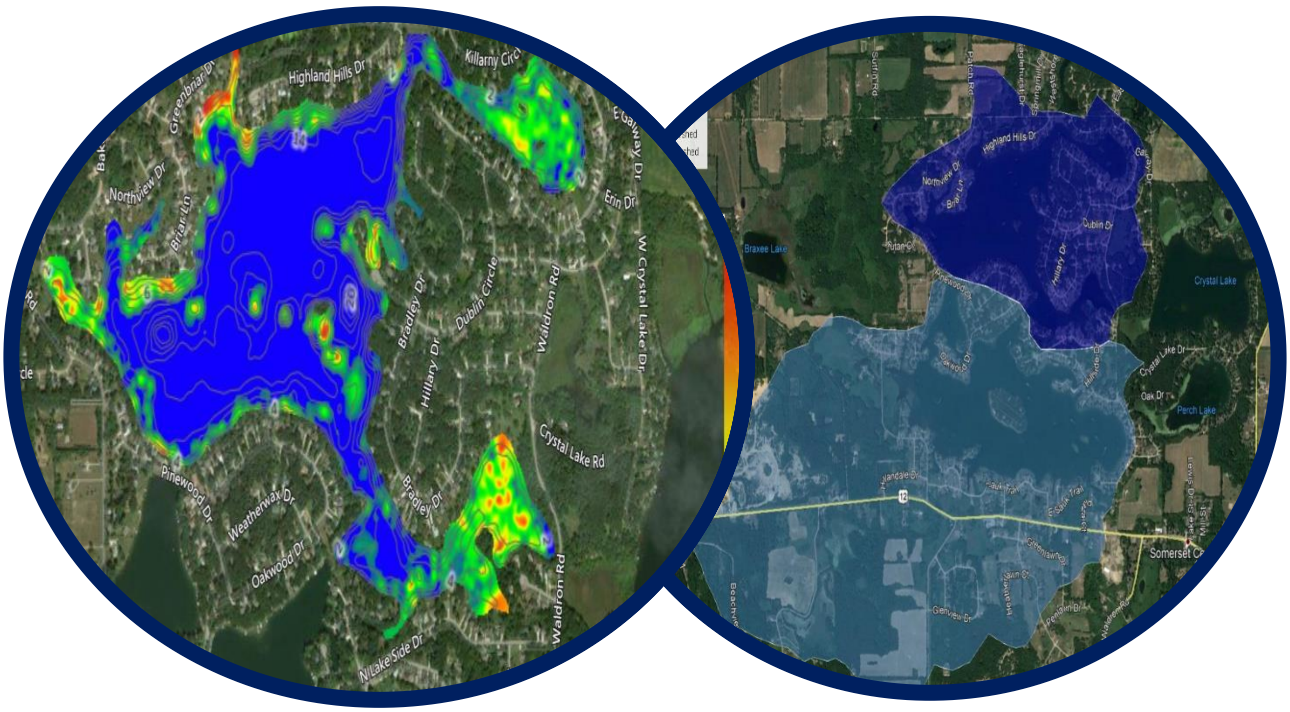
PART I. Lake LeAnn Improvement Study and Management Plan
Hillsdale County, Michigan



Provided for: Lake LeAnn Property Owners Association (LLPOA) Board

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Hillsdale County, Michigan

October 2019

1.0 EXECUTIVE SUMMARY

Lake LeAnn is located in Somerset Township in Hillsdale County, Michigan (T.5S, R.1W, sections 3,4,5,8,9, and 10; Figure 1). The north lake basin is comprised of 200.3 acres and the south lake basin consists of 268 acres (RLS, 2019). The lake is a man-made impoundment with a dam located at the north end of the north basin with a second dam on the south lake. The north lake basin has 1 area of water influx which includes 1 drain and the south lake basin has 3 drainage areas. The north lake basin has nearly 6.4 miles of shoreline and the south lake basin has nearly 7.3 miles of shoreline. The mean depth of the north lake basin is approximately 7.6 feet and the mean depth of the south lake basin is approximately 9.7 feet. The maximum depth of the north lake basin is approximately 22.5 feet and the maximum depth of the south lake basin is approximately 39.0 feet (RLS, 2019 bathymetric scan data; Figure 2). The north lake basin also has a fetch (longest distance across the lake) of around 0.8 miles and the south lake basin has a fetch of around 1.2 miles (RLS, 2019). The north basin of Lake LeAnn has an approximate water volume of 1,927.3 acre-feet and the south lake basin has an approximate water volume of 2,555.7 acre-feet (RLS, 2019 bathymetric data). The immediate watershed (which is the area directly draining into the lakes) differs for each basin with the north being approximately 3,582 acres and the south being approximately 1,515 acres. This is about 7.6 times the size of the lake, which is moderately large. Legal lake levels have been established for both lakes with the summer and winter levels for the north lake at elevations of 1041.25' and 1040.50 feet, respectively, and summer and winter levels for the south lake at elevations of 1046.85' and 1046.40 feet, respectively.

Based on the current study, Lake LeAnn contains 5 invasive aquatic plant species which includes the submersed hybrid Eurasian Watermilfoil (EWM), Curly-leaf Pondweed (CLP), and Starry Stonewort and the emergents Purple Loosestrife and Phragmites. Continued surveys and vigilance are needed to assure that additional invasives do not enter Lake LeAnn. Recommendations for prevention of invasives are offered later in this management plan report. There are a total of 11 submersed, 3 floating-leaved, and 3 emergent native aquatic plant species in Lake LeAnn that were present during the lake survey on May 10, 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 bloom in early October 2019 proved to have total microcystins at 55 µg/L which is well above the EPA standard for microcystin at 8.0 µg/L and a no contact advisory was issued by the Michigan Department of Health and Human Services (MDHHS).

A total of 9 water quality sampling locations were sampled with 4 in the north lake basin and 5 in the south lake basin on April 26, 2019, July 24, 2019 and September 11, 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 Lake LeAnn 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 north basin ranged from was 0.025-0.047 mg/L which is over the eutrophic threshold. Additionally, the bioavailable TP (SRP) mean concentration ranged from 0.010-0.026 mg/L in the north basin with a peak during July. This means that some of the TP is usable for aquatic biota including the algae. The mean TKN concentration in the lake north basin ranged from 0.6-1.2 mg/L which is moderate, and the total inorganic nitrogen (TIN) mean concentration ranged from 0.057-0.240 mg/L. The north lake N:P ratio is 25 which means that the lake is P-limited with 25 times more nitrogen. Total suspended solids (TSS) in the north lake ranged from 10.5-25.0 mg/L which is well above the detection limit. The mean conductivity of the north lake ranged from 472-584 mS/cm which is moderately high and indicative of a large watershed. The mean water clarity (secchi transparency) ranged from 3.3-8.4 feet with the lowest values measured in September and preceded a marked *Microcystis* bloom. Mean chlorophyll-a, which is a measure of algal pigment, was low at 0.0-0.34 µg/L, which although low, indicates clearer water under the top layers where the blue-green blooms concentrate due to the gas vacuoles of the blue green algae. Dissolved oxygen depletion was prevalent in the north basin with depth after July. Sediments were sampled in the four sampling locations and were moderate in organic matter and consisted of sands and fines.

The mean TP concentration in the lake south basin ranged from was 0.018-0.039 mg/L which is at or over the eutrophic threshold. Additionally, the bioavailable TP (SRP) mean concentration ranged from 0.010-0.012 mg/L in the north basin with a peak during July. This means that some of the TP is usable for aquatic biota including the algae. The mean TKN concentration in the lake south basin ranged from 0.5-1.1 mg/L which is moderate, and the total inorganic nitrogen (TIN) mean concentration ranged from 0.223-0.397 mg/L. The south lake N:P ratio is 33 which means that the lake is P-limited with 33 times more nitrogen.

Mean total suspended solids (TSS) in the south lake ranged from 10.0-16.0 mg/L which is well above the detection limit. The mean conductivity of the south lake ranged from 494-570 mS/cm which is moderately high and indicative of a large watershed. The mean water clarity (secchi transparency) ranged from 5.5-8.7 feet with the lowest values measured in September. Mean chlorophyll-a, which is a measure of algal pigment, was low at 0.0-1.78 µg/L, which although low, indicates clearer water under the top layers where the blue-green blooms concentrate due to the gas vacuoles of the blue green algae. Dissolved oxygen depletion was prevalent in the south basin with depth after July. Sediments were sampled in the five sampling locations and were moderate in organic matter and consisted of sands and fines.

Four critical source areas (CSA's) that flow into the lake were sampled on three dates which included April 26, July 24, and September 11. One CSA was located at the northwest portion of the north lake basin and the remaining three were located along the south lake basin. 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 614-928 mS/cm which is much higher than the lake basin means. The corresponding total dissolved solids were also high with a mean range of 421-601 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 0.070-1.1 mg/L with the two highest concentrations in CSA #S1 and CSA #N4. Of particular concern was the high mean nitrate concentration in CSA #N4. All CSA's had levels of nitrite below detection. The TP mean concentrations ranged from 0.018-0.047 mg/L which is similar to the lake basins, with the exception of CSA #S3 which had the highest TP. All of the ortho-phosphorus concentrations were favorable. The TSS mean concentrations ranged from 10-43 mg/L with the highest values noted in CSA #S3. Top priority should be given to CSA #3 and #4 for implementation of BMP'S which are likely to include drain filters and retention ponds or grassed areas that can intercept these nutrients from agricultural runoff before they enter the lake basins.

Lake LeAnn has multiple land uses such as wetlands, beaches, and riparian properties. Lake improvement strategies to reduce external loading of P and N 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 as soon as possible 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 Lake LeAnn community implement Best Management Practices (BMP's) discussed in the 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. An urgent septic tank and drainfield maintenance program is needed to help riparians reduce nutrients such as nitrogen to the lake. Such a program is supported by the findings from this July 24-25 when Environmental Canine Services utilized a special canine to detect failing septic tanks along the north shore). In all, 411 lakefront lots (388 on North lake and 23 on South lake) were surveyed using a scent-detection canine trained specifically to detect the discharge of human sewage, such as might arise from failing septic systems. The dog walked the lake shoreline accompanied by its handler and members of the Water Quality Subcommittee. It 'alerted', or indicated the potential presence of human waste, on 40 lots, or approximately 10% of all inspected lots.

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 Lake LeAnn.

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. Lake LeAnn may be categorized as a drainage lake since it has numerous drainage areas as well as an outlet at the northern section of the North Basin which enters the Grand River which empties into Lake Michigan near Grand Haven, Michigan.

2.1.2 Biodiversity and Habitat Health

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

2.1.3 Watersheds and Land Use

A watershed is defined as an area of land that drains to a common point and is influenced by both surface water and groundwater resources that are often impacted by land use activities. In general, larger watersheds possess more opportunities for pollutants to enter the 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 124).

3.0 LAKE LEANN PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Lake LeAnn North and South Basins

Lake LeAnn is located in Somerset Township in Hillsdale County, Michigan (T.5S, R.1W; sections 3,4,5,8,9, and 10 Figure 1). The north lake basin is comprised of 200.3 acres and the south lake basin consists of 268 acres (RLS, 2019). The lake is a man-made impoundment with a dam located at the north end of the north basin with a second dam on the south lake. The north lake basin has 1 area of water influx which includes 1 drain and the south lake basin has 3 drainage areas. The north lake basin has nearly 6.4 miles of shoreline and the south lake basin has nearly 7.3 miles of shoreline. The mean depth of the north lake basin is approximately 7.6 feet and the mean depth of the south lake basin is approximately 9.7 feet. The maximum depth of the north lake basin is approximately 22.5 feet and the maximum depth of the south lake basin is approximately 39.0 feet (RLS, 2019 bathymetric scan data; Figures 2-3).

The north lake basin also has a fetch (longest distance across the lake) of around 0.8 miles and the south lake basin has a fetch of around 1.2 miles (RLS, 2019).

The north basin of Lake LeAnn has an approximate water volume of 1,927.3 acre-feet and the south lake basin has an approximate water volume of 2,555.7 acre-feet (RLS, 2019 bathymetric data). The immediate watershed (which is the area directly draining into the lakes) differs for each basin with the north being approximately 3,582 acres and the south being is approximately 1,515 acres. This is about 7.6 times the size of the lake, which is moderately large. Legal lake levels have been established for both lakes with the summer and winter levels for the north lake at elevations of 1041.25' and 1040.50 feet, respectively, and summer and winter levels for the south lake at elevations of 1046.85' and 1046.40 feet, respectively.

A bottom sediment hardness scan was conducted of the entire lake bottom on September 11-12, 2019. The bottom hardness map shows (Figure 4-5) 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. Tables 1 and 2 below show 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 two lake basins. 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. Lake LeAnn north basin relative hardness of the lake bottom by category or hardness and percent cover of each category (relative cover).

Lake Bottom Relative Hardness Category	# GPS Points in Each Category (Total =11,739)	% Relative Cover of Bottom by Category
0.0-0.1	3	0.3
0.1-0.2	18	0.2
0.2-0.3	1,237	10.5
0.3-0.4	4,746	40.4
>0.4	5,735	48.9

Table 2. Lake LeAnn south basin relative hardness of the lake bottom by category or hardness and percent cover of each category (relative cover).

Lake Bottom Relative Hardness Category	# GPS Points in Each Category (Total =16,872)	% Relative Cover of Bottom by Category
0.0-0.1	38	0.2
0.1-0.2	100	0.6
0.2-0.3	2,976	17.6
0.3-0.4	8,356	49.5
>0.4	5,402	32.0

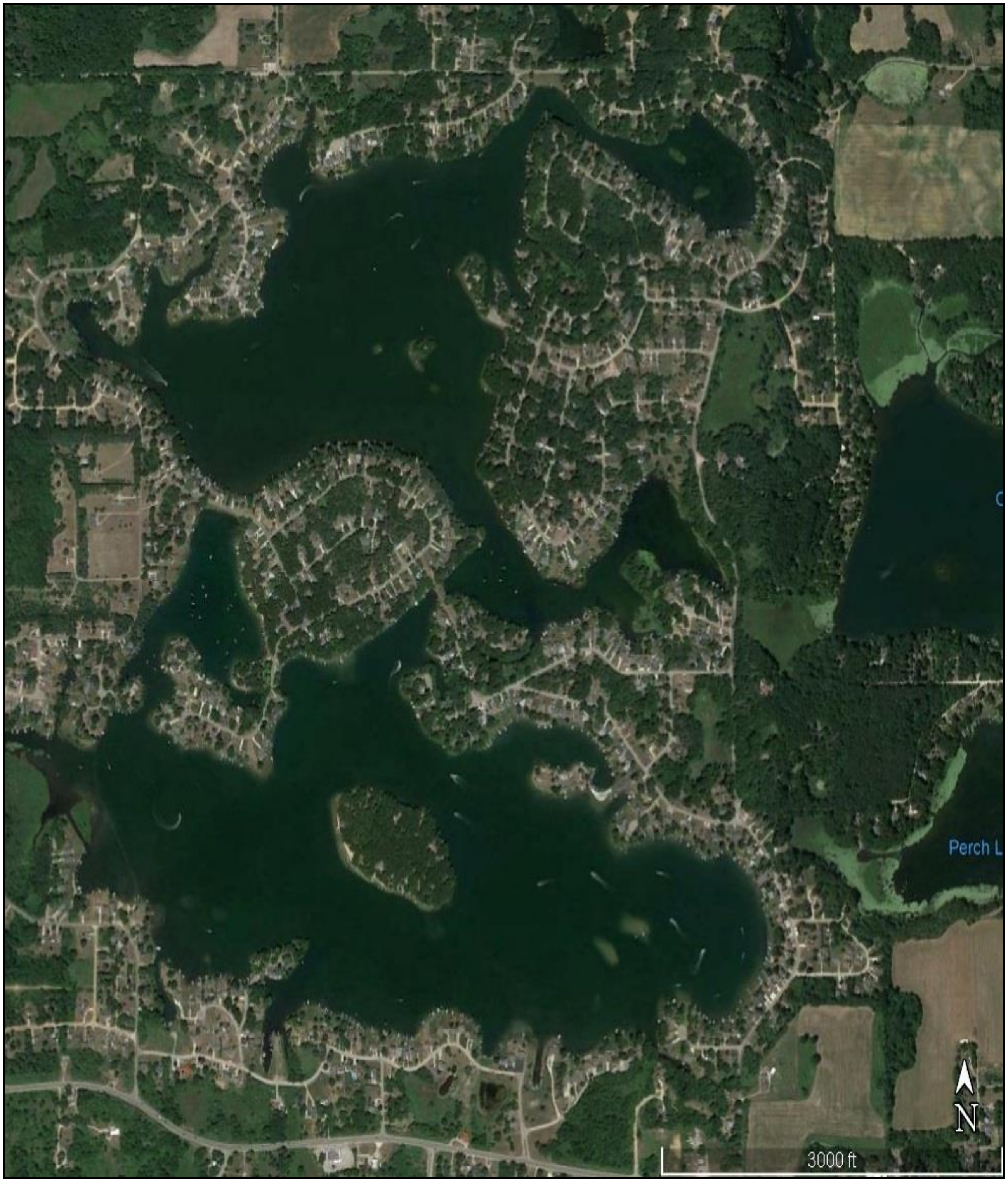


Figure 1. Lake LeAnn Aerial Photo of North and South Basins, Hillsdale County, Michigan.

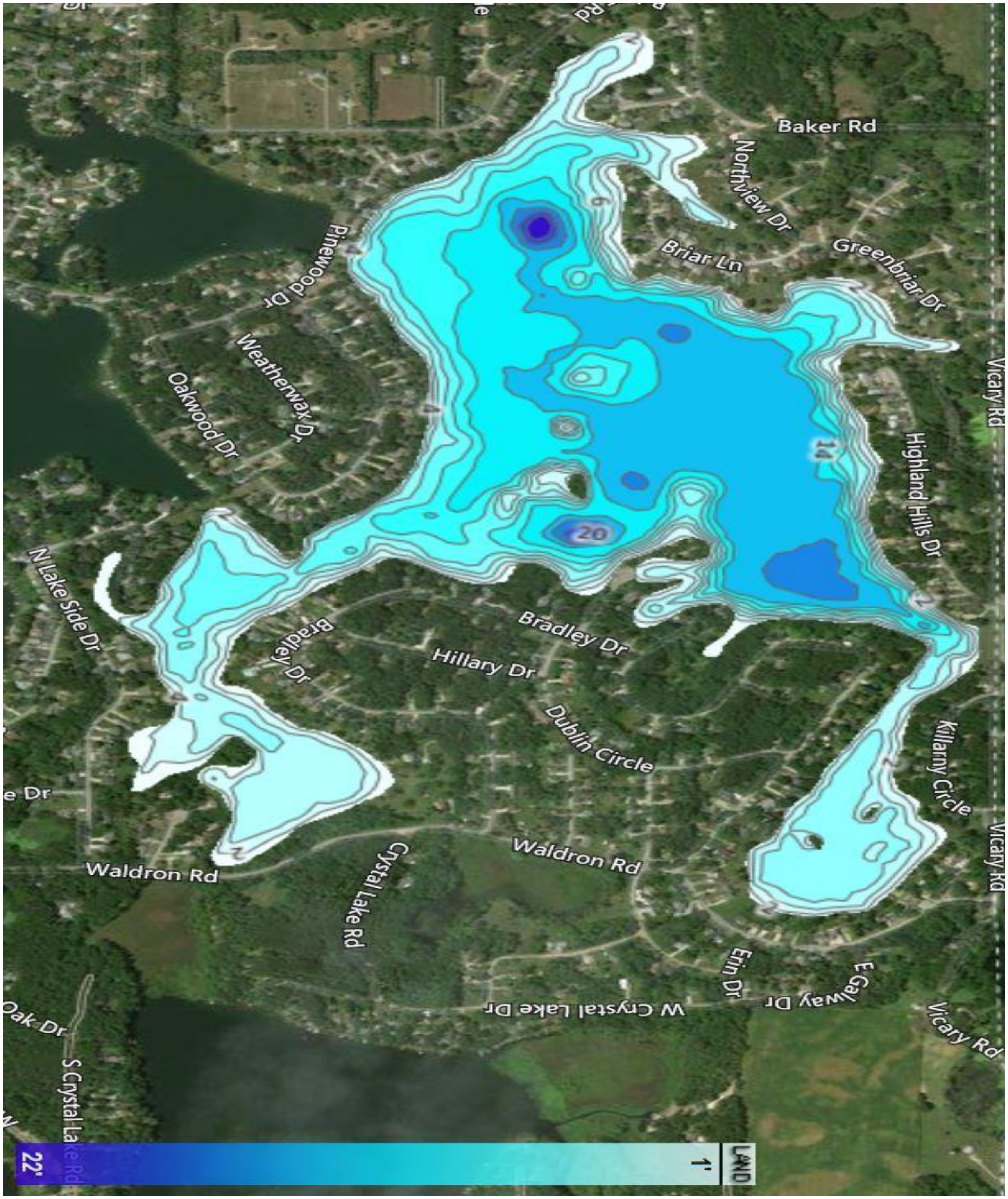


Figure 2. Lake LeAnn north basin depth contour map (September 11, 2019).

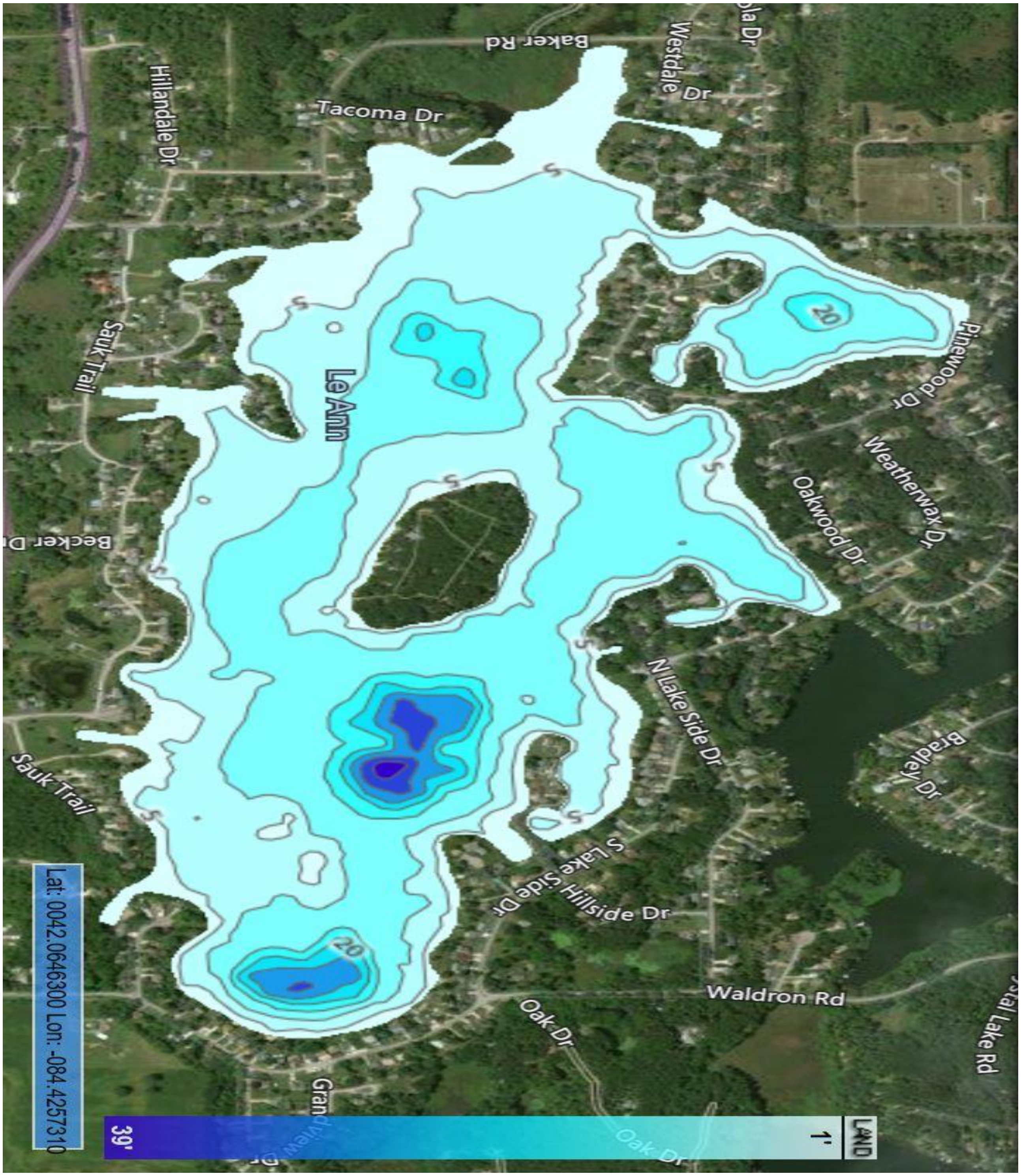


Figure 3. Lake LeAnn south basin depth contour map (September 11, 2019).

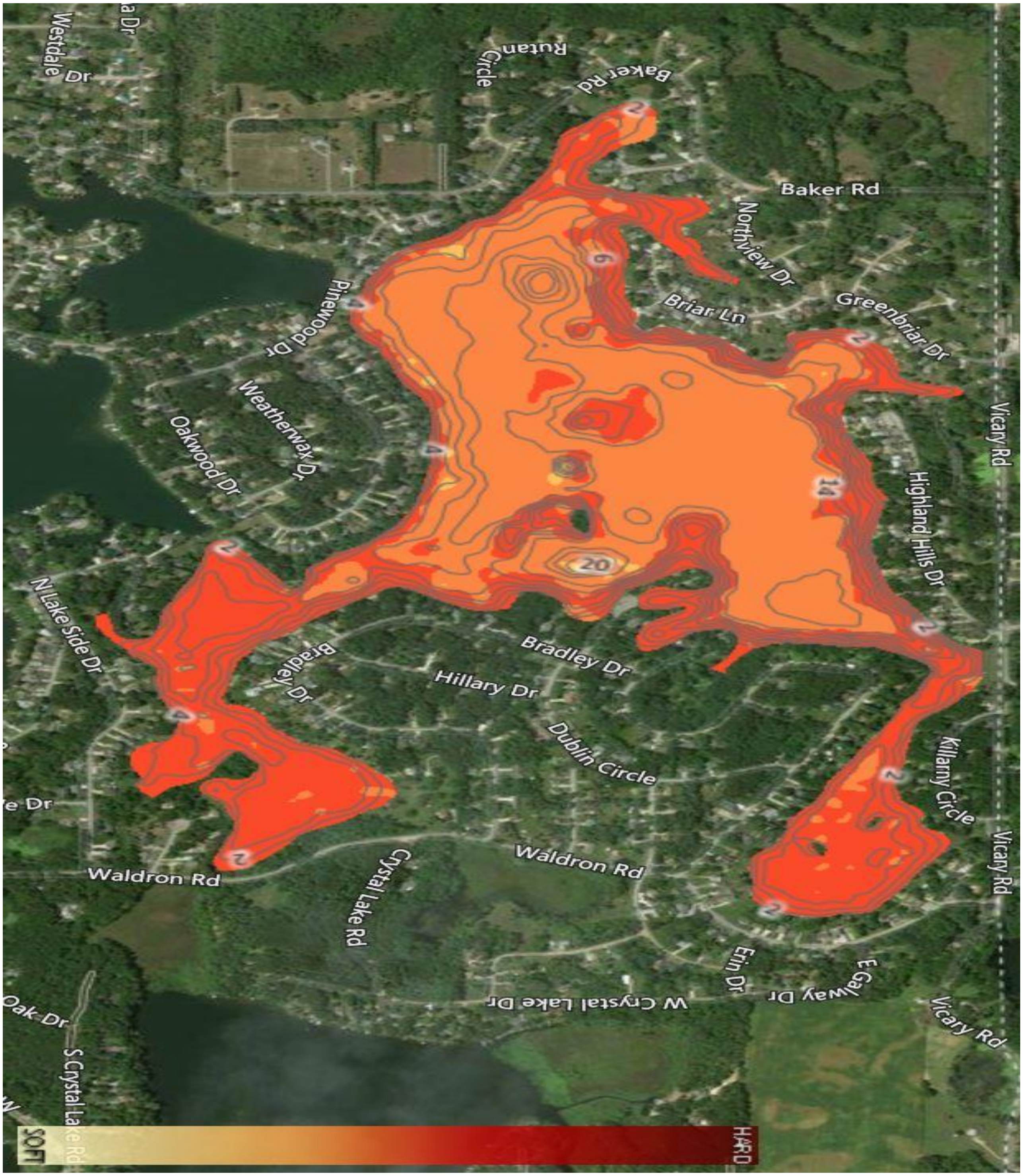


Figure 4. Lake LeAnn north basin sediment relative hardness map (September 11, 2019).

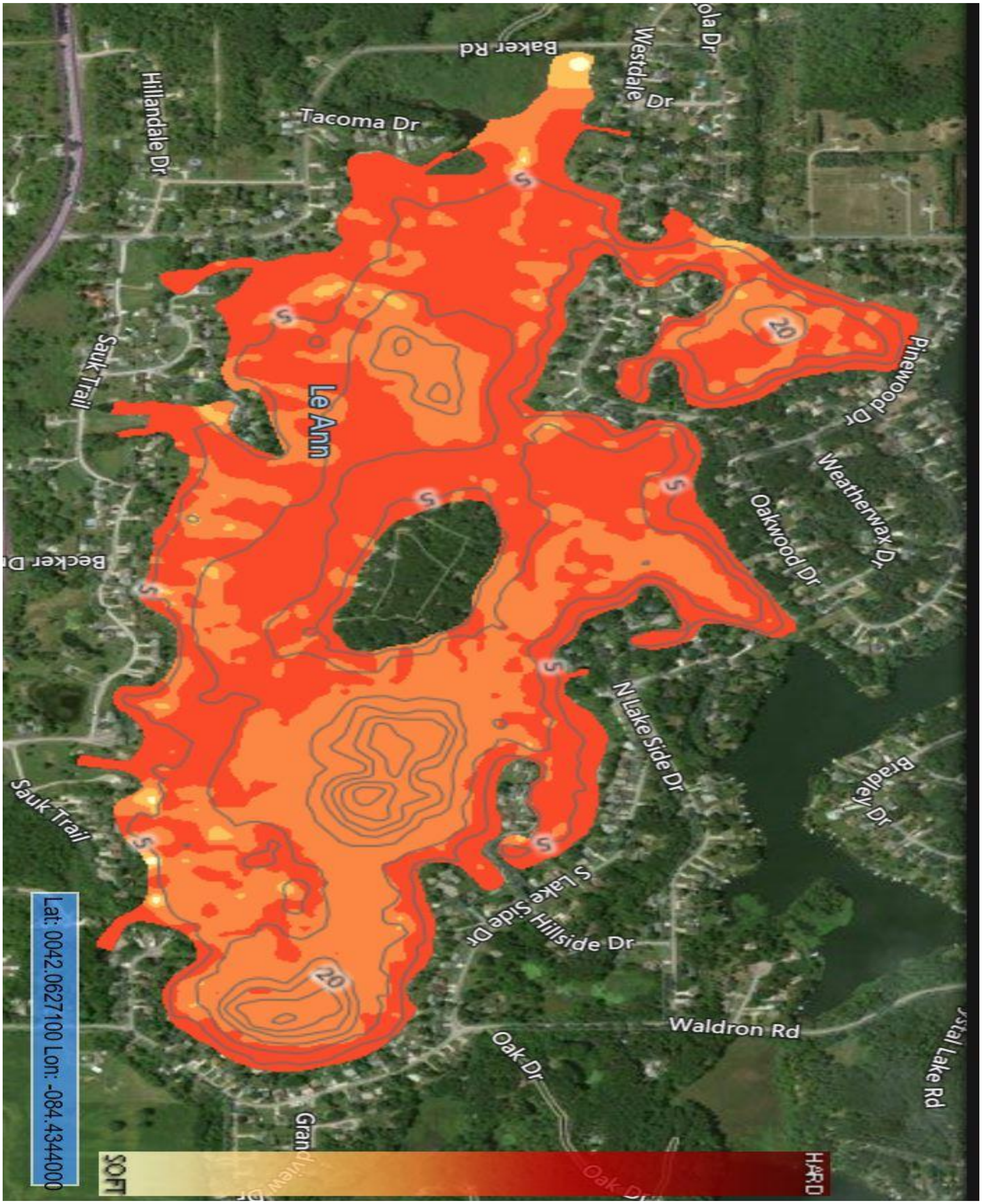


Figure 5. Lake LeAnn south basin sediment relative hardness map (September 11, 2019).

4.0 LAKE LEANN 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 3). Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a*, and low in transparency are classified as eutrophic; whereas those that are low in nutrients and chlorophyll-*a*, and high in transparency are classified as oligotrophic. Lakes that fall in between these two categories are classified as mesotrophic. Both basins of Lake LeAnn are classified as eutrophic (nutrient-enriched) basins due to the high nutrients and low Secchi transparency and marked dissolved oxygen depletion with depth (Figure 6).

Table 3. General Lake Trophic Status Classification Table.

Lake Trophic Status	*Total Phosphorus (mg L^{-1})*	*Chlorophyll-a (µg 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

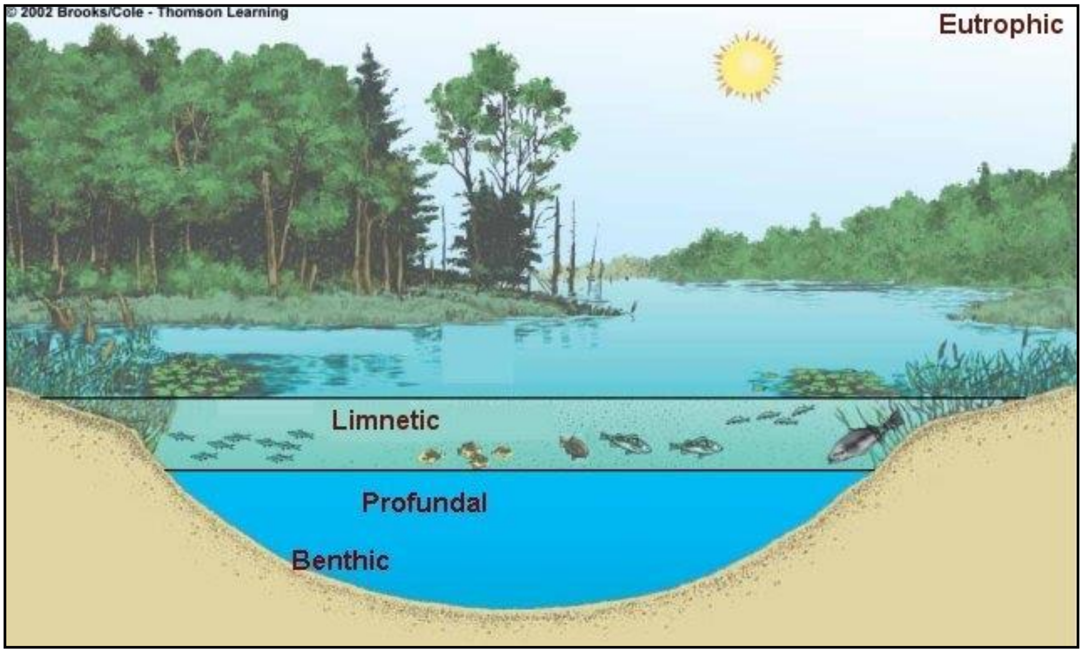


Figure 6. Diagram showing a eutrophic or nutrient-enriched lake ecosystem (photo adapted from Brooks/Cole Thomson learning online).

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 4-74. A map showing the sampling locations for all water quality samples is shown below in Figure 7. All water samples and readings were collected at the 9 deepest basins on April 26, 2019, July 24, 2019, and September 11, 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 were taken to a NELAC-certified laboratory for analysis. In addition, 9 sediment samples (Figure 8) were collected at the 9 sampling basins using an Ekman hand dredge on September 11, 2019. Sediment samples were analyzed for sediment organic matter percentage in mg/kg and also for particle size and substrate type. Specific sampling methods for each parameter are discussed in each parameter section below.

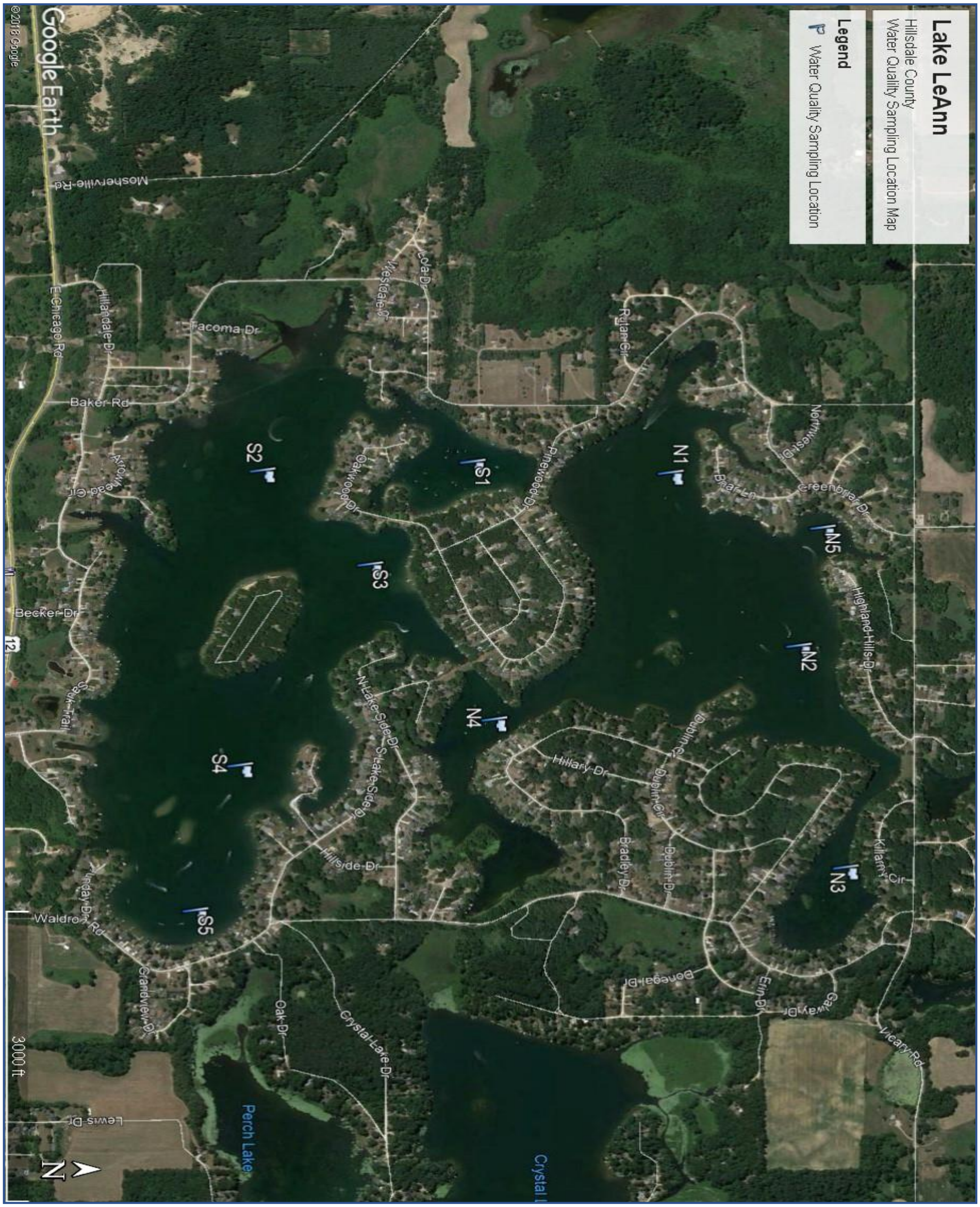


Figure 7. Locations for water quality sampling of the deep basins in Lake LeAnn (April 26, July 24, and September 11, 2019).

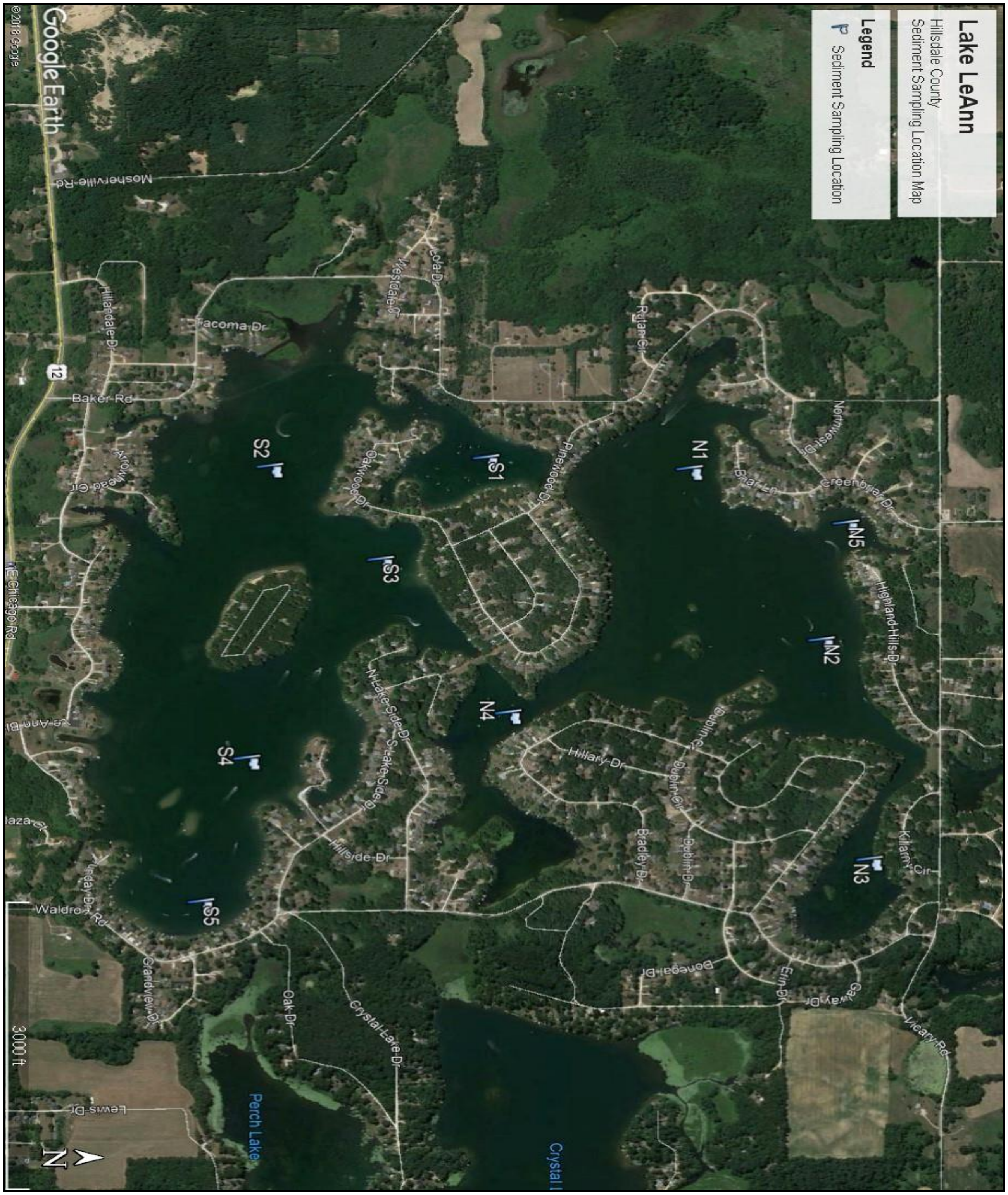
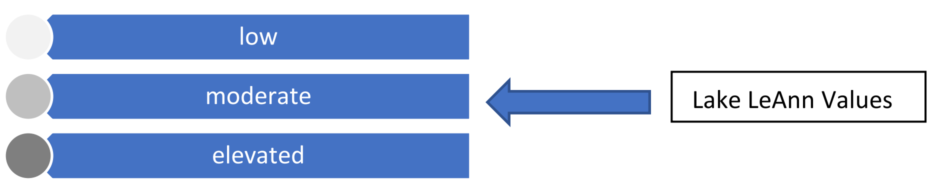


Figure 8. Sediment sampling locations in Lake LeAnn (September 11, 2019).

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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 10.1 mg/L, 7.3 mg/L, and 8.2 mg/L, respectively. The mean dissolved oxygen concentrations in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 10.3 mg/L, 6.7 mg/L, and 7.1 mg/L, respectively.

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. None of the basins in both lakes experienced DO depletion during the April sampling event. However, by July, most of the basins in both lakes with the exception of north basins #3 and #4 and south basin #3 experienced significant DO depletion. This was most likely due to the fact that these basins were shallow and well-mixed relative to the others that stratify.



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 9). 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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 12.9°C, 26.3°C, and 22.6°C, respectively. The mean water temperature measurements in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 12.7°C, 23.9°C, and 21.2°C, respectively. Overall, the south basin tends to have cooler water temperatures. Cooler water temperatures generally also hold more dissolved oxygen.

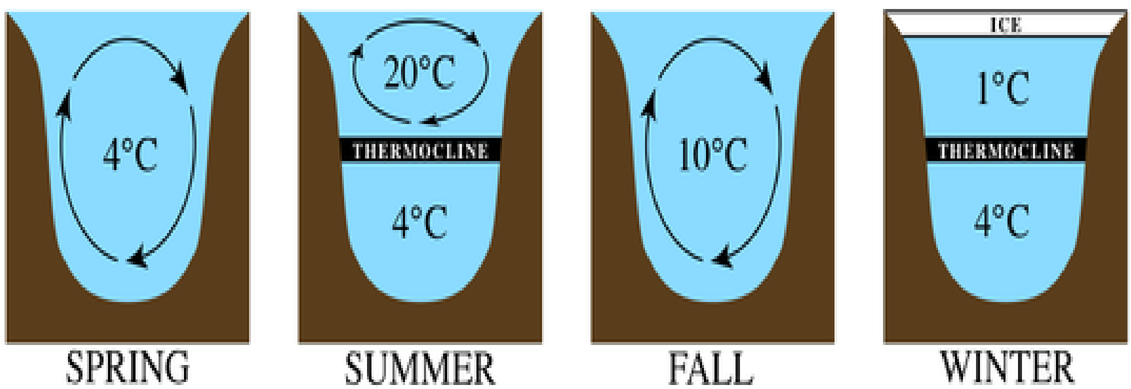


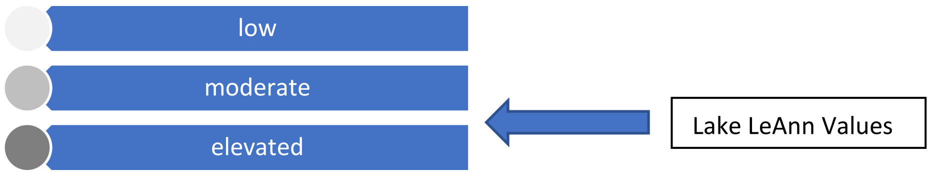
Figure 9. The lake thermal stratification process.

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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 509 mS/cm, 584 mS/cm, and 472 mS/cm, respectively. The mean conductivity values in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 544 mS/cm, 494 mS/cm, and 570 mS/cm, respectively.

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.

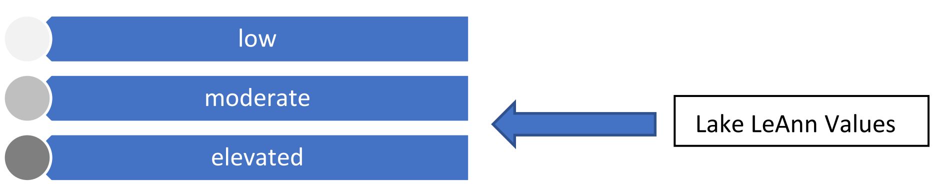
Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Lake LeAnn over a long period of time, or to trace the origin of a substance to the lake in an effort to reduce pollutant loading. Elevated conductivity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



4.1.4 Turbidity, Total Dissolved Solids, and Total Suspended Solids

Turbidity

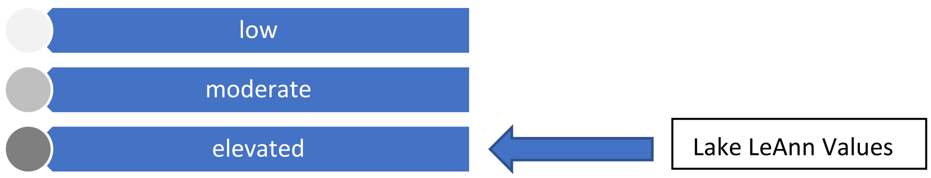
Turbidity is a measure of the loss of water transparency due to the presence of suspended particles. The turbidity of water increases as the number of total suspended particles increases. Turbidity may be caused by erosion inputs, phytoplankton blooms, storm water discharge, urban runoff, re-suspension 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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 4.9 NTU's, 4.9 NTU's, and 8.2 NTU's mg/L, respectively. The mean turbidity values in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 4.9 NTU's, 4.6 NTU's, and 6.5 NTU's mg/L, respectively. These values demonstrate an increase as the season progressed. 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

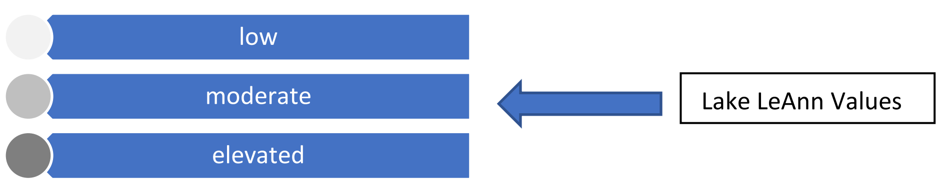
Total dissolved solids (TDS) are the measure of the amount of dissolved organic and inorganic particles in the water column. Particles dissolved in the water column absorb heat from the sun and raise the water temperature and increase conductivity.

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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 327 mg/L, 378 mg/L, and 301 mg/L, respectively. The mean TDS concentrations in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 348 mg/L, 316 mg/L, and 366 mg/L, respectively. These values are 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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 25 mg/L, 10.5 mg/L, and 10.6 mg/L, respectively. The mean TSS concentrations in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 16 mg/L, 14 mg/L, and 10 mg/L, respectively. Ideally values should be < 10 mg/L. The TSS values from the drains were much higher and indicate that most of the TSS that reaches the lake settles in the lake bottom.



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).

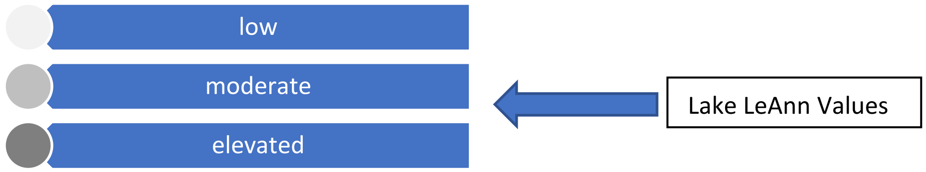
The mean pH values in the north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 8.3 S.U., 8.5 S.U., and 8.4 S.U., respectively. The mean pH values in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 8.4 S.U., 8.5 S.U., and 8.4 S.U., respectively. 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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.025 mg/L, 0.047 mg/L and 0.037 mg/L, respectively. The mean TP concentrations in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.018 mg/L, 0.039 mg/L and 0.023 mg/L, respectively.

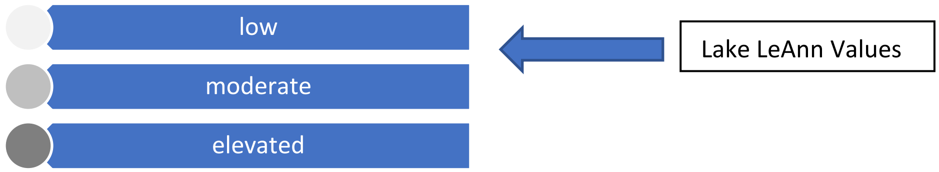
These concentrations tend to be higher at the bottom depths and are indicative of internal loading of TP which means that the TP is accumulating in the lake bottom and is released when the dissolved oxygen level is low. This in turn re-circulates the TP throughout the lake and makes it constantly available for algae and aquatic plants to use for growth.



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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.010 mg/L, 0.026 mg/L and 0.010 mg/L, respectively.

The mean SRP concentrations in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.010 mg/L, 0.012 mg/L and 0.012 mg/L, respectively. These values tend to peak in July which may be indicative of septic field contributions.



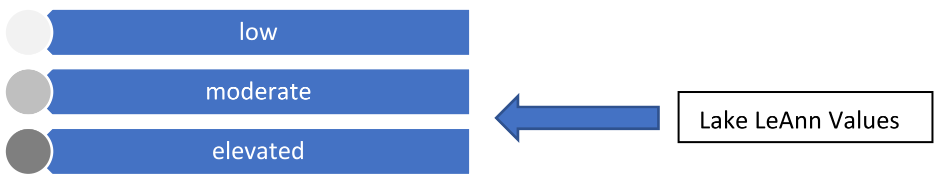
4.1.7 Total Kjeldahl Nitrogen and Total Inorganic Nitrogen

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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.6 mg/L, 1.2 mg/L and 1.0 mg/L, respectively. The mean TKN concentrations in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.5 mg/L, 1.1 mg/L and 1.1 mg/L, respectively. These values are normal for an inland lake of similar size. In the absence of dissolved oxygen, nitrogen is usually in the ammonia form and will contribute to rigorous submersed aquatic plant growth if adequate water transparency is present which is the case in Lake LeAnn for part of the growing season.

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 north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.240 mg/L, 0.172 mg/L and 0.057 mg/L, respectively.

The mean TIN concentrations in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.223 mg/L, 0.253 mg/L and 0.397 mg/L, respectively. Nitrogen gas readings at the bottom deepest basins were less than .008 ppm.

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 mean nitrate concentrations in the north basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.166 mg/L, 0.100 mg/L and 0.0100 mg/L, respectively. The mean nitrate concentrations in the south basin of Lake LeAnn during the April 26, July 24, and September 11 sampling events were 0.191 mg/L, 0.100 mg/L and 0.100 mg/L, respectively. These numbers were elevated in April for both basins and are likely associated with runoff. The mean nitrite values for both lakes on all sampling dates were below detection at <0.100 mg/L which is normal. Overall, there is an abundance of nitrogen in Lake LeAnn which 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 9 sampling locations during the April 26, July 24, and September 11 sampling dates. High chlorophyll-a concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg/L are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg/L are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* was measured in micrograms per liter (µg/L) with method SM 10200H. The chlorophyll-*a* concentrations in Lake LeAnn were determined by collecting composite (depth-integrated) samples of the algae throughout the water column (photic zone) at the deep basin site from just above the lake bottom to the lake surface. The mean chlorophyll-*a* concentrations in the north basin during the April 26, July 24, and September 11 sampling events were 0.13 µg/L, 0.34 µg/L, and 0 µg/L, respectively. The mean chlorophyll-*a* concentrations in the south basin during the April 26, July 24, and September 11 sampling events were 1.78 µg/L, 0.54 µg/L, and 0 µg/L, respectively. Although these concentrations do not appear to be elevated, they are often lower in the water column as they must be composite samples which can underestimate surface floating algae such as Microcystis. The south basin tends to have a higher concentration of chlorophyll-a.

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 Lake LeAnn, 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 September 11, 2019 sampling event and are shown below in Tables 4 and 5. The genera were then graphed to show the relative abundance by algal type. In both basins, the blue-green algae were more dominant than both green algae and diatoms (Figures 10-11). In the north basin there were 11 taxa of green algae, 3 taxa of blue-green algae, and 5 taxa of diatoms. In the south basin there were 10 taxa of green algae, 3 taxa of blue-green algae, and 5 taxa of diatoms. Diatoms and green algae are the more favorable algal genera.

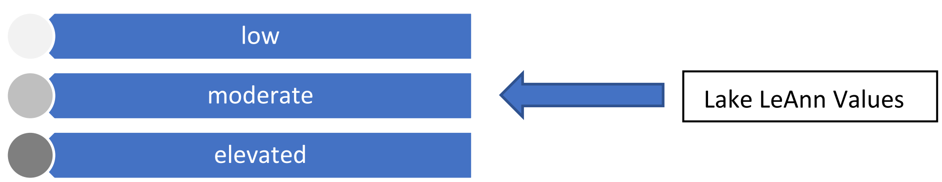


Table 4. Counts (# cells per 1 mL sub-sample) for each genera of algae found at each sampling location (n=4) in the north lake basin of Lake LeAnn (September 11, 2019).

Taxa Present	Type	N1	N2	N3	N4
Chlorella sp.	G	9	4	12	6
Scenedesmus sp.	G	2	1	0	0
Pediastrum sp.	G	4	7	1	0
Mougeotia sp.	G	9	12	14	7
Ulothrix sp.	G	6	17	24	1
Oocystis sp.	G	6	1	1	0
Staurastrum sp.	G	4	2	2	1
Closterium sp.	G	3	7	9	4
Cladophora sp.	G	26	37	15	20
Rhizoclonium sp.	G	37	25	18	4
Pithophora sp.	G	6	7	0	0
Microcystis sp.	BG	462	385	267	318
Anabaena sp.	BG	12	26	4	0
Oscillatoria sp.	BG	5	24	12	7
Navicula sp.	D	6	10	17	13
Synedra sp.	D	22	13	16	28
Rhoicosphenia sp.	D	2	1	0	0
Cymbella sp.	D	0	0	5	0
Fragillaria sp.	D	1	4	1	1

Note: G = green algae (Chlorophyta); BG = blue-green algae (Cyanophyta); D = diatoms (Bacillariophyta).

Table 5. Counts (# cells per 1 mL sub-sample) for each genera of algae found at each sampling location (n=5) in the south lake basin of Lake LeAnn (September 11, 2019).

Taxa Present	Type	S1	S2	S3	S4	S5
Chlorella sp.	G	10	2	18	6	14
Scenedesmus sp.	G	2	13	4	7	9
Pediastrum sp.	G	1	1	0	0	0
Mougeotia sp.	G	0	0	0	0	0
Ulothrix sp.	G	1	8	4	0	0
Oocystis sp.	G	0	0	0	0	0
Staurastrum sp.	G	2	7	2	0	1
Closterium sp.	G	6	4	15	0	4
Cladophora sp.	G	12	0	5	1	0
Rhizoclonium sp.	G	9	14	1	0	0
Pithophora sp.	G	1	1	0	0	0
Microcystis sp.	BG	400	128	344	160	18
Anabaena sp.	BG	12	36	5	0	7
Oscillatoria sp.	BG	26	48	0	0	7
Navicula sp.	D	15	6	0	2	11
Synedra sp.	D	8	19	0	1	0
Rhoicosphenia sp.	D	5	0	0	0	0
Cymbella sp.	D	7	0	1	0	1
Fragillaria sp.	D	4	1	1	0	0

Note: G = green algae (Chlorophyta); BG = blue-green algae (Cyanophyta); D = diatoms (Bacillariophyta).

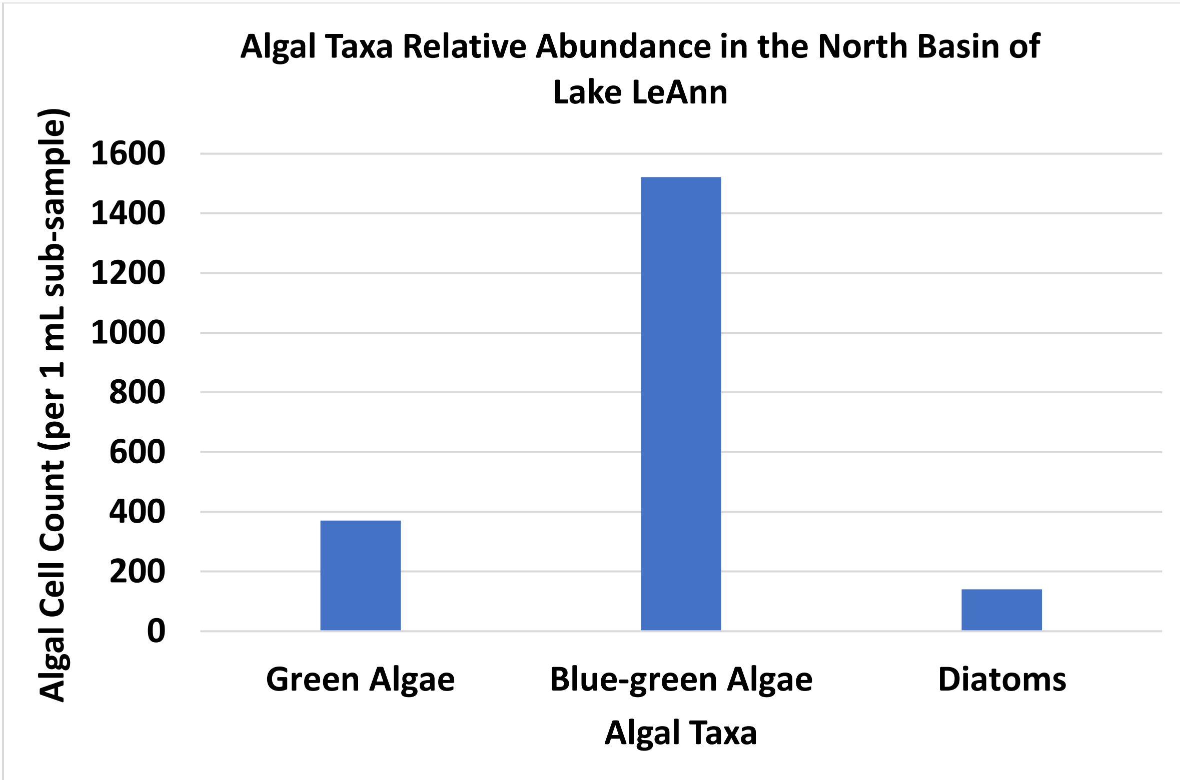


Figure 10. Algal relative abundance by taxa in the north lake basin (September 11, 2019).

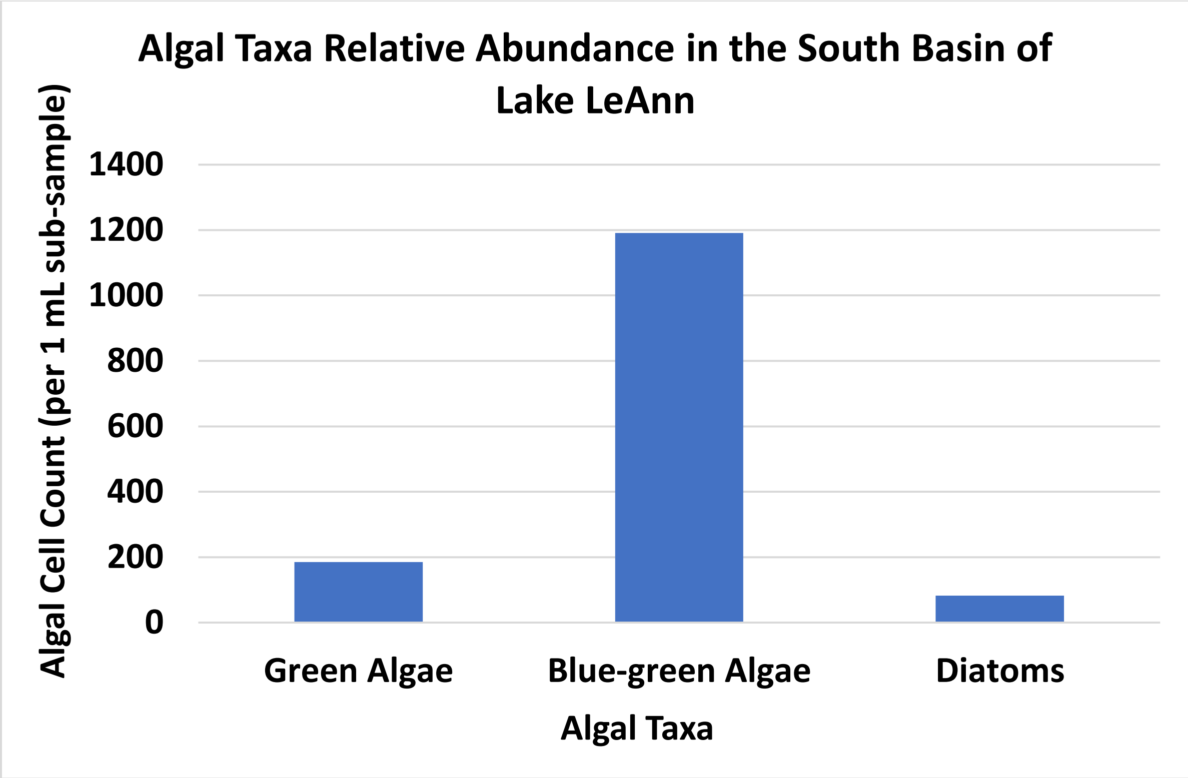
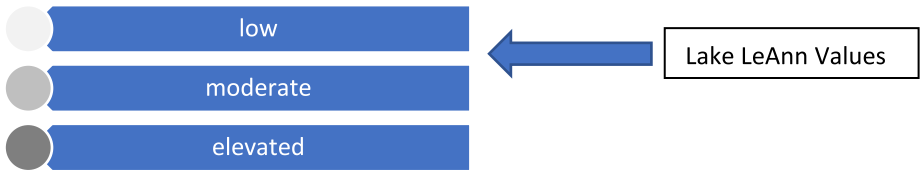


Figure 11. Algal relative abundance by taxa in the south lake basin (September 11, 2019).

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 12). 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 north basin of Lake LeAnn on April 26, July 24, and September 11 was 8.4 feet, 6.1 feet, and 3.3 feet, respectively. It is clear that the Secchi transparency declined throughout the season which was largely due to the growth of blue-green algal blooms. The mean Secchi transparency of the south basin of Lake LeAnn on April 26, July 24, and September 11 was 6.0 feet, 8.7 feet, and 5.5 feet, respectively. The highest measurement for the south basin was during July. 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.



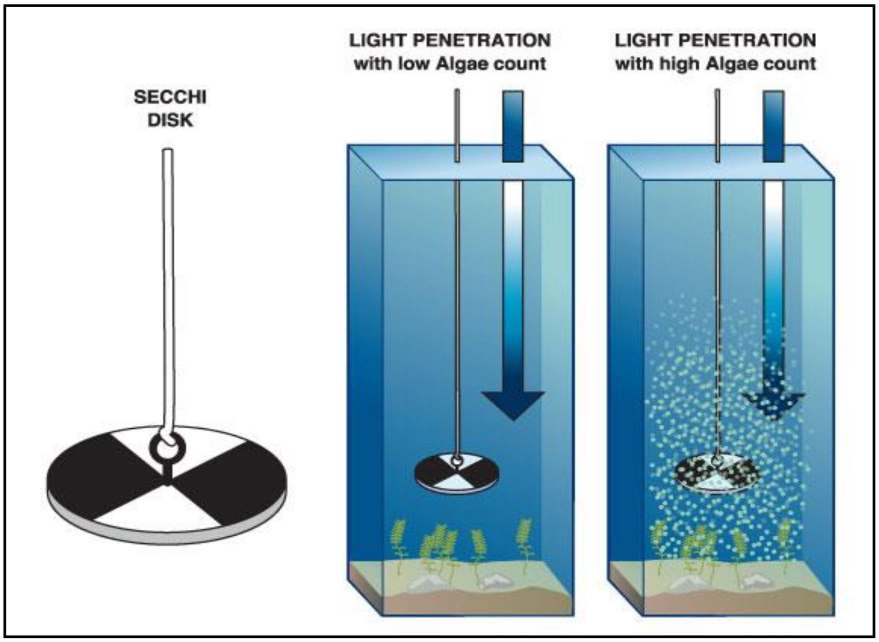
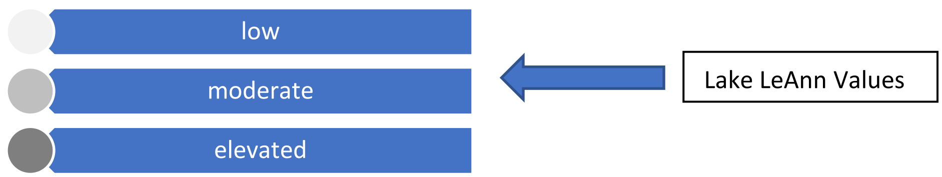


Figure 12. Measurement of water transparency with a Secchi disk.

4.1.10 Sediment Organic Matter and Particle Size

Organic matter (OM) contains a high amount of carbon which is derived from biota such as decayed plant and animal matter. Detritus is the term for all dead organic matter which is different than living organic and inorganic matter. OM may be autochthonous or allochthonous in nature where it originates from within the system or external to the system, respectively. Sediment samples were collected during the September 11, 2019 sampling event using an Ekman hand dredge at each of the 9 sampling locations. Sediment OM is measured with the ASTM D2974 Method and is usually expressed in a percentage (%) of total bulk volume. Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present. There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then fermented to alcohol, CO_2, or CH_4.

Second, proteins may be proteolyzed to amino acids, deaminated to NH_3+, nitrified to NO_2- or NO_3-, and denitrified to N_2 gas. Bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979). The mean organic content was 27.7% which is moderate and ranged from 14-39%, which is highly variable and not uncommon in impoundments. The north basin has slightly higher concentrations than the south basin.



Sediment particle size was estimated using ASTM Method D-422-63. Sediments were analyzed for the particle type (i.e. sand, gravel, etc.) and that data is shown below in Table 6. The major sediment types included sands and organic fines with sands being more abundant.

Table 6. Lake LeAnn sediment nutrient data collected at n= 9 locations (September 11, 2019).

Site	%OM	Total Sand Fractional Components	Total Fines Fractional Components
N1	39	64.6	35.4
N2	39	61.3	38.7
N3	38	46.3	53.7
N4	20	50.2	49.8
S1	34	62.6	37.4
S2	14	40.0	60.0
S3	27	59.7	40.3
S4	19	51.1	48.9
S5	19	54.9	45.1

All baseline water quality data are shown below in Tables 7-60 and descriptive statistics summary tables of all data are shown in Tables 61-62.

Table 7. Lake LeAnn physical water quality parameter data collected at deep basin north #1 (April 26, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	13.6	9.9	8.3	509	4.8	325	10.1
0.5	13.6	10.0	8.3	509	4.8	325	
1.0	13.6	10.0	8.3	509	4.8	325	
1.5	13.3	10.1	8.3	509	4.8	326	
2.0	13.2	10.0	8.3	513	4.9	328	
2.5	12.4	9.9	8.2	514	5.1	329	
3.0	12.2	9.5	8.2	514	5.1	329	
3.5	11.9	9.4	8.2	514	5.1	329	
4.0	12.0	9.2	8.2	514	5.1	329	
4.5	11.9	9.2	8.2	514	5.4	329	
5.0	11.9	9.2	8.2	514	5.4	329	
5.5	11.0	9.0	8.1	515	5.4	330	
6.0	10.4	9.0	8.1	515	5.4	329	
6.5	10.4	8.7	8.1	507	5.4	363	

Table 8. Lake LeAnn chemical water quality parameter data collected at deep basin north #1 (April 26, 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	0.6	0.260	0.093	0.170	<0.10	38	0.017	<0.010	0
3.5	0.7	0.250	0.089	0.160	<0.10	<10	0.033	<0.010	
6.5	0.6	0.280	0.087	0.190	<0.10	<10	0.027	<0.010	

Table 9. Lake LeAnn physical water quality parameter data collected at deep basin north #2 (April 26, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	13.5	10.2	8.3	508	4.7	325	9.4
0.5	13.4	10.2	8.3	508	4.7	325	
1.5	13.4	10.2	8.3	508	4.8	325	
2.0	13.3	10.3	8.3	508	4.8	325	
2.5	13.3	10.3	8.3	508	4.8	325	
3.0	13.2	10.3	8.3	509	5.0	325	
3.5	13.1	10.3	8.3	510	5.0	326	
4.0	12.7	10.4	8.3	511	5.0	327	
4.5	12.4	10.1	8.3	512	5.1	328	
5.0	11.8	9.9	8.2	513	5.2	328	

Table 10. Lake LeAnn chemical water quality parameter data collected at deep basin north #2 (April 26, 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	<0.5	0.260	0.088	0.170	<0.10	28	0.013	<0.010	0
2.5	0.7	0.250	0.091	0.160	<0.10	<10	0.032	<0.010	
5.0	0.7	0.260	0.096	0.160	<0.10	18	0.035	<0.010	

Table 11. Lake LeAnn physical water quality parameter data collected at deep basin north #3 (April 26, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	13.9	10.5	8.4	503	4.7	322	7.1
0.5	13.9	10.7	8.4	503	4.7	322	
1.0	13.8	10.9	8.4	503	4.8	322	
1.5	13.8	11.0	8.4	504	4.8	322	
2.0	13.7	11.0	8.4	504	4.8	323	
2.5	13.5	11.2	8.4	507	4.8	324	

Table 12. Lake LeAnn chemical water quality parameter data collected at deep basin north #3 (April 26, 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	0.9	0.210	0.046	0.170	<0.10	36	0.034	0.010	0
2.5	--	--	--	--	--	--	--	--	--

Table 13. Lake LeAnn physical water quality parameter data collected at deep basin north #4 (April 26, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	13.4	9.8	8.4	507	4.6	325	7.1
0.5	13.4	10.3	8.4	507	4.6	325	
1.0	13.4	10.5	8.4	507	4.7	325	
1.5	13.4	10.7	8.4	507	4.8	325	
2.0	13.3	10.9	8.4	507	4.8	325	
2.5	13.3	11.0	8.4	508	4.8	325	
3.0	13.3	11.1	8.4	508	5.1	325	

Table 14. Lake LeAnn chemical water quality parameter data collected at deep basin north #4 (April 26, 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	<0.5	0.210	0.046	0.160	<0.10	34	0.020	<0.010	0.534
1.5	<0.5	0.220	0.053	0.160	<0.10	36	0.022	<0.010	
3.0	<0.5	0.200	0.041	0.160	<0.10	30	0.018	<0.010	

Table 15. Lake LeAnn physical water quality parameter data collected at deep basin south #1 (April 26, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	14.3	10.6	8.5	536	4.8	343	5.7
0.5	14.2	10.7	8.5	536	4.8	343	
1.0	14.1	10.7	8.5	536	4.8	343	
1.5	14.1	10.8	8.5	535	4.8	349	
2.0	14.1	10.8	8.5	535	4.9	349	
2.5	12.5	11.0	8.5	533	4.9	342	
3.0	11.6	11.4	8.5	533	4.9	341	
3.5	11.1	11.7	8.5	532	5.1	341	
4.0	10.9	11.8	8.5	533	5.2	341	
4.5	10.8	11.8	8.5	533	5.2	341	
5.0	10.4	11.7	8.4	536	5.4	343	

Table 16. Lake LeAnn chemical water quality parameter data collected at deep basin south #1 (April 26, 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	<0.50	0.150	<0.010	0.150	<0.10	<10	0.015	<0.010	1.78
2.5	<0.50	0.170	0.017	0.160	<0.10	<10	0.015	<0.010	
5.0	<0.50	0.190	0.024	0.160	<0.10	<10	0.015	<0.010	

Table 17. Lake LeAnn physical water quality parameter data collected at deep basin south #2 (April 26, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	13.1	10.0	8.4	548	4.7	351	6.0
0.5	13.1	10.1	8.4	548	4.7	351	
1.0	13.1	10.2	8.4	548	4.7	351	
1.5	13.0	10.2	8.4	548	4.8	351	
2.0	13.0	10.2	8.4	548	4.8	350	
2.5	13.0	10.2	8.4	548	4.8	350	
3.0	12.9	10.2	8.4	548	4.9	350	
3.5	12.5	10.2	8.4	548	4.9	351	
4.0	12.2	10.0	8.3	549	4.9	351	
4.5	12.0	9.8	8.3	549	5.1	351	
5.0	11.9	9.5	8.3	549	5.1	351	
5.5	11.2	9.4	8.2	550	5.3	352	
6.0	10.8	9.0	8.2	551	5.4	352	

Table 18. Lake LeAnn chemical water quality parameter data collected at deep basin south #2 (April 26, 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	<0.50	0.180	0.028	0.160	<0.10	14	0.025	<0.010	0
3.0	0.6	0.190	0.048	0.140	<0.10	36	0.024	<0.010	
6.0	<0.50	0.160	<0.010	0.160	<0.10	<10	0.013	<0.010	

Table 19. Lake LeAnn physical water quality parameter data collected at deep basin south #3 (April 26, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	13.0	10.0	8.4	546	4.8	349	5.0
0.5	13.0	10.1	8.4	545	4.8	349	
1.0	13.0	10.3	8.4	545	4.8	349	
1.5	12.9	10.3	8.4	545	4.8	349	
2.0	12.9	10.4	8.4	545	4.9	349	
2.5	12.9	10.4	8.4	545	4.9	349	
3.0	12.7	10.4	8.4	544	5.3	349	

Table 20. Lake LeAnn chemical water quality parameter data collected at deep basin south #3 (April 26, 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	<0.50	0.180	0.024	0.160	<0.10	<10	0.017	<0.010	1.07
1.5	<0.50	0.200	0.025	0.180	<0.10	<10	0.018	<0.010	
3.0	<0.50	0.190	0.017	0.180	<0.10	<10	0.013	<0.010	

Table 21. Lake LeAnn physical water quality parameter data collected at deep basin south #4 (April 26, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	13.2	10.2	8.5	544	4.5	348	6.0
1.5	13.3	10.3	8.4	544	4.5	348	
3.0	13.3	10.4	8.4	544	4.5	348	
4.5	13.3	10.4	8.4	544	4.7	348	
6.0	13.2	10.4	8.4	544	4.7	348	
7.5	12.4	10.3	8.4	545	4.9	347	
9.0	10.2	9.8	8.3	549	4.9	352	
10.5	9.8	9.4	8.2	550	4.9	352	
12.0	9.4	7.9	7.8	541	5.0	347	

Table 22. Lake LeAnn chemical water quality parameter data collected at deep basin south #4 (April 26, 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	<0.50	0.560	0.023	0.540	<0.10	<10	0.018	<0.010	0
6.0	<0.50	0.330	0.170	0.160	<0.10	<10	0.020	<0.010	
12.0	<0.50	0.160	0.014	0.150	<0.10	36	0.032	<0.010	

Table 23. Lake LeAnn physical water quality parameter data collected at deep basin south #5 (April 26, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	13.2	10.2	8.4	545	4.7	349	7.5
0.5	13.2	10.3	8.4	545	4.7	349	
1.0	13.3	10.3	8.4	545	4.7	349	
1.5	13.4	10.4	8.4	545	4.7	349	
2.0	13.3	10.4	8.4	545	4.7	349	
2.5	13.4	10.4	8.4	545	4.8	349	
3.0	13.4	10.5	8.4	545	4.8	349	
3.5	13.4	10.4	8.4	545	4.8	349	
4.0	13.4	10.4	8.4	545	4.8	349	
4.5	13.3	10.5	8.4	545	5.0	349	
5.0	13.3	10.5	8.4	545	5.0	349	
5.5	13.3	10.5	8.4	544	5.0	349	

Table 24. Lake LeAnn chemical water quality parameter data collected at deep basin south #5 (April 26, 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	<0.50	0.200	0.021	0.180	<0.10	42	0.017	<0.010	6.05
2.5	<0.50	0.280	0.074	0.210	<0.10	<10	0.015	<0.010	
5.5	<0.50	0.200	0.024	0.180	<0.10	14	0.016	<0.010	

Table 25. Lake LeAnn physical water quality parameter data collected at deep basin north #1 (July 24, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	27.5	7.1	8.5	477	4.9	305	6.0
0.5	27.4	6.9	8.5	477	4.9	305	
1.0	27.0	6.8	8.5	476	4.9	305	
1.5	27.0	6.7	8.5	476	4.9	304	
2.0	26.7	6.7	8.5	706	4.9	454	
2.5	26.4	6.7	8.5	699	5.0	446	
3.0	26.3	6.6	8.5	608	5.0	387	
3.5	26.2	6.5	8.4	473	5.0	308	
4.0	25.8	6.5	8.4	472	5.0	304	
4.5	25.7	6.5	8.3	514	5.4	348	
5.0	22.3	4.3	8.3	566	5.4	370	
5.5	21.0	2.2	8.3	625	5.4	303	

Table 26. Lake LeAnn chemical water quality parameter data collected at deep basin north #1 (July 24, 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	<0.5	<0.010	<0.010	<0.10	<0.10	10	0.026	<0.010	1.34
3.5	0.63	0.022	0.022	<0.10	<0.10	<10	0.033	0.13	
5.5	2.8	1.2	1.2	<0.10	<0.10	14	0.160	0.017	

Table 27. Lake LeAnn physical water quality parameter data collected at deep basin north #2 (July 24, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	27.1	7.5	8.4	663	4.8	392	6.1
0.5	26.8	6.8	8.4	586	4.8	378	
1.0	26.6	6.5	8.5	616	4.8	391	
1.5	26.5	6.4	8.5	618	4.9	408	
2.0	26.4	6.3	8.5	610	5.1	425	
2.5	26.3	6.1	8.5	649	5.1	422	
3.0	26.3	5.9	8.5	503	5.1	338	
3.5	26.3	5.7	8.5	580	5.0	388	
4.0	26.3	5.6	8.5	477	5.0	305	
4.5	25.6	1.7	8.4	500	5.1	320	

Table 28. Lake LeAnn chemical water quality parameter data collected at deep basin north #2 (July 24, 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	<0.50	<0.010	<0.010	<0.10	<0.10	<10	0.023	<0.010	0
2.5	0.89	0.028	0.028	<0.10	<0.10	10	0.032	<0.010	
4.5	2.4	0.076	0.076	<0.10	<0.10	10	0.037	<0.010	

Table 29. Lake LeAnn physical water quality parameter data collected at deep basin north #3 (July 24, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	27.3	9.0	8.6	619	4.6	393	6.1
0.5	27.3	9.5	8.6	600	4.6	386	
1.0	27.1	10.0	8.5	594	4.6	384	
1.5	26.9	10.4	8.5	584	4.6	377	
2.0	26.5	10.3	8.5	489	4.7	379	
2.5	25.9	10.3	8.5	637	4.8	396	

Table 30. Lake LeAnn chemical water quality parameter data collected at deep basin north #3 (July 24, 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	0.93	0.020	0.020	<0.10	<0.10	<10	0.028	<0.010	0
2.5									

Table 31. Lake LeAnn physical water quality parameter data collected at deep basin north #4 (July 24, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	27.5	8.3	8.5	677	4.5	434	6.0
0.5	27.4	8.6	8.4	675	4.5	492	
1.0	27.2	9.1	8.4	654	4.6	422	
1.5	26.5	9.5	8.4	633	4.7	404	
2.0	26.6	10.2	8.4	633	4.7	405	
2.5	26.0	10.2	8.4	636	5.0	406	
3.0	25.7	9.4	8.4	623	5.0	433	

Table 32. Lake LeAnn chemical water quality parameter data collected at deep basin north #4 (July 24, 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	0.69	0.011	0.011	<0.10	<0.10	10	0.033	<0.010	0
3.0									

Table 33. Lake LeAnn physical water quality parameter data collected at deep basin south #1 (July 24, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	27.6	8.9	8.5	435	3.8	278	9.8
0.5	27.7	9.2	8.5	434	3.8	278	
1.0	27.6	9.4	8.5	435	3.7	278	
1.5	27.1	9.5	8.5	436	4.1	279	
2.0	26.9	9.7	8.5	430	4.1	275	
2.5	26.7	9.9	8.5	429	4.1	274	
3.0	26.6	10.0	8.5	437	4.1	280	
3.5	26.6	10.1	8.5	438	4.3	281	
4.0	26.5	10.1	8.4	442	4.6	283	
4.5	26.0	7.8	8.4	482	4.6	308	
5.0	25.6	3.8	8.4	502	4.6	321	
5.5	24.2	1.7	8.3	517	4.8	331	
6.0	22.1	1.1	8.3	520	5.1	334	

Table 34. Lake LeAnn chemical water quality parameter data collected at deep basin south #1 (July 24, 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	0.52	<0.010	<0.010	<0.10	<0.10	<10	0.014	<0.010	0.801
3.0									
6.0	0.55	<0.010	<0.010	<0.10	<0.10	<10	0.019	<0.010	

Table 35. Lake LeAnn physical water quality parameter data collected at deep basin south #2 (July 24, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	27.5	8.1	8.5	464	4.6	297	8.1
0.5	27.6	8.5	8.5	464	4.6	297	
1.0	27.5	8.6	8.5	464	4.6	297	
1.5	27.0	9.3	8.5	460	4.6	295	
2.0	26.5	9.5	8.5	464	4.6	297	
2.5	26.1	10.1	8.5	455	4.6	292	
3.0	26.0	10.3	8.5	464	4.8	297	
3.5	25.8	10.2	8.5	555	4.8	339	
4.0	25.8	10.0	8.5	463	4.8	296	
4.5	25.8	9.9	8.5	469	4.8	298	
5.0	25.6	9.5	8.4	472	4.8	301	
5.5	24.6	5.4	8.4	505	4.8	323	
6.0	22.0	2.4	8.4	537	4.9	343	
6.5	20.5	1.1	8.4	559	4.9	357	

Table 36. Lake LeAnn chemical water quality parameter data collected at deep basin south #2 (July 24, 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	<0.5	<0.010	<0.010	<0.10	<0.10	<10	0.014	<0.010	0
3.5	0.63	<0.010	<0.010	<0.10	<0.10	<10	0.019	<0.010	
6.5	2.0	0.240	0.240	<0.10	<0.10	12	0.086	<0.010	

Table 37. Lake LeAnn physical water quality parameter data collected at deep basin south #3 (July 24, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	27.4	8.8	8.5	466	3.8	298	9.6
0.5	27.4	9.0	8.5	462	3.8	296	
1.0	27.0	9.1	8.5	464	3.8	297	
1.5	26.8	9.1	8.5	464	3.9	297	
2.0	26.6	9.1	8.5	486	3.9	310	
2.5	26.5	9.2	8.4	462	4.0	300	
3.0	26.4	9.5	8.4	459	4.0	293	

Table 38. Lake LeAnn chemical water quality parameter data collected at deep basin south #3 (July 24, 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	<0.50	<0.010	<0.010	<0.10	<0.10	<10	0.014	<0.010	0.534
1.5	0.86	0.023	0.023	<0.10	<0.10	<10	0.020	<0.010	
3.0	0.61	0.011	0.011	<0.10	<0.10	<10	0.019	<0.010	

Table 39. Lake LeAnn physical water quality parameter data collected at deep basin south #4 (July 24, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	27.5	8.4	8.5	468	4.5	299	8.0
0.5	27.5	8.6	8.5	468	4.5	299	
1.0	27.5	8.7	8.5	468	4.5	299	
1.5	27.3	8.7	8.5	467	4.5	298	
2.0	27.0	8.9	8.5	466	4.6	298	
2.5	27.0	9.0	8.5	466	4.6	298	
3.0	26.5	9.1	8.5	466	4.6	298	
3.5	26.3	8.9	8.4	466	4.6	298	
4.0	26.3	8.7	8.4	463	4.5	296	
4.5	26.2	8.7	8.4	464	4.5	297	
5.0	26.1	8.5	8.4	466	4.5	298	
5.5	25.7	7.9	8.3	474	4.7	303	
6.0	25.5	6.9	8.3	479	4.7	306	
6.5	24.3	4.9	8.5	506	4.7	326	
7.0	20.5	3.7	8.5	537	4.8	343	
7.5	19.5	2.2	8.5	542	4.8	347	
8.0	18.2	1.6	8.5	545	4.6	349	
8.5	17.4	1.0	8.5	548	4.9	351	
9.0	16.7	0.8	8.5	555	4.9	355	
9.5	14.9	0.4	8.5	565	5.0	362	
10.0	14.0	0.3	8.4	572	5.0	366	
10.5	12.7	0.2	8.4	586	5.2	375	
11.0	12.4	0.1	8.4	590	5.1	377	
11.5	12.0	0.1	8.4	595	5.2	381	
12.0	11.8	0.1	8.4	598	5.4	382	

Table 40. Lake LeAnn chemical water quality parameter data collected at deep basin south #4 (July 24, 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	<0.50	<0.010	<0.010	<0.10	<0.10	<10	0.012	<0.010	1.34
6.0	0.62	0.078	0.078	<0.10	<0.10	<10	0.016	<0.010	
12.0	4.9	3.0	3.0	<0.10	<0.10	50	0.190	0.041	

Table 41. Lake LeAnn physical water quality parameter data collected at deep basin south #5 (July 24, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	28.0	8.3	8.5	469	4.7	300	7.8
0.5	27.9	8.5	8.5	469	4.7	300	
1.0	27.8	8.6	8.5	468	4.7	300	
1.5	27.6	8.7	8.5	468	4.7	300	
2.0	27.2	8.9	8.4	467	4.8	299	
2.5	26.7	8.9	8.4	466	4.9	298	
3.0	26.6	9.0	8.4	466	4.9	298	
3.5	26.6	8.9	8.4	466	5.0	299	
4.0	26.4	8.7	8.4	468	4.8	299	
4.5	26.4	8.7	8.5	506	4.8	299	
5.0	25.8	8.5	8.5	476	5.1	303	
5.5	24.2	6.8	8.5	506	5.0	324	
6.0	22.0	5.4	8.5	534	5.0	343	
6.5	19.5	4.3	8.5	546	5.2	350	
7.0	18.3	3.1	8.5	550	5.2	351	
7.5	17.4	2.1	8.5	551	5.2	353	
8.0	16.4	1.5	8.5	565	5.1	359	
8.5	14.6	1.1	8.5	581	5.2	372	
9.0	13.6	0.7	8.4	599	5.1	384	
9.5	13.1	0.5	8.4	610	5.1	391	

Table 42. Lake LeAnn chemical water quality parameter data collected at deep basin south #5 (July 24, 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	0.71	<0.010	<0.010	<0.10	<0.10	<10	0.017	<0.010	0
2.5	<0.50	<0.010	<0.010	<0.010	<0.10	<10	0.016	<0.010	
5.5	1.9	0.110	0.110	<0.10	<0.10	20	0.096	<0.010	

Table 43. Lake LeAnn physical water quality parameter data collected at deep basin north #1 (September 11, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	23.0	8.5	8.7	462	8.1	296	3.2
1.0	22.8	9.3	8.6	462	8.1	297	
1.5	22.0	8.9	8.6	466	8.4	299	
2.0	21.7	8.5	8.4	464	8.4	304	
2.5	21.7	7.5	8.4	466	8.4	298	
3.0	21.4	6.9	8.2	465	8.4	298	
3.5	21.4	6.2	8.3	468	8.5	299	
4.0	21.3	4.7	8.3	482	8.4	303	
4.5	21.3	4.1	8.3	472	8.5	302	
5.0	21.3	3.6	8.3	472	8.5	302	
5.5	21.1	3.0	7.8	475	8.5	306	

Table 44. Lake LeAnn chemical water quality parameter data collected at deep basin north #1 (September 11, 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	1.1	0.012	0.012	<0.10	<0.010	16	0.035	<0.010	0
3.5	<0.5	0.087	0.087	<0.10	<0.10	<10	0.035	<0.010	
5.5	0.7	0.250	0.250	<0.10	<0.10	<10	0.040	<0.010	

Table 45. Lake LeAnn physical water quality parameter data collected at deep basin north #2 (September 11, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	24.0	8.4	8.8	462	7.9	295	3.2
0.5	24.1	9.1	8.7	461	7.9	295	
1.0	24.1	9.9	8.5	462	7.9	295	
1.5	23.5	10.2	8.5	461	7.9	295	
2.0	23.4	10.3	8.5	463	8.2	296	
2.5	23.3	10.2	8.5	505	8.2	301	
3.0	21.6	8.7	8.3	465	8.2	297	
3.5	21.4	6.2	8.1	465	8.2	298	
4.0	21.4	5.4	8.1	465	8.4	298	
4.5	21.4	5.4	8.1	465	8.6	298	

Table 46. Lake LeAnn chemical water quality parameter data collected at deep basin north #2 (September 11, 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	0.025	0.025	<0.10	<0.10	<10	0.034	<0.010	0
2.5	0.95	<0.010	<0.010	<0.10	<0.10	10	0.034	<0.010	
4.5	0.89	0.100	0.100	<0.10	<0.10	<10	0.032	<0.010	

Table 47. Lake LeAnn physical water quality parameter data collected at deep basin north #3 (September 11, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	25.0	8.0	8.4	468	8.4	300	3.3
0.5	24.3	8.9	8.4	471	8.4	300	
1.0	23.6	9.1	8.4	469	8.4	300	
1.5	22.1	10.4	8.4	452	8.5	289	
2.0	21.8	10.7	8.4	472	8.5	308	

Table 48. Lake LeAnn chemical water quality parameter data collected at deep basin north #3 (September 11, 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	0.59	0.014	0.014	<0.10	<0.10	<10	0.030	<0.010	0
2.0									

Table 49. Lake LeAnn physical water quality parameter data collected at deep basin north #4 (September 11, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	24.6	9.1	8.7	472	7.9	300	3.4
0.5	24.3	9.8	8.7	477	7.9	308	
1.0	23.1	11.0	8.7	489	7.9	311	
1.5	22.7	10.0	8.7	496	8.1	314	
2.0	22.2	9.7	8.7	508	8.0	314	
2.5	21.7	8.8	8.4	491	8.1	314	
3.0	21.7	8.8	8.4	495	8.1	314	

Table 50. Lake LeAnn chemical water quality parameter data collected at deep basin north #4 (September 11, 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	0.88	<0.010	<0.010	<0.10	<0.10	<10	0.031	<0.010	0
1.5	1.2	0.013	0.013	<0.10	<0.10	<10	0.036	<0.010	
3.0	1.4	0.049	0.049	<0.10	<0.10	<10	0.060	<0.010	

Table 51. Lake LeAnn physical water quality parameter data collected at deep basin south #1 (September 11, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	23.5	8.5	8.6	467	8.1	299	3.1
0.5	23.6	8.5	8.6	481	8.1	304	
1.0	23.4	8.6	8.6	496	8.1	338	
1.5	22.4	8.9	8.6	544	8.1	350	
2.0	22.1	8.9	8.6	512	8.1	333	
2.5	21.9	8.9	8.6	489	8.2	337	
3.0	21.8	8.9	8.6	484	8.1	310	
3.5	21.7	8.5	8.6	475	8.1	304	
4.0	21.5	8.2	8.4	478	8.2	306	
4.5	21.4	7.7	8.4	481	8.2	307	
5.0	21.3	7.0	8.4	482	8.2	308	
5.5	21.2	6.2	8.3	484	8.2	310	
6.0	21.1	4.0	8.3	489	8.2	313	

Table 52. Lake LeAnn chemical water quality parameter data collected at deep basin south #1 (September 11, 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	0.75	0.010	0.010	<0.10	<0.10	<10	0.017	<0.010	0
3.0	1.2	0.011	0.011	<0.10	<0.10	<10	0.017	<0.010	
6.0	0.56	0.077	0.077	<0.10	<0.10	<10	0.019	<0.010	

Table 53. Lake LeAnn physical water quality parameter data collected at deep basin south #2 (September 11, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	23.0	8.8	8.5	609	8.0	387	3.0
0.5	23.0	8.7	8.5	619	8.0	398	
1.0	23.0	8.7	8.5	634	8.0	417	
1.5	23.0	8.6	8.5	657	8.0	426	
2.0	23.0	8.6	8.5	688	8.2	441	
2.5	22.7	8.7	8.4	702	8.2	448	
3.0	22.0	8.8	8.4	552	8.2	344	
3.5	21.8	8.9	8.4	489	8.2	313	
4.0	21.6	8.9	8.3	503	8.4	347	
4.5	21.3	8.7	8.3	563	8.2	355	
5.0	21.1	7.7	8.3	572	8.1	366	
5.5	21.0	7.3	8.3	593	8.4	373	
6.0	20.9	6.2	8.2	500	8.4	320	
6.5	20.8	5.9	8.1	628	8.4	362	

Table 54. Lake LeAnn chemical water quality parameter data collected at deep basin south #2 (September 11, 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	0.62	<0.010	<0.010	<0.10	<0.10	<10	0.015	<0.010	0
3.5	0.75	<0.010	<0.010	<0.10	<0.10	<10	0.020	<0.010	
6.5	0.72	0.045	0.045	<0.10	<0.10	<10	0.021	<0.010	

Table 55. Lake LeAnn physical water quality parameter data collected at deep basin south #3 (September 11, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	23.2	8.5	8.5	551	4.8	354	7.1
0.5	23.2	8.5	8.5	566	4.9	349	
1.0	23.2	8.5	8.5	572	5.2	369	
1.5	23.2	8.5	8.5	593	5.2	372	
2.0	23.0	8.6	8.5	594	5.4	375	
2.5	22.1	8.7	8.5	575	5.9	368	
3.0	22.0	8.7	8.5	491	5.9	313	

Table 56. Lake LeAnn chemical water quality parameter data collected at deep basin south #3 (September 11, 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	0.62	0.100	<0.010	0.100	<0.10	<10	0.015	<0.010	0
1.5	0.76	<0.010	<0.010	<0.10	<0.10	<10	0.017	<0.010	
3.0	0.74	0.026	0.026	<0.10	<0.10	<10	0.017	<0.010	

Table 57. Lake LeAnn physical water quality parameter data collected at deep basin south #4 (September 11, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	23.3	8.4	8.5	655	4.9	418	7.2
0.5	23.3	8.5	8.5	643	4.9	411	
1.0	23.3	8.5	8.5	677	4.9	427	
1.5	23.3	8.5	8.5	668	4.9	434	
2.0	23.2	8.5	8.5	681	4.9	435	
2.5	22.2	8.6	8.5	689	4.9	440	
3.0	21.8	8.6	8.4	640	5.0	401	
3.5	21.5	8.1	8.4	489	4.8	432	
4.0	21.4	7.8	8.4	670	4.9	428	
4.5	21.3	7.7	8.5	638	5.0	412	
5.0	21.2	7.6	8.3	622	4.9	397	
5.5	21.2	7.5	8.3	599	4.9	400	
6.0	21.2	7.3	8.3	641	4.9	419	
6.5	21.1	7.2	8.3	606	5.2	382	
7.0	21.1	7.1	8.3	649	5.2	412	
7.5	21.0	6.9	8.3	614	5.2	379	
8.0	20.8	6.3	8.3	659	6.3	365	
8.5	20.8	5.9	8.3	533	6.4	352	
9.0	19.9	4.1	8.3	516	6.4	330	
9.5	16.9	1.5	8.3	582	6.4	372	
10.0	15.2	1.0	8.2	592	7.4	381	
10.5	14.4	0.8	8.1	605	7.5	387	
11.0	13.0	0.5	8.1	618	7.2	396	
11.5	12.7	0.3	8.1	627	7.5	401	

Table 58. Lake LeAnn chemical water quality parameter data collected at deep basin south #4 (September 11, 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	0.65	0.015	0.015	<0.10	<0.10	<10	0.029	<0.010	0
5.5	0.76	0.066	0.066	<0.10	<0.10	<10	0.020	<0.010	
11.5	3.8	3.1	3.1	<0.10	<0.10	10	0.061	0.026	

Table 59. Lake LeAnn physical water quality parameter data collected at deep basin south #5 (September 11, 2019).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	Turb. (NTU)	TDS (mg/L)	Secchi Depth (ft)
0	23.4	8.5	8.5	483	4.9	309	7.1
0.5	23.5	8.5	8.5	483	4.8	309	
1.0	23.0	8.5	8.5	489	4.8	313	
1.5	22.5	8.4	8.5	489	4.9	313	
2.0	21.5	8.3	8.5	488	4.9	312	
2.5	21.2	8.0	8.5	487	4.9	312	
3.0	21.2	7.7	8.3	487	5.4	312	
3.5	21.0	6.8	8.3	489	6.0	313	
4.0	20.7	4.2	8.3	494	6.0	316	
4.5	16.5	2.3	8.1	622	6.0	398	
5.0	14.1	0.8	8.1	688	6.1	440	
5.5	14.1	0.8	8.0	689	6.1	441	

Table 60. Lake LeAnn chemical water quality parameter data collected at deep basin south #5 (September 11, 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	0.60	0.032	0.032	<0.10	<0.10	<10	0.015	0.027	0
2.5	1.2	0.042	0.042	<0.10	<0.10	<10	0.019	<0.010	
5.5	3.2	2.4	2.4	<0.10	<0.10	10	0.047	<0.010	

Table 61. Descriptive statistics of all water quality parameters in the north basin of Lake LeAnn for LFA baseline parameters collected on April 26, July 24, and September 11, 2019.

Parameter	Baseline April 26 Means ± SD	Baseline July 24 Means ± SD	Baseline Sept 11 Means ± SD
Water temp (°C)	12.9±0.9	26.3±1.3	22.6±1.2
pH (S.U.)	8.3±0.1	8.5±0.1	8.4±0.2
Dissolved oxygen (mg/L)	10.1±0.6	7.3±2.1	8.2±2.2
Conductivity (mS/cm)	509±3.6	584±75	472±14
Total dissolved solids (mg/L)	327±7.0	378±51	301±7
Turbidity (NTU)	4.9±0.2	4.9±0.2	8.2±0.2
Secchi transparency (ft.)	8.4±1.6	6.1±0.1	3.3±0.1
Chlorophyll-a (µg/L)	0.13±0.3	0.34±0.7	0.0±0.0
Total kjeldahl nitrogen (mg/L)	0.6±0.1	1.2±0.9	1.0±0.3
Total inorganic nitrogen (mg/L)	0.240±0.0	0.172±0.4	0.057±0.1
Ammonia nitrogen (mg/L)	0.073±0.0	0.172±0.4	0.057±0.1
Nitrate nitrogen (mg/L)	0.166±0.0	0.100±0.0	0.100±0.0
Nitrite nitrogen (mg/L)	0.100±0.0	0.100±0.0	0.100±0.0
Total phosphorus (mg/L)	0.025±0.0	0.047±0.0	0.037±0.0
Ortho-Phosphorus (mg/L)	0.010±0.0	0.026±0.0	0.010±0.0
Total suspended solids (mg/L)	25±12	10.5±1.4	10.6±1.9

Table 62. Descriptive statistics of all water quality parameters in the south basin of Lake LeAnn for LFA baseline parameters collected on April 26, July 24, and September 11, 2019.

Parameter	Baseline April 26 Means ± SD	Baseline July 24 Means ± SD	Baseline Sept 11 Means ± SD
Water temp (°C)	12.7±1.1	23.9±4.8	22.1±2.6
pH (S.U.)	8.4±0.1	8.5±0.1	8.4±0.1
Dissolved oxygen (mg/L)	10.3±0.7	6.7±3.5	7.1±2.5
Conductivity (mS/cm)	544±5.3	494±49	570±74
Total dissolved solids (mg/L)	348±3.0	316±31	366±46
Turbidity (NTU)	4.9±0.2	4.6±0.4	6.5±1.5
Secchi transparency (ft.)	6.0±0.9	8.7±1.0	5.5±2.2
Chlorophyll-a (µg/L)	1.78±2.5	0.54±0.6	0.0±0.0
Total kjeldahl nitrogen (mg/L)	0.5±0.0	1.1±1.2	1.1±1.0
Total inorganic nitrogen (mg/L)	0.223±0.1	0.253±0.8	0.397±1.0
Ammonia nitrogen (mg/L)	0.035±0.0	0.253±0.8	0.391±1.0
Nitrate nitrogen (mg/L)	0.191±0.1	0.100±0.0	0.100±0.0
Nitrite nitrogen (mg/L)	0.100±0.0	0.100±0.0	0.100±0.0
Total phosphorus (mg/L)	0.018±0.0	0.039±0.1	0.023±0.0
Ortho-Phosphorus (mg/L)	0.010±0.0	0.012±0.0	0.012±0.0
Total suspended solids (mg/L)	16±11	13.7±1.1	10.0±0.0

4.2 Lake LeAnn 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. Lake LeAnn 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 Lake LeAnn was conducted on September 11, 2019 with a WAAS-enabled Lowrance HDS 9 GPS with variable frequency transducer. This data included 11,739 data points in the north basin and 16,872 data points in the south basin. Points were then uploaded into a cloud software program to reveal maps that displayed depth contours, sediment hardness, and aquatic vegetation biovolume (Figures 13-14). 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 or Coontail. In addition, any emergent canopies or lily pads will show as red 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. Tables 63 and 64 show the biovolume categories by plant cover during the September 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 north basin of Lake LeAnn consisted of 370 sampling locations around the littoral zone and the survey of the south basin consisted of 314 sampling locations and was conducted in spring during May 10, 2019 with follow-up post treatment surveys later in the season to confirm treatment efficacy. Data were placed in a table showing the relative abundance of each aquatic plant species found and a resultant calculation showing the frequency of each plant, and cumulative cover.

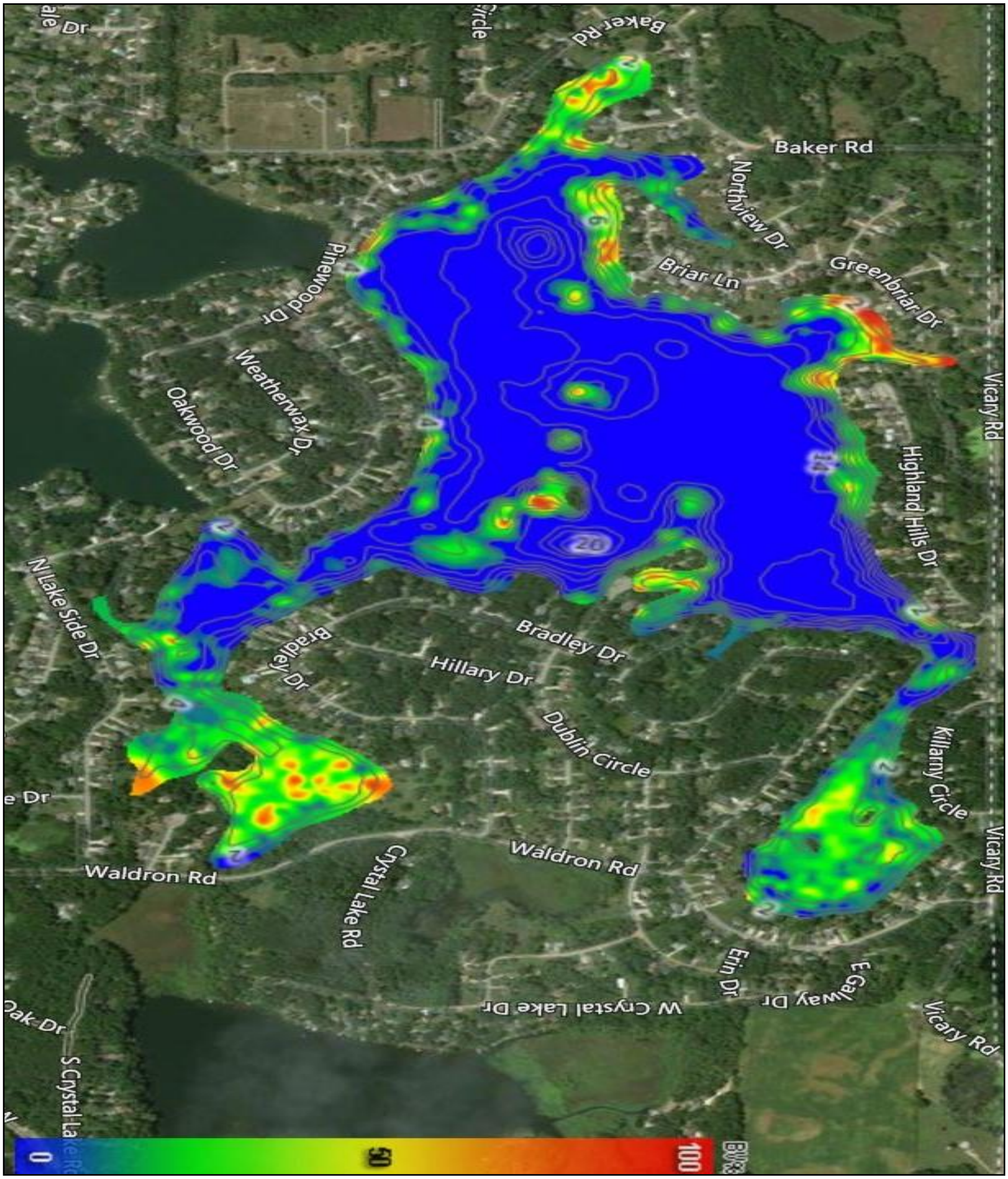


Figure 13. Aquatic plant biovolume of all aquatic plants in north Lake LeAnn, Hillsdale County, Michigan (September 11, 2019). Note: Red color denotes high-growing aquatic plants, green color denoted low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

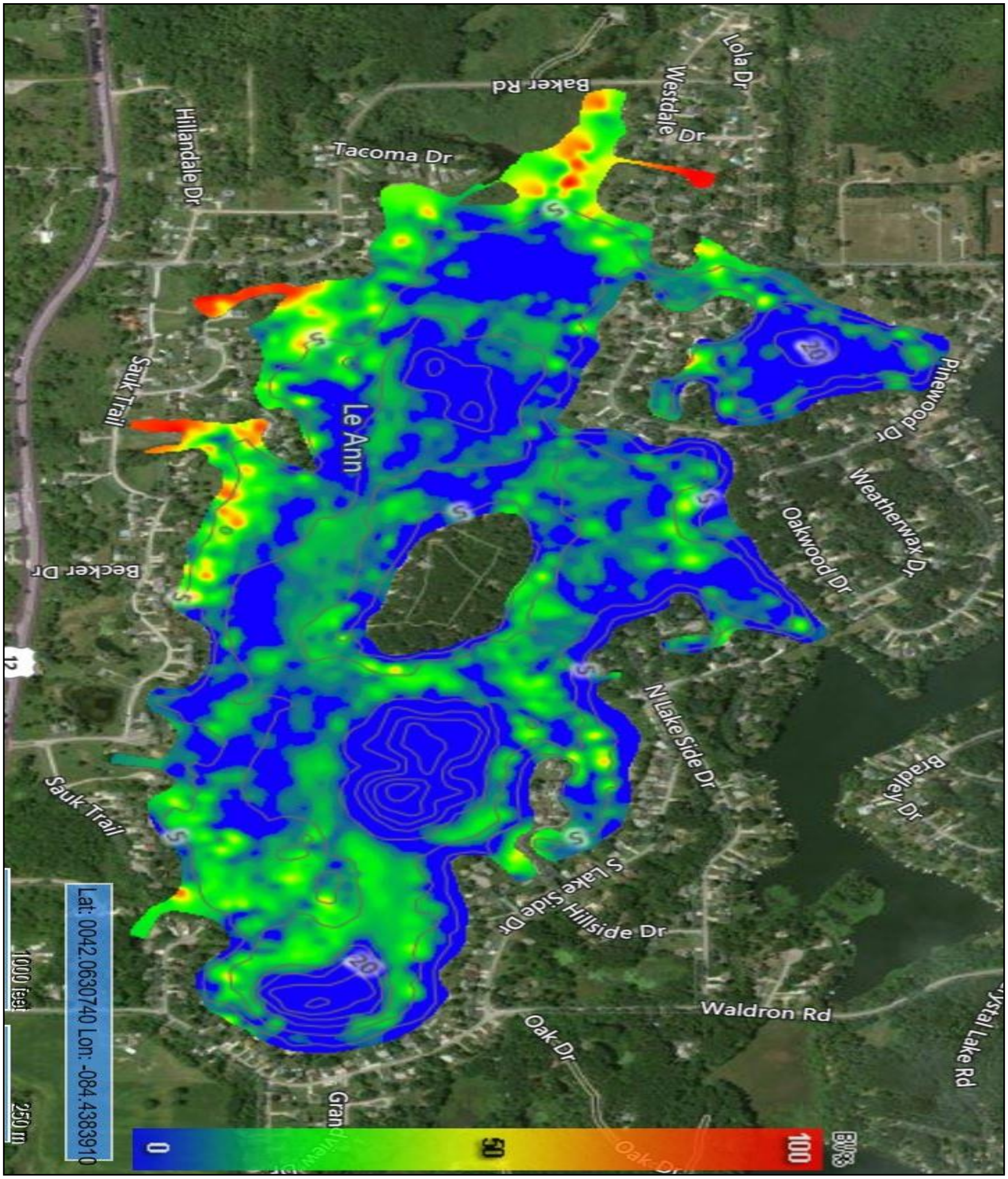


Figure 14. Aquatic plant biovolume of all aquatic plants in south Lake LeAnn, Hillsdale County, Michigan (September 11, 2019). Note: Red color denotes high-growing aquatic plants, green color denoted low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

Table 63. Lake LeAnn north basin aquatic vegetation biovolume by category percent over of each category (relative cover on September 11, 2019).

Biovolume Cover Category	% Relative Cover of Bottom by Category
<5%	59.7
5-20%	15.7
20-40%	9.9
40-60%	5.5
60-80%	3.4
>80%	5.7

Table 64. Lake LeAnn south basin aquatic vegetation biovolume by category percent over of each category (relative cover on September 11, 2019).

Biovolume Cover Category	% Relative Cover of Bottom by Category
<5%	58.0
5-20%	22.3
20-40%	12.3
40-60%	3.2
60-80%	1.8
>80%	2.4

4.2.1 Lake LeAnn 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 north basin of Lake LeAnn contained 8 native submersed, 3 floating-leaved, and 2 emergent aquatic plant species, for a total of 13 native aquatic macrophyte species (Table 65). The south basin of Lake LeAnn contained 7 native submersed, 2 floating-leaved, and 2 emergent aquatic plant species, for a total of 11 native aquatic macrophyte species (Table 66). Photos of all native aquatic plants are shown below in Figures 15-30. 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 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 north basin of the lake included the Chara (23.5% of the sampling sites), and Coontail (5.9% of the sampling sites). The dominant native aquatic plants in the south basin of the lake included the Chara (36.0% of the sampling sites), and Thin-leaf Pondweed (6.1% of the sampling sites). The Pondweeds grow tall in the water column and serve as excellent fish cover. In dense quantities, they can be a nuisance for swimming and boating and can be controlled with selective herbicide management or with mechanical harvesting.

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 (Cattails) are critical for shoreline stabilization as well as for wildlife and fish spawning habitat.

Table 65. Lake LeAnn north basin native aquatic plants (May 10, 2019).

Aquatic Plant Common Name	Aquatic Plant Latin Name	A level	B level	C level	D level	# Sites Found (% of total)
Muskgrass	*Chara vulgaris*	16	71	0	0	23.5
Thin-leaf Pondweed	*Stuckenia pectinatus*	3	9	2	2	4.3
Flat-stem Pondweed	*Potamogeton zosteriformis*	1	5	0	0	1.6
White-stem Pondweed	*Potamogeton praelongus*	1	0	0	0	0.2
Large-leaf Pondweed	*Potamogeton amplifolius*	3	1	2	0	1.6
Coontail	*Ceratophyllum demersum*	2	19	0	1	5.9
Bladderwort	*Utricularia vulgaris*	1	2	0	0	0.8
Whorled Watermilfoil	*Myriophyllum verticillatum*	2	5	0	0	1.9
Duckweed	*Lemna minor*	0	1	0	0	0.2
White Waterlily	*Nymphaea odorata*	0	18	3	0	5.7
Yellow Waterlily	*Nuphar varigata*	1	3	0	0	1.1
Cattails	*Typha latifolia*	2	2	1	1	1.6
Iris sp.	*Iris* sp.	2	2	0	0	1.1

Table 66. Lake LeAnn south basin native aquatic plants (May 10, 2019).

Aquatic Plant Common Name	Aquatic Plant Latin Name	A level	B level	C level	D level	# Sites Found (% of total)
Muskgrass	*Chara vulgaris*	17	92	4	0	36.0
Thin-leaf Pondweed	*Stuckenia pectinatus*	10	5	1	3	6.1
Variable-leaf Pondweed	*Potamogeton gramineus*	0	1	0	0	0.3
Large-leaf Pondweed	*Potamogeton amplifolius*	2	5	1	0	2.5
Coontail	*Ceratophyllum demersum*	2	6	0	0	2.5
Northern Watermilfoil	*Myriophyllum sibiricum*	0	4	3	0	2.2
Whorled Watermilfoil	*Myriophyllum verticillatum*	1	2	0	0	1.0
White Waterlily	*Nymphaea odorata*	0	5	0	0	1.6
Yellow Waterlily	*Nuphar varigata*	1	3	0	0	1.3
Cattails	*Typha latifolia*	1	1	4	1	2.2
Swamp Loosestrife	*Decodon verticillatus*	0	0	1	0	0.3

Figure 15. Chara (Muskgrass) ©RLS

Figure 16. Thin-leaf Pondweed ©RLS

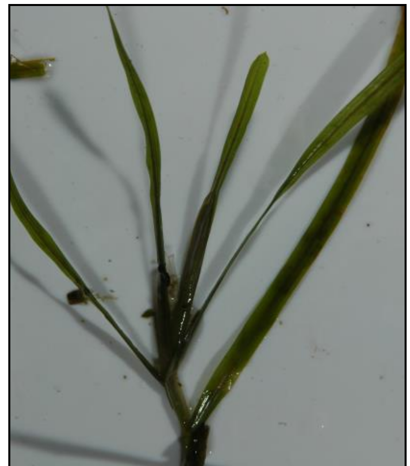


Figure 17. Flat-stem Pondweed ©RLS

Figure 18. Variable-leaf Pondweed ©RLS

Figure 19. Large-leaf Pondweed ©RLS

Figure 20. Coontail ©RLS

Figure 21. White-stem Pondweed ©RLS

Figure 22. Bladderwort ©RLS

Figure 23. Northern watermilfoil ©RLS

Figure 24. Whorled watermilfoil ©RLS

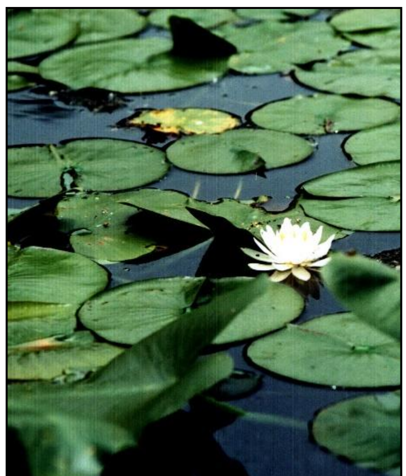


Figure 25. White Waterlily ©RLS

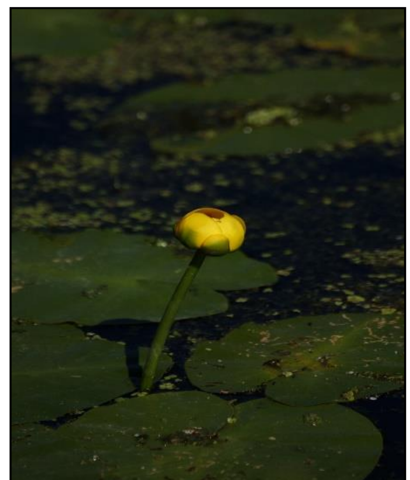


Figure 26. Yellow Waterlily ©RLS

Figure 27. Duckweed ©RLS

Figure 28. Swamp Loosestrife ©RLS

Figure 29. Cattails ©RLS

Figure 30. Iris ©RLS

4.2.2 Lake LeAnn 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 31) 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 32) 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 more abundant in the south basin (35 acres) compared to the north basin (20.25 acres) yet is a substantial threat to both lakes. Eurasian Watermilfoil growth in Lake LeAnn is capable of producing dense surface canopies. Figures 33-34 shows the distribution of milfoil within each lake. Tables 67-68 show the various invasives found and their relative abundance in both lakes.

Figure 31. Hybrid Eurasian Watermilfoil plant with seed head and fragments (©RLS).

Figure 32. Hybrid Eurasian Watermilfoil Canopy on an inland lake (©RLS).

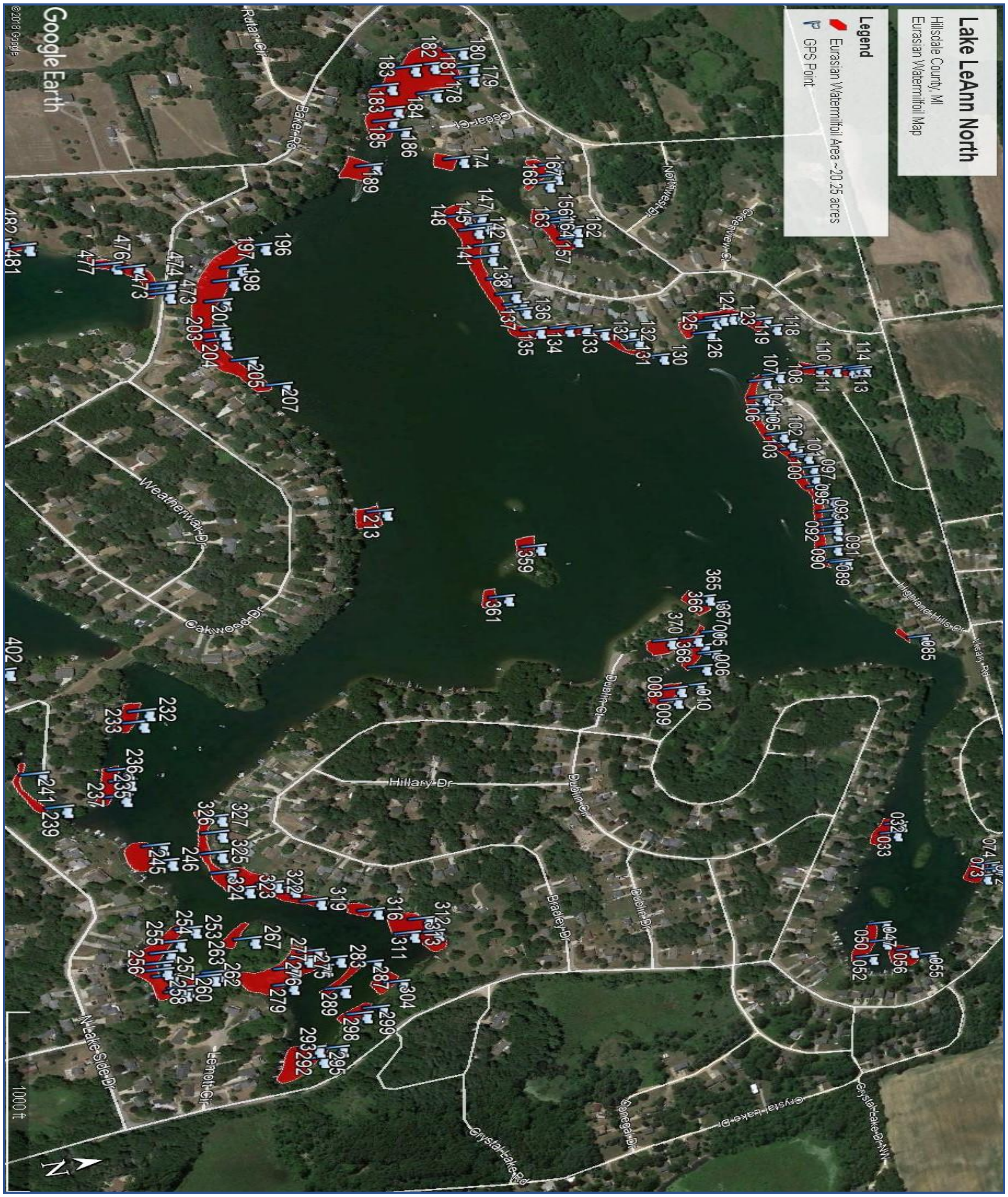


Figure 33. Distribution of EWM in the north basin of Lake LeAnn (May 10, 2019).

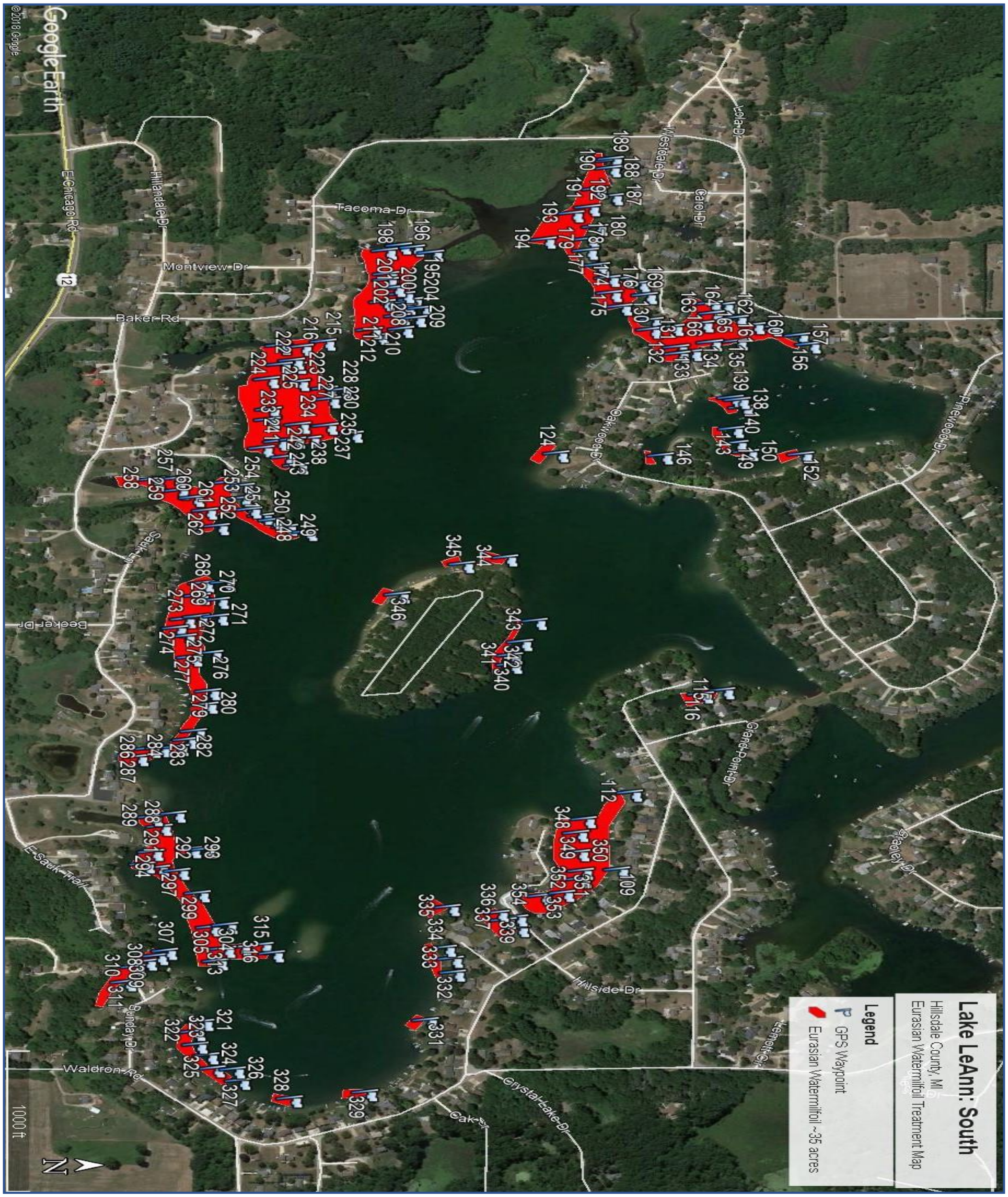


Figure 34. Distribution of EWM in the south basin of Lake LeAnn (May 10, 2019).

Curly-leaf Pondweed (*Potamogeton crispus*; Figure 35) 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 more prevalent in the north basin of Lake LeAnn (43.5 acres) compared to the south basin (11.2 acres). Distribution maps are shown below in Figures 36-37.

Figure 35. Curly-leaf Pondweed (©RLS).

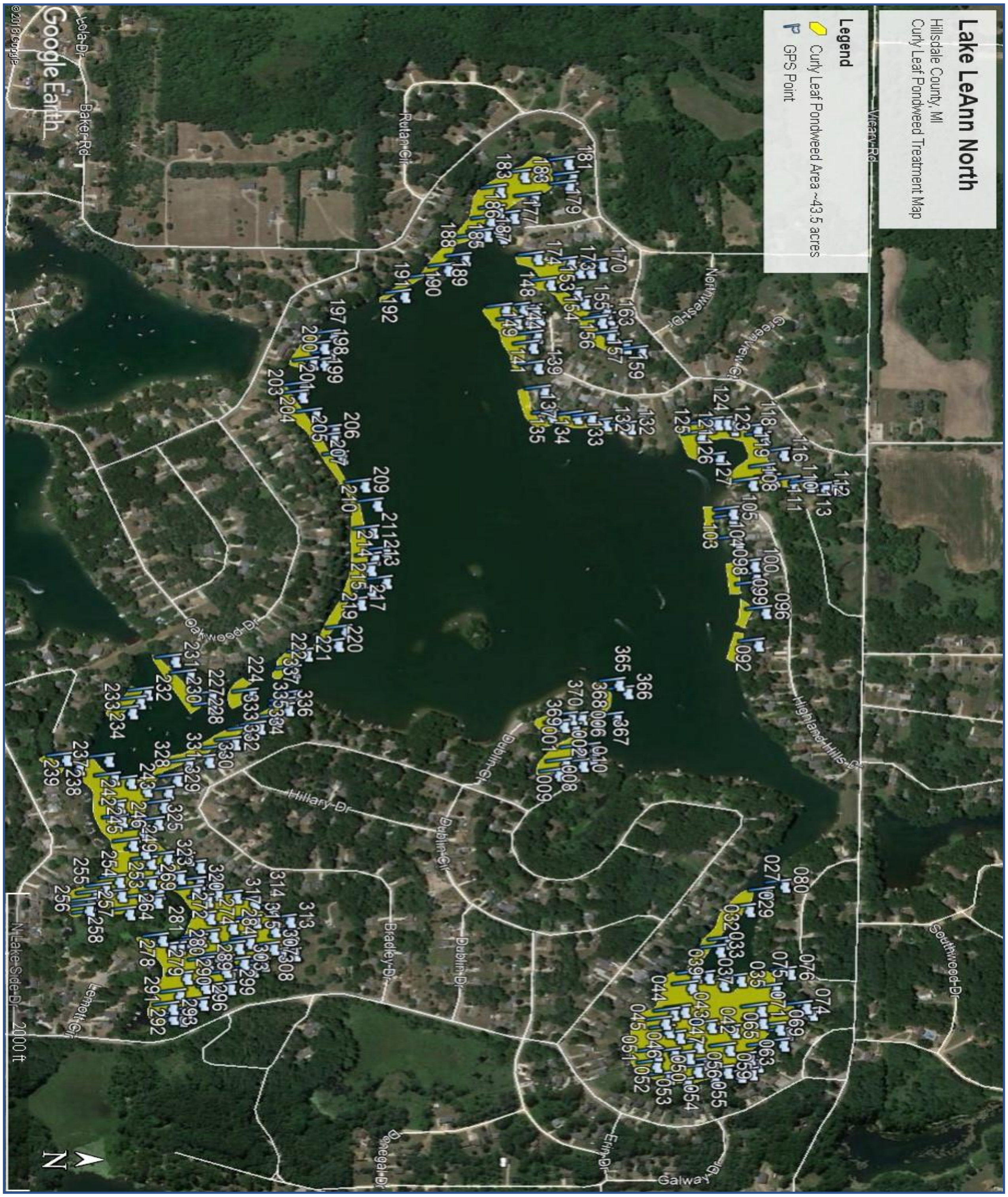


Figure 36. Distribution of CLP in the north basin of Lake LeAnn (May 10, 2019).

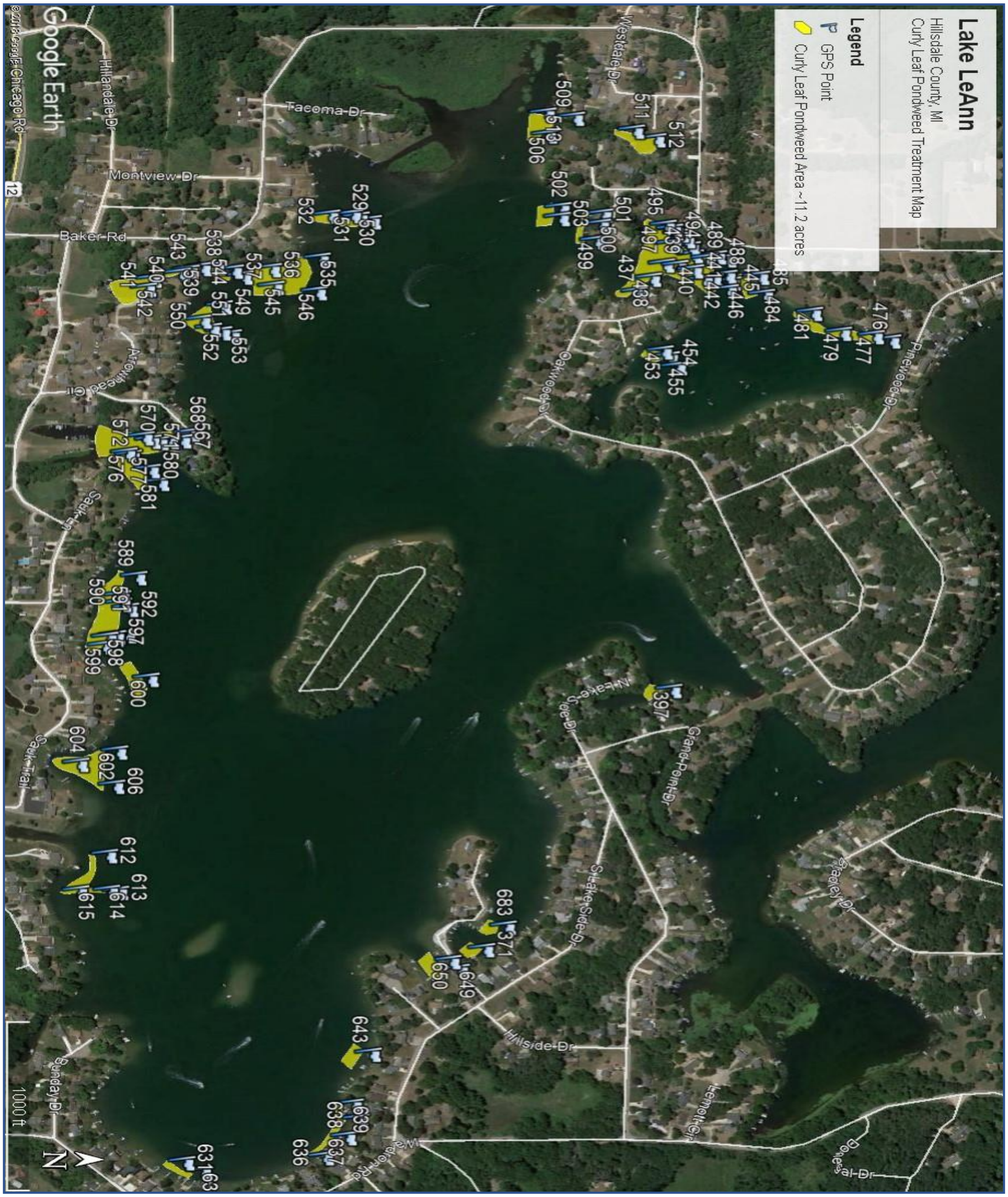


Figure 37. Distribution of CLP in the south basin of Lake LeAnn (May 10, 2019).

Starry Stonewort (*Nitellopsis obtusa*; Figure 38) is an invasive macro alga that has invaded many inland lakes and was originally discovered in the St. Lawrence River. The "leaves" appear as long, smooth, angular branches of differing lengths. The alga has been observed in dense beds at depths beyond several meters in clear inland lakes and can grow to heights in excess of a few meters. It prefers clear alkaline waters and has been shown to cause significant declines in water quality and fishery spawning habitat Individual fragments can be transported to the lake via waterfowl or boats. It was found in approximately 5.9 acres of the north basin of Lake LeAnn (Figure 39).

Figure 38. A fragment of Starry Stonewort (©RLS).

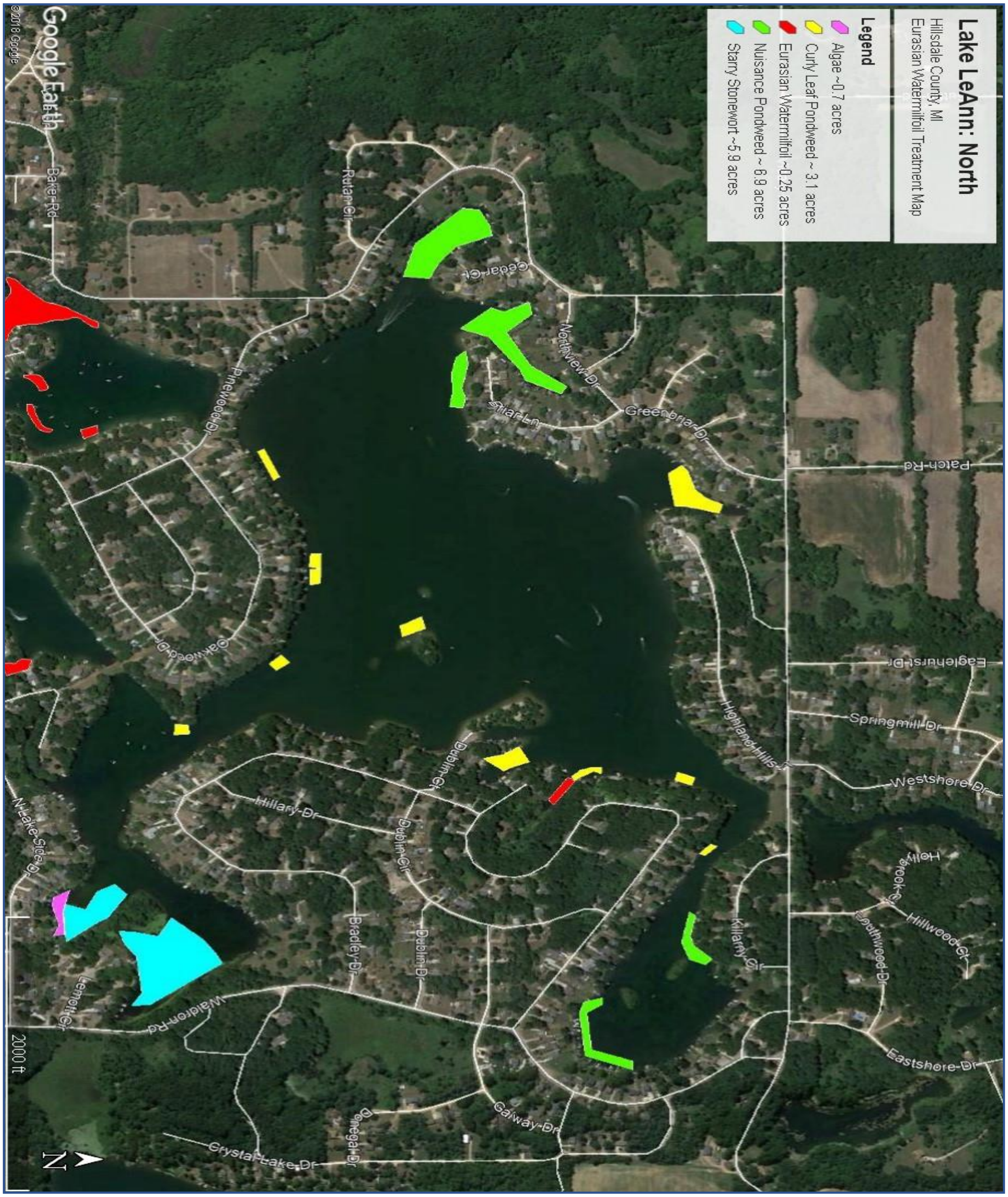


Figure 39. Distribution of Starry Stonewort and other nuisance plants in the north basin of Lake LeAnn (May 10, 2019).

Purple Loosestrife (*Lythrum salicaria*; Figure 40) is an invasive (i.e. exotic) emergent aquatic plant that inhabits wetlands and shoreline areas and was found in a few locations on the north shoreline of the north basin of Lake LeAnn. *L. salicaria* has showy magenta-colored flowers that bloom in mid-July and terminate in late September. The seeds are highly resistant to tough environmental conditions and may reside in the ground for extended periods of time. It exhibits rigorous growth and may out-compete other favorable native emergents such as Cattails (*Typha latifolia*) and thus reduce the biological diversity of localized ecosystems. The plant is spreading rapidly across the United States and is converting diverse wetland habitats to monocultures with substantially lower biological diversity. It should be removed promptly if found (i.e. by hand pulling or using a shovel to remove the roots and then discarding the plant into the garbage) to avoid further infestation. If the plant is not promptly removed by hand, it could dominate in wetland areas and require larger-scale systemic herbicide treatments. It was found in a few areas on the north lake shoreline.

Figure 40. The invasive emergent Purple Loosestrife (©RLS).

The Giant Common Reed (*Phragmites australis*; Figure 41) 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 two locations along the north region of the south lake basin. A map showing the distribution of all emergent invasives can be found in Figures 42-43.

Figure 41. The invasive emergent Phragmites (©RLS).

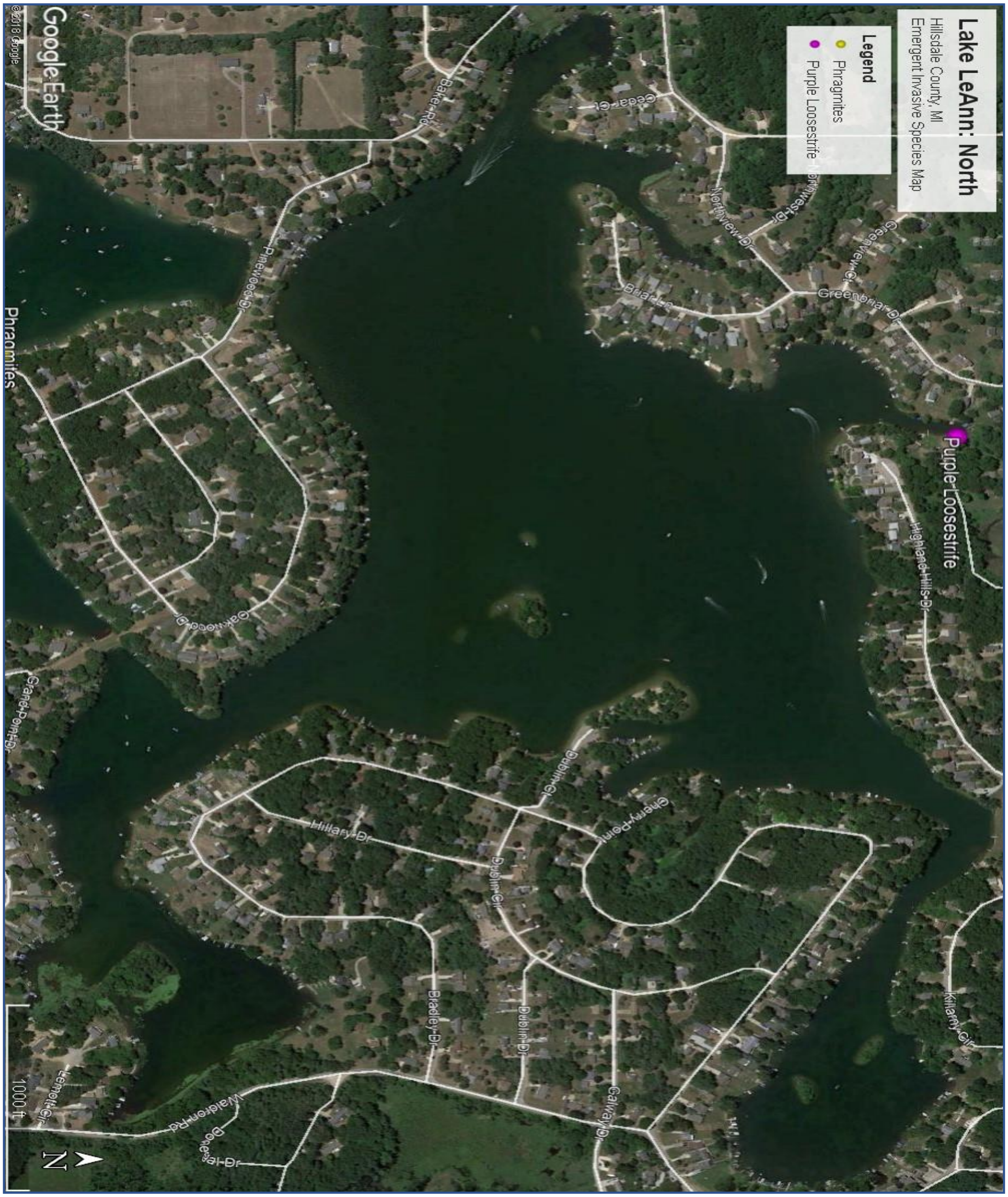


Figure 42. Distribution of emergent invasives around the north basin of Lake LeAnn (May 10, 2019).

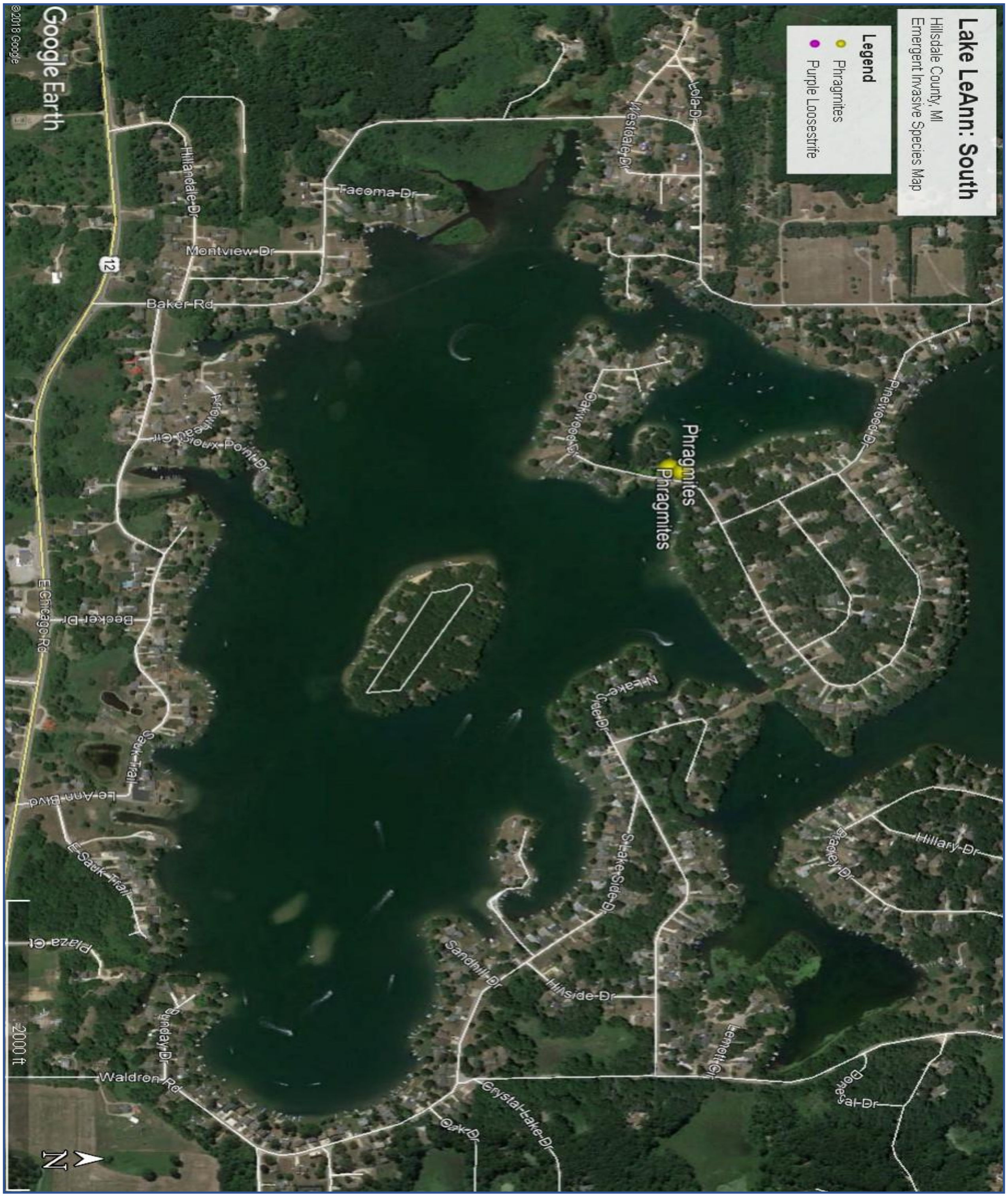


Figure 43. Distribution of emergent invasives around the south basin of Lake LeAnn (May 10, 2019).

Table 67. Lake LeAnn north basin invasive aquatic plants (May 10, 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*	3	50	50	49	41.1
Curly-leaf Pondweed	*Potamogeton crispus*	29	80	42	37	50.8
Starry Stonewort	*Nitellopsis obtusa*	1	12	4	4	5.7
Purple Loosestrife	*Lythrum salicaria*	0	0	2	0	0.5

Table 68. Lake LeAnn south basin invasive aquatic plants (May 10, 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*	1	13	22	76	35.7
Curly-leaf Pondweed	*Potamogeton crispus*	13	114	15	2	45.9
Giant Common Reed	*Phragmites australis*	0	1	1	0	0.6

4.3 Lake LeAnn 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 44) was conducted by RLS scientists on April 26, 2019 and September 11, 2019 over the 9 deep basins of Lake LeAnn. 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 CO_2 tablet to anesthetize the zooplankton. The sample was then preserved with a 70% ethyl alcohol solution.

Plankton sub-samples (in 1 ml aliquots) were analyzed under a Zeiss® dissection scope with the use of a Bogorov counting chamber. Taxa were keyed to species when possible and are shown in Tables 69-72 below.

Table 69. Zooplankton taxa and count data from the north basin of Lake LeAnn (April 26, 2019).

Zooplankton Taxa	N1	N2	N3	N4
Cladocerans				
Daphnia parvula	2	8	1	0
D. retrocurva	3	2	0	1
Bosmina longirostris	0	0	5	1
Chydorus sp.	0	0	1	0
Copepods/Cyclopods				
Diaptomus copepodites	2	6	1	0
Mesocyclops edax	7	11	2	1
Rotifers				
Keratella	6	16	1	7
Kellicotia	1	0	0	0

Table 70. Zooplankton taxa and count data from the north basin of Lake LeAnn (September 11, 2019).

Zooplankton Taxa	N1	N2	N3	N4
Cladocerans				
Daphnia parvula	1	4	13	0
D. retrocurva	2	6	1	0
Bosmina longirostris	1	1	0	0
Chydorus sp.	0	5	1	1
Copepods/Cyclopods				
Mesocyclops edax	2	2	1	0
Rotifers				
Keratella	1	7	2	0

Table 71. Zooplankton taxa and count data from the south basin of Lake LeAnn (April 26, 2019).

Zooplankton Taxa	S1	S2	S3	S4	S5
Cladocerans					
Daphnia parvula	4	11	2	0	1
D. retrocurva	1	8	13	9	0
Bosmina longirostris	0	0	5	0	0
Chydorus sp.	0	0	4	1	0
Copepods/Cyclopods					
Diaptomus copepodites	2	4	0	0	4
Rotifers					
Keratella	0	5	7	2	1

Table 72. Zooplankton taxa and count data from the south basin of Lake LeAnn (September 11, 2019).

Zooplankton Taxa	S1	S2	S3	S4	S5
Cladocerans					
Daphnia parvula	6	2	2	4	1
D. retrocurva	18	4	9	2	0
Chydorus sp.	0	0	0	0	1
Copepods/Cyclopods					
Diaptomus copepodites	2	0	0	4	8
Mesocyclops edax	0	0	5	1	0
Rotifers					
Keratella	6	2	1	0	0

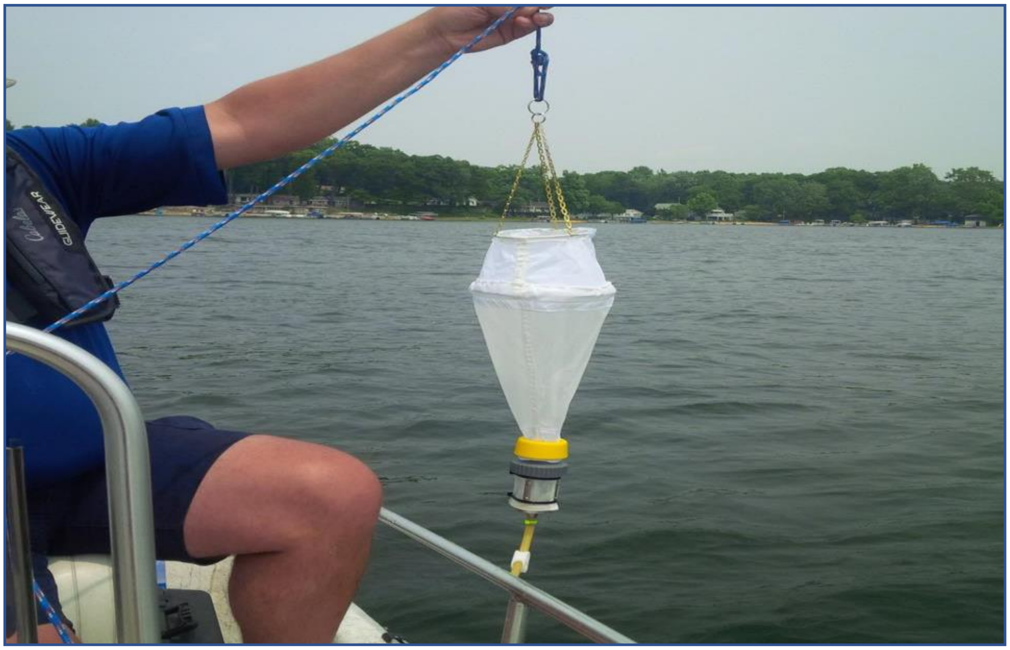


Figure 44. A zooplankton collection tow net (RLS, 2018).

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 45). 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 Lake LeAnn sediment samples included midges (Chironomindae), Jute snails (Pleuroceridae), Wheel snails (Planorbidae), and Zebra Mussels (Dreisseniidae). Of all the species found, all were native except for the Zebra Mussels. While the majority of the species were native, some are located universally in low quality and high-quality water. The midge larvae family Chironomidae can be found in both high- and low-quality water (Lenat and Barbour 1994). Tables 73-74 display the taxa and abundance found at the 9 sites.

Figure 45. 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 Lake LeAnn 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 73. Macroinvertebrates found in the north basin of Lake LeAnn, Hillsdale County, MI (July 24, 2019).

Site N1	**Family**	**Genus**	**Number**	**Common name**
	Chironimidae	*Chironomus* spp.	9	Midges
	Planorbidae		11	Wheel snails
	Dreisseniidae		4	Zebra mussels
		Total	**23**	
Site N2	**Family**	**Genus**	**Number**	**Common name**
	Planorbidae		12	Wheel snails
	Chironomidae	*Chironomus* spp.	3	Midges
		Total	**15**	
Site N3	**Family**	**Genus**	**Number**	**Common name**
	Chironomidae	*Chironomus* spp.	8	Midges
	Pleuroceridae		1	Jute snails
	Planorbidae		13	Wheel snails
		Total	**22**	
Site N4	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae		2	Jute snails
	Chironmidae		6	Midges
		Total	**8**	

Table 74. Macroinvertebrates found in the south basin of Lake LeAnn, Hillsdale County, MI (July 24, 2019).

Site S1	**Family**	**Genus**	**Number**	**Common name**
	Chironimidae	*Chironomus spp.*	1	Midges
	Planorbidae		12	Wheel snails
		Total	**13**	
Site S2	**Family**	**Genus**	**Number**	**Common name**
	Planorbidae		16	Wheel snails
	Chironomidae	*Chironomus spp.*	9	Midges
		Total	**25**	
Site S3	**Family**	**Genus**	**Number**	**Common name**
	Planorbidae		10	Wheel snails
		Total	**10**	
Site S4	**Family**	**Genus**	**Number**	**Common name**
	Pleuroceridae		2	Jute snails
	Chironmidae		19	Midges
		Total	**21**	
Site S5	**Family**	**Genus**	**Number**	**Common name**
	Chironomidae	*Chironomus* spp.	7	Midges
	Planorbidae		5	Wheel snails
		Total	**12**	

4.4 Lake LeAnn Fishery

Currently, Lake LeAnn has healthy populations of Bluegill and Large-mouth bass but there were also 12 other species noted during a 2018 lake fishery study by AEM. These species include the Black crappie, Bluntnose minnow, Central mud minnow, Common carp, Fathead minnow, Northern pike, Pumpkinseed, Spot fin shiner, Walleye, Warmouth, Yellow bullhead, and the Yellow perch. Historically, the LLPOA has stocked the lake with Smallmouth bass, Walleye, Yellow perch, Channel catfish, Black crappie, Northern pike, and Fathead minnows. During the lake vegetation surveys in 2019, RLS noted a lack of woody debris for fish spawning habitat. This could help the fishery since the lake is well stocked with fish and forage habitat with submersed aquatic vegetation.

The fishery habitat is more plentiful along the undeveloped shorelines of the lakes and fish beds were located near the shoreline areas in both the developed and undeveloped areas in both lakes. For the most part, erosion is not a problem around the lakes and sediment burial of fish beds does not seem to be problematic.

5.0 LAKE LEANN 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 Lake LeAnn. Watershed improvements are discussed in the second section of this report for immediate watershed management.

5.1 Lake LeAnn 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 Lake LeAnn. The lake management components involve both within-lake (basin) and around-lake (watershed) solutions to protect and restore complex aquatic ecosystems such as Lake LeAnn. 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 Lake LeAnn 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 Lake LeAnn 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 Lake LeAnn is awareness and education (Figures 46 and 47). 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 Lake LeAnn through the use of a professionally developed educational newsletter such as the one distributed by the LLPOA.

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 Lake LeAnn, the LLPOA 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 48).

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 46. An aquatic invasive prevention sign for public access sites.

Figure 47. An aquatic invasive prevention sign for public access sites.

Figure 48. A public boat washing station for boat access sites.

Zebra Mussels

Zebra Mussels (*Dreissena polymorpha*; Figure 49) were first discovered in Lake St. Clair in 1988 and likely arrived in ballast water or on shipping vessels from Europe (McMahon 1996). They are easily transferred to other lakes because they inherit a larval (nearly microscopic) stage where they can easily avoid detection. The mussels then grow into the adult (shelled) form and attach to substrates (i.e. boats, rafts, docks, pipes, aquatic plants, and lake bottom sediments) with the use of byssal threads. The fecundity (reproductive rate) of female Zebra Mussels is high, with as many as 40,000 eggs laid per reproductive cycle and up to 1,000,000 in a single spawning season (Mackie and Schlosser 1996). Although the mussels only live 2-3 years, they are capable of great harm to aquatic environments. In particular, they have shown selective grazing capabilities by feeding on the preferred zooplankton food source (green algae) and expulsion of the non-preferred blue green algae (cyanobacteria). Additionally, they may decrease the abundance of beneficial diatoms in aquatic ecosystems (Holland 1993). Such declines in favorable algae, can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations. Zebra Mussels are viewed by some as beneficial to lakes due to their filtration capabilities and subsequent contributions to increased water clarity. However, such water clarity may allow other photosynthetic aquatic plants to grow to nuisance levels (Skubinna et *al*. 1995). Some specimens were found in Lake LeAnn by RLS scientists during the lake study.

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 Lake LeAnn. Fishing poles, lures, and other equipment used in other lakes (and especially the Great Lakes) should also be thoroughly steam-washed before use in Lake LeAnn. 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 49. 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 50) and *Trapa natans* (Water Chestnut; Figure 51). *Hydrilla* was introduced to waters of the United States from Asia in 1960 (Blackburn et *al*. 1969) and is a highly problematic submersed, rooted, aquatic plant in tropical waters. Many years ago, *Hydrilla* was found in Lake Manitou (Indiana, USA) and the lake public access sites were immediately quarantined in an effort to eradicate it. *Hydrilla* retains many physiologically distinct reproductive strategies which allow it to colonize vast areas of water and to considerable depths, including fragmentation, tuber and turion formation, and seed production. Currently, the methods of control for *Hydrilla* include the use of chemical herbicides, rigorous mechanical harvesting, and Grass Carp (*Ctenopharyngodon idella* Val.), with some biological controls currently being researched.

Water Chestnut (*Trapa natans*) is a non-native, annual, submersed, rooted aquatic plant that was introduced into the United States in the 1870's yet may be found primarily in the northeastern states. The stems of this aquatic plant can reach lengths of 12-15 feet, while the floating leaves form a rosette on the lake surface.

Seeds are produced in July and are extremely thick and hardy and may last for up to 12 years in the lake sediment. If stepped on, the seed pods may even cause deep puncture wounds to those who recreate on the lakes. Methods of control involve the use of mechanical removal and chemical herbicides. Biological controls are not yet available for the control of this aquatic plant.

Figure 50. Hydrilla from a Florida lake (RLS, 2012).

Figure 51. 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 52). The permit contains a list of approved herbicides for a particular body of water, as well as dosage rates, treatment areas, and water use restrictions. Contact and systemic aquatic herbicides are the two primary categories used in aquatic systems.

Figure 52. 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 Lake LeAnn, the use of contact herbicides (such as diquat and flumioxazin) would be recommended only for nuisance submersed native aquatic plant growth which is usually limited to pondweeds. An early May 14, 2019 treatment for the Curly-leaf in both lakes was conducted by PLM using the contact herbicide diquat with great success. An adjuvant was used to increase the herbicide contact time with the plants.

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 lakes, which is an indicator of poor water quality (Figure 53). A bloom on the north lake in early October 2019 proved to have total microcystins at 55 µg/L which is well above the EPA standard for microcystin at 8.0 µg/L and a no contact advisory was issued by the Michigan Department of Health and Human Services (MDHHS). *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 Lake LeAnn 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 (Figures 16 and 17) will also continue to increase in stagnant areas due to high nutrient levels in the lake.

Figure 53. A late season algal bloom on the north lake of Lake LeAnn (October 2019; LLPOA).

Algae was also treated with chelated copper. On Jul 11, 2019 an additional algae treatment was conducted in the two southwest bays of the north lake and the southwest corner of LaMott Bay. Diquat was also used for nuisance pondweeds in the south side of Waldron Bay, and two small areas along the west and south shoreline of the north lake.

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. Systemic herbicides such as triclopyr were used in Lake LeAnn during the 2019 season with great success. The initial treatment in 2019 occurred on June 19, 2019 and utilized triclopyr to systemically kill the roots of all milfoil plants. RLS recommends aeration for the control of all algae in the future and only the use of systemic herbicides for milfoil (granular formulation) and diquat for nuisance Curly-leaf and other pondweeds as needed.

5.1.3 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 54). 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 Lake LeAnn if the milfoil is not present and the residents desire a biomass removal technique that does not consist of the use of contact herbicides for nuisance pondweed removal.

Figure 54. 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 55) or Weed Rollers (Figure 56) 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 Lake LeAnn and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth if it becomes prevalent in future years.

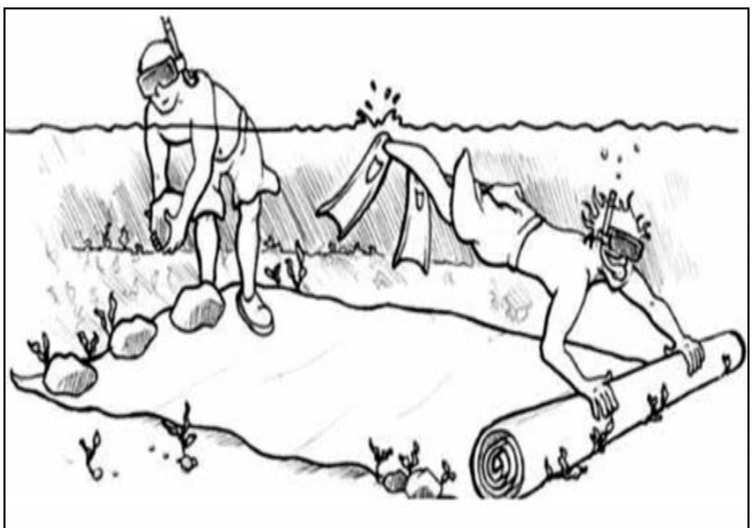


Figure 55. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.

Figure 56. A Weed Roller.

5.1.5 Diver Assisted Suction Harvesting (DASH)

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 57) 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.

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.

Figure 57. A DASH boat used for aquatic plant removal (RLS, 2018).

5.2 Lake LeAnn Water Quality Improvements

In addition to lake improvement methods that improve the aquatic plant communities (both invasive and nuisance 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 muck, and allowing for enhanced recreational activities.

5.2.1 Laminar Flow Aeration (LFA) and Bioaugmentation

Laminar flow aeration systems (Figure 58) 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). There are some sediments in Lake LeAnn that contain moderate quantities of organic matter so there may be some muck reduction. The largest benefit of LFA for Lake LeAnn 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).

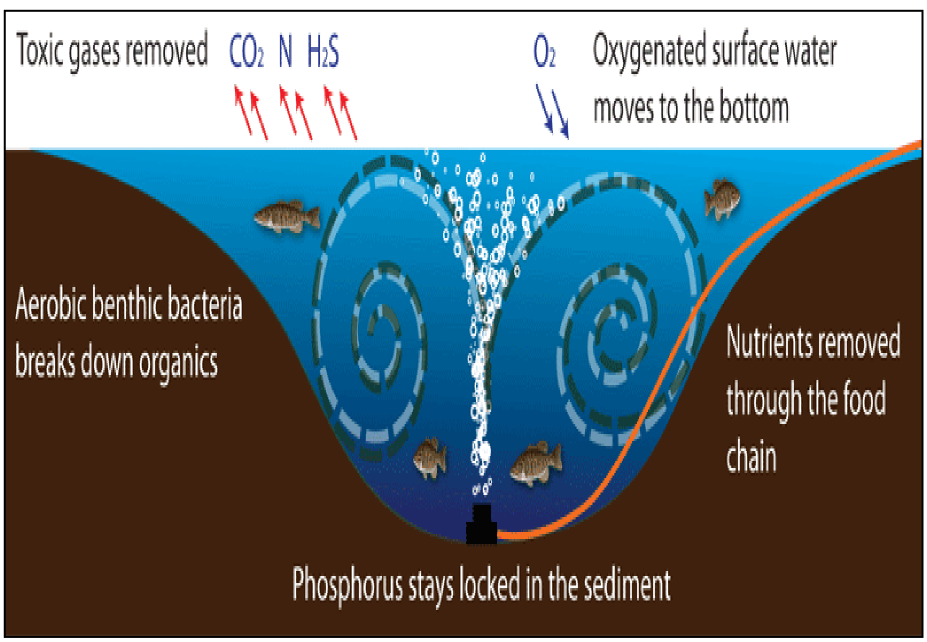


Figure 58. Diagram of laminar flow aeration. ©RLS

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 Lake LeAnn 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 59).

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 Lake LeAnn at this time but could be used in shallow bays in the future if the water level becomes too low or in retention ponds for BMP's.

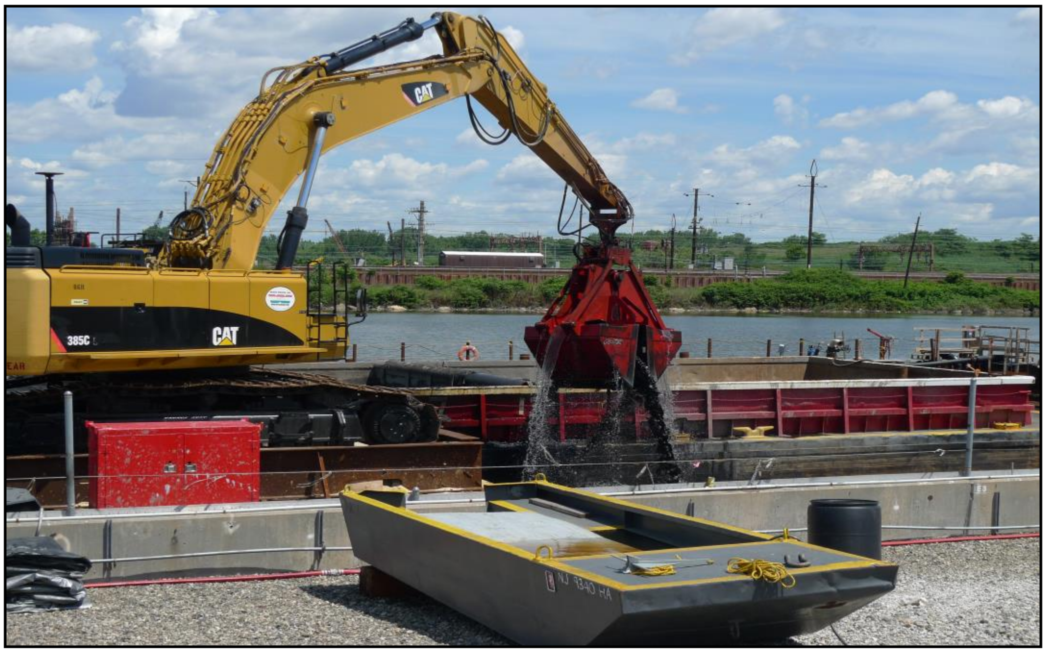


Figure 59. A mechanical dredge for sediment removal in inland waters.

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 lakeshore and shallow water vegetation into lawns, rocky riprap, and sand beaches. Native plants have been removed in many areas and helped sustain healthy fish populations. 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 for 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 root in 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, 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 LAKE LEANN IMPROVEMENT PROJECT CONCLUSIONS & RECOMMENDATIONS

Lake LeAnn is facing significant issues that degrade water quality over time, including inputs of nutrients and sediments from surrounding drains and leaking septic tanks and drain fields which lead to a decline in lake health. 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. The high nutrients have also led to increased blue-green algal blooms that 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 sediments 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 two critical source areas (CSA's) that drain to the lake which includes CSA #4 at the north region of the north basin and CSA#3 at the southwest region of the south basin. 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 detention ponds to slow the velocity of sediment particles before entering the lake.

Whole lake laminar flow aeration is recommended for both lake basins 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 prior to and after treatments to determine treatment efficacy. Continuous monitoring of the lake for potential influxes of other exotic aquatic plant genera (i.e. *Hydrilla*) that could also significantly disrupt the ecological stability of Lake LeAnn 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 harvester or herbicide applicator to 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 75 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 75. List of Lake LeAnn 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 invasives	Reduce invasives in lake	Reduce long-term use of herbicides in lake	Entire lake where invasives present
Laminar flow aeration system/bioaug	Increase DO, reduce blue-green algae, increase water clarity	Reduce nutrients in the water column and sediments	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	Both the lake and all major drains (CSA's)
Annual lake surveys pre and post-treatment	To determine efficacy of herbicide treatments on invasives	To determine ability of native aquatic vegetation biodiversity to recover post-management implementation	Entire lake
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 Lake LeAnn Improvements

The proposed lake improvement and management program for Lake LeAnn 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 Lake LeAnn is presented in Table 76. 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 76. Lake LeAnn 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 Lake LeAnn Improvement Item	Year 1 Costs	Years 2-5 (Annual) Costs[4]
Systemic herbicides [1] for invasives; CLP treatment; Nuisance treatments	$49,865	$49,865
LFA System[2] (includes installation for first year; annual lease cost and electrical for each year as well as bioaugmentation and maintenance)	$372,000*	$282,000*
Drain filters[3] for drains Note: maintenance for future years	$15,000**	$15,000**
Professional services (limnologist management of lake, oversight, processing, education)[4]	$33,000	$33,000
Contingency[5]	$46,987	$37,987
Total Annual Estimated Cost	$516,852	$417,852

[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.

7.0 SCIENTIFIC REFERENCES

Aiken, S.G., P.R. Newroth, and I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. *Canadian Journal of Aquatic Plant Science* 59: 201-215.

Allen, J. 2009. Ammonia oxidation potential and microbial diversity in sediments from experimental bench-scale oxygen-activated nitrification wetlands. MS thesis, Washington State University, Department of civil and Environmental Engineering.

Barbiero, R., R.E. Carlson, G.D. Cooke, and A.W. Beals. 1988. The effects of a continuous application of aluminum sulfate on lotic benthic macroinvertebrates. *Lake and Reservoir Management* 4(2):63-72.

Blackburn, R.D., L.W. Weldon, R.R. Yeo, and T.M. Taylor. 1969. Identification and distribution of certain similar-appearing submersed aquatic weeds in Florida. *Hyacinth Control Journal* 8:17-23.

Beutel, M.W. 2006. Inhibition of ammonia release from anoxic profundel sediments in lakes using hypolimnetic oxygenation. *Ecological Engineering* 28(3): 271-279.

Couch, R., and E. Nelson 1985. *Myriophyllum spicatum* in North America. Pp. 8-18. In: Proc. First Int. Symp. On Watermilfoil (*M. spicatum*) and related Haloragaceae species. July 23-24, 1985. Vancouver, BC, Canada. Aquatic Plant Management Society, Inc.

Eiswerth, M.E., S.G. Donaldson, and W.S. Johnson. 2000. Potential environmental impacts and economic damages of Eurasian Watermilfoil (*M. spicatum*) in Western Nevada and Northeastern California. *Weed Technology* 14(3):511-518.

Engstrom, D.R., and D.I. Wright. 2002. Sedimentological effects of aeration-induced lake circulation. *Lake and Reservoir Management* 18(3):201-214.

Fenchel, T., and T.H. Blackburn. 1979. Bacteria and mineral cycling. Academic.

Gosch, N. J. C., Phelps, Q. E. and D.W. Willis. 2006. Habitat characteristics at bluegill spawning colonies in a South Dakota glacial lake. *Ecology of Freshwater Fish*, 15: 464–469. doi: 10.1111/j.1600-0633.2006.00178. x.

Halstead, J.M., J. Michaud, and S, Hallas-Burt. 2003. Hedonic analysis of effects of a non-native invader (*Myriophyllum heterophyllum*) on New Hampshire (USA) lakefront properties. *Environmental Management* 30 (3): 391-398.

Henderson, C.L., C. Dindorf, and F. Rozumalski. 1998. Lakescaping for Wildlife and Water Quality. Minnesota Department of Natural Resources, 176 pgs.

Herrick, B.M., and Wolf, A.T. 2005. Invasive plant species in diked vs. undiked Great Lakes wetlands. *Journal of Great Lakes Research*., Internat. Assoc. Great. Lakes. Res. 31(3): 277-287.

Holland, R.E. 1993. Changes in planktonic diatoms and water transparency in Hatchery Bay, Bass Island Area, Western Lake Erie since the establishment of the zebra mussel, *Journal of Great Lakes Research* 19:617-624.

Jermalowicz-Jones, J.L. 2009-2019. Evaluation studies of laminar flow aeration efficacy on various water quality parameters in Michigan inland lakes. *Unpublished data.*

Laing, R.L. 1978. Pond/Lake Management organic waste removal through multiple inversion. In house report. Clean-Flo Lab, Inc.

Laitala, K.L., T.S. Prather, D. Thill, and B. Kennedy. 2012. Efficacy of benthic barriers as a control measure for Eurasian Watermilfoil (*Myriophyllum spicatum*). *Invasive Plant Science* 5(2):170-177.

Lenat, D.R. and M.T. Barbour. Using benthic macroinvertebrate community structure for rapid, cost-effective, water quality monitoring: rapid bioassessment. Biological monitoring of aquatic systems. Lewis Publishers, Boca Raton, Florida (1994): 187-215.

Lillie, R.A., and J. Budd. 1992. Habitat architecture of *Myriophyllum spicatum* L. as an Index to habitat quality for fish and macroinvertebrates. *Journal of Freshwater Ecology* 7(2): 113-125.

Lyons, J. 1989. Changes in the abundance of small littoral-zone fishes in Lake Mendota, Wisconsin. *Canadian Journal of Zoology* 67:2910-2916, 10.1139/z89-412

Mackie, G.L., and D.W. Schloesser. 1996. Comparative biology of Zebra Mussels in Europe and North America: An Integrative and Comparative Biology 36(3):244-258.

Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies, *Journal of Aquatic Plant Management* 29, 94-99.

Malueg, K., J. Tilstra, D. Schults, and C. Powers. 1973. Effect of induced aeration upon stratification and eutrophication processes in an Oregon farm pond. *Geophysical Monograph Series* 17: 578-587. American Geophysical Union. Washington DC.

Margenau, T.L., AveLallemant, S.P., Giehtbrock, D., and S. Schram. 2008. Ecology and management of northern pike in Wisconsin. *Hydrobiologia* 601(1):111-123.

McMahon, R.F., and C.J. Williams. 1986. A reassessment of growth rate, life span, life cycles, and population dynamics in a natural population dynamics in a natural population and field caged individuals of *Corbicula fluminea* (Müller) (Bivalvia: Corbicula). Am. Malacol. Bull. Spec. ed. No. 2:151-166.

Merritt, R., W. Cummins, and M.B. Berg. 2008. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co. 1158 pgs.

Nayar, S., DJ Miller, A. Hunt, BP Goh, and LM Chou. 2007. Environmental effects of dredging on sediment nutrients, carbon, and granulometry in a tropical estuary. *Environmental Monitoring and Assessment* 127(1-3):1-13.

Newroth, P.R. 1985. A review of Eurasian watermilfoil impacts and management in British Columbia. Pp. 139-153. In: Proc. First Int. Symp. On watermilfoil (*M. spicatum*) and related Haloragaceae species. July 23-24, 1985. Vancouver, BC, Canada. Aquatic Plant Management Society, Inc.

Nürnberg, G. 2017. Attempted management of cyanobacteria by Phoslock (lanthanum-modified) clay in Canadian Lakes: Water quality results and predictions. *Lake and Reservoir Management* 33:163-170.

Ogwada, R.A., K.R. Reddy, and D.A. Graetz. 1984. Effects of aeration and temperature on nutrient regeneration from selected aquatic macrophytes. *Journal of Environmental Quality* 13(2):239-243.

Parsons, J.K., and R.A. Matthews. 1995. Analysis of the camps between macroinvertebrates and macrophytes in a freshwater pond. *Northwest Science* 69: 265-275.

Pilgrim, K.M., and P.L. Brezonik, 2005. Evaluation of the potential adverse effects of lake inflow treatment with alum. *Lake and Reservoir Management* 21(1):77-87.

Price, J.D., and C.C. Long. 2010. Lake LeAnn, Hillsdale County, Michigan 2008-2009 walleye evaluations. Michigan Department of Fish and Wildlife.

Radomski, P. and T. J. Goeman. 2001. Consequences of human lakeshore development on emergent and floating-leaf vegetation abundance. *North American Journal of Fisheries Management* 21(1):46-61.

Reed, C.G. 1977. History and disturbance of Eurasian milfoil in the United States and Canada. *Phytologia* 36: 417-436.

Rinehart, K.L., M. Namikoshi, and B. W. Choi. 1994. Structure and biosynthesis of toxins from blue-green algae (cyanobacteria). *Journal of Applied Phycology* 6: 159-176.

Skelton, 1997. Lake LeAnn tributary macroinvertebrate study. Biology and Environmental Science Department. St. Norbert College. 19 pp.

Skubinna, J.P., T.G. Coon, and T.R. Batterson. 1995. Increased abundance and depth of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Michigan. *Journal of Great Lakes Research* 21(4): 476-488.

Stewart, T.W. and J.M. Haynes. 1994. Benthic macroinvertebrate communities of southwestern Lake Ontario following invasion of *Dreissena*. *Journal of Great Lakes Research* 20(2): 479-493.

Stewart, P.M., Butcher, J.T. and T.O. Swinford. 2000. Land use, habitat, and water quality effects on macroinvertebrate communities in three watersheds of a Lake Michigan associated marsh system. *Aquatic Ecosystem Health & Management*: 3(1):179-189.

Toetz, D.W., 1981. Effects of whole lake mixing on water quality and phytoplankton. *Water Research* 15: 1205-1210.

Turcotte, A.C., C.V. Déry, and K.F. Ehrlich. 1988. Manipulation of microbial ecosystems to control the aquatic plant Eurasian Watermilfoil. Preprint paper. Département de Biologie, Université de Sherbrooke, Sherbrooke, Québec, CANADA J1K 2R1.

Valley, R., and M. T. Bremigan. 2002. Effects of selective removal of Eurasian watermilfoil on age-0 largemouth bass piscivory and growth in southern Michigan lakes. *Journal of Aquatic Plant Management* 40: 79-87.

Verma, N. and S. Dixit. 2006. Effectiveness of aeration units in improving water quality of Lower Lake, Bhopal, India. *Asian Journal of Experimental Science* 20(1): 87-95.

Weiss, C., and B. Breedlove. 1973. Water quality changes in an impoundment as a consequence of artificial destratification. 216 pp. Water Resources Research Institute. University of North Carolina. Raleigh.

Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Third Edition. Academic Press, 1006 pgs.

Part II. A Practical Immediate Watershed Management Plan for Lake LeAnn, Hillsdale County, Michigan

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1.0 EXECUTIVE SUMMARY

There were a total of 4 Critical Source Areas (CSA's) around Lake LeAnn that could contribute nutrient and sediment loading to Lake LeAnn and impair water quality. These CSA's consist of: 1) CSA#S1, 2) CSA#S2, 3) CSA#S3, and 4) CSA #N4. All but the latter are located along the south basin. During sampling, the CSA's had measurable flow rates that ranged from 0.1-0.6 cubic feet per second (cfs) but this likely varies with time and precipitation events.

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 #S3. The highest TSS concentrations were also measured in CSA #S3. The highest TIN, nitrate, and ammonia concentrations were measured in CSA #N4. Thus, improvements in CSA BMP's should be prioritized for these two CSA's before the others are improved. 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 Lake LeAnn.

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).

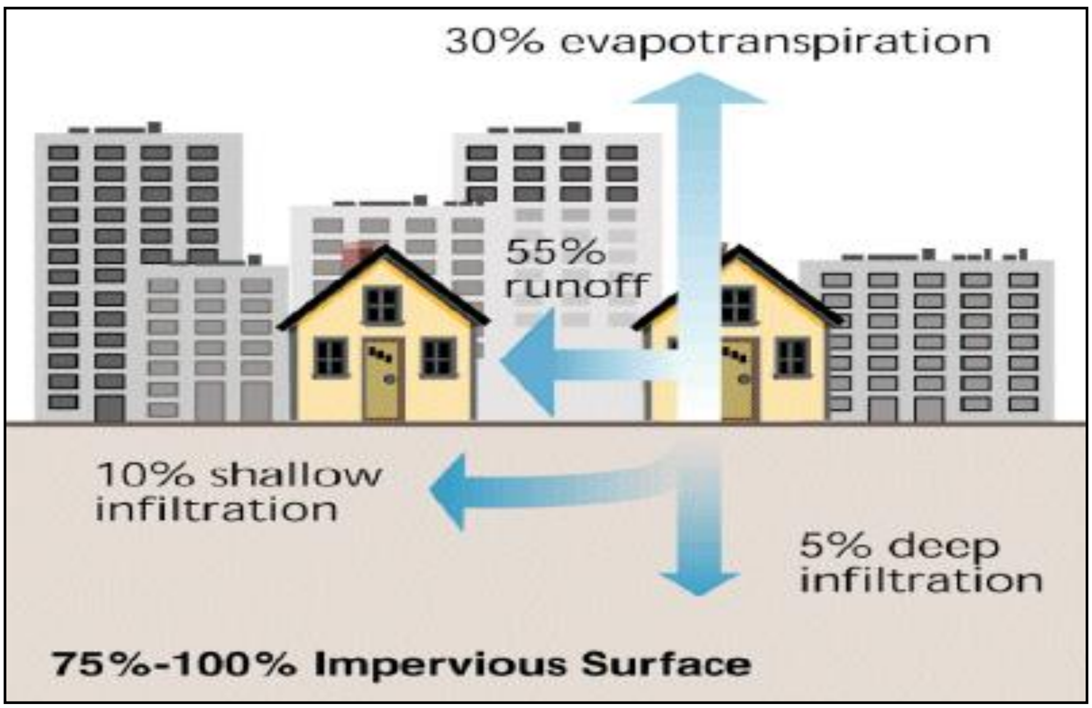

Figure 1. Impervious surfaces in a watershed.

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. Although Lake LeAnn contains a healthy biodiversity of fish and aquatic vegetation, it is also 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 LAKE LEANN 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).

Lake LeAnn is located within the Upper Grand River extended watershed (HUC 04050004) which is the headwaters of the Grand River. The watershed flows from Hillsdale County north through the City of Jackson, past Eaton Rapids, and through Lansing and Grand Rapids before exiting to Lake Michigan at Grand Haven. 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 Lake LeAnn community.

The immediate watershed, (Figure 4) which is the area directly draining into the lakes, differs for each basin with the north being approximately 3,582 acres and the south being is approximately 1,515 acres which is about 7.6 times the size of the lake and is moderately large. The lakefront itself has a diverse application of land uses such as wetlands (Figure 5), beachfront for swimming, and forested lands.

Thus, management options should also consider all of these land uses and preserve their unique functions. Erosion and drain influxes of soils and nutrients are the largest threat to the water quality of Lake LeAnn.

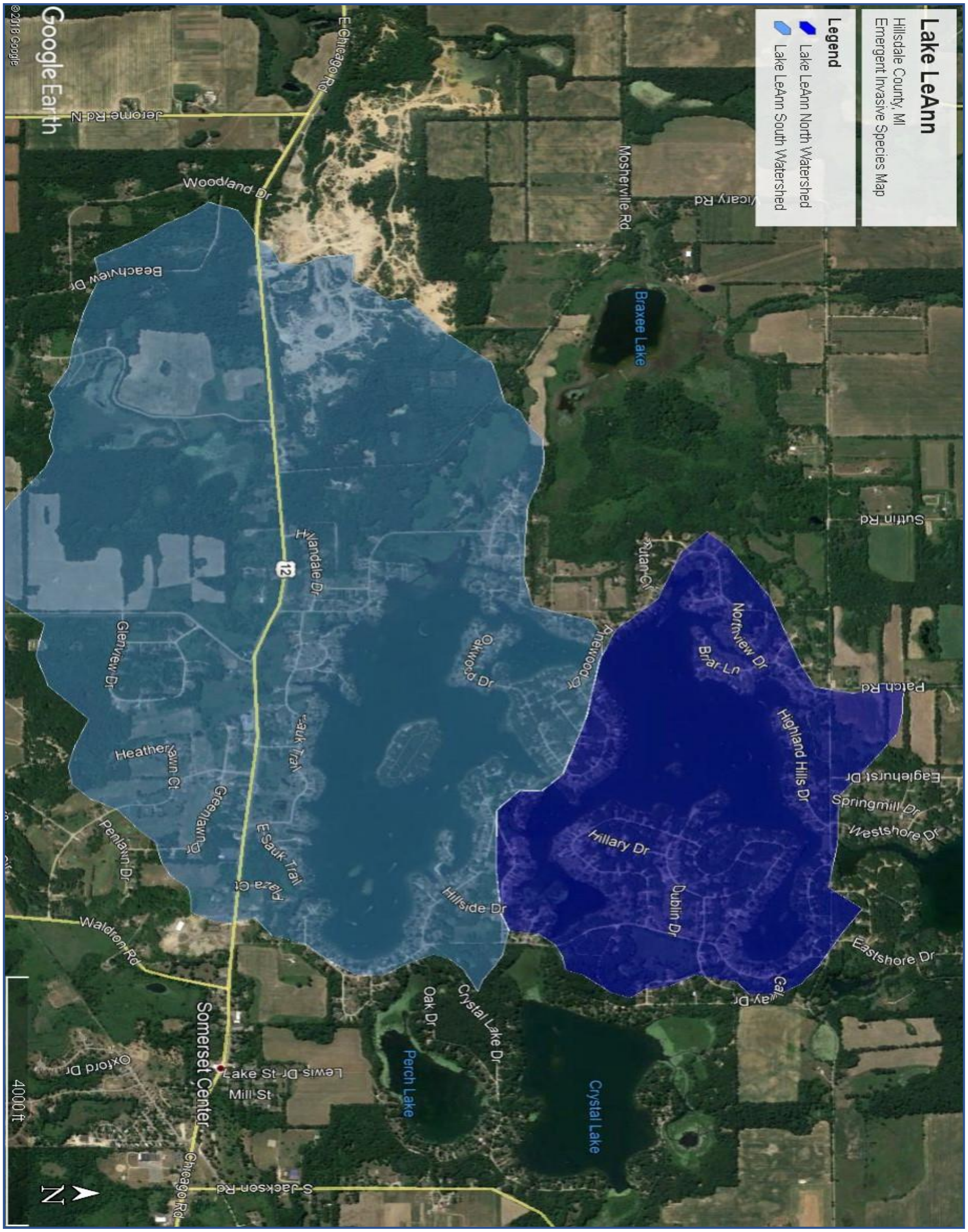

Figure 4. Lake LeAnn north and sound basin immediate watershed (RLS, 2019).

Many 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 12 major soil types immediately surrounding the North Basin of Lake LeAnn (Table 1) and 8 soils surrounding the South Basin of Lake LeAnn (Table 2) 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 Lake LeAnn. Major characteristics of the dominant soil types directly surrounding the Lake LeAnn shoreline are discussed below. The locations of each soil type are listed in Table 2 below.

Table 1. Lake LeAnn north basin shoreline soil types (USDA-NRCS data).

USDA-NRCS Soil Series	***Lake LeAnn North Basin Soil Type Location***
Coloma sand; 18-35% slopes	SW shore
Fox sandy loam; till plain;2-6% slopes	SW shore
Fox gravelly sandy loam;18-35% slopes	SW, SE, NE shores
Spinks loamy sand;0-6% slopes	N shore
Locke fine sandy loam;0-3% slopes	N shore
Boyer gravelly loamy sand;18-35% slopes	N shore
Glendora mucky loamy sand, flooded	NE shore
Hillsdale-Riddles sandy loams;18-30% slopes	NE shore
Arkport-Okee loamy fine sand;2-6% slopes	NE shore
Hillsdale-Riddles complex;18-35% slopes	NE shore
Fox sandy loam, Huron lobe; 6-12% slopes	NE shore
Fox gravelly sandy loam, eroded; 12-18% slopes	E shore

Table 2. Lake LeAnn south basin shoreline soil types (USDA-NRCS data).

USDA-NRCS Soil Series	***Lake LeAnn South Basin Soil Type Location***
Coloma sand; 18-35% slopes	NW shore
Coloma sand; 0-6% slopes	NW shore
Coloma sand; 6-18% slopes	NW, S shores
Houghton muck, moraine; 0-2%slopes	NW shore
Fox gravelly sandy loan; 12-18% slopes	W shore
Matherton loam; 0-3% slopes	W, S shores
Fox sandy loam, Huron lobe; 6-12% slopes	S, E shores
Fox gravelly sandy loam;18-35% slopes	NE, E shores

The majority of the soils around Lake LeAnn are loamy sands and many are located on high slopes (>6%). This often results in erosion on properties without proper erosion control management and also during periods of high water.

The only saturated soils present were near the northwest shore of the south lake basin (Houghton mucks) and the Glendora mucky loamy sands located at the northeast shore of the north lake basin. 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.

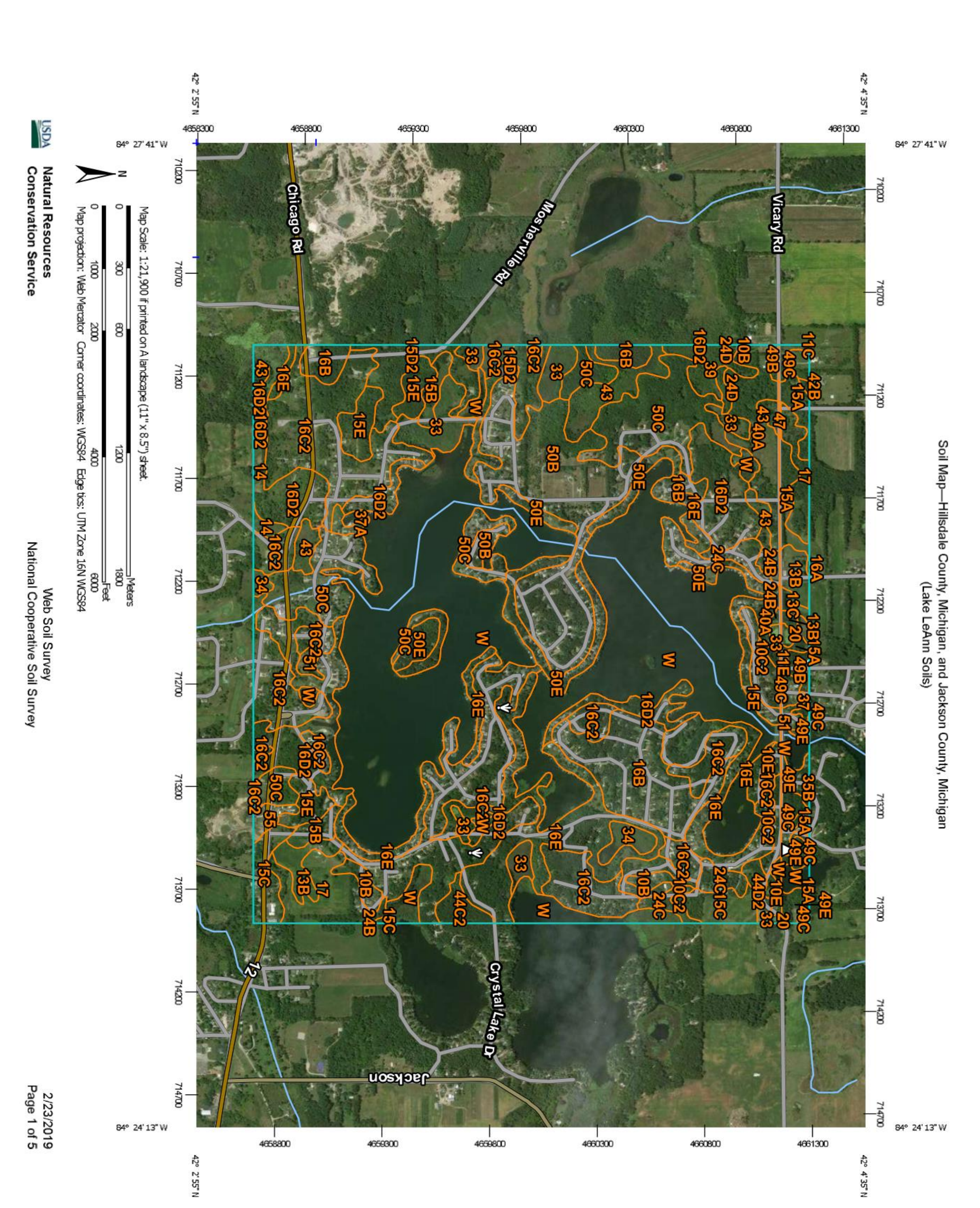

Figure 5. Lake LeAnn soil types around the lake shorelines (NRCS-USDA data).

Erosion Control/Shoreline Survey:

RLS conducted a survey of erosion around the Lake LeAnn shoreline on September 11, 2019. Although erosion was well controlled in most locations, the following section offers protection tips for riparians to implement. 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.

Figure 6 demonstrates how a shoreline without riprap, or a seawall should appear with vegetation of the soils on the lakeshore.

Figure 6. A photograph of a well-vegetated and stabilized shoreline on a lake (RLS, 2019).

A small watershed will generally allow for reduced transport of pollutants, nutrients, or soils to a lake and is a major reason for the observed excellent water clarity of Lake LeAnn. Responsible management of Lake LeAnn 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 Lake LeAnn, 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 Lake LeAnn 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 Hillsdale 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 7).

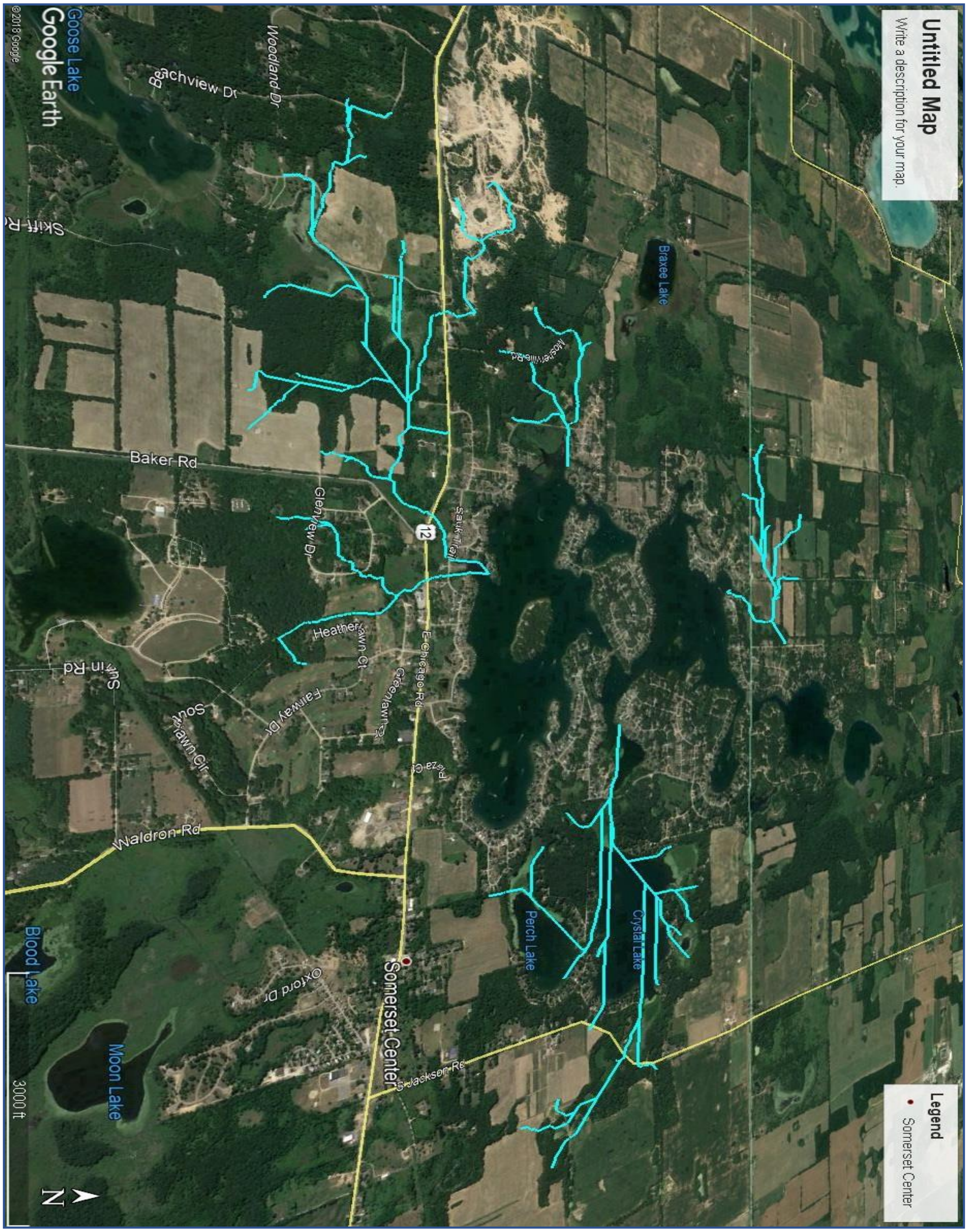

Figure 7. Lake LeAnn LiDAR-based flow map of the immediate watershed (LLPOA, 2019).

4.0 LAKE LEANN 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 8). Submersed aquatic vegetation also increases with high levels of phosphorus (Figure 9) 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 8. Toxic *Microcystis* blue-green algae on Spring Lake, Ottawa County, MI. Photo: Restorative Lake Sciences, 2009.

Figure 9. 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 Lake LeAnn

RLS conducted a formal inventory of potential nutrient and pollutant sources to Lake LeAnn 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 Lake LeAnn 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 Lake LeAnn. 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 Lake LeAnn, 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 4 CSA's were found in the immediate watershed around Lake LeAnn and are shown in Figure 10. Figures 11-14 show each CSA in detail. 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 Lake LeAnn. 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 Lake LeAnn.

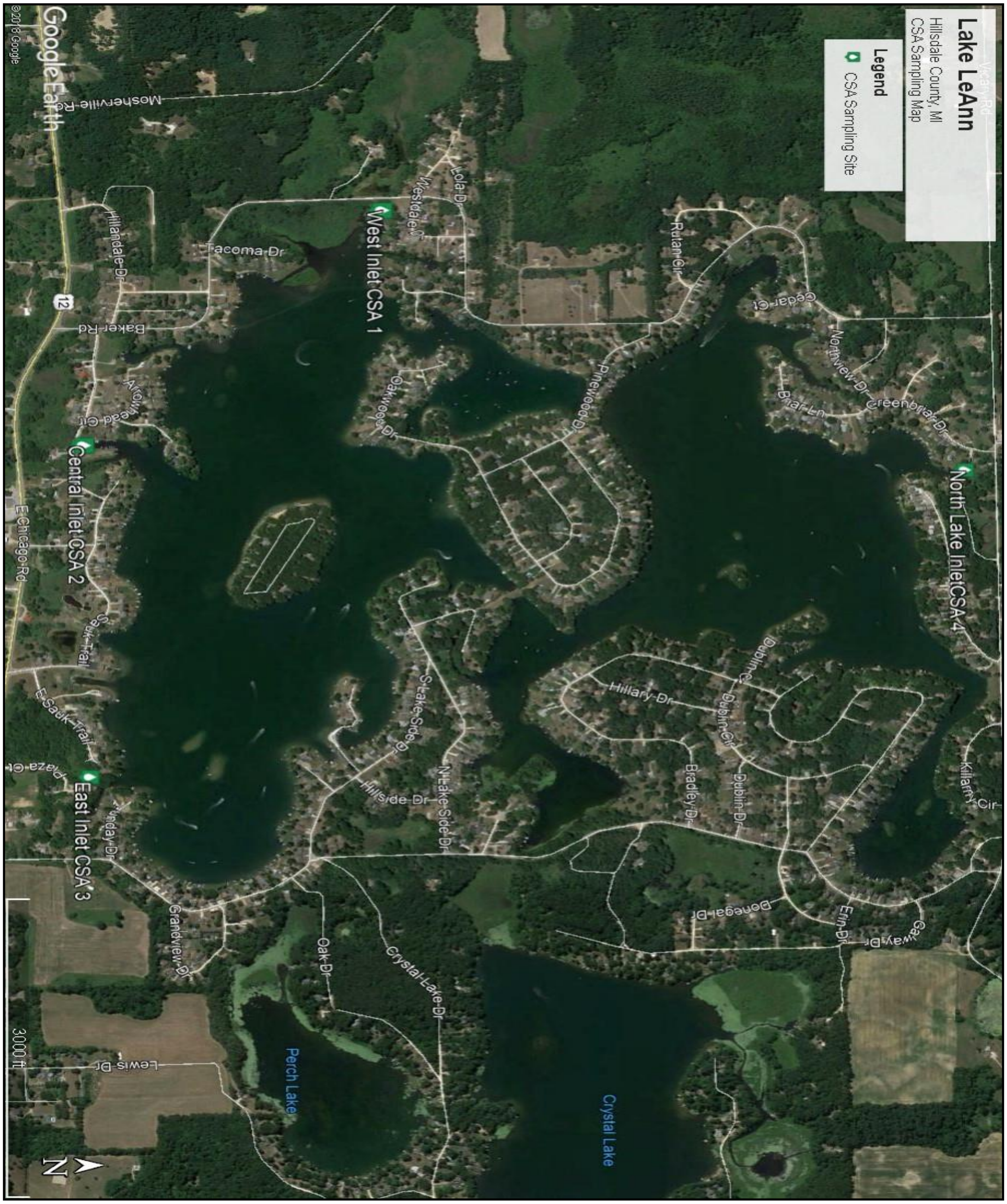

Figure 10. A map of the 4 CSA’s around the Lake LeAnn immediate watershed (RLS, 2019).

CSA 1 – West Inlet (South Basin; Figure 11)

This is a small inlet that runs under Baker Road (approximately 78 yards from Westdale Drive) that flows through wetlands and forest. It has a flow rate measured in 2019 that ranged from 0.5-0.6 cfs. This inlet originates from a stream entering a pond prior to entering the culvert at the lake. It was not found to be problematic during the monitoring. It is likely that the pond acts as a natural retention basin to settle out solids prior to them entering the culvert and ultimately the lake. BMP's include deepening of the pond with aeration and bioaugmentation to reduce nutrients in the pond.

Figure 11. CSA #1 on the south basin of Lake LeAnn (RLS, 2019).

CSA 2 – Central Inlet (South Basin; Figure 12)

This drain is located approximately 75 yards east of Arrowhead Circle and traverses wetland, forest, agricultural land, a golf course, and an aggregate mine. It has a flow rate measured in 2019 that ranged from 0.1-0.2 cfs. The latter is not likely problematic as the sands are not being transferred away from the mine site (likely due to regulations). The golf course drains into a stream and pond at Heatherlawn Court. Approximately 135 yards southwest of Heatherlawn Court is a dividing point where some of the golf course flows away from the lake. Anything south of Penlawn Drive flows away from Lake LeAnn whereas north of Penlawn Drive flows into Lake LeAnn. The golf course is encouraged to follow proper BMP's to reduce fertilizer runoff. This CSA was also overall not problematic during the monitoring.

Figure 12. CSA #2 Central Inlet in the south basin of Lake LeAnn (RLS, 2019).

CSA 3 – East Inlet (South Basin; Figure 13)

This drain does not actually show up on the flow path map but was found to be a flow contributor. It has a flow rate measured in 2019 that ranged from 0.1-0.2 cfs. It is emptying wetlands and likely contributes nutrients since wetlands can act as a nutrient source when fully saturated. It was the largest contributor of total phosphorus and total suspended solids to the lake which may also contribute more nutrients.

Figure 13. CSA #3 East Inlet on south basin of Lake LeAnn (RLS, 2019).

CSA 4 – North Lake Inlet (Figure 14)
This is also a high priority critical source area. This drain traverses abundant agricultural fields and exits at Vicary Road and Greenbriar Drive. There is a pond to the northeast of the culvert which enters the lake at the culvert. This inlet had a measurable flow rate in 2019 that ranged from 0.1-0.2 cfs. If the farmers on these fields use manure, the LLPOA may want to meet with them to discuss alternatives or a larger buffer to reduce the nutrients flowing into the lake. Perhaps a settling basin between the farmlands and the lake would be best. An additional aeration system with bioaugmentation may benefit such a pond. The existing pond could be dredged and also possibly used as a retention pond, yet this may necessitate regular maintenance through dredging the pond with a mechanical dredge over time. This CSA demonstrated the highest measured concentrations of total inorganic nitrogen with elevated ammonia and nitrate forms. It also had the highest specific conductivity of all CSA's. This CSA may be a major contributor to the nutrient issues in the lake.

RLS will be completing calculations of loading rates for each CSA in future years based on additional flow rate and nutrient concentration data.

Figure 14. CSA #4 North Lake Inlet on the north basin of Lake LeAnn (RLS, 2019).

4.2.2 Lake LeAnn Septic Fields:

On July 24-25 2019, a private company called Environmental Canine Services (ECS; https://www.ecsk9s.com/) conducted a survey of waterfront lots chosen based on a number of parameters (e.g. the density of nuisance weeds nearby, the nature of the soil and slope of the property, the age of the subdivision, and associated septics). In all, 411 lakefront lots (388 on North lake and 23 on South lake) were surveyed using a scent-detection canine trained specifically to detect the discharge of human sewage, which might arise from failing septic systems. The dog walked our shoreline accompanied by its handler and members of the Water Quality Subcommittee and RLS staff. It 'alerted', or indicated the potential presence of human waste, on 40 lots, or approximately 10% of all inspected lots. The owners of these lots will be contacted soon with the suggestion that they have their septic systems and fields inspected, as this is the only way to verify or rule out a septic-related problem on their property. Regardless of how many were found, there is a critical need for a lake-wide septic management program. The infrastructure and impacts of septic tanks and drain fields are discussed in great detail in Section 5.0 of this report. The following maps (Figures 15-19) show the areas surveyed by ECS during the July 24-25, 2019 survey:

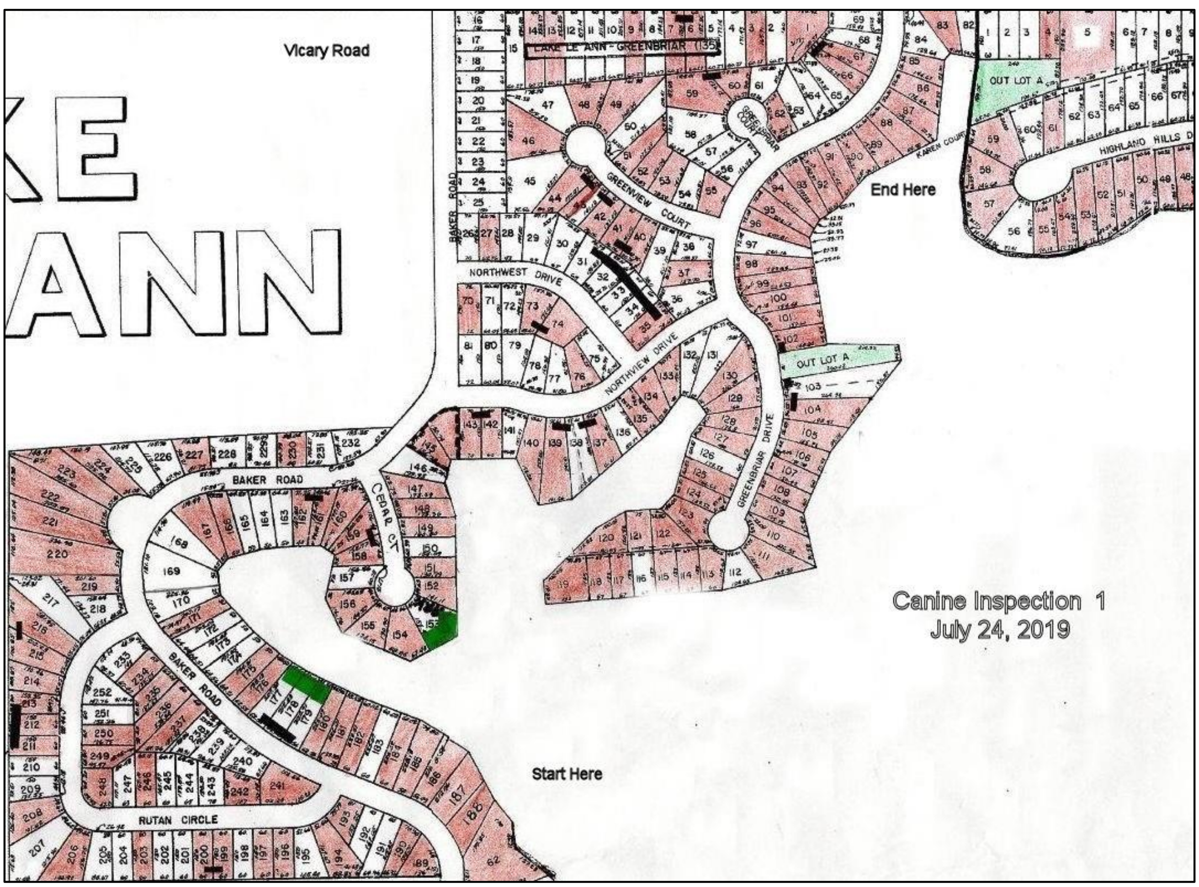

Figure 15. Canine inspection area #1 along the north lake basin.

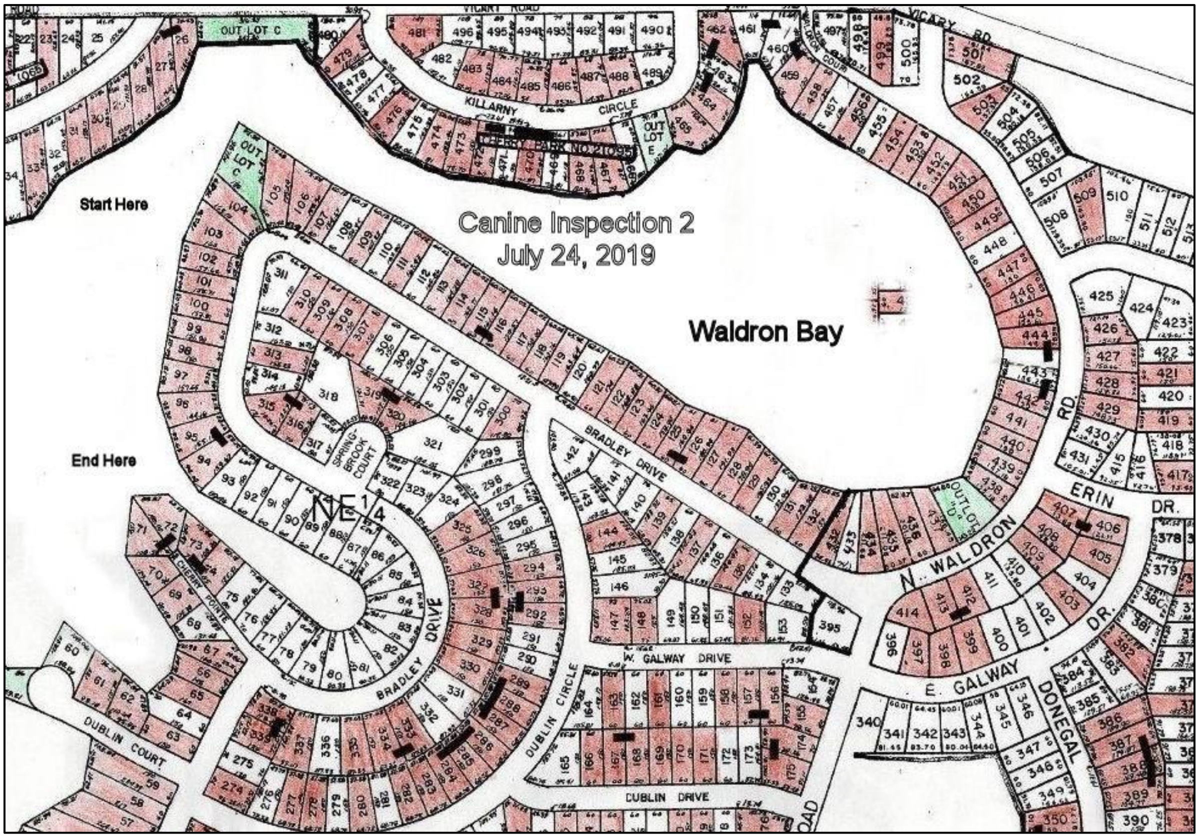

Figure 16. Canine inspection area #2 along the north lake basin.

Figure 17. Canine inspection area #3 along the north lake basin.

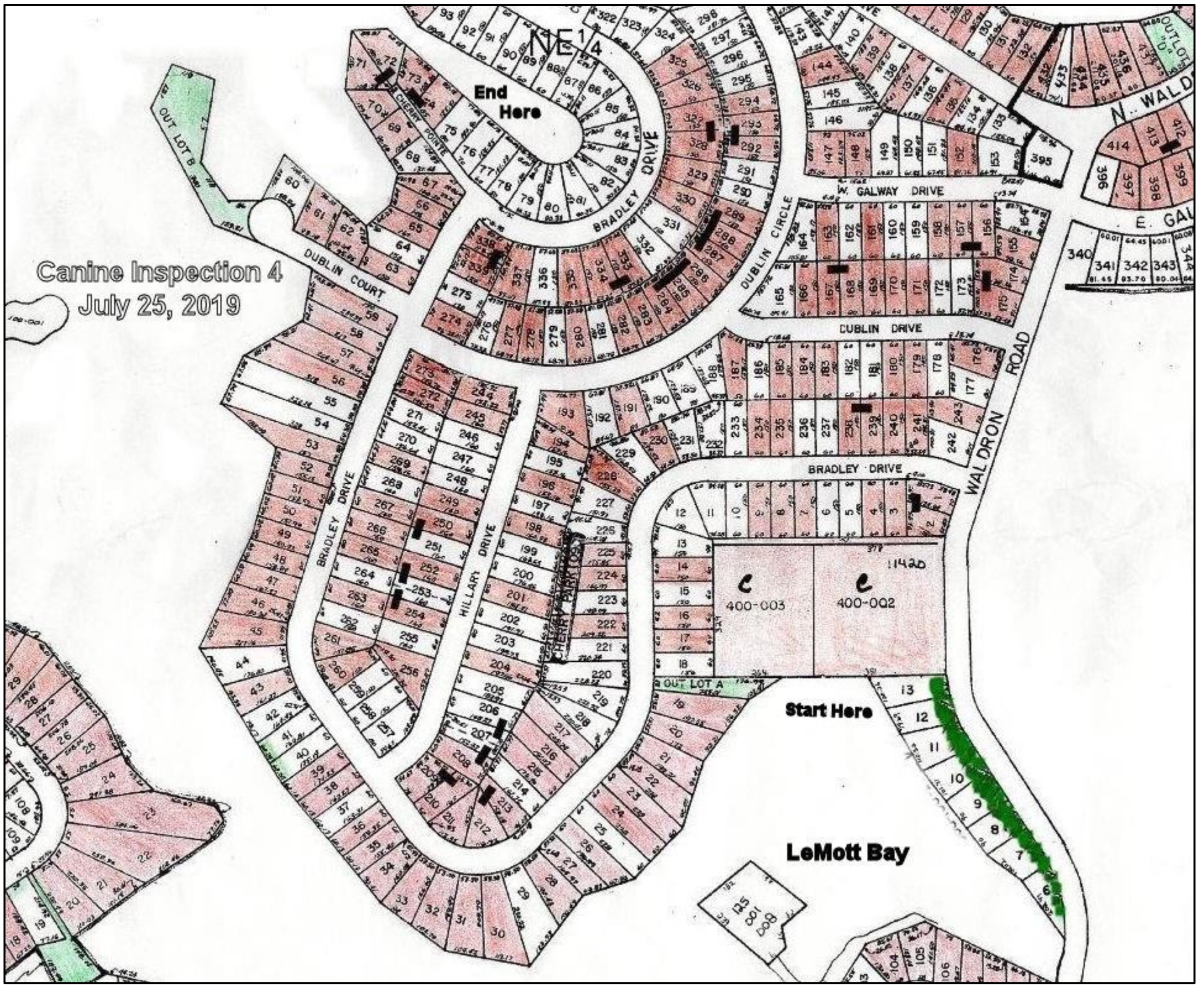

Figure 18. Canine inspection area #4 along the north lake basin.

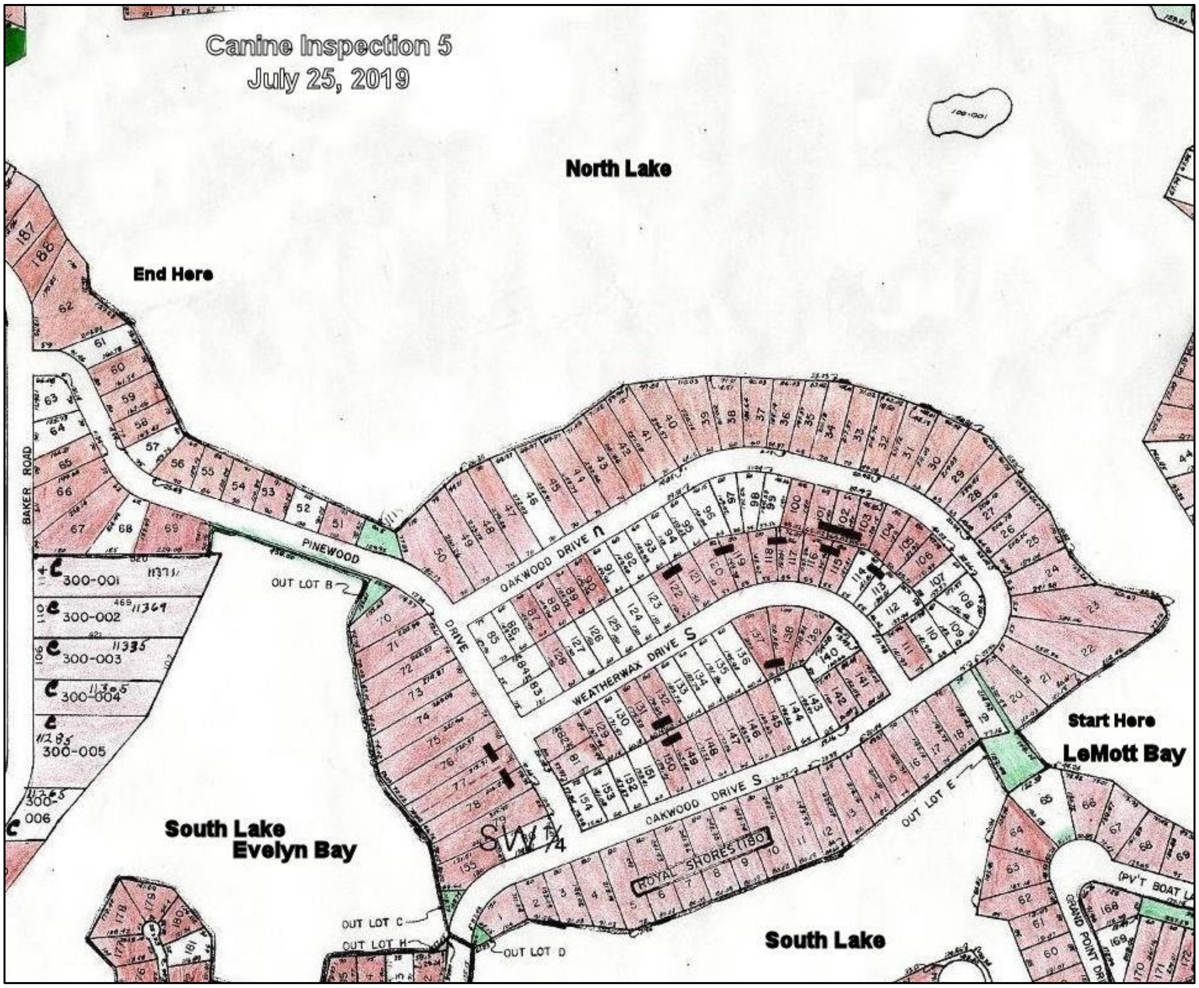

Figure 19. Canine inspection area #5 along the north lake basin.

4.2.3 Lake LeAnn CSA Water Quality Data

RLS has collected water quality samples from Lake LeAnn in 2019 and has characterized the lake as eutrophic. However, recent evidence suggests that the CSA's around the lake are contributing nutrient and sediment 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, conductivity, total dissolved solids, total suspended solids, total phosphorus, ortho-phosporus, 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 3-8 with descriptive statistics for all data shown in Table 9. Samples and water quality measurements were collected on April 26, 2019, July 24, 2019 and September 11, 2019. Measurements were taken with a calibrated Eureka Manta II® multi-parameter probe. A discussion of each parameter and how they are collected and measured follows.

Lake LeAnn CSA Site	***Water Temp ºC***	***DO mg/L***	***pH S.U.***	***Cond. µS/cm***	***TDS mg/L***
CSA #S1	9.6	7.8	8.0	660	389
CSA #S2	9.6	8.0	7.7	552	377
CSA #S3	8.8	7.9	7.6	607	379
CSA #N4	9.2	8.2	8.2	588	390

Table 3. Lake LeAnn CSA physical water quality parameter data collected on April 26, 2019.

Lake LeAnn CSA Site	NO2 mg/L	NO3 mg/L	NH3 mg/L	TIN mg/L	TKN mg/L	SRP mg/L	TP mg/L	TSS mg/L
CSA #S1	<0.10	2.2	0.025	2.2	1.0	0.035	0.075	<10
CSA #S2	<0.10	0.270	0.011	0.280	<0.5	<0.010	0.026	26
CSA #S3	<0.10	<0.10	<0.010	<0.010	<0.5	<0.010	0.010	36
CSA #N4	<0.10	0.160	0.048	0.200	<0.5	<0.010	0.015	34

Table 4. Lake LeAnn CSA chemical water quality parameter data collected on April 26, 2019.

Lake LeAnn CSA Site	Water Temp ºC	DO mg/L	pH S.U.	Cond. µS/cm	TDS mg/L
CSA #S1	26.0	10.6	8.7	543	347
CSA #S2	14.4	9.1	8.6	731	468
CSA #S3	14.5	8.5	7.3	925	592
CSA #N4	18.0	7.9	7.9	1,267	812

Table 5. Lake LeAnn CSA physical water quality parameter data collected on July 24, 2019.

Lake LeAnn CSA Site	NO2 mg/L	NO3 mg/L	NH3 mg/L	TIN mg/L	TKN mg/L	SRP mg/L	TP mg/L	TSS mg/L
CSA #S1	<0.10	<0.10	0.036	0.036	0.5	<0.010	<0.010	<10
CSA #S2	<0.10	0.460	0.015	0.480	<0.5	<0.010	0.018	<10
CSA #S3	<0.10	<0.10	<0.010	0.180	<0.5	<0.010	0.022	10
CSA #N4	<0.10	1.90	0.050	1.90	<0.5	<0.010	0.021	<10

Table 6. Lake LeAnn CSA chemical water quality parameter data collected on July 24, 2019.

Lake LeAnn CSA Site	*Water Temp ºC*	*DO mg/L*	*pH S.U.*	*Cond. µS/cm*	*TDS mg/L*
CSA #S1	20.6	7.5	8.0	658	501
CSA #S2	21.2	8.1	8.1	558	472
CSA #S3	21.0	9.1	8.1	562	477
CSA #N4*	--	--	--	--	--

Table 7. Lake LeAnn CSA physical water quality parameter data collected on September 11, 2019. *Note: CSA #4 could not be collected due to lack of flow.

Lake LeAnn CSA Site	*NO2 mg/L*	*NO3 mg/L*	*NH3 mg/L*	*TIN mg/L*	*TKN mg/L*	*SRP mg/L*	*TP mg/L*	*TSS mg/L*
CSA #S1	<0.10	<0.10	0.031	0.031	0.6	<0.010	<0.010	<10
CSA #S2	<0.10	0.500	0.017	0.520	<0.5	<0.010	0.016	<10
CSA #S3	<0.10	<0.10	0.019	0.019	1.7	0.021	0.110	84
CSA #N4*	--	--	--	--	--	--	--	--

Table 8. Lake LeAnn CSA chemical water quality parameter data collected on September 11, 2019. *Note: CSA #4 could not be collected due to lack of flow.

Table 9. Descriptive statistics of all water quality parameters in the CSA's of Lake LeAnn for parameters collected on April 26, July 24, and September 11, 2019.

Water Quality Parameter	CSA #S1	CSA #S2	CSA #S3	CSA #N4
Water temp (°C)	18.7±8.4	15.1±5.8	14.8±6.1	13.6±6.0
pH (S.U.)	8.2±0.4	8.1±0.5	7.7±0.4	8.1±0.2
Dissolved oxygen (mg/L)	8.6±1.7	8.4±0.6	8.5±0.6	8.1±0.2
Conductivity (mS/cm)	620±67	614±102	698±198	928±480
Total dissolved solids (mg/L)	412±80	439±54	483±107	601±298
Total kjeldahl nitrogen (mg/L)	0.7±0.3	0.5±0.0	0.9±0.7	0.5±0.0
Total inorganic nitrogen (mg/L)	0.800±1.3	0.427±0.1	0.070±0.1	1.1±1.2
Ammonia nitrogen (mg/L)	0.031±0.0	0.014±0.0	0.013±0.0	0.049±0.0
Nitrate nitrogen (mg/L)	0.8±1.2	0.410±0.1	0.10±0.0	1.03±1.2
Nitrite nitrogen (mg/L)	0.10±0.0	0.10±0.0	0.10±0.0	0.10±0.0
Total phosphorus (mg/L)	0.032±0.1	0.020±0.0	0.047±0.1	0.018±0.0
Ortho-Phosphorus (mg/L)	0.018±0.1	0.010±0.0	0.014±0.0	0.010±0.0
Total suspended solids (mg/L)	10±0.0	15.3±9.2	43±38	22±17

5.0 Septic Tanks and Other Non-Point Source Inputs

Nutrient pollution of inland lakes from septic systems and other land use activities is not a modern realization and has been known for multiple decades. The problem is also not unique to Michigan Lakes and was first described in Montreal Canada by Lesauteur (1968) who noticed that summer cottages were having negative impacts on many water bodies. He further noted that a broader policy was needed to garner control of these systems because they were becoming more common over time. Many of our inland lakes are in rural areas and thus sewer systems or other centralized wastewater collection methods are not practical. Thus, septic systems have been common in those areas since development on inland lakes began. Septic systems have four main components consisting of a pipe from the residence, a septic tank or reservoir, a drainage field, and the surrounding soils Figure 20).

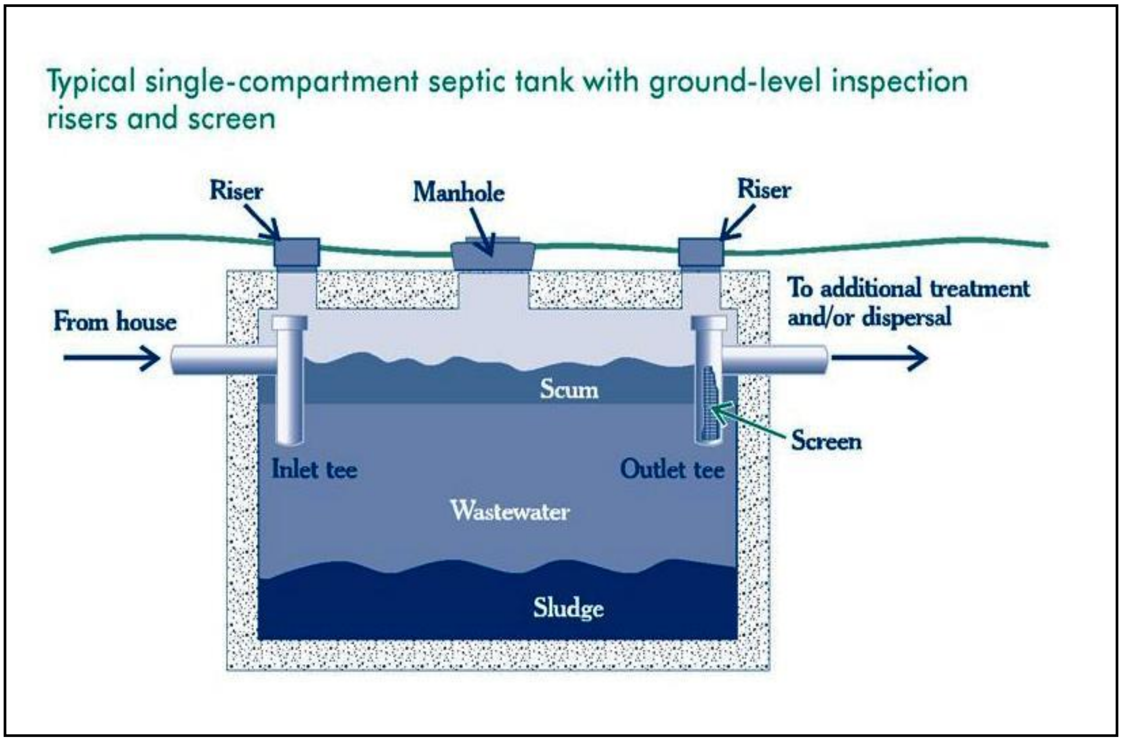

Figure 20. Diagram of essential septic tank components (US EPA).

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

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

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

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

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

It is estimated that Michigan has over 1.2 million septic systems currently installed with many of them occurring in rural areas around inland lakes. Currently only seven counties in Michigan (Benzie, Grand Traverse, Macomb, Ottawa, Shiawassee, Washtenaw, and Wayne) require a septic system inspection prior to a property being sold. The number of septic systems that are a risk to the aquatic environment is unknown which makes riparian awareness of these systems critical for protection of lake water. Construction of new septic tanks require notification and application by the homeowner to the county Department of Public Health and also that soils must be tested to determine suitability of the system for human health and the environment. It is recommended that each septic tank be inspected every 2-3 years and pumped every 3-5 years depending upon usage. The drain field should be inspected as well and only grasses should be planted in the vicinity of the system since tree roots can cause the drain field to malfunction. Additionally, toxins should not be added to the tank since this would kill beneficial microbes needed to digest septic waste. Areas that contain large amounts of peat or muck soils may not be conducive to septic tank placement due to the ability of these soils to retain septic material and cause ponding in the drain field. Other soils that contain excessive sands or gravels may also not be favorable due to excessive transfer of septage into underlying groundwater. Many sandy soils do not have a strong adsorption capacity for phosphorus and thus the nutrient is easily transported to groundwater. Nitrates, however, are even more mobile and travel quickly with the groundwater and thus are also a threat to water quality.

The utilization of septic systems by riparians is still quite common around inland lake shorelines. A basic septic system typically consists of a pipe leading from the home to the septic tank, the septic tank itself, the drain field, and the soil. The tank is usually an impermeable substance such as concrete or polyethylene and delivers the waste from the home to the drain field. The sludge settles out at the tank bottom and the oils and buoyant materials float to the surface. Ultimately the drain field receives the contents of the septic tank and disperses the materials into the surrounding soils. The problem arises when this material enters the zone of water near the water table and gradually seeps into the lake bottom. This phenomenon has been noted by many scholars on inland waterways as it contributes sizeable loads of nutrients and pathogens to lake water. Lakebed seepage is highly dependent upon water table characteristics such as slope (Winter 1981). The higher the rainfall, the more likely seepage will occur and allow groundwater nutrients to enter waterways. Seepage velocities will different greatly among sites and thus failing septic systems will have varying impacts on the water quality of specific lakes. Lee (1977) studied seepage in lake systems and found that seepage occurs as far as 80 meters from the shore. This finding may help explain the observed increases in submersed aquatic plant growth near areas with abundant septic tank systems that may not be adequately maintained. Loeb and Goldman (1978) found that groundwater contributes approximately 44% of the total soluble reactive phosphorus (SRP) and 49% of total nitrates to Lake Tahoe from the Ward Valley watershed. Additionally, Canter (1981) determined that man-made (anthropogenic) activities such as the use of septic systems can greatly contribute nutrients to groundwater.

Poorly maintained septic systems may also lead to increases in toxin-producing blue-green algae such as *Microcystis.* This alga is indicative of highly nutrient-rich waters and forms an unsightly green scum on the surface of a water body. Toxins are released from the algal cells and may be dangerous to animals and humans in elevated concentrations. Furthermore, the alga may shade light from underlying native aquatic plants and create a sharp decline in biomass which leads to lower dissolved oxygen levels in the water column. Repeated algae treatments are often not enough to compensate for this algal growth and the problem persists.

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, wadeable 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 Lake LeAnn.

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 sediment and nutrient loads to Lake LeAnn.

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 Lake LeAnn. 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 21 demonstrates a lakefront property with poor management of the shoreline.

Figure 21. 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, *Schoenoplectus* sp. (Bulrushes) or Cattails present around a lake may offer satisfactory stabilization of shoreline sediments and assist in the minimization of sediment release into a lake.
12) The U.S. Environmental Protection Agency (USEPA) offers excellent educational resources and reference materials that riparians can use to care for their septic systems. To learn more about septic systems and how to care for them, visit the website: http://water.epa.gov/infrastructure/septic/. Some lake associations have created "annual septic pump out" days where septic tank contractors visit individual properties and clean out the septic tanks as well as inspect the drain fields for any issues that may negatively affect water quality. Annual pump out days are a great way to interact with riparian neighbors and learn about the many different types and locations of individual septic systems. Additionally, riparians should always maintain an awareness of the aquatic vegetation and algae in their lake so they can report any significant deviations from the normal observations. An awareness of the ambient lake water quality is also useful since degradations in water quality often occur over a long period of time and can be subtle.

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. Figures 22-33 demonstrate various BMP's that may be used for immediate watershed management.

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.

A. Vegetated Buffer Strips and Conservation Areas

Figure 22. Example of a vegetated buffer area.

Figure 23. Example of a vegetated buffer area.

B. Brush Bundles and Live Staking

Figure 24. Example of brush bundles.

C. Critical Area Planting

Figure 25. Example of critical area planting.

D. Retention Ponds and Constructed Wetlands

Figure 26. Example of a retention pond.

Figure 27. Example of a retention pond and constructed wetland.

E. Armored Protection/Rip Rap

Figure 28. Example of armored protection/riprap.

F. Low Impact Storm Water Development (Green Infrastructure)

Figure 29. Example of a rain garden.

G. Tributary Filters

Figure 30. Example of a tributary/drain filter.

H. Storm water Facilities Maintenance

Figure 31. Example of storm water maintenance.

Figure 32. Example of storm water maintenance (sewer cleaning).

Figure 33. Example of storm water maintenance (sediment trap removal).

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 LLPOA, local township officials, conservation district officials, specialists from the Natural Resources Conservation Service (NRCS), 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 Lake LeAnn 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 regards to issues that compromise inland lakes over the past decade and historically. The creation of the Michigan Lake and Stream Associations (MLSA) over 50 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 34 demonstrates a sound model for stakeholder engagement that applies to both lake and immediate watershed management.

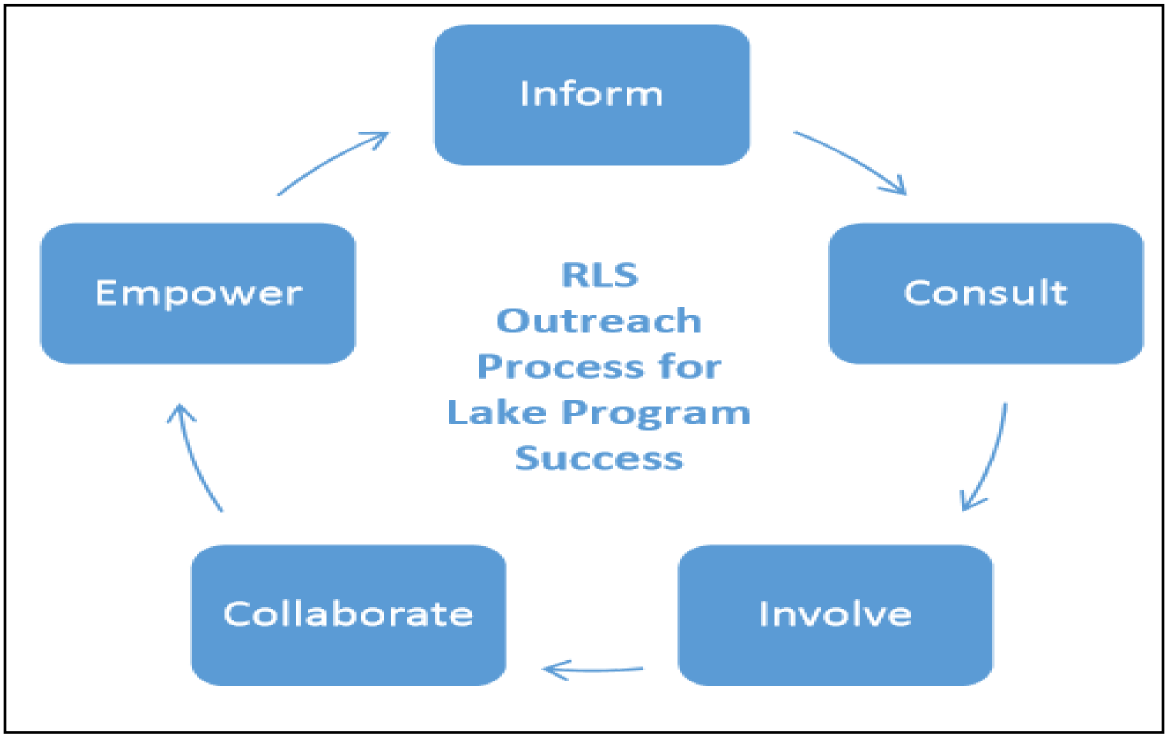

Figure 34. A flow model showing steps for successful lake and watershed program improvements.

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 Lake LeAnn 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.

7.0 REFERENCES CITED

Annadotter, H., G. Cronberg, R. Aagren, B. Lundstedt, P. Nilsson, and S. Ströbeck., 1999. Multiple techniques for lake restoration. Hydrobiologia 395/396:77-85.

Canter, L.W., and R.C. Knox. Septic tank system effluents on groundwater quality. Chelsea, Michigan, Lewis Publications, Inc. 336 p.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphors and nitrogen. *Ecological Applications* 8(3): 559-568

Cheruvelil Spence, K., and P. Soranno. 2008. Relationships between lake macrtophyte cover and lake and landscape features. Aquatic Botany 88:219-227.

Detenbeck, N.E., C.A. Johnston, and G.J. Niemi. 1993. Wetland effects on lake water quality in the Minneapolis/St.Paul metropolitan area. *Landscape Ecology* 8(1):39-61.

Dosi, C., and N. Zeitouni. 2001. "Controlling groundwater pollution from agricultural non-point sources: An overview of policy instruments" Chapter 6, In: Agricultural Use of Groundwater: Towards Integration between Agricultural Policy and Water Resources Management. Springer. 301 pp.

Elder, J.F. 1985. Nitrogen and phosphorus speciation and flux in a large Florida river wetland system. *Water Resources Research* 21(5):724-732.

Engstrom, D.R., and D.I. Wright. 2002. Sedimentological effects of aeration-induced lake circulation. *Lake and Reservoir Management* 18(3):201-214.

Feeny, D., F. Berkes, B.J. McCay, and J.M. Acheson. 1990. The tragedy of the commons: Twenty-two years later. *Human Ecology* 18(6): 1-19.

Gilliom, R.J., and Patmont, C.R. 1983. Lake phosphorus loading from septic systems by seasonally perched groundwater. Journal of the Water Pollution Control Federation. 55(10):1297-1305.

Goldston, D. 2009. Science, policy, and the US Congress. *Cell* 139:647-48.

Henderson, C.L., C. Dindorf, and F. Rozumalski. 1998. Lakescaping for Wildlife and Water Quality. Minnesota Department of Natural Resources, 176 pgs.

Jermalowicz-Jones, J.L. 2005-2007. Submersed aquatic macrophyte growth and groundwater nutrient contributions associated with development around White Lake, Muskegon County, Michigan. MS thesis. Grand Valley State University, Allendale, Michigan. 89 pp.

Kimmerer, R.W. 2002. Weaving traditional ecological knowledge into biological education: A call to action. *Bioscience* 52(5): 432-438.

Lee, D.R. 1977. A device for measuring seepage flux in lakes and estuaries. Limnology and Oceanography 22(1):140-147.

Lemberg, D., R. Fraser, and J. Marsch. 2002. Implications for planning sustainable lake shores, Part I. In: The Michigan Riparian, publication of the Michigan Lake and Stream Associations. P.8-11.

Lesauteur, T. 1968. Water pollution in summer cottage areas. Canadian Journal of Public Health 59(7):276-277.

Loeb, S., amd C.R. Goldman. 1978. Water and nutrient transport via groundwater from Ward Valley into Lake Tahoe. Limnology and Oceanography 24(6):1146-1154.

Maguire, R.O., G.H. Rubaek., B.E. Haggard, and B.H. Foy. 2009. Critical evaluation of the implementation of mitigation options for phosphorus from field to catchment scales. *Journal of Environmental Quality* 38:1989-1997.

Middendorf, G., and L. Busch. 1997. Inquiry for the public good: Democratic participation in agricultural research. *Agriculture and Human Values* 14:45-57.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Wetlands and water synthesis. World Resources Institute, Washington, DC.

Morgan, C., and N. Owens. 2001. Benefits of water quality policies: The Chesapeake Bay. *Ecological Economics* 39:271-284.

Nizeyimana, E., B. Evans, M. Anderson, G. Peterson., D. DeWalle, W. Sharpe, J. Hamlett, and B. Swistock. 1997. Quantification of NPS loads within Pennsylvania watershed. Final report to the Pennsylvania Department of Environmental Protection, Environmental Resources Research Institute, The Pennsylvania State University, University Park, Pennsylvania.

Orr, D.W. 2003. Four challenges of sustainability, School of Natural Resources-The University of Vermont. Spring Seminar Series-Ecological Economics.

Osborne, L.L., and M.J. Wiley. 1988. Empirical relationships between land use cover and stream water quality in an agricultural watershed. *Journal of Environmental Management* 26:9-27.

Ostrom, E. 1999. Coping with the tragedy of the commons. *Annual Review of Political Science* 2:493-535.

Plummer, J. 2002. Focusing Partnerships: A sourcebook for municipal capacity building in public-private relationships. Earthscan Publications, Ltd. 335 pp.

Rosenberger, E.E., Hampton, S.E., Fradkin, S.C., and Kennedy, B.P. 2008. Effects of shoreline development on the nearshore environment in large, deep, oligotrophic lakes. Freshwater Biology 53:1673-1691.

Rutherford, F.J., and A. Ahlgren. 1991. Science for all Americans, Oxford University Press. 272 pp.

Sass. L.L., Bozek, M.A., Hauxwell, J.A., Wagner, K., and Knights, S. 2010. Response of aquatic macrophytes to human land use perturbations in the watersheds of Wisconsin lakes, USA. Aquatic Botany 93:1-8.

Sawhney, B.L., and J.L. Starr. 1977. Movement of phosphorus from a septic system drainfield 49(11):2238-2242.

Stynes, D. J. 2002. Michigan statewide tourism spending and economic impact estimates: Accessed at URL http://www.prr.msu.edu/miteim

Walker, B. 1995. Conserving biological diversity through ecosystem resilience. Conservation Biology, 9(4): 747-752.

Walters, D.T., D.A. Mortensen, C.A. Francis, R.W. Elmore, and J.W. King. 1990. Specificity: The context of research for sustainability. *Journal of Soil and Water Conservation* January-February, 55.

Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Third Edition. Academic Press, 1006 pgs.

White, M.J., D.E. Storm, P.R. Busteed, H.S. Stoodley, and S.J. Phillips. 2009. Evaluating nonpoint source critical source area contributions at the watershed scale. *Journal of Environmental Quality* 38(4):1654-1663.

Winter, T.C. 1981. Effects of water-table configuration on seepage through lake beds. Limnology and Oceanography 26(5):925-934.

Young, S. 1996. Stepping stones to empowerment? Participation in the context of Local Agenda 21, *Local Government Policy Making* 22(4): 25-31.