Impact Development (LID) which aim to reduce the amount of imperviousness in developed areas. Since so many lake shorelines are already developed or are being further developed, the use of LID practices will help reduce runoff and protect water quality.

Critical Source Areas (CSA's) were determined based on characteristics that would likely contribute nutrient or sediment loads to Loch Erin, including: 1.) unfavorable soil types, 2.) high erosion areas and regions with steep slopes or other runoff characteristics, and 3.) areas that are likely to utilize high nutrient fertilizers (i.e. golf courses, large farms, drains, etc.) that may drain to the lake. A total of 3 CSA's were found in the immediate watershed around Loch Erin and are shown in Figure 11. Figures 12-14 show each CSA in detail and Figures 15-18 show the local (field) view of each CSA. Elder (1985) discusses the sink-source interactions between wetlands and rivers or other waterways. He cites timing and duration of flooding events as being the key predictors of nutrient and material transport from the wetland to the waterway. It is important to retain many of the wetland features, as any entry portals cut through the wetland (i.e., via cutting emergent cattails or other vegetation), may cause overland flow which could carry nutrients and sediments directly from wetlands into Loch Erin. Wetlands have been traditional for the treatment of storm water in that they filter out nutrients and sediments. However, during very intense rainfall events, the hydric (saturated) soils in the wetland may actually contribute nutrients to Loch Erin.

Figure 11. A map of the 3 CSA's around the Loch Erin immediate watershed (RLS, 2019).

CSA 1 –East Inlet (Figure 12)

This is a small inlet that runs under Donegal Drive which is approximately 170 feet east of the intersection of Kingsley Drive and Donegal Drive, running north to south. It has a flow rate measured in 2019 that ranged from 0.1-0.2 cfs. This inlet originates from tiled agricultural land up-drain. This drain contained the highest total dissolved solids and moderate total phosphorus but had very elevated nitrate nitrogen and total coliform. Potential BMP's include updrain agricultural best management practices and possibly nutrient-reduction filters near the drain entry to the lake or further updrain.

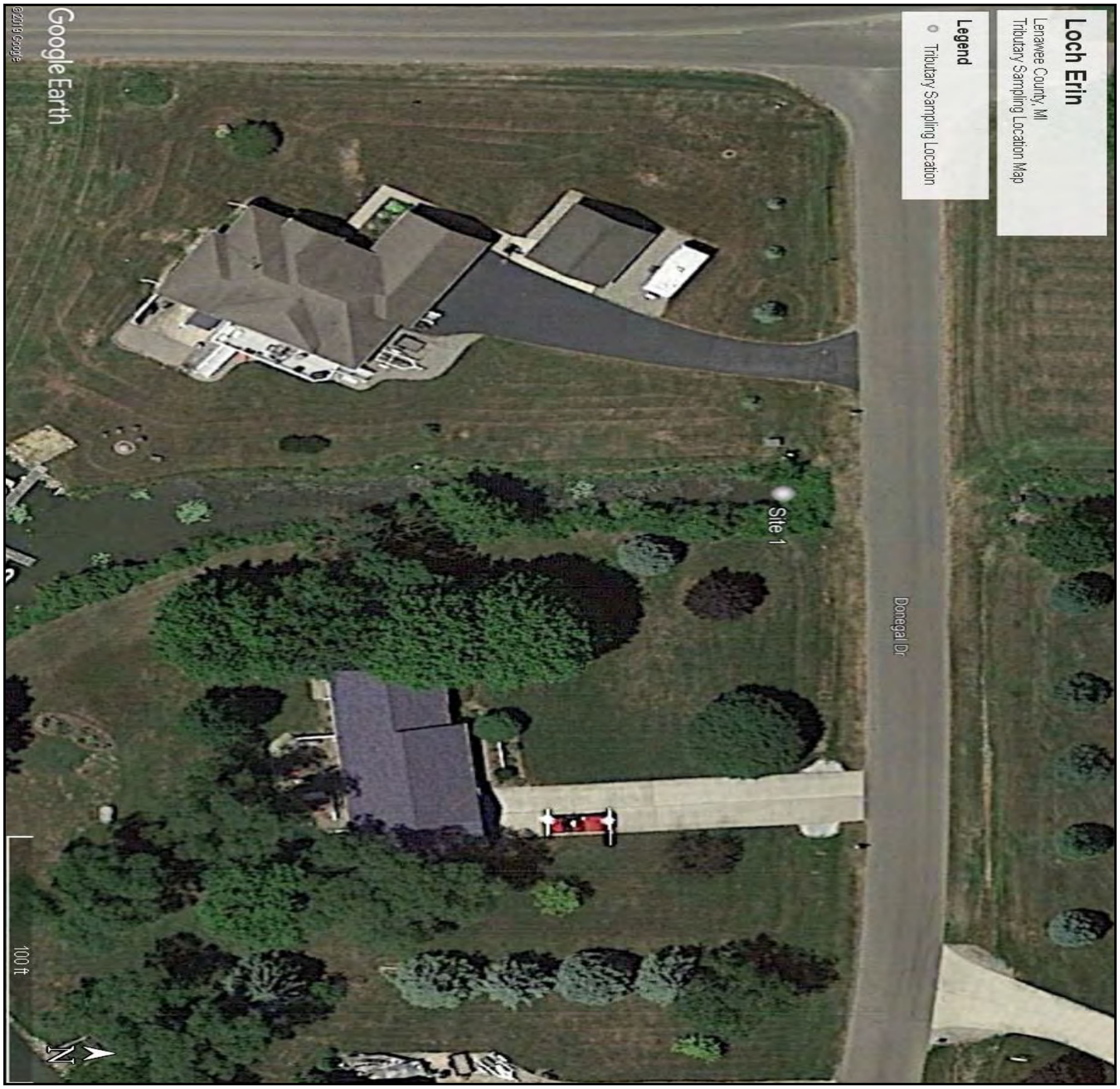

Figure 12. CSA #1 on the East shore of Loch Erin (RLS, 2019).

CSA 3 – West Inlet (Figure 13)

This drain is located approximately 450 feet north of the intersection of Castlebar Lane and Dalton road, running northeast. The approximate flow rate was around 0.2-0.3 cfs. This tributary is a combination of two separate drains that merge into one single drain just prior to entering the lake. The north drain originates in agricultural land with bordered forests and the south drain flows through forest and agricultural land just prior to entering the lake. This drain had very high total phosphorus in September and slightly elevated concentrations in October. The total coliform and E. coli bacteria counts were also very high. The total inorganic nitrogen was low but the total Kjeldahl nitrogen was elevated. BMP's should include reduction of bacteria and phosphorus from the upstream farms.

Figure 13. CSA #3 West Inlet near the west shore of Loch Erin (RLS, 2019).

CSA 4 – North Inlet (Figure 14)

This drain is located on Stephenson Road, approximately 0.45 miles east of the intersection of Stephenson road and Springville Highway, running northwest to southeast. The approximate flow rate was around 0.2 cfs. Sampling the flow at Springville Highway may yield more information about flow rates since they slow down prior to entering the lake and these values may yield more insight to nutrient loading. This tributary had elevated total dissolved solids and total phosphorus and nitrate nitrogen. BMP's would include agricultural improvements to reduce the entry of nutrients into the drain prior to entering the lake.

Figure 14. CSA #4 North Inlet on northwest shore of Loch Erin (RLS, 2019).

Figure 15. CSA #1 (land side).

Figure 16. CSA #3 (lake side).

Figure 17. CSA #3 (land side).

Figure 18. CSA #4 (lake side).

4.2.2 Loch Erin CSA Water Quality Data

RLS collected water quality samples from Loch Erin in 2019 and has characterized the lake as hyper-eutrophic. However, recent evidence suggests that the CSA's around the lake are contributing nutrient and solid loads to the lake which could lead to water quality degradation over time if these areas are not identified and mitigated. RLS has identified the sites and the data is presented here.

Water quality is highly variable among the CSA's and this variability is due to 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.

CSA Water Quality Parameters Measured:

Water quality parameters such as dissolved oxygen, water temperature, pH, specific conductivity, total dissolved solids, total suspended solids, total phosphorus, ortho-phosphorus, total inorganic nitrogen (specifically ammonia, nitrate, and nitrite), and total Kjeldahl nitrogen were measured at each of the CSA areas under flowing conditions. Samples consisted of preserved grab bottles which were placed on ice and transported to the NELAC-certified laboratory for analysis. The data for the CSA's are discussed below and are presented in Tables 2-9 below. Samples and water quality measurements were collected on September 12, 2019 and October 21, 2019 by RLS and May 10, 2019, May 21, 2019, July 22, 2019, July 23, 2019, and August 7, 2019 by LEPOA. Measurements collected on September 12, 2019 and October 21, 2019 by RLS were taken with a calibrated Eureka Manta II® multi-parameter probe and those collected by LEPOA with a calibrated YSI meter. Laboratory samples collected by RLS were taken to NELAC-certified laboratory, TRACE Analytical.

Loch Erin CSA Site	***Water Temp ºC***	***DO mg/L***	***pH S.U.***	***Cond. µS/cm***	***TDS mg/L***
CSA #1	19.9	7.5	7.9	478	306
CSA #3	22.9	6.3	7.9	517	333
CSA#4	17.3	8.1	8.1	920	590

Table 2. Loch Erin CSA physical water quality parameter data collected on September 12, 2019.

Loch Erin CSA Site	***Total Coliform (CFU/100 ml)***	***E. coli CFU/100 ml***	***TKN mg/L***	***TP mg/L***	***TSS mg/L***
CSA #1	TNTC	600	0.5	0.045	<10
CSA #3	TNTC	1600	1.0	0.130	20
CSA#4	TNTC	300	1.0	0.092	<10

Table 3. Loch Erin CSA chemical water quality parameter data collected on September 12, 2019.

Loch Erin CSA Site	***Water Temp ºC***	***DO mg/L***	***pH S.U.***	***Cond. µS/cm***	***TDS mg/L***	***Chl-a µg/L***
CSA #1	13.2	9.5	7.8	974	635	3.0
CSA #3	12.0	9.8	8.4	716	464	19.0
CSA#4	12.3	9.7	8.2	532	340	21.0

Table 4. Loch Erin CSA physical water quality parameter data collected on October 21, 2019.

Loch Erin CSA Site	*NO2 mg/L*	*NO3 mg/L*	*NH3 mg/L*	*TIN mg/L*	*TKN mg/L*	*SRP mg/L*	*TP mg/L*
CSA #1	<0.10	0.810	0.120	0.930	0.9	<0.010	0.051
CSA #3	<0.10	<0.10	0.046	0.046	1.4	<0.010	0.039
CSA #4	<0.10	0.430	0.035	0.470	0.8	<0.010	0.052

Table 5. Loch Erin CSA chemical water quality parameter data collected on October 21, 2019.

Table 6. Mean of all water quality parameters in the CSA's of Loch Erin for parameters collected on September 12, 2019 and October 21, 2019.

Water Quality Parameter	**CSA #1**	**CSA #3**	**CSA #4**
Water temp (°C)	16.7	17.5	14.7
pH (S.U.)	7.7	8.2	8.1
Dissolved oxygen (mg/L)	8.5	8.1	8.9
Conductivity (mS/cm)	726	617	726
Total dissolved solids (mg/L)	471	399	465
Total Kjeldahl nitrogen (mg/L)	0.7	1.2	0.9
Total inorganic nitrogen (mg/L)	0.930	0.046	0.470
Ammonia nitrogen (mg/L)	0.120	0.046	0.035
Nitrate nitrogen (mg/L)	0.810	<0.10	0.430
Nitrite nitrogen (mg/L)	<0.10	<0.10	<0.10
Total phosphorus (mg/L)	0.051	0.039	0.052
Ortho-Phosphorus (mg/L)	<0.010	<0.010	<0.010
Total suspended solids (mg/L)	<10	20	<10

Table 7. Loch Erin Tributary Data collected 5-20-19 & 5-21-19.

Site & Location	E. Coli	Temp (ºC)	DO (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	TP (mg/l)	NH_3 (mg/l)
3: Onstead Creek (Castlebar Dr.)	774.6	13.2	8.6	1.0	0	0.1	0.14
4: Wolf Creek Inlet (Stephenson Rd.)	160.7	14.5	7.9	0	0	0.7	0.03
5: Unnamed Tributary (Springville Rd.)	155.9	13.4	9.3	1.5	0	0.05	0.05
6: Wolf Creek (Springville Rd. North)	308.4	16.2	7.84	0	0	0.08	0.11
7: Boat Ramp Dock (Kingsley Dr.)	29.5	15.9	8.75	0	0	0.08	0.03
8: Galway Park (Kingsley Dr.)	0.2	15.9	8.7	0	0	0.07	0.03
9: Daniels Park (O'Dowling Dr.)	0.3	15.7	8.25	0	0	0.07	0.03
10: Loch Erin Exit (Gilbert Rd.)	64.3	16.5	8.8	0.5	0	0.07	0.03
14: Springville Rd. North (Slee Rd.)	1017.3	11.9	8.99	2	0	0.07	0.04
100: Drain 7801 (Norfolk Rd.)	83.7	12.1	2.5	0	0	0.1	0.1

Table 8. Loch Erin Tributary Data collected 7-22- 19 & 7-23-19.

Site & Location	E. Coli	Temp (ºC)	DO (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	PO_4 (mg/l)	TP (mg/l)	NH_3 (mg/l)
1: Geddes Drain (Donegal Dr.)		15.5	6.3	2	0	0.02	0.03	0.24
4: Wolf Creek Inlet (Stephenson Rd.)	235.1	24.5	5.67	0	0	0.05	0.11	0.11
5: Unnamed Tributary (Springville Rd.)	2419.6	16.8	9.45	0	0	0.08	0.12	0.12
6: Wolf Creek (Springville Rd. North)	2419.6	22.6	5.6	0	0	0.29	0.34	0.34
7: Boat Ramp Dock (Kingsley Dr.)	10.4	25.9	5.12	0	0	0.05	0.09	0.09
8: Galway Park (Kingsley Dr.)	21.9	25.9	5.46	0	0	0.02	0.1	0.09
10: Loch Erin Exit (Gilbert Rd.)	27.6	18.7	7.33	0	0	0.05	0.09	0.1
12: Chisholm Rd Bridge (Chisholm Rd.)	80.5	27.8	4.77	0	0	0	0.02	0.03
14: Springville Rd. North (Slee Rd.)	1986.3	16.3	8.16	0	0	0.04	0.05	0.06
15: Onstead Creek (Springville /Dalton)	2419.6	18.4	8.41	0	0	0.11	0.13	0.06

Table 9. Loch Erin Tributary Data collected 8-7-19.

Site & Location	Temp (ºC)	DO (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	PO_4 (mg/l)	NH_3 (mg/l)
6: Wolf Creek (Springville Rd. North)	22.3	7.11	0	0	10	0.15
14: Springville Rd. North (Slee Rd.)	16.5	8.56	2	0	10	0.25
15: Onstead Creek (Springville/ Dalton	18.3	8.42	2	0	15	0.25

5.0 Other Non-Point Source Inputs

5.1 Nutrient Shifts and Reduction

The control of nutrients from a surrounding watershed or catchment to any lake is a proven necessity for long-term nutrient reduction. Although nutrients are a necessity for the primary production of algae and aquatic plants in a lake ecosystem, an overabundance of nutrients causes substantial problems as noted above. Lakes that lie within an agricultural watershed may experience acute and chronic influx of sediments, nutrients, and bacteria, among other pollutants. Those within urbanized watersheds face other stressors that include nutrient pollution but also influx of metals, dissolved solids, among other pollutants. In many areas, however, the watershed reduction approach is limited, and restorative measures must begin within the lake basin. Annadotter et *al*., (1999) noted that even years after a sewage treatment plant was built along the shores of Lake Finjasjön (Sweden), the lake trophic status continued to decline. This was due to the existence of sediments that continuously leaked phosphorus into the overlying waters. A combination of intensive lake restoration methods was needed to significantly improve the water quality and consisted of sediment removal, constructed wetlands for watershed nutrient removal, and food web manipulation to improve the fishery. Their study proved that in cases of extreme water quality degradation, multiple techniques are often needed to bring a marked balance back to the lake ecosystem. In other words, one solution may not be enough to accomplish restoration.

5.2 Impacts of NPS Pollution on Inland Waters:

Beginning in 2007 and continuing to the present day, the USEPA Office of Water and Office of Research and Development has partnered with multiple stakeholders at both the state and federal levels to derive comparisons among the nation's aquatic resources which include lakes, wadable streams, large rivers, coastal estuaries, and wetlands. During the assessment, 1,028 lakes have been sampled along with 124 reference lakes and 100 lakes which were re-sampled. Lakes were selected from the National Hydrography Data Set (NHD) using a set of criteria that addressed trophic status, locale, and physical characteristics. Water quality indicators such as biological integrity, habitat quality, trophic status, chemical stressors, pathogens, and paleolimnological changes were measured. Although 56% of the nation's lakes possessed healthy biological communities, approximately 30% of lakes had the toxin Microcystin, which is produced by the blue-green algae *Microcystis*. This was also the case for Loch Erin.

Approximately 49% of the lakes had mercury concentrations in fish tissues that exceeded healthy limits. The key stressors of the lakes were determined to be poor shoreline habitat and excessive nutrients. A favorable outcome of the inventory revealed that half of the lakes exhibited declines in phosphorus levels compared to levels noted in the early 1970's. Despite this observed decline, many of our inland lakes continue to experience degradations in water quality. One reason for this problem is that many lakes have properties that utilize septic systems. Since riparians have little control over local pollutant loading from agriculture to inland lakes, the maintenance of septic systems is critical for water quality protection.

6.0 REDUCTION OF NPS IN INLAND LAKES

There are several different methods available to reduce the threat of NPS pollution to inland lakes and each are able to be site-specific. The following sections offer many of these methods with specific applications to the individual areas (CSA's) that are contributing significant solids and nutrient loads to Loch Erin.

6.1 Best Management Practices (BMPs)

The increased developmental pressures and usage of aquatic ecosystems necessitate inland lake management practices as well as watershed Best Management Practices (BMP's) to restore balance within the Loch Erin. For optimum results, BMP's should be site-specific and tailored directly to the impaired area (Maguire et *al.*, 2009). Best Management Practices (BMP's) can be implemented to improve a lake's water quality. The guidebook, Lakescaping for Wildlife and Water Quality (Henderson et *al*. 1998) provides the following guidelines:

1) Maintenance of brush cover on lands with steep slopes (>6% slope)
2) Development of a vegetation buffer zone 25-30 feet from the land-water interface with approximately 60-80% of the shoreline bordered with vegetation
3) Limiting boat traffic and boat size to reduce wave energy and thus erosion potential
4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion
5) Using only <u>native</u> genotype plants (those native to a particular lake and region) around the lake since they are most likely to establish and thrive than those not acclimated to growing in the area soils
6) Avoid the use of lawn fertilizers that contain phosphorus (P). P is the main nutrient required for aquatic plant and algae growth, and plants grow in excess when P is abundant. When possible, water lawns with lake water that usually contains adequate P for successful lawn growth. If you must fertilize your lawn, assure that the middle number on the bag of fertilizer reads "0" to denote the absence of P. If possible, also use low N in the fertilizer or use lake water.
7) Preserve riparian vegetation buffers around a lake (such as those that consist of Cattails, Bulrushes, and Swamp Loosestrife), since they act as a filter to catch nutrients and pollutants that occur on land and may run off into a lake. As an additional bonus, Canada geese (*Branta canadensis*) usually do not prefer lakefront lawns with dense riparian vegetation because they are concerned about the potential of hidden predators within the vegetation. Figure 19 demonstrates a lakefront property with poor management of the shoreline.

Figure 19. An example of poor shoreline management with no vegetation buffer present. ©RLS

8) Do not burn leaves near the lake shoreline since the ash is a high source of P. The ash is lightweight and may become airborne and land in the water eventually becoming dissolved and utilized by aquatic vegetation and algae.
9) Assure that all areas that drain to a lake from the surrounding land are vegetated and that no fertilizers are used in areas with saturated soils.
10) The construction of impervious surfaces (i.e. paved roads and walkways, houses) should be minimized and kept at least 100 feet from the lakefront shoreline to reduce surface runoff potential. In addition, any wetland areas around a lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat. Construction practices near the lakeshore should minimize the chances for erosion and sedimentation by keeping land areas adjacent to the water stabilized with rock, vegetation, or wood retaining walls. This is especially critical in areas that contain land slopes greater than 6%.
11) In areas where the shoreline contains metal or concrete seawalls, placement of natural vegetation or tall emergent plants around the shoreline is encouraged. Erosion of soils into the water may lead to increased turbidity and nutrient loading to a lake. Seawalls should consist of riprap (stone, rock), rather than metal, due to the fact that riprap offers a more favorable habitat for lakeshore organisms, which are critical to the ecological balance of the lake ecosystem. Riprap should be installed in front of areas where metal seawalls are currently in use. The riprap should extend into the water to create a presence of microhabitats for enhanced biodiversity of the aquatic organisms within a lake. The emergent aquatic plants such as Arrowhead or Cattails present around the lake may offer satisfactory

stabilization of shoreline sediments and assist in the minimization of sediment release into a lake.

Best Management Practices (BMPs) are land management practices that treat, prevent, or reduce water pollution. Structural BMPs are physical improvements that require construction during installation. Examples of structural BMPs include check dams, detention basins, and rock riprap. BMPs that utilize plants to stabilize soils, filter runoff, or slow water velocity are categorized as Vegetative BMPs. Managerial BMPs involve changing operating procedures to lessen water quality impairments. Conservation tillage and adoption of ordinances are examples of these types of BMPs. For inland lakes, the emphasis should be on BMPs that are designed to reduce storm water volume, peak flows, and/or nonpoint source pollution through proper storm water management and erosion control practices. Below is a summary of BMPs that are designed to meet these requirements. Identifying opportunities for implementation of BMPs is based on several factors including stakeholder willingness/preferences, cost, time, and effectiveness of specific management options. Table 10 lists commonly used BMP’s associated with improved water quality.

Table 10. Common BMP's used for water quality protection.

BMPs	Type	Description
A. Vegetated Buffer Strips and Conservation Areas 	**Vegetative**	• Establish and maintain vegetative cover in areas adjacent to ecologically sensitive water features. • Filters sediment and pollutant from runoff. • Vegetation dissipates the energy of flowing water. • Improves water quality in a more natural manner and maintains habitat.
B. Brush Bundles and Live Staking 	**Vegetative**	• Provides protection for stream banks and shorelines against erosion. • Vegetation dissipates the energy of flowing water. • Plants take-up nutrients in the soil, reducing the amount that can enter a lake. • Improves water quality in a more natural manner and maintains habitat.
C. Critical Area Planting 	**Vegetative**	• Planting vegetation on highly erodible or critically eroding areas to protect water quality. • Quickly reduces the movement of soil into storm water runoff. • Plants take-up nutrients in the soil, reducing the amount that can enter a lake. • Improves water quality in a more natural manner and maintains habitat.

D. Retention/Detention Ponds and Constructed Wetlands 	**Structural**	• Controls storm water runoff volume through constructed storage and infiltration basins. • Improves water quality by reducing erosion and preventing flooding. • Helps stabilize lake level fluctuations. • Naturally bio filters storm water runoff more efficiently than commercial filter systems.
E. Armored Protection/Rip Rap 	**Structural**	• Protects shoreline, river and stream structures from water and ice erosion. • Absorbs wave energy and protects against ice damage for bridge supports, sea walls, housing structures and roadways.
F. Low Impact Development (LID) and Green Infrastructure 	**Structural**	• Designed to integrate green space, native landscaping and passive storm water treatment into commercial and residential communities. • Less costly and more efficient at reducing storm water pollution. • Includes bio filtration systems, rainwater harvesting, and porous pavement.
G. Tributary Filter Strips 	**Structural**	• Provides point-source pollution reduction. • Reduces TSS and phosphorus loads in drains/culverts

H. Storm water Infrastructure Maintenance 	**Managerial**	• Helps maintain the design capacity and control of runoff, sediment and other pollutants. • Prevents failures and ensures long-lasting usage. • Provides documentation and system tracking.
I. Storm water Pollution Prevention Plans and Local Ordinances 	**Managerial**	• Community level initiatives to identify and prevent storm water pollution. • Detailed documentation that guides landowners and regulatory agencies to operate and comply under specific conditions.

When choosing a BMP, advantages and disadvantages must be weighed against physical site constraints, management goals, and costs. The physical characteristics of a specific site makes some BMPs more beneficial than others. In fully developed areas or on small sites, the use of BMPs that require a lot of land, such as ponds and basins, may not be practical. Vegetative BMPs may not be suitable for some sites due to space limitations and economic restrictions. BMP maintenance can be implemented by watershed/conservation districts, local governments, homeowner/lake associations, or the private sector. Local ordinances are the most common method used to control the operation of storm water systems and to establish how storm water controls will be administered. These ordinances are adopted by governing bodies and because they are part of the local law, have enforcement power. For Michigan lakes, this includes the Drain Code, Soil Erosion and Sedimentation Control Act, post-construction storm water management ordinances, among others. Additionally, ordinances can generate methods of collecting funds to construct, maintain, operate and expand storm water management systems.

To gain support from stakeholders, demonstration projects can be initially implemented and monitored to gain a better understanding of effectiveness and help guide future modifications and additional projects. Through measurement and analysis, demonstration projects reveal unanticipated barriers, making the adoption and implementation of future projects more feasible.

The areas determined to contribute the highest amount of sediment and nutrient to the lake (Critical Source Areas) were listed above along with their corresponding impairments.

Many of the observed and measured impairments consisted of high total nitrogen, high total phosphorus, high total and dissolved solids, presence of easily ponded soils, presence of easily erodible soils, and relative position in the landscape to drains and other watercourses. Osborne and Wiley (1988) emphasize the importance of maintaining a healthy vegetation buffer zone around a water body to protect it from land use activities that contribute nutrient and sediment loads. It is proposed that scientists from Restorative Lake Sciences, LLC work with the LEPOA, local township officials, conservation district officials, specialists from the Natural Resources Conservation Service (NRCS), EGLE, and owners of properties with impairments to the watershed to assist the community with implementation of Best Management Practices (BMP) where needed (the CSA's). The selection of BMP's should be a collective decision by all listed stakeholders and include evaluation of the best methods for the improvements based on cost, scientific efficacy, and sustainability. Such a program will select the BMP's and also determine long-term goals for sustainability of the selected improvements. It is critical to realize that watershed management is an adaptive process where the results of each finding determine the next objectives so that future goals can be achieved. Each watershed is unique relative to impairments and solutions such as BMP's are highly site-specific. This program will be critical for the future health of Loch Erin since a lack of NPS prevention would result in further water quality degradation.

6.2 Public Education and Awareness

In 1997, the Michigan Department of Environmental Quality (MDEQ) and the United States Geological Survey (USGS) formed the Lake Water-Quality Assessment Monitoring Program (LWQA) to assess the conditions of over 700 inland lakes by 2015. Even though these efforts are critical to determine the baseline conditions of many recreational lakes in the state, they do not establish a long-term process for the conservation and management of these systems. Many environmental management programs have failed because of a scarcity in stakeholder participation. One major cause of this scant participation is due to a lack of adequate education regarding the complexities of environmental issues and resources to help assist individuals with solving challenging environmental problems. Yet, the State of Michigan has 1,240 townships and numerous other municipalities that incorporate many passionate minds to assist with service to their local communities. Clearly, we have some great, untapped resources that could be utilized to help govern and conserve lake resources. There have been significant increases in public education and awareness in regard to issues that compromise inland lakes over the past decade and historically. The creation of the Michigan Lake and Stream Associations (MLSA) over 53 years ago along with the Michigan Sea Grant, the Michigan Chapter of the North American Lake Management Society (McNALMS), and many other small yet effective water resource protection programs have provided the public with awareness tools to begin protection strategies of a particular lake or water resource. Education is thus an important piece in the sustainability puzzle.

It is surprising that many municipalities and public citizens have never even heard of these organizations and how they can help us with lake and water resource conservation. Figure 20 demonstrates a sound model for stakeholder engagement that applies to both lake and immediate watershed management.

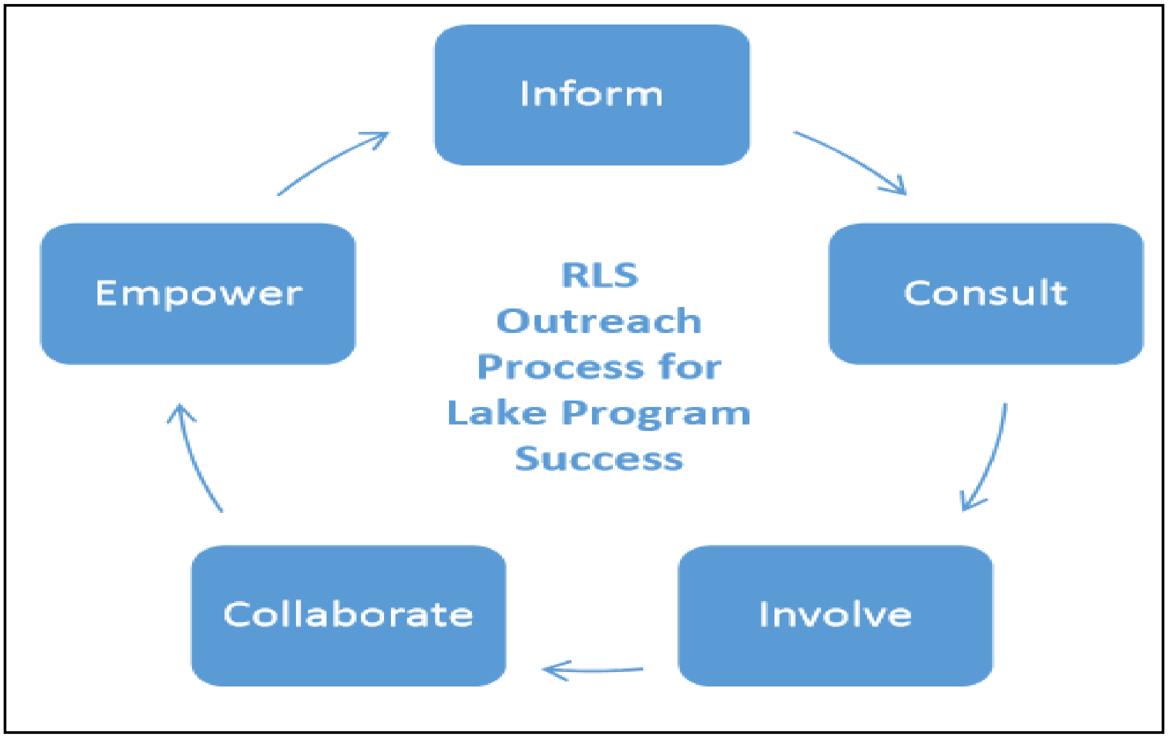

Figure 20. A flow model showing steps for successful lake and watershed program improvements.

6.3 Additional Recommendations for a Sustainable NPS Pollution Control Program

As proposed by Feeny et *al*. (1999), sustainability of an NPS pollution program must include both human and resource valuation which are not mutually exclusive. Furthermore, the socio-political structure of the community that utilizes a resource and the interactions with the larger political system has impacts on managerial qualities of local groups in reference to the shared resource (Ostrom, 1987; 1988). Surface waters such as Loch Erin should then be considered a "commons" where management and policy implementation of NPS pollution control should consider the nature of the resource, decision-making strategies by stakeholders, property rights of riparians, and attributes of relationships among resource users and regulators. Due to the nature of this multiple ownership of the "commons", world views held by each stakeholder will have to be considered for significant advances in a program. Orr (2003) mentions that the transition to sustainability is more a function of social, political, and psychological behaviors than strictly a technological process.

If this concept is implemented in the process of an NPS pollution control program, then the local governments and citizens can develop a mutualistic trust that would be derived from attentive exchange of personal values and the needs of the local government, the riparians, and the water resource.

Furthermore, strategies recommended by Middendorf and Busch (1997), included public involvement in research *a priori* to establish common research priorities and increase a wider range of values in the decision-making process. These strategies may assist the municipalities towards a sustainable program because public involvement combined with the expertise of scientific innovations would perpetuate a self-driven program where common goals can be continuously evaluated from metrics developed by all stakeholders. A measure of sustainability can then be assessed through the projected measurement of selected metrics over an extended period of time. Evaluation metrics for a NPS pollution control program may consist of: 1) measurements of pollutant loads and transport dynamics, 2) changes in water quality parameters and 3) indices of biotic integrity (IBIs), among many others. It should be cautioned that such metrics may be site-specific given the heterogeneity in surface water ecology; however, this potential outcome only emphasizes the need for local governance and involvement for the long-term adaptive management of water resources. Changes in the perceptions of all stakeholders both before and after implementation of the program may also be evaluated to determine the efficacy of the program in terms of sustainability and betterment of the local community. The evaluation process should be initiated by an independent party or through statistical methods to assure that conclusions are not obscured by influences of political agendas, world views, or biases.

Although it may be useful to dissect the components and operations of other adaptive water resource programs, it would be wise to form an innovative program through the lenses of multiple viewpoints possessed by the stakeholders. The primary research problems or objectives will ultimately determine the critical aspects of a program which allows an objective structure to serve as the foundation of the program. Sustainability of an innovative program will then ultimately depend on the ability of the objective program structure to adapt to community and governance needs and lead to water resource improvement. A successful program for NPS pollution reduction would likely harbor the many characteristics described above with regards to stakeholder dynamics and composition, local governance, and objectivity of the determined research problems. With the increases in human population around water resources and the pollution thresholds of many surface waters exceeded, current legislative Acts must also incorporate prevention and monitoring sections to accompany existing improvement clauses. With these modifications, a sustainable framework will exist for all municipalities to utilize for the detection and reduction of NPS pollution in their jurisdictions.

6.4 Successful Strategies Used by Stakeholders for a Sustainable NPS Pollution Management Program

Goldston (2009) discusses the challenges involved with the influence of science on the adoption of environmental policy. Emphasis is placed on the necessity to separate scientific inquiry from questions regarding policy. Thus, it may be advantageous for the formation of a cohesive board that could identify the scientific and policy questions to be investigated prior to the conductance of any intense research. In Minnesota, the formation of Watershed Management Organizations (WMOs) which interact with Local Government Units (LGUs), has provided the state with a powerful group of resources for surface water management that allows for a transfer of scientific knowledge from the WMOs to the LGUs which have taxation authority. The Minnesota Legislature passed the Metropolitan Area Surface Water Management Act in 1982 which mandates local governments in the seven-county metro area to prepare and implement surface water management plans in coordination with WMOs. In Michigan, the two governing Acts which involve protection of surface waters include Public Act (PA) 188 and allows townships and municipalities to levy taxes for surface water and other environmental improvements, and PA 451 which allows statutorily formed boards to levy taxes for water quality improvements. Both Acts were designed more for solution implementation than for prevention programs that are urgently needed to address the NPS pollution effects on surface waters.

If communication regarding a sustainable program was strictly between riparians and the local municipality, a voice for the necessary lifestyle adjustment would be absent with counterproductive consequences. With this realization, the outside can objectively assess the existing surface water conditions and offer unbiased solutions to be considered by the riparians and the LGUs. Kimmerer (2002) discusses the positive role that Traditional Ecological Knowledge (TEK) can have on issues regarding environmental sustainability. TEK is distinguished from Scientific Ecological Knowledge (SEK) in that social and spiritual attributes of the culture cannot be separated from the knowledge in the former. Riparian communities may be a significant source of TEK since many riparians have resided on particular lakes for decades and have likely experienced interactions with the lake system that may be shielded from the objective views of an expert scientist. Additionally, bias that may be unknowingly present in the sampling methods or by the researcher can be reduced through having multiple investigators work on a common water quality issue (Rutherford and Ahlgren 1991).

Objective assistance on the issues pertaining to NPS pollution may be provided to municipalities by the private sector, which may assist in the determination of initial goals and implementation of objective solutions (Plummer 2002). In order to ascertain that decisions made by the private sector are effectively targeted, riparians may contribute a wealth of knowledge regarding their collective needs which reduces uncertainty in the eyes of the municipality officials and garners needed support for successful immediate watershed management.

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