Indian Lake Laminar Flow Aeration and Bioaugmentation Evaluation & Future Restoration Recommendations

Provided for: The Indian Hill Lake Property Owners Association

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1.0 EXECUTIVE SUMMARY

Restorative Lake Sciences (RLS) was selected to independently study and evaluate the Indian Lake whole-lake laminar flow aeration (LFA) system and report this data to the Indian Hill Lake Property Owners Association. The data presented in this evaluation represents the baseline lake conditions (2021) and the first year of LFA (2022). A total of 4 water quality sampling locations were selected in the lake basin and were sampled on August 16, 2021, October 22, 2021, March 10, 2022, August 31, 2022, and October 13, 2022. These basins were monitored for physical water quality parameters such as water temperature, dissolved oxygen, pH, specific conductivity, total dissolved solids, and Secchi transparency. Additional chemical water quality parameters were also measured at each site and included total Kjeldahl nitrogen, total inorganic nitrogen (which consists of ammonia, nitrate, and nitrite), chlorophyll-a, total phosphorus, and ortho (soluble reactive) phosphorus, and dissolved inorganic carbon.

Indian Lake is located in Crawford County, Missouri near the town of Cuba. It is a man-made impoundment with a sizeable dam or water control structure located at the north end of the lake. The lake is approximately 311 acres in surface area with a shoreline of approximately 7.9 miles. The fetch, which is the longest distance across the lake surface, is approximately 1.5 miles. The maximum depth recorded in 2022 was 40 feet (RLS, GIS data) and the mean depth is approximately 15.4 feet (Clean-Flo, 2019). The immediate watershed of the lake, which is the area of land draining directly towards the lake, is approximately 9,252 acres. Thus, the watershed to lake ratio is 30 which implicates a large immediate watershed. The lake is highly developed with many areas of shoreline erosion. The lake bottom is mostly silty clay and is easily disrupted during storm events leading to an increase in turbidity. Indian Lake may be categorized as a drainage lake since it has numerous drainage areas as well as an outlet at the northern section of the lake which drains to Brush Creek which empties into the Bourbeuse River and the Meramec River, before emptying into the Mississippi River and the Gulf of Mexico.

In 2021, RLS collected samples from drain tributary sites T1 and T2 and recommends at least 4 samplings per season at sites T1-T5 only when conditions represent flowing waters. The tributaries/drains may represent a significant source of incoming nutrients that are contributing to internal loading of phosphorus. Another significant source of phosphorus is likely from septic tanks and drain fields. The lake residents utilize septic systems rather than a municipal sewer system and the challenges for this relative to water quality are discussed later in this report. RLS recommends an educational program for the lake residents on proper maintenance of these systems and how to use new on-site technologies to reduce nutrients.

Initial restoration goals for the Indian Lake restoration included the following:

1. Reduction in total cyanobacteria count, total chlorophyll-a, and increase in other favorable algae.
2. Increase in dissolved oxygen concentrations throughout the water column and especially at depth where TP release is a threat.
3. Reduction of all forms of nutrients (TP, SRP, TKN, TIN and maybe even DIC)

Indian Lake has been experiencing widespread blue-green algal (cyanobacteria) blooms for several years. This occurred when the lake became super-saturated with nutrients and low in dissolved oxygen. Blue-green algae are highly adapted to living in low oxygen concentrations. A whole-lake laminar flow aeration (LFA) system was installed in Indian Lake in 2021 and is currently operating to improve the previously low dissolved oxygen concentrations. This approach is used by numerous drinking water reservoirs around the world to reduce harmful algal blooms (HAB's). There are three major groups of algae—green algae, diatoms, and blue-green algae. The former two are beneficial and preferred and the latter is problematic in that it can excrete toxins. Based on a thorough review of all algal data collected to date (for algal cell count and biovolume and toxin testing), the following conclusions can be made:

1. Although the blue-green algal counts in Indian Lake are very high, they have not been secreting toxins. This is favorable given the high concentrations of algae. The toxins were tested in five areas of the lake in 2021-2022 including Cove 7, Beach, Hamm, Cove 1, and the Dam. All had a microcystin toxin level of 0 ppb. There are other toxins that could be tested but low microcystins is a positive finding.

2. The actual concentrations and relative biovolumes of blue-green algae have increased since 2021. It may take considerable time for the LFA to reduce these concentrations. In addition, inputs from the immediate watershed (such as drains and septic systems) may be contributing to the algal growth.

3. The Indian Lake total algal concentrations have increased in 2022. This would be expected when the blue-green algae increase. This parameter may also require time for successful declines.

4. The Indian Lake algal communities are beginning to shift from less desirable genera of blue-green algae (i.e., *Aphanizomenon* and *Dolichospermum*) to green algae and less harmful HAB's. The goal is to increase the presence of green algae and diatoms to reduce the relative abundance of blue-green algae. This type of ecosystem shift requires time.

The LFA system in Indian Lake has resulted in significant water quality improvements over the past year. The data collected to date were analyzed for means and standard deviations and also for statistical significance. Based on these analyses, the following conclusions can be made:

1. The mean Indian Lake water temperatures have slightly increased in August and October of each year due to LFA, but this finding is statistically insignificant.
2. The mean Indian Lake pH has increased in August but declined in October after LFA, but this finding is statistically insignificant.
3. The mean Indian Lake dissolved oxygen concentration has increased in both August and October after LFA and this result is statistically significant, especially at depth.
4. The mean Indian Lake specific conductivity has declined in both August and October after LFA, and this result is statistically significant.
5. The mean Indian Lake total dissolved solids have declined in both August and October after LFA, and this result is statistically significant.
6. The mean Indian Lake Secchi transparency remained similar in August but significantly increased in October after LFA.
7. The mean Indian Lake chlorophyll-a concentration increased in both August and October after LFA, and this result is statistically significant.
8. The mean Indian Lake total Kjeldahl nitrogen declined in both August and October after LFA, but this result is statistically insignificant.
9. The mean Indian Lake total inorganic nitrogen declined in both August and October after LFA, and this result is statistically significant.
10. The mean Indian Lake ammonia nitrogen declined in both August and October after LFA, and this result is statistically significant.
11. The mean Indian Lake total phosphorus declined in both August and October after LFA, and this result is statistically significant.
12. The mean Indian Lake ortho-phosphorus declined in both August and October after LFA, and this result is statistically significant.
13. The mean Indian Lake dissolved inorganic carbon decreased in August but increased in October after LFA and this result is statistically significant.

Continued operation of the LFA system with bioaugmentation is recommended with a possible innovative bioaugmentation agent to further reduce CO_2 in the lake water as green algae will have a competitive advantage with increased bicarbonate and pH. Green algae are needed to reduce HAB's and allow for more light penetration to help shift Indian Lake from an algal-dominated state to a plant-dominated state with clearer water.

In addition, it is recommended that the Indian Lake community implement the Best Management Practices (BMP's) discussed in the 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. A whole-lake shoreline erosion survey is recommended.

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 drain field maintenance program is needed to help riparians reduce nutrients such as nitrogen to the lake.

Dredging would remove accumulate silt but will not address the dissolved oxygen depletion or harmful algal blooms (HAB's) or nutrient loads. In addition, it is extremely costly and would induce even further light limitation on submersed aquatic vegetation (SAV) which is needed in much higher abundance to shift Indian Lake from an algal-dominated to a submersed plant-dominated state that is needed to help increase clarity over time and to compete with algae for nutrients.

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 Indian Lake

2.1.1 Lake Hydrology

Aquatic ecosystems include rivers, streams, ponds, lakes, and the Laurentian Great Lakes. There are numerous of lakes in the Midwest, 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. Indian Lake may be categorized as a drainage lake since it has numerous drainage areas as well as an outlet at the northern section of the lake which leads to Brush Creek which then empties into the Bourbeuse River and the Meramec River, before emptying into the Mississippi River and the Gulf of Mexico.

2.1.2 Biodiversity and Habitat Health

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. Indian Lake may not have much muck accumulation from decaying aquatic plants but would be susceptible to inputs from decaying algae and incoming sediment loads from the immediate watershed. The lake is surrounded 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.

2.1.3 Watersheds and Land Use

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 (Figures 1 and 2). In general, a large watershed such as Indian 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, 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.

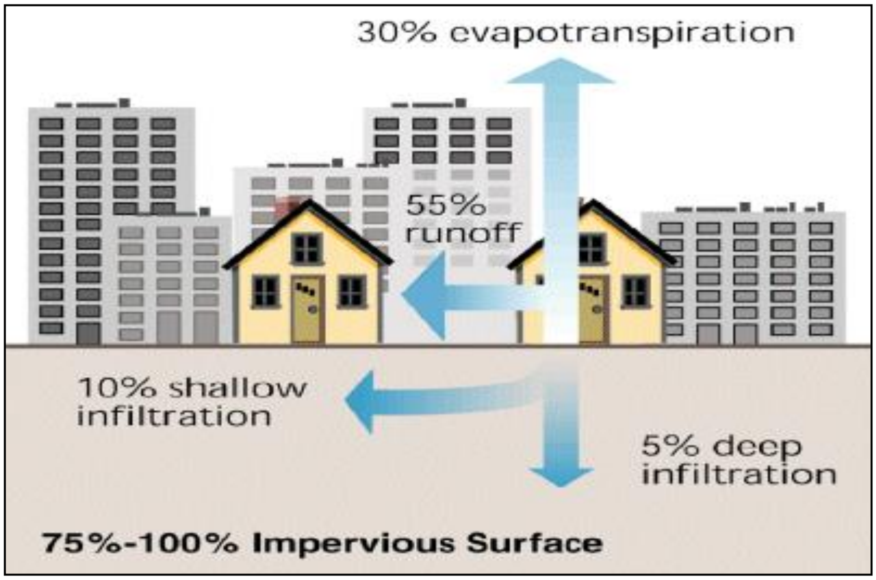


Figure 1. Impervious surfaces in a watershed.

Figure 2. A storm drain emptying a residential street that empties into a lake.

There are 8 major soil types immediately surrounding the shoreline of Indian Lake (Table 1) which may impact the water quality of the lake and may dictate the particular land use activities within the area. Figure 3 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service, 1999) demonstrates the precise soil types and locations around Indian Lake.

Major characteristics of the dominant soil types directly surrounding the Indian Lake shoreline are discussed below. The locations of each soil type are listed in Table 1 below.

Table 1. Indian Lake shoreline soil types (USDA-NRCS data).

USDA-NRCS Soil Series	***Indian Lake Basin Soil Type Location***
Union silt loam; 3-8% slopes	East, SE, SW shores
Swiss gravelly silt loam; 3-15% slopes	West, NW shores
Beemont-Gatewood complex;15-35% slopes	Northwest, NE shores
Beemont-Gatewood complex;3-15% slopes	Northeast, E, SW shores
Hartville silt loam;3-8% slopes	Southeast shore
Deible silt loam;1-5% slopes	North shore
Razort silt loam;0-2% slopes	South shore
Huzzah silt loam;0-3% slopes	North shore

The majority of the soils around Indian Lake are loams, and many are located on high slopes (>6%). This results in erosion on properties without proper erosion control management and also during periods of high water. The Razort and Huzzah soils in particular are occasionally or frequently flooded during heavy rainfall and thus can be problematic for runoff.

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.

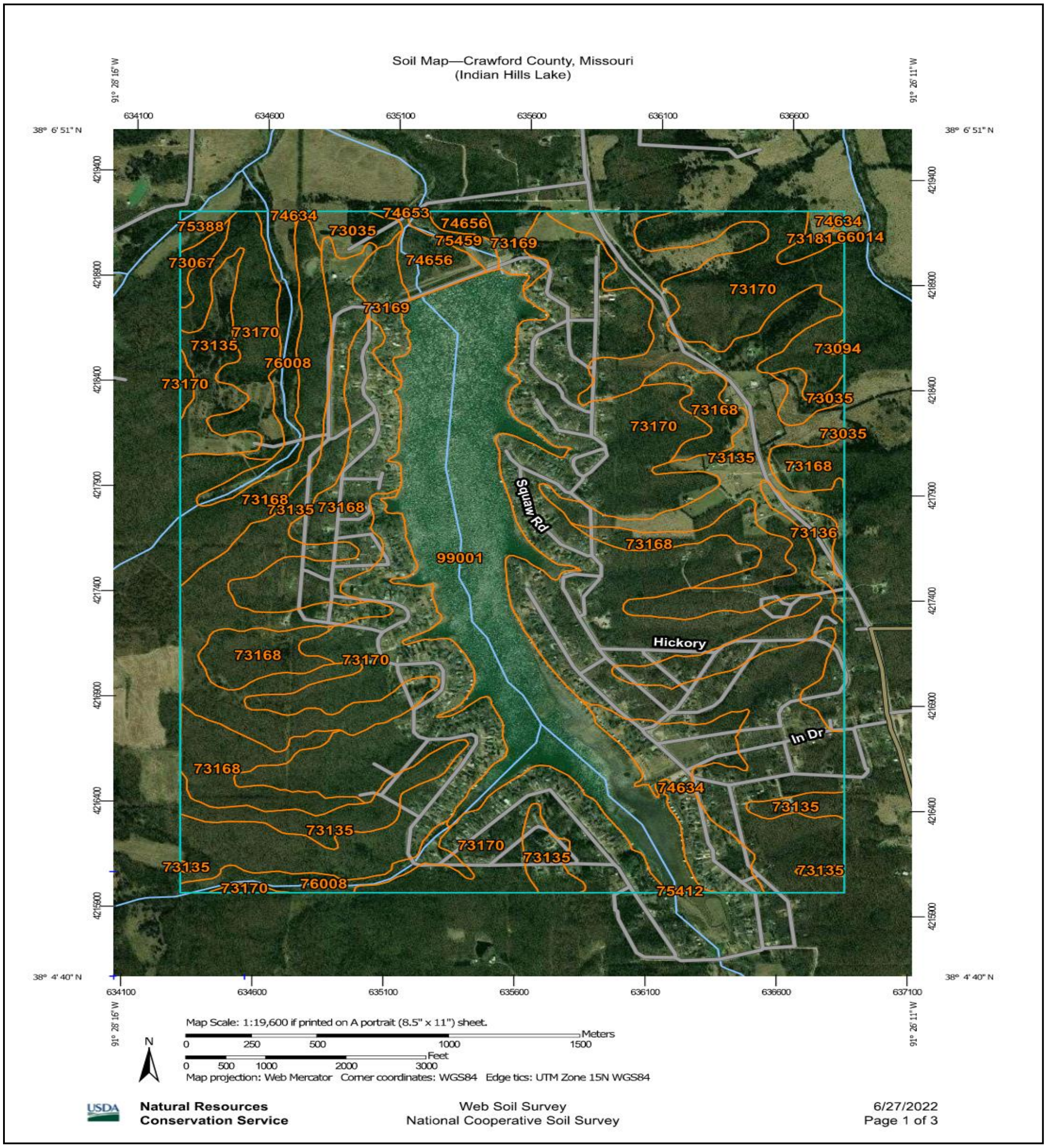


Figure 3. Indian Lake shoreline soils map (NRCS USDA data).

2.1.4 Laminar Flow Aeration

Laminar flow aeration systems (Figure 4) 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 basin 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 (Jermalowicz-Jones, 2010-2022). 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.

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.

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

The LFA system has some limitations including the inability to break down mineral sediments such as the silts present in Indian Lake, 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). The largest benefit of LFA for Indian Lake 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, 2009-2022, among others).

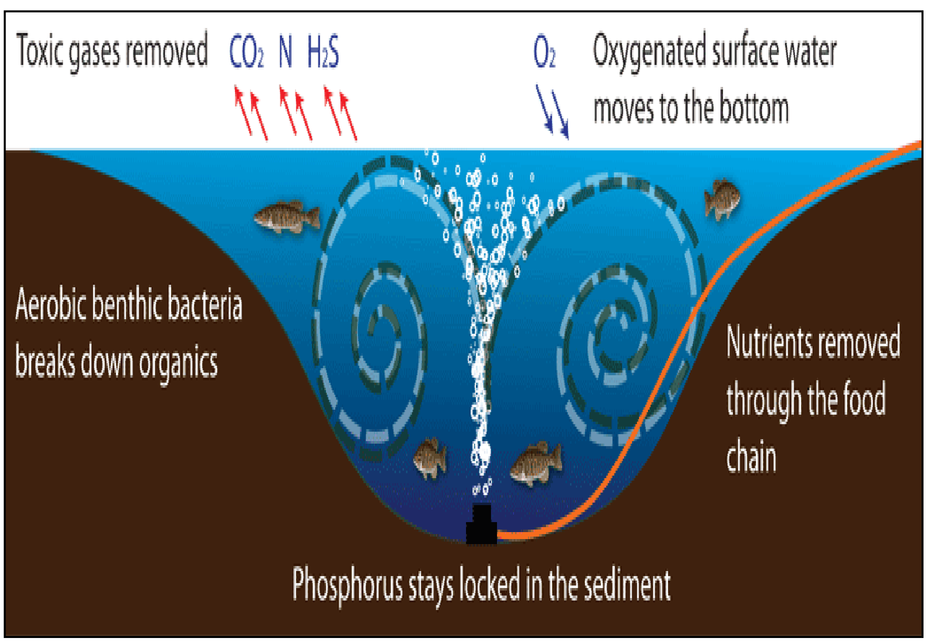


Figure 4. Diagram of laminar flow aeration. ©RLS

3.0 INDIAN LAKE PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Indian Lake Basin & Immediate Watershed Boundary

Indian Lake is located in Crawford County, Missouri near the town of Cuba. It is a man-made impoundment with a sizeable dam (Figure 5), or water control structure located at the north end of the lake. The lake is approximately 311 acres in surface area with a shoreline of approximately 7.9 miles. The fetch, which is the longest distance across the lake surface, is approximately 1.5 miles. The maximum depth recorded in 2022 was 40 feet (RLS, GIS data) and the average depth was previously determined at 15.4 feet (Clean-Flo 2019 data). The immediate watershed of the lake, which is the area of land draining directly towards the lake is approximately 9,252 acres (Figure 7). Thus, the watershed to lake ratio is 30 which denotes a large immediate watershed. There are 5 areas of inflow that drain into the lake (Figure 6).

The lake is highly developed with many areas of shoreline erosion. The lake bottom is mostly silt and clay and is easily disrupted during storm and high wind events leading to an increase in turbidity. The majority of the lake sediments are low in organic matter (≤12%) based on sediment core data previously collected by Clean-Flo, Inc.

The lake residents utilize septic systems rather than a municipal sewer system and the challenges for this relative to water quality are discussed later in this report.

Figure 5. Indian Lake with a view of the large dam.

Figure 6. Indian Lake inflow area.

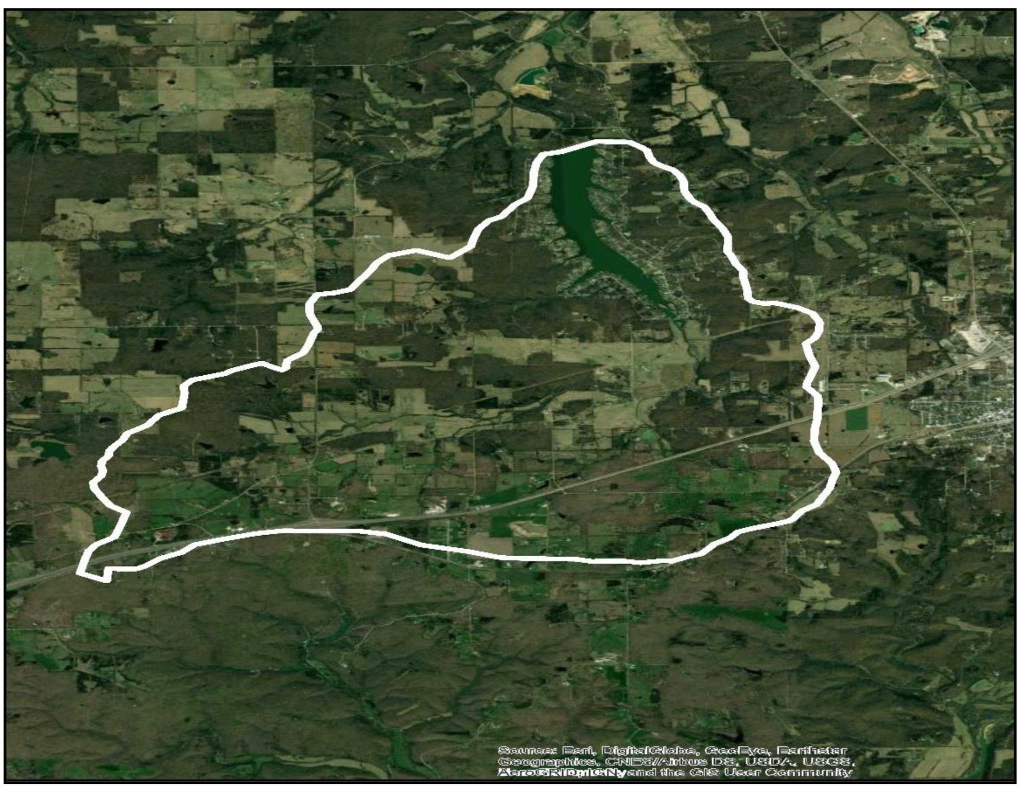


Figure 7. Indian Lake Immediate Watershed Boundary (RLS, 2022).

4.0 INDIAN LAKE WATER QUALITY DATA

Water quality is highly variable among inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by both land use practices and climatic events. Climatic factors (i.e. spring runoff, heavy rainfall) may alter water quality in the short term; whereas, anthropogenic (man-induced) factors (i.e. shoreline development, lawn fertilizer use) alter water quality over longer time periods. Since many lakes have a fairly long hydraulic residence time, the water may remain in the lake for years and is therefore sensitive to nutrient loading and pollutants. Furthermore, lake water quality helps to determine the classification of particular lakes (Table 2). Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a*, and low in transparency are classified as eutrophic; whereas those that are low in nutrients and chlorophyll-*a*, and high in transparency are classified as oligotrophic. Lakes that fall in between these two categories are classified as mesotrophic. Indian Lake is classified as highly eutrophic (nutrient-enriched) due to the elevated nutrients and low Secchi transparency and elevated chlorophyll-a concentrations (Figure 8).

Table 2. General Lake Trophic Status Classification Table.

Lake Trophic Status	*Total Phosphorus (mg/L)*	*Chlorophyll-a (µg/L)*	*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

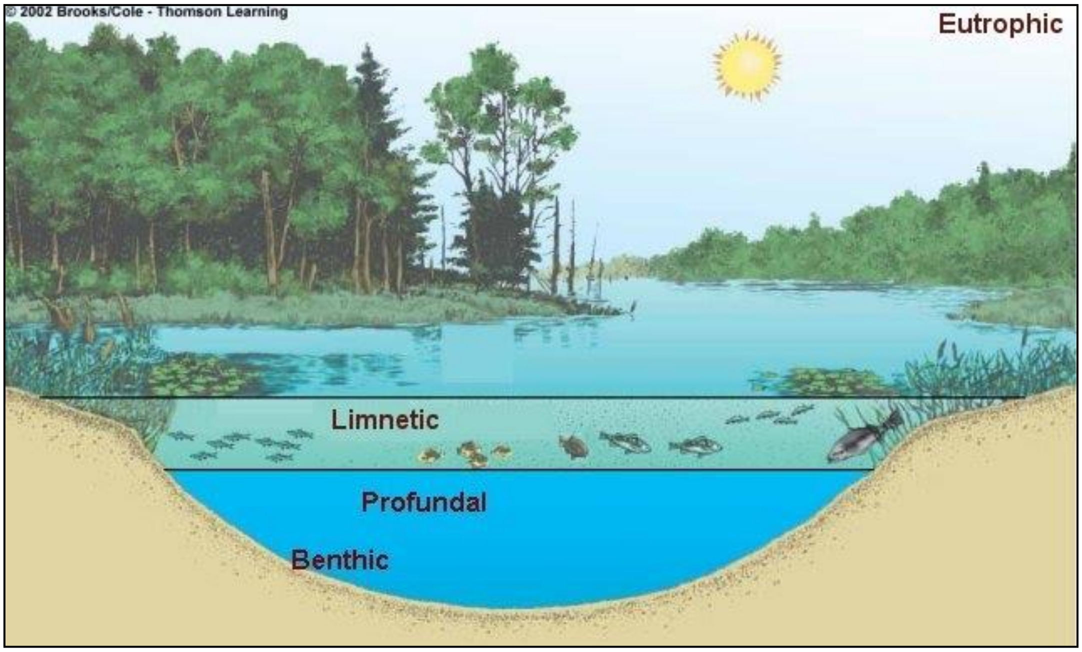


Figure 8. Diagram showing a eutrophic or nutrient-enriched lake ecosystem (photo adapted from Brooks/Cole Thomson learning online).

4.1 Water Quality Parameters

Parameters such as dissolved oxygen (in mg/L), water temperature (in °C), specific conductivity (mS/cm), total dissolved solids (mg/L), total suspended solids (mg/l), pH (S.U.), total alkalinity (mg/L), total phosphorus and ortho-phosphorus (also known as soluble reactive phosphorus or SRP measured in mg/L), total Kjeldahl nitrogen and total inorganic nitrogen (in mg/L), dissolved inorganic carbon (in mg/L), chlorophyll-a (in µg/L), and Secchi transparency (in meters) are parameters that respond to changes in water quality and consequently serve as indicators of change. The deep basin results are discussed below and are presented in Tables 4-44. A map showing the sampling locations for all water quality samples is shown below in Figure 9. All water samples and readings were collected in the 4 deepest basins on and August 16, 2021, October 22, 2021, March 10, 2022, August 31, 2022, and October 13, 2022 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. Specific sampling methods for each parameter are discussed in each parameter section below.

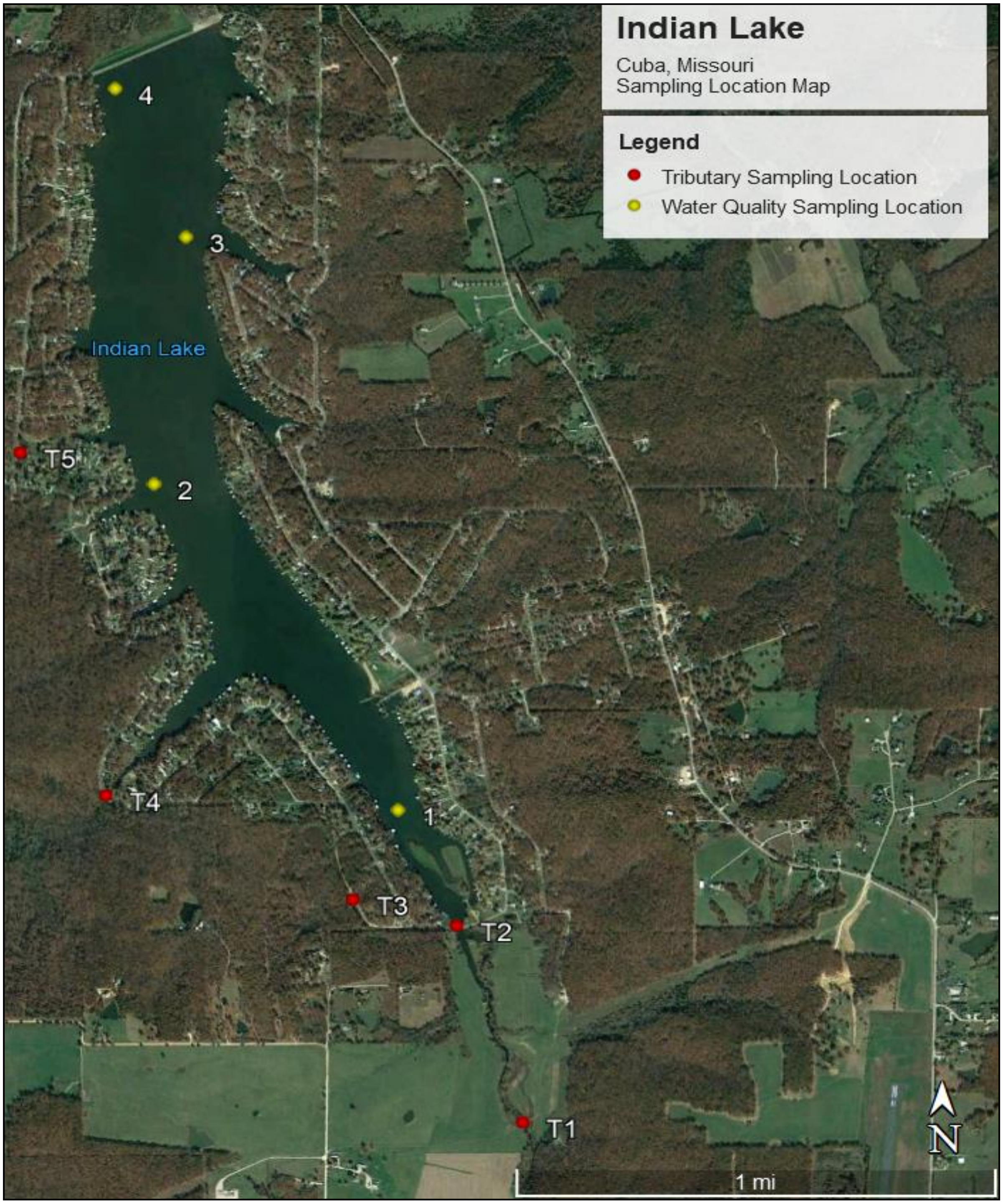
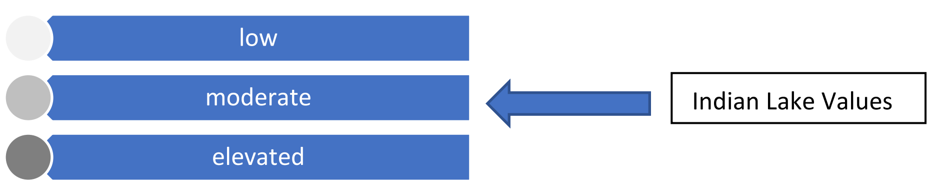


Figure 9. Locations for water quality sampling of the deep basins and major tributaries in and around Indian Lake, Cuba, Missouri.

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 Indian Lake varied with time (season) and depth. With implementation of the LFA system, Indian Lake exhibits weak to absent stratification and thus water temperature will be the most determining factor for dissolved oxygen content. Dissolved oxygen increased in both August and October with LFA and thus these increases could be attributed to LFA and not just seasonal changes (Figure 10). A spike in March 2022 concentrations would be expected since colder waters hold more oxygen, Previous measurements collected by Clean-Flo in 2019 found rapid dissolved oxygen depletion between a depth of 11-14 feet with unacceptable anoxic concentrations below a depth of 13 feet.

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.



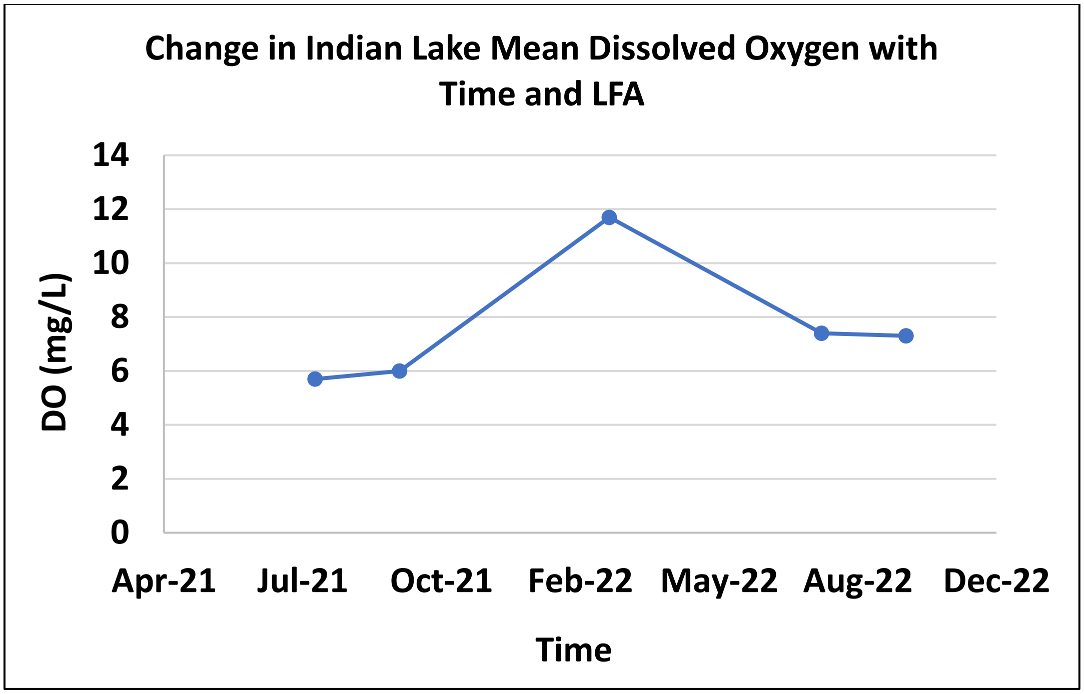


Figure 10. Change in Indian Lake mean dissolved oxygen with time and LFA.

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 11). 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. Typically, LFA will result in higher water temperatures in deeper waters but usually temperatures are homogenized and cooler near the surface (Figure 12).

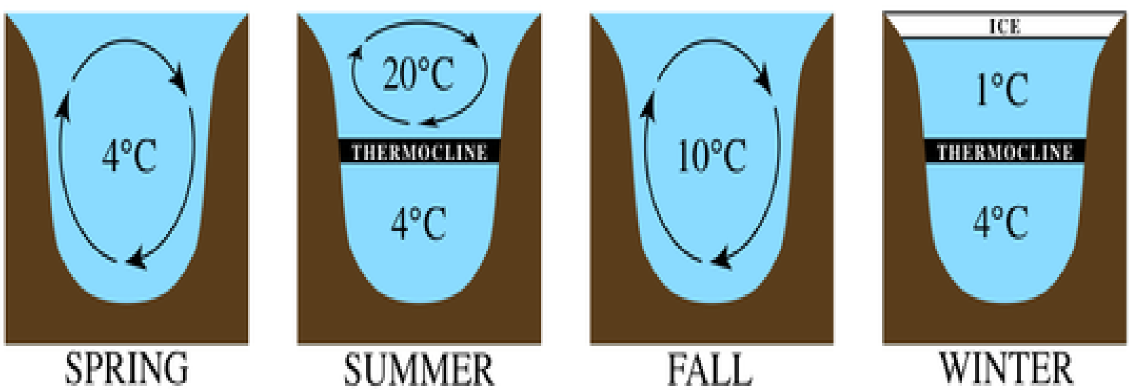


Figure 11. The lake turnover process.

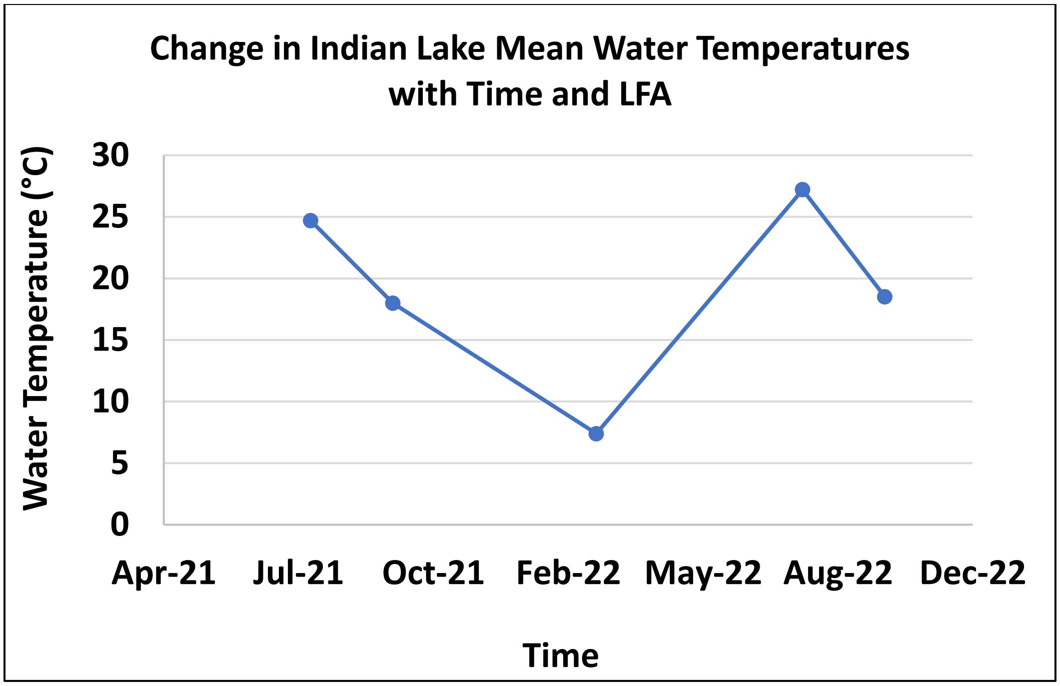


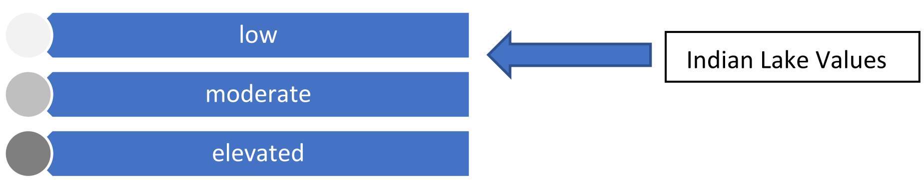
Figure 12. Change in Indian Lake mean water temperatures with time and LFA.

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.

Overall, the specific conductivity has declined with time and LFA (Figure 13). These values are moderately low for an inland lake, and thus the lake water contains minimal 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 Indian Lake over a long period of time, or to trace the origin of a substance to the lake in an effort to reduce pollutant loading. Elevated conductivity values over 800 mS/cm can negatively impact aquatic life.



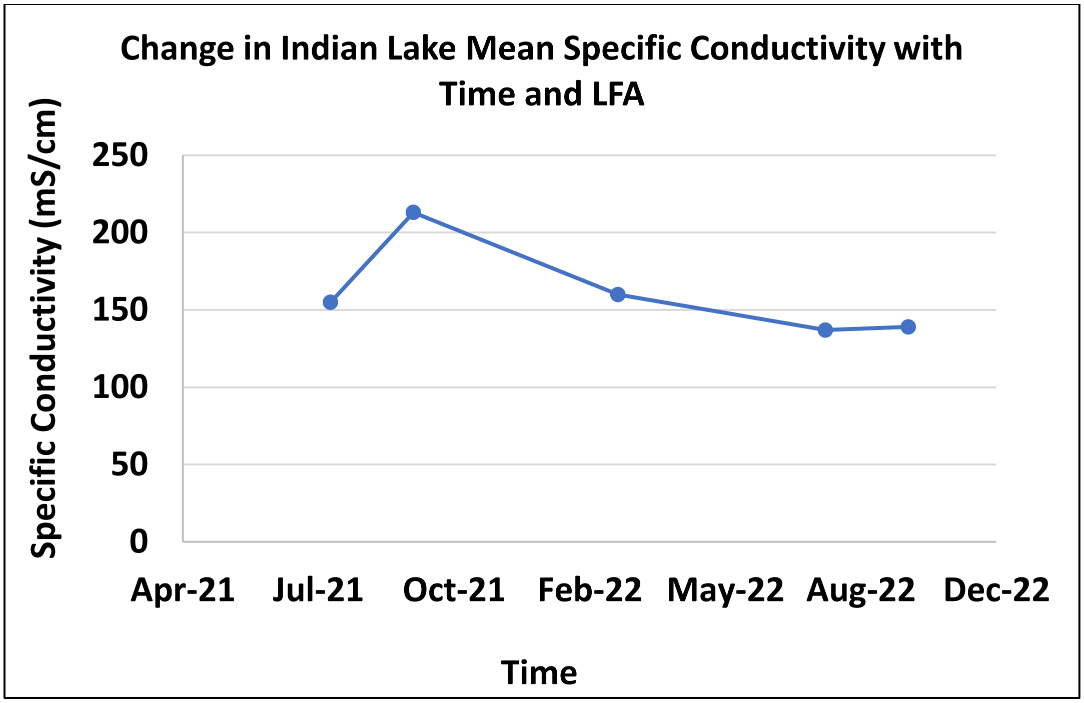


Figure 13. Change in Indian Lake mean specific conductivity with time and LFA.

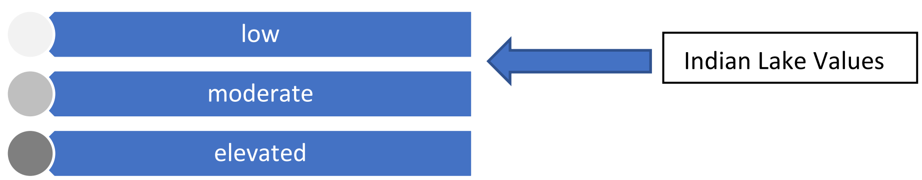
4.1.4 Total Dissolved Solids

There are two different types of solids found in freshwaters. Total dissolved solids (TDS) are those that cannot be seen in solution but that impact the water chemistry through contributions of tannins, salts, and minerals that enter the water. Total suspended solids (TSS) are those solids in particulate form that result in increased water turbidity (reduced clarity) and are often a result of soils and sediments that are not able to dissolve in the lake water. TSS would be inherently high for Indian Lake due to bottom substrate and mixing.

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 TDS declined with time in Indian Lake (Figure 14) which correlates with the decline in specific conductivity. These values are moderately low for an inland lake and favorable.



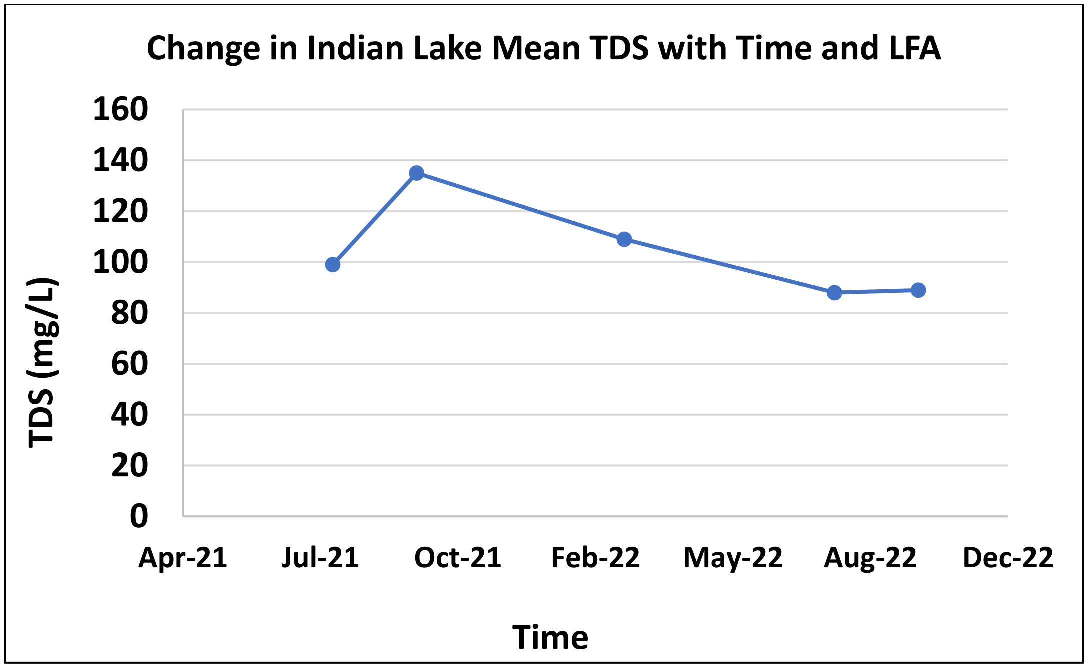


Figure 14. Change in Indian Lake mean TDS with time and LFA.

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).

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. The pH in Indian Lake has narrowly varied from 7.5-7.8 S.U. which is ideal for an inland lake (Figure 15).

4.1.6 Total Alkalinity

Total alkalinity is a measure of the amount of calcium carbonate present in a lake. This parameter is usually higher in hardwater and lower in soft or acidic waters. Indian Lake has highly variable concentrations that may also interact with CO2 and pH. Indian Lake total alkalinity measurements have ranged from 13-64 mg $CaCO_3$/L which is quite low,

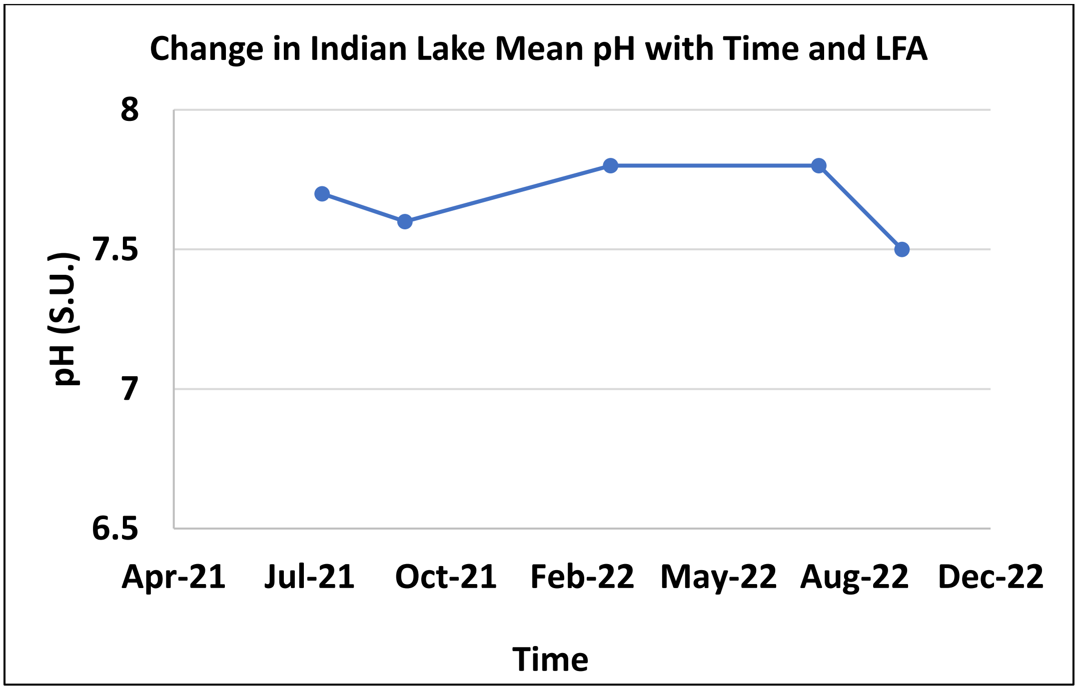


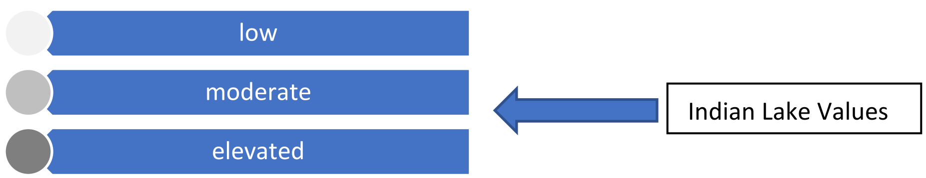
Figure 15. Change in Indian Lake mean pH with time and LFA.

4.1.7 Total Phosphorus and Ortho-Phosphorus (SRP)

Total Phosphorus

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Lakes which contain greater than 0.020 mg/L 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 Indian Lake declined since LFA began (Figure 16) which is highly favorable. There was also a dramatic decline in TP at the lake bottom which has resulted in a reduced internal load of phosphorus. These concentrations are still elevated however and should decline with continued LFA, bioaugmentation, and additional nutrient load reductions.

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.



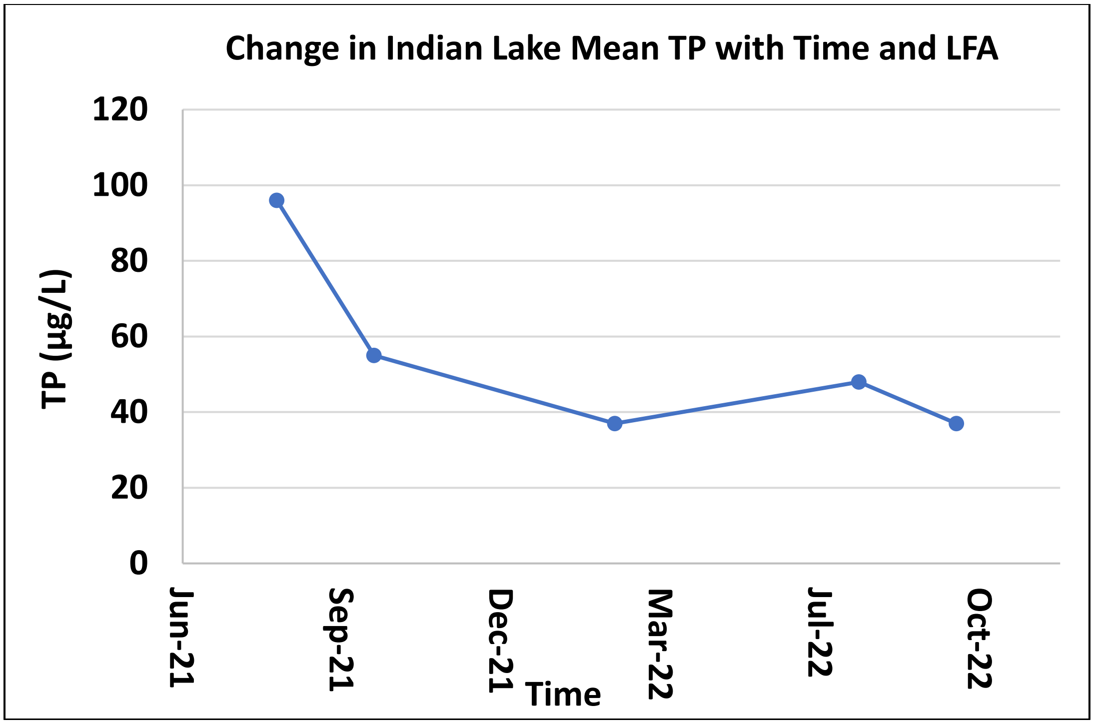
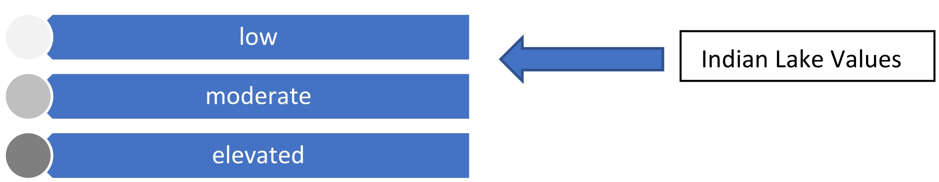


Figure 16. Change in Indian Lake mean TP with time and LFA (2021-2022).

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 Indian Lake also declined with time and LFA (Figure 17) which is also favorable.



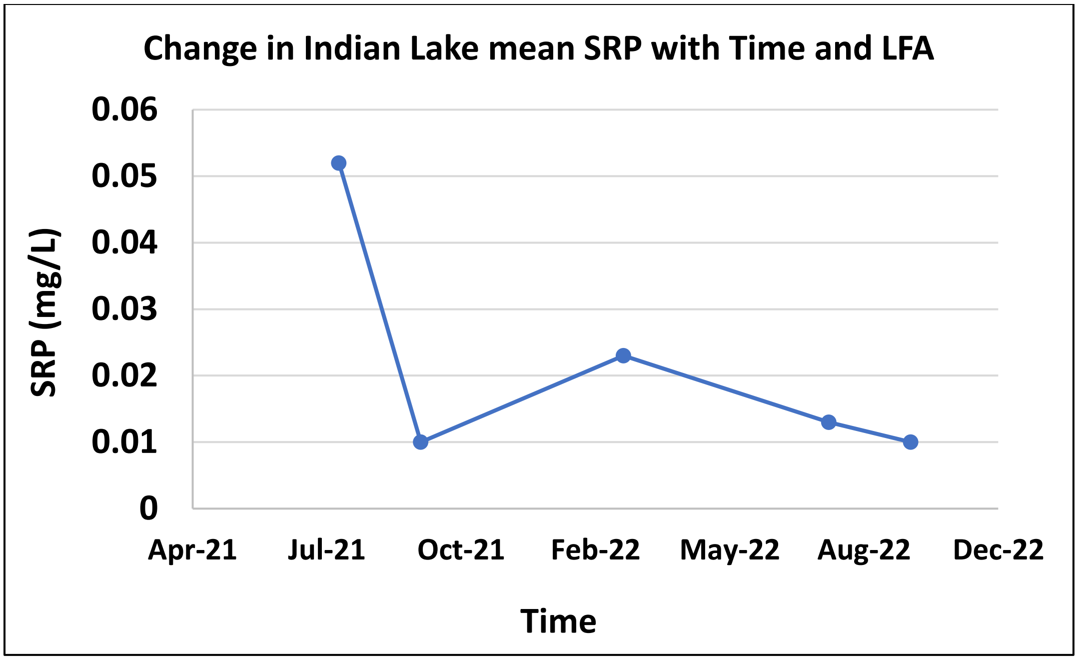


Figure 17. Change in Indian Lake mean SRP with time and LFA.

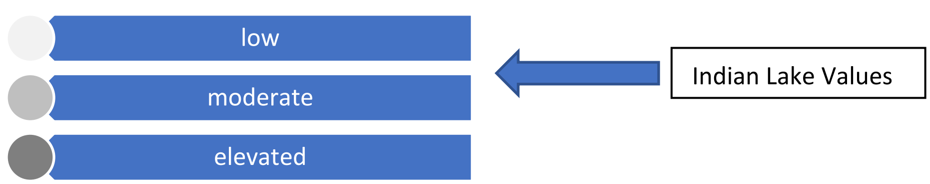
4.1.8 Total Kjeldahl Nitrogen and Total Inorganic Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. TKN was measured with Method EPA 351.2 (Rev. 2.0) and Total Inorganic Nitrogen (TIN) was calculated based on the aforementioned three different forms of nitrogen 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. 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.

The total inorganic nitrogen (TIN) consists of nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3) forms of nitrogen without the organic forms of nitrogen. All of the inorganic nitrogen in the Indian lake samples was present in the ammonia form.

The mean TKN and TIN concentrations declined with time (Figures 18 and 19) which is favorable.

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.



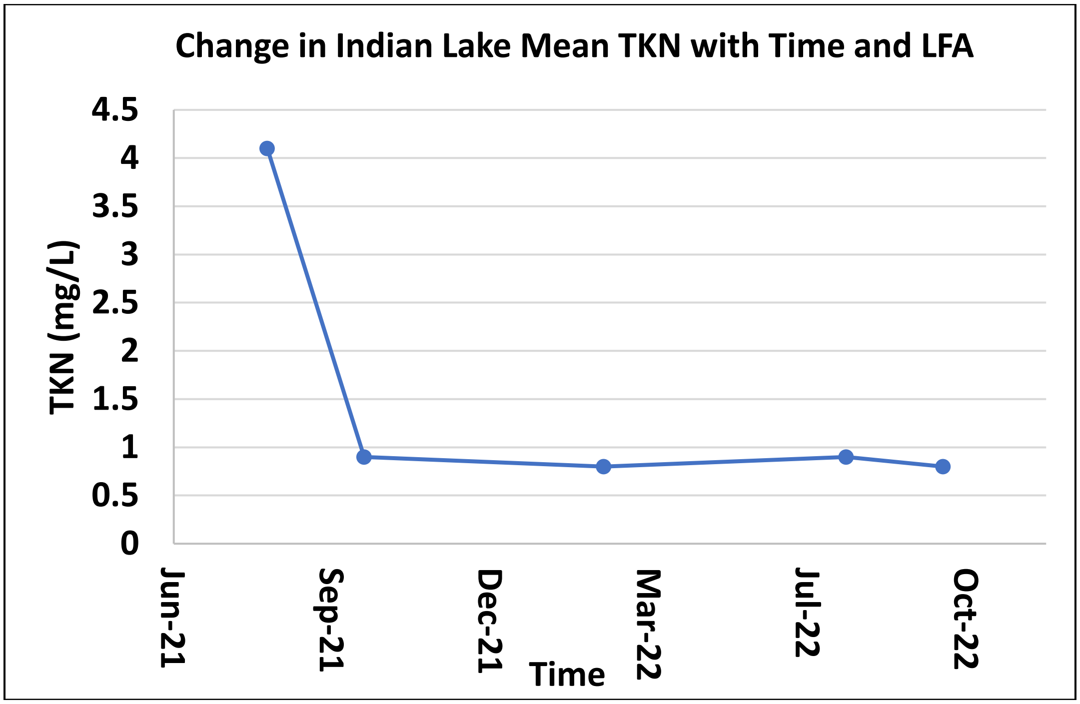


Figure 18. Change in Indian Lake mean TKN with time and LFA.

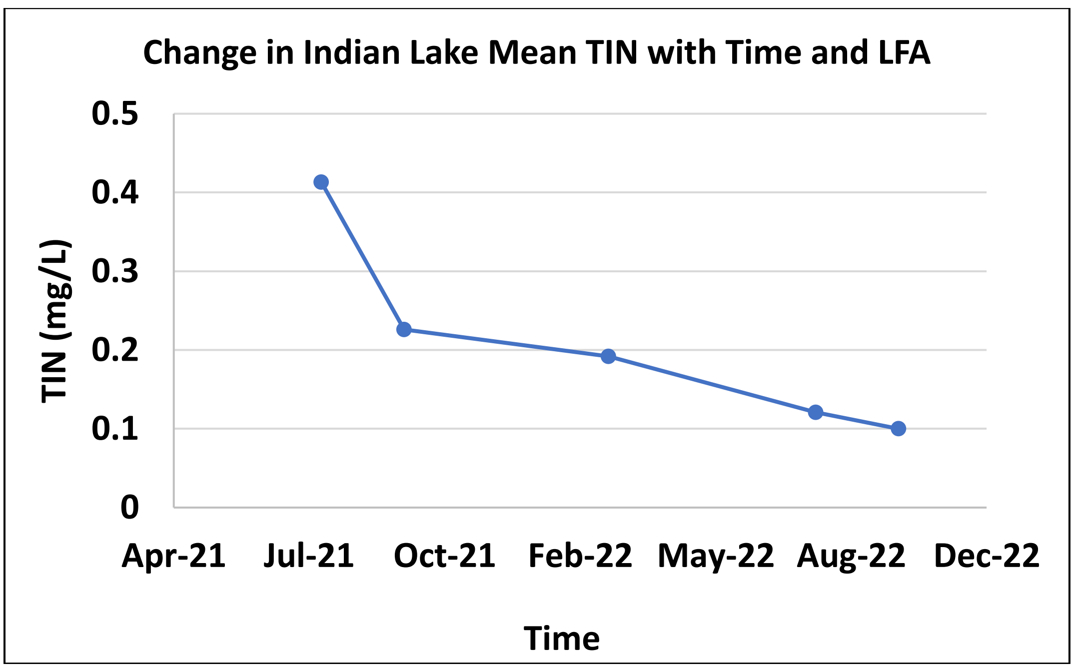


Figure 19. Change in Indian Lake mean TIN with time and LFA.

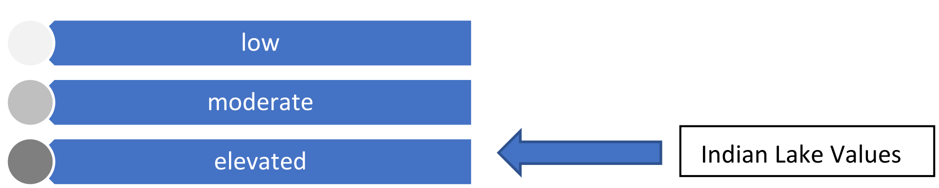
4.1.9 Chlorophyll-a and Algae

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. Chlorophyll-a water samples were measured in situ with a calibrated Turner Designs® fluorimeter. 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. The chlorophyll-*a* concentrations in Indian Lake 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 have increased with time since LFA began (Figure 20).

The dominant algae in the lake (blue-green algae) tends to be buoyant and float on the surface which reduces light to other favorable algae or plants below (Figures 21-22). 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. As ammonia declines in Indian Lake, the algae should decline. Additionally, recent algal analyses have demonstrated a shift from earlier *Aphanizomenon* algae to *Dolichospermum* algae to general HAB's and even green algae (Table 3) present in late 2023. Previous evaluation of toxins demonstrated low concentrations that were not a public threat. RLS does recommend additional testing for other toxins in 2023 and these are discussed in the conclusions and recommendations section.

The total algal concentration has increased slightly with LFA (Figure 23) as has the HAB relative biovolume, but the HAB relative concentration has very slightly declined (Figure 24).

The goal is to shift the lake towards a plant-dominated lake to reduce turbidity and algae over time (Figure 25).



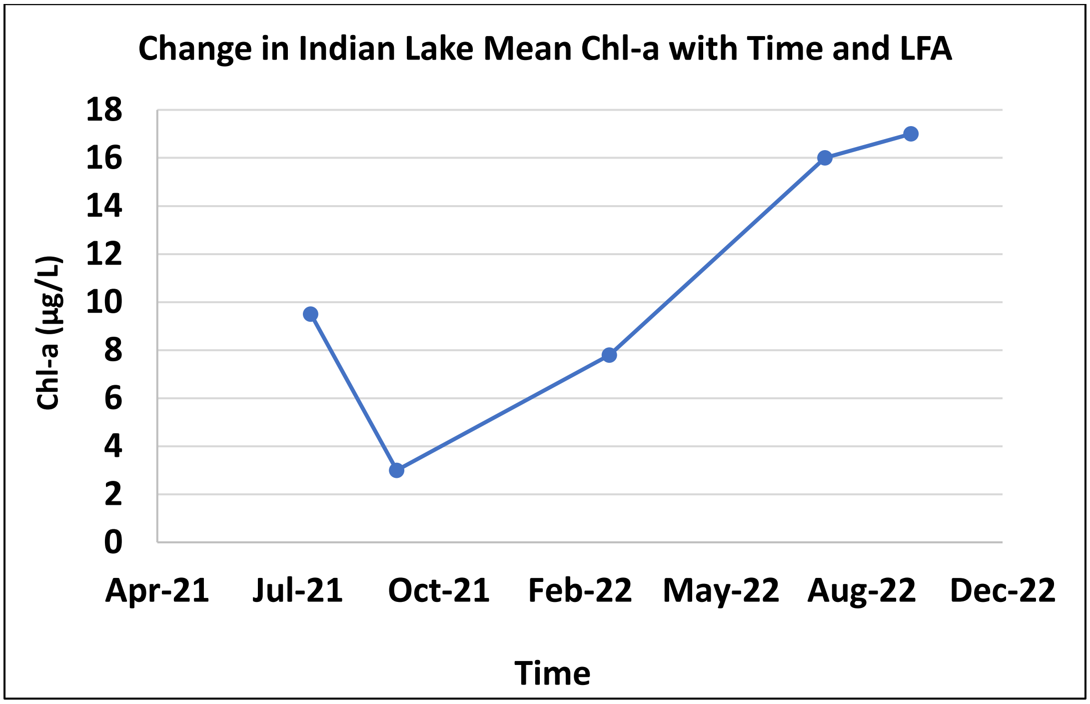


Figure 20. Change in Indian Lake mean chlorophyll-a with time and LFA.

Figure 21. Blue-green algal bloom on Indian Lake (August, 2022).

Figure 22. Blue-green algal bloom on Indian Lake (May, 2022).

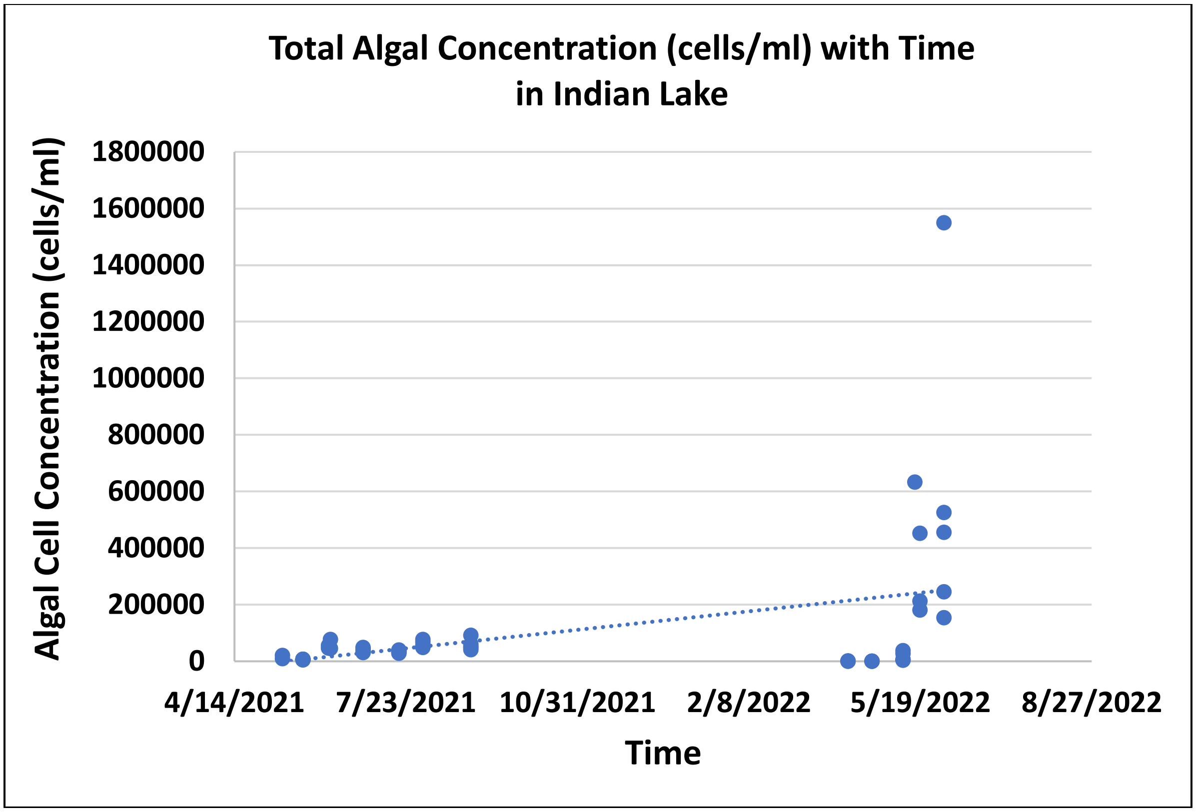


Figure 23. Change in algal concentration (cells/ml) with time in Indian Lake (2021-2022).

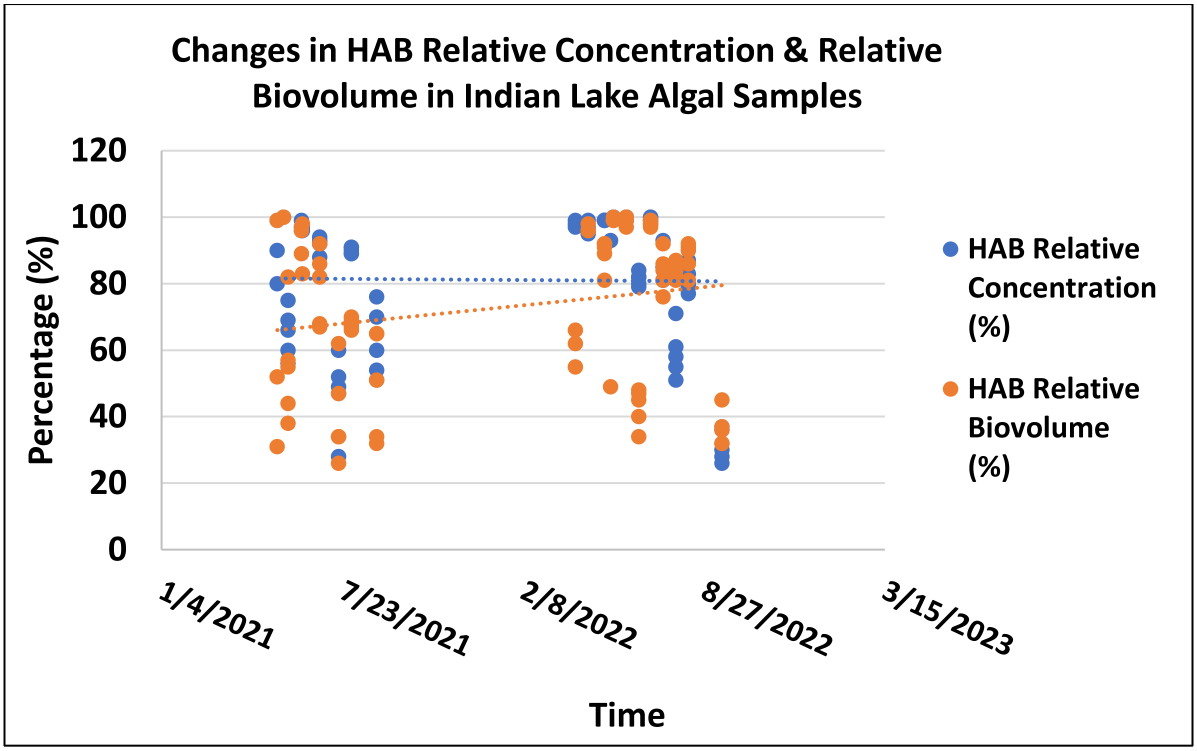


Figure 24. Change in relative HAB concentration and biovolume with time in Indian Lake (2021-2022).

Table 3. Dominant algal taxa found in Indian Lake samples with time (Phyco Tech data as prepared for the Association)

Date	Dominant Algal Taxa
May 12, 2021	*Aphanizomenon*
May 24, 2021	HAB
June 8, 2021	*Dolichospermum*
June 28, 2021	*Dolichospermum*
July 19, 2021	*Aphanizomenon*
August 2, 2021	*Dolichospermum*
August 30, 2021	*Dolichospermum*
April 7, 2022	HAB
April 21, 2022	HAB
May 9, 2022	HAB
May 16, 2022	HAB
June 2, 2022	HAB
June 16, 2022	HAB
June 29, 2022	HAB
July 13, 2022	HAB
July 27, 2022	HAB
August 10, 2022	HAB
September 16, 2022	HAB and Green

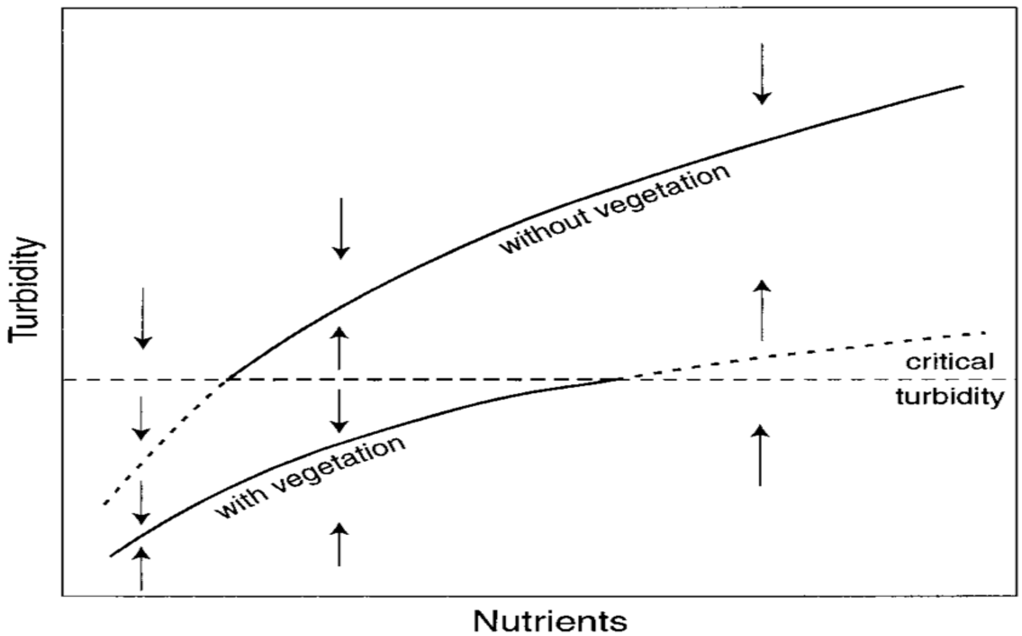
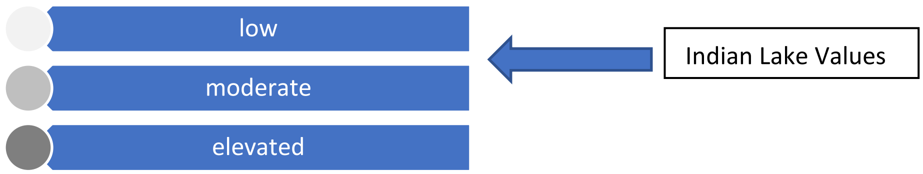


Figure 25. Graph adapted from Scheffer et *al* (2001). Catastrophic shifts in ecosystems. Nature 413, 591-596.

4.1.10 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and is measured with the use of an 8-inch diameter standardized Secchi disk during calm to light wind conditions. Secchi disk transparency was measured in meters (m) by lowering the disk over the shaded side of a boat and taking the mean of the measurements of disappearance and reappearance of the disk (Figure 26). 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 Indian Lake has increased significantly with time and LFA (Figure 27).

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. It is interesting that Secchi transparency increased given the increase in algal cell concentration. It is possible that submersed aquatic vegetation (SAV) could be increasing due to increased light availability, and this could be allowing for a shift towards a more favorable “alternate stable state” which should further increase clarity as more SAV grows. The Secchi transparency is still considered low and a goal of at least 2 meters should be reached in the long term.



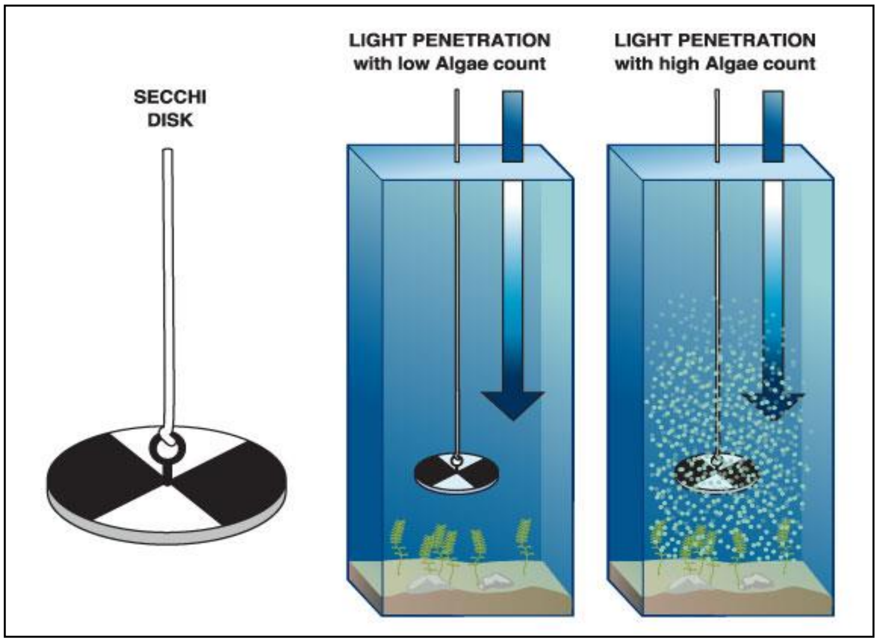


Figure 26. Measurement of water transparency with a Secchi disk.

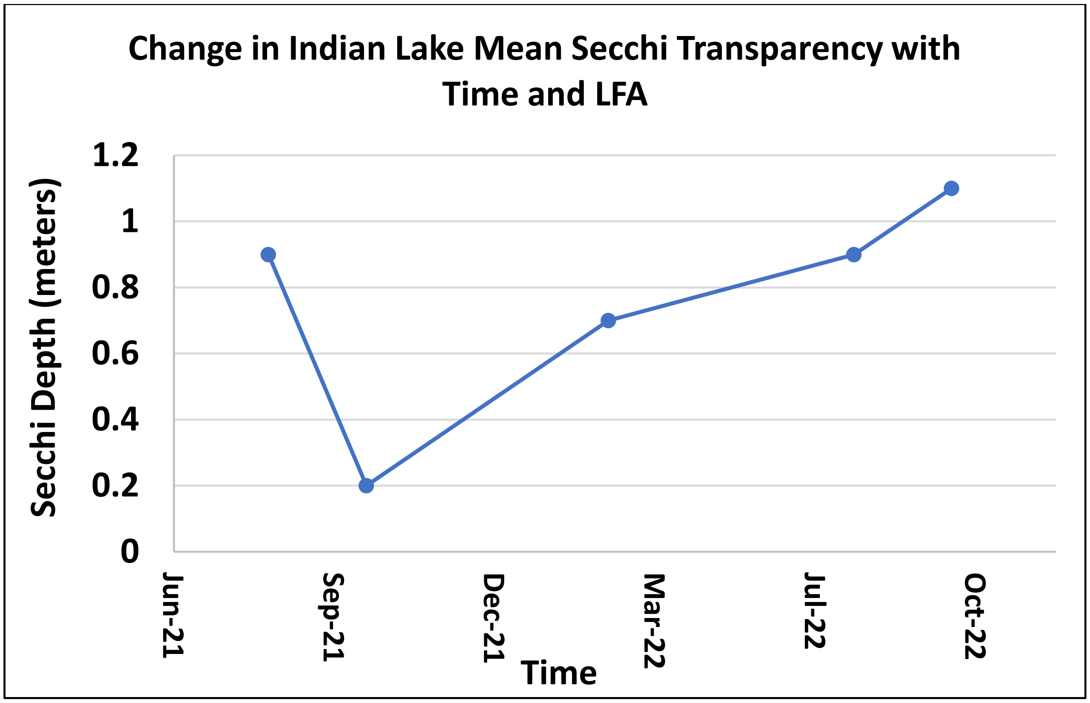
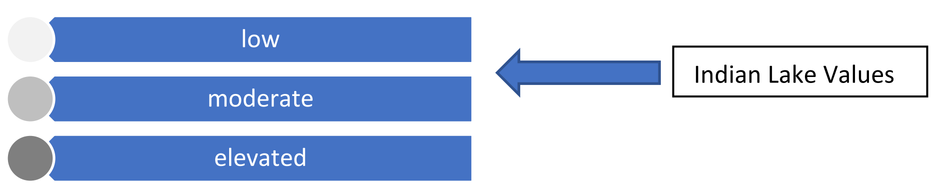


Figure 27. Change in Indian Lake mean secchi transparency with time and LFA.

4.1.11 Dissolved Inorganic Carbon (DIC)

Dissolved inorganic carbon consists of three major forms of carbon that include carbon dioxide (CO_2), carbonic acid, bicarbonate, and carbonate. The quantity of each of these forms of carbon varies with pH values with a higher proportion of carbon dioxide (CO_2) present in waters with lower pH. As pH rises, the carbonate and bicarbonate forms are more prevalent. There is a scarcity of research on baseline concentrations of DIC in inland waters and thus mean values are subject to interpretation. The DIC found in the atmosphere is approximately 350 ppm (mg/L) which is much higher than the concentrations present in most lakes (Dodds, 2002), including Indian Lake. Since CO_2 is essential for the photosynthesis of plants and algae, those taxa are expected to increase over time with global CO_2 concentrations. It is too early to determine if CO_2 concentrations will continue to decline with LFA, but it would be advantageous if that occurred. Fortunately, CO_2 gas has limited solubility in acidic water so as pH declines it will be off gassed and decrease. A bioaugmentation microbe that reduces DIC in the water may help facilitate this process as bacteria are the largest decomposers of organic material (Fenchel and Blackburn, 1979). Because the atmosphere is much higher in DIC than most waters, these environments will continue to serve as sinks for CO_2 and this enrichment will alter the health of waters. In marine environments, it is associated with coral damage as the coral becomes softer due to less calcium as a result of higher acidity.



Alternatively, organic carbon is related to living or decaying organisms that add carbon to lake sediments over time upon decay. Aerobic respiration (as opposed to anoxic low oxygen conditions) is the most efficient pathway for reduction of organic matter (Hutchinson, 1938 among others). Thus, LFA will continue to facilitate reduction of organic matter as well. Another form of carbon is dissolved organic matter (DOM) that may undergo photodegradation and can result in increased DIC as well. Thus, lakes with high DOM may also experience enhanced increases in DIC over time (Granéli et *al*., 1996).

There is evidence that each species or at least genera of cyanobacteria may vary in their ability to efficiently utilize the different forms of carbon, and this is being researched by many scholars (Ji et *al*., 2017, among numerous others). Ji et *al*., 2017 found that green algae are well adapted to growth under low CO_2 conditions. It is thus possible that as pH is increased in Indian Lake, green algae may begin to outgrow the HAB’s.

The DIC declined with time and LFA (Figure 28) but increased sharply in October 2022 and the reason for this is unclear.

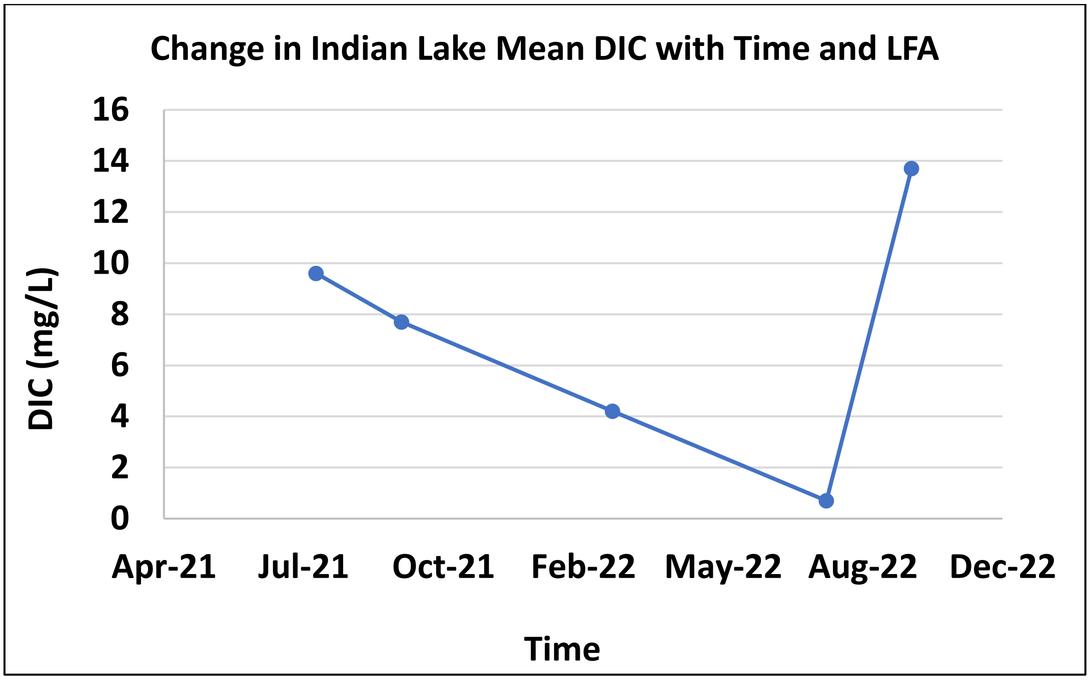


Figure 28. Change in Indian Lake mean DIC with time and LFA.

4.1.12 E. coli Bacteria

Escherichia coli (*E. coli*) is a rod-shaped bacterium that constitutes fecal coliform, which is the dominant bacteria present in the feces of warm-blooded animals. *E. coli* bacteria are useful indicators of bacteriological contamination in aquatic ecosystems. *E. coli* may be contributed from fecal matter from warm-blooded animals directly, or from leaking septic seepage.

Typically, if three or more samples are collected over a 30-day period and average over 130 *E. coli* Colony Forming Units (CFU's) per 100 ml, then local health officials are required to close public beaches. In addition, if any one sample detects an *E. coli* concentration of 300 CFU's per 100 milliliters, then the beaches will be closed as well. Other (non-body contact) activities (such as fishing and boating) will be halted if concentrations exceed 1,000 CFU's per 100 ml. Another unit of measure is the most probable number or (MPN). *E. coli* was sampled on May 24, 2021 by Ozark Testing at the locations listed in Table 4 below. None of the samples resulted in high *E. coli* counts which is favorable.

This is not indicative of septic system performance due to the distance from septic system locations where the samples were collected. The data below are favorable with low counts that did not pose a public health hazard.

Table 4. *E. coli* concentration sampling conducted by Ozark Testing in 2021.

Date Sampled	*E. Coli* Concentration (MPN)	Location
5-24-21	32.3	20 feet from swim beach
5-24-21	5.2	20-30 feet from beach corner
5-24-21	11.0	Cove 9
5-24-21	9.6	Cove 7
5-24-21	13.4	Star dock by buoy
5-24-21	3.1	Spillway buoys
5-24-21	2.0	Cove 1 by buoys

Table 5. Indian Lake physical water quality parameter data collected in deep basin #1 (August 16, 2021).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	27.9	8.3	8.1	147	94	0.72
0.5	27.9	8.3	8.1	147	94	
1.0	26.5	8.0	7.9	148	95	
1.2	26.6	7.5	7.7	148	95	

Table 6. Indian Lake chemical water quality parameter data collected in deep basin #1 (August 16, 2021).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
1.0	2.0	<0.10	0.060	<0.010	0.039	<0.10	<0.10	9.3	11.0	50

Table 7. Indian Lake physical water quality parameter data collected in deep basin #2 (August 16, 2021).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	28.2	8.0	8.5	145	93	0.88
0.5	28.2	8.4	8.4	145	93	
1.0	27.9	8.6	8.4	145	93	
1.5	27.5	8.6	8.2	145	93	
2.0	27.4	8.2	7.9	145	93	
2.5	27.4	7.7	7.9	145	93	
3.0	27.4	7.5	7.8	145	93	
3.5	27.3	7.2	7.8	146	93	
4.0	27.0	6.7	7.6	144	92	
4.5	26.8	5.7	7.4	145	93	
5.0	24.9	5.0	7.2	174	112	
5.1	24.0	2.6	7.3	176	113	

Table 8. Indian Lake chemical water quality parameter data collected in deep basin #2 (August 16, 2021).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	1.0	<0.10	0.038	<0.010	0.011	<0.10	<0.10	9.5	7.0	60
2.5	22	<0.10	0.045	<0.010	<0.010	<0.10	<0.10	7.8		39
5.1	4.2	0.230	0.074	<0.010	0.230	<0.10	<0.10	10.0		38

Table 9. Indian Lake physical water quality parameter data collected in deep basin #3 (August 16, 2021).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	28.6	7.3	8.5	145	93	0.81
0.5	28.6	8.2	8.3	145	93	
1.0	28.3	8.3	8.3	145	93	
1.5	27.5	8.5	8.3	144	92	
2.0	27.4	8.5	8.2	144	92	
2.5	27.4	8.4	8.1	144	92	
3.0	27.3	8.3	8.0	144	92	
3.5	27.2	8.2	8.2	144	92	
4.0	27.2	7.9	7.9	145	93	
4.5	25.9	6.2	7.5	155	100	
5.0	25.1	3.8	7.3	169	109	
5.5	23.6	2.0	7.3	176	113	
6.0	21.3	1.3	7.3	169	108	
6.5	19.2	0.8	7.2	167	107	
7.0	18.1	0.5	7.1	168	108	
7.5	17.4	0.3	7.1	167	107	
7.7	16.9	0.2	7.1	173	111	

Table 10. Indian Lake chemical water quality parameter data collected in deep basin #3 (August 16, 2021).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	1.9	<0.10	0.031	<0.010	<0.010	<0.10	<0.10	9.5	11.0	61
4.0	5.9	<0.10	0.036	<0.010	<0.010	<0.10	<0.10	8.9		51
7.7	<0.50	1.4	0.250	0.170	1.4	<0.10	<0.10	12.0		58

Table 11. Indian Lake physical water quality parameter data collected in deep basin #4 (August 16, 2021).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	27.9	8.0	8.5	200	100	1.09
0.5	27.9	8.1	8.3	145	93	
1.0	27.3	8.2	8.1	145	93	
1.5	27.1	7.7	8.0	145	93	
2.0	27.0	7.5	7.9	144	92	
2.5	26.9	7.0	7.8	144	92	
3.0	26.9	6.8	7.8	145	93	
3.5	26.8	6.7	7.8	145	93	
4.0	26.8	6.6	7.8	145	93	
4.5	26.7	6.5	7.7	145	93	
5.0	26.1	5.5	7.6	171	110	
5.5	22.7	5.1	7.4	170	109	
6.0	20.9	3.8	7.3	166	106	
6.5	19.0	2.5	7.2	163	105	
7.0	18.1	1.8	7.1	163	104	
7.5	16.9	1.1	7.1	165	106	
8.0	16.3	0.9	7.1	166	106	
8.5	15.9	0.7	7.1	169	108	
9.0	15.4	0.6	7.1	173	111	
9.5	15.2	0.4	7.1	176	113	

Table 12. Indian Lake chemical water quality parameter data collected in deep basin #4 (August 16, 2021).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.8	<0.10	0.032	<0.010	<0.010	<0.10	<0.10	9.6	9.0	64
5.0	2.2	<0.10	0.034	<0.010	<0.010	<0.10	<0.10	8.7	--	58
9.5	0.9	1.8	0.360	0.270	1.8	<0.10	<0.10	11.0	--	50

Table 13. Indian Lake physical water quality parameter data collected in deep basin #1 (October 22, 2021).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	16.0	8.0	7.9	217	138	0.2
0.5	16.0	8.3	7.9	224	146	
1.0	15.8	8.3	7.8	234	152	
1.2	15.8	8.3	7.8	234	152	

Table 14. Indian Lake chemical water quality parameter data collected in deep basin #1 (October 22, 2021).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
1.0	0.8	0.130	0.027	<0.010	0.130	<0.10	<0.10	9.0	3.0	57

Table 15. Indian Lake physical water quality parameter data collected in deep basin #2 (October 22, 2021).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	18.1	9.4	7.8	244	156	0.2
0.5	18.1	7.1	7.7	243	155	
1.0	18.1	6.9	7.6	244	155	
1.5	18.1	6.8	7.6	237	152	
2.0	18.1	6.8	7.6	241	155	
2.5	18.1	6.8	7.6	240	154	
3.0	18.0	6.7	7.6	243	154	
3.5	18.0	6.6	7.6	243	154	
4.0	18.0	6.6	7.6	237	152	
4.5	18.0	6.6	7.6	219	141	
5.0	18.0	6.6	7.6	211	132	
5.5	18.0	6.0	7.6	206	127	

Table 16. Indian Lake chemical water quality parameter data collected in deep basin #2 (October 22, 2021).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.7	0.160	0.032	<0.010	0.160	<0.10	<0.10	7.1	3.0	57
2.5	0.7	0.270	0.028	<0.010	0.160	<0.10	0.120	6.4		57
5.5	1.5	0.160	0.300	<0.010	0.160	<0.10	<0.10	6.8		51

Table 17. Indian Lake physical water quality parameter data collected in deep basin #3 (October 22, 2021).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	18.4	7.2	7.6	239	152	0.2
0.5	18.4	6.9	7.6	233	150	
1.0	18.4	6.7	7.6	237	154	
1.5	18.4	6.7	7.6	245	156	
2.0	18.3	6.6	7.6	244	155	
2.5	18.3	6.5	7.6	246	158	
3.0	18.3	6.5	7.6	248	159	
3.5	18.3	6.5	7.6	248	159	
4.0	18.3	6.5	7.6	246	157	
4.5	18.3	6.4	7.6	241	154	
5.0	18.3	6.3	7.6	223	143	
5.5	18.3	6.3	7.6	218	124	
6.0	18.3	6.3	7.6	170	114	

Table 18. Indian Lake chemical water quality parameter data collected in deep basin #3 (October 22, 2021).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.9	0.210	0.029	<0.010	0.210	<0.10	<0.10	7.1	3.0	58
4.0	0.8	0.200	0.031	<0.010	0.200	<0.10	<0.10	9.0		58
6.0	0.7	0.210	0.029	<0.010	0.210	<0.10	<0.10	8.6		56

Table 19. Indian Lake physical water quality parameter data collected in deep basin #4 (October 22, 2021).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	18.6	6.5	7.7	208	128	0.2
0.5	18.6	6.3	7.6	195	123	
1.0	18.4	6.2	7.6	202	126	
1.5	18.3	5.8	7.5	202	134	
2.0	18.3	5.7	7.5	207	133	
2.5	18.3	5.7	7.5	206	132	
3.0	18.3	5.4	7.5	206	132	
3.5	18.3	5.3	7.5	202	128	
4.0	18.3	5.3	7.5	179	117	
4.5	18.3	5.2	7.5	187	108	
5.0	18.2	5.1	7.5	166	118	
5.5	18.2	5.1	7.5	172	104	
6.0	18.2	5.1	7.5	172	104	
6.5	18.2	5.1	7.5	170	107	
7.0	18.2	5.0	7.5	171	113	
7.5	18.2	5.0	7.5	168	100	
8.0	18.1	4.2	7.4	162	104	
8.5	18.1	2.8	7.3	163	105	
9.0	18.0	1.5	7.3	171	110	
9.5	17.8	1.2	7.3	179	114	
10.0	17.4	0.5	7.3	189	121	

Table 20. Indian Lake chemical water quality parameter data collected in deep basin #4 (October 22, 2021).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.9	0.240	0.024	<0.010	0.240	<0.10	<0.10	6.5	3.0	58
5.0	0.8	0.260	0.024	<0.010	0.260	<0.10	<0.10	7.2		56
10.0	1.0	0.420	0.022	<0.010	0.420	<0.10	<0.10	9.6		51

Table 21. Indian Lake physical water quality parameter data collected in deep basin #1 (March 10, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	7.5	13.2	7.7	88.8	138.2	0.5
0.5	7.5	12.8	7.7	87.4	138.2	
1.0	7.4	12.4	7.7	88.1	138.7	
1.2	7.3	12.4	7.7	88.0	138.7	

Table 22. Indian Lake chemical water quality parameter data collected in deep basin #1 (March 10, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
1.0	0.9	0.260	0.030	0.031	<0.10	<0.10	0.260	2.4	7.0	13.0

Table 23. Indian Lake physical water quality parameter data collected in deep basin #2 (March 10, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	8.1	12.9	7.8	212.4	132.8	0.8
0.5	8.1	12.7	7.8	228.4	146.4	
1.0	8.0	12.6	7.8	229.3	146.8	
1.5	8.0	12.5	7.8	229.4	146.5	
2.0	7.9	12.4	7.8	229.1	146.5	
2.5	7.7	12.5	7.8	179.1	117.1	
3.0	7.7	12.4	7.8	140.5	89.8	
3.5	7.7	12.4	7.8	140.5	89.8	
4.0	7.7	12.4	7.8	140.5	89.8	
4.5	7.7	12.4	7.7	140.5	89.8	
5.0	7.7	12.3	7.7	140.5	89.8	

Table 24. Indian Lake chemical water quality parameter data collected in deep basin #2 (March 10, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.6	0.160	0.034	0.019	<0.10	<0.10	0.160	4.9	10.0	48
2.5	0.8	0.170	0.051	0.025	<0.10	<0.10	0.170	4.7		17
5.1	0.7	0.180	0.037	0.018	<0.10	<0.10	0.180	4.3		45

Table 25. Indian Lake physical water quality parameter data collected in deep basin #3 (March 10, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	7.7	13.0	7.8	225.2	144.3	0.8
0.5	7.6	12.1	7.8	226.8	145.4	
1.0	7.6	12.0	7.8	225.7	144.7	
1.5	7.6	12.0	7.8	223.0	142.5	
2.0	7.5	11.9	7.8	208.8	132.9	
2.5	7.4	11.9	7.8	202.9	129.4	
3.0	7.4	11.9	7.8	147.6	99.6	
3.5	7.4	11.9	7.8	137.8	88.3	
4.0	7.4	11.8	7.8	137.3	87.9	
4.5	7.3	11.7	7.8	134.1	85.8	
5.0	7.3	11.5	7.8	132.5	84.8	
5.5	7.3	11.5	7.8	132.5	84.8	
6.0	7.3	11.5	7.8	132.5	84.8	
6.5	7.3	11.5	7.8	132.5	84.8	
7.0	7.3	11.4	7.7	131.8	84.0	

Table 26. Indian Lake chemical water quality parameter data collected in deep basin #3 (March 10, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.6	0.180	0.039	0.023	<0.10	<0.10	0.180	4.8	7.0	47
4.0	0.7	0.190	0.021	0.021	<0.10	<0.10	0.190	4.0		15
7.7	1.3	0.210	0.036	0.026	<0.10	<0.10	0.210	4.6		34

Table 27. Indian Lake physical water quality parameter data collected in deep basin #4 (March 10, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	7.2	7.5	7.9	161.8	105.7	0.7
0.5	7.2	9.7	7.9	168.5	108.6	
1.0	7.2	10.5	7.9	164.9	106.3	
1.5	7.2	10.9	7.8	163.1	106.4	
2.0	7.2	11.1	7.8	166.9	106.8	
2.5	7.2	11.1	7.8	144.7	92.2	
3.0	7.2	11.2	7.8	139.1	88.9	
3.5	7.2	11.3	7.8	138.3	88.5	
4.0	7.2	11.3	7.8	162.4	120.9	
4.5	7.2	11.3	7.7	220.2	126.6	
5.0	7.2	11.4	7.7	180.6	112.2	
5.5	7.2	11.4	7.7	139.0	89.2	
6.0	7.2	11.4	7.7	138.9	88.9	
6.5	7.2	11.4	7.7	138.9	88.9	
7.0	7.2	11.4	7.7	138.9	88.9	
7.5	7.2	11.4	7.7	138.9	88.9	
8.0	7.2	11.3	7.6	137.5	88.0	
8.5	7.2	11.3	7.6	137.5	88.0	

Table 28. Indian Lake chemical water quality parameter data collected in deep basin #4 (March 10, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	<0.5	0.180	0.038	0.021	<0.10	<0.10	0.180	4.6	7.0	49
5.0	0.9	0.190	0.039	0.024	<0.10	<0.10	0.190	4.2		34
9.5	0.9	0.200	0.041	0.025	<0.10	<0.10	0.200	3.3		16

Table 29. Indian Lake physical water quality parameter data collected in deep basin #1 (August 31, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	26.7	8.7	8.2	140	90	0.6
0.5	26.7	8.8	8.3	140	90	
1.0	26.6	8.8	8.2	140	90	
1.2	26.4	8.7	8.2	139	89	

Table 30. Indian Lake chemical water quality parameter data collected in deep basin #1 (August 31, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
1.0	1.1	<0.10	0.043	<0.010	0.033	<0.10	<0.10	<0.7	16	43

Table 31. Indian Lake physical water quality parameter data collected in deep basin #2 (August 31, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	27.7	8.8	8.2	137	88	0.9
0.5	27.7	8.8	8.2	137	88	
1.0	27.5	8.8	8.2	137	88	
1.5	27.4	8.6	8.0	137	88	
2.0	27.4	8.3	7.9	137	88	
2.5	27.3	8.1	7.9	137	88	
3.0	27.3	8.0	7.9	137	88	
3.5	27.3	8.0	7.9	137	88	
4.0	27.2	7.9	7.9	137	88	
4.5	27.2	7.9	7.9	137	88	
5.0	27.2	7.9	7.9	138	88	

Table 32. Indian Lake chemical water quality parameter data collected in deep basin #2 (August 31, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.7	<0.10	0.031	<0.010	0.020	<0.10	<0.10	<0.7	17	42
2.5	1.1	<0.10	0.036	<0.010	0.030	<0.10	<0.10	<0.7		38
5.1	1.0	<0.10	0.034	<0.010	0.025	<0.10	<0.10	<0.7		29

Table 33. Indian Lake physical water quality parameter data collected in deep basin #3 (August 31, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	27.7	8.7	8.2	137	88	0.9
0.5	27.7	8.7	8.2	137	88	
1.0	27.6	8.7	8.2	137	88	
1.5	27.3	8.0	7.9	137	88	
2.0	27.3	7.9	7.8	137	88	
2.5	27.3	7.7	7.8	137	88	
3.0	27.2	7.4	7.7	137	88	
3.5	27.2	7.2	7.7	137	88	
4.0	27.2	7.0	7.6	137	88	
4.5	27.2	6.8	7.6	137	88	
5.0	27.2	6.8	7.6	137	88	
5.5	27.1	6.7	7.6	137	88	
6.0	27.1	6.7	7.6	137	88	
6.5	27.1	6.7	7.6	137	88	
7.0	27.1	6.7	7.5	137	88	

Table 34. Indian Lake chemical water quality parameter data collected in deep basin #3 (August 31, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.6	<0.10	0.026	<0.010	0.018	<0.10	<0.10	<0.7	15	42
4.0	0.7	<0.10	0.031	<0.010	0.026	<0.10	<0.10	<0.7		42
7.7	0.8	<0.10	0.036	<0.010	0.50	<0.10	<0.10	<0.7		34

Table 35. Indian Lake physical water quality parameter data collected in deep basin #4 (August 31, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	27.4	7.8	7.7	138	88	1.0
0.5	27.4	7.3	7.7	138	88	
1.0	27.4	7.2	7.7	138	88	
1.5	27.2	7.0	7.6	138	88	
2.0	27.0	6.7	7.6	138	88	
2.5	27.0	6.5	7.5	138	88	
3.0	27.0	6.3	7.5	138	88	
3.5	27.0	6.3	7.5	137	87	
4.0	27.0	6.3	7.5	137	87	
4.5	27.0	6.3	7.5	137	87	
5.0	27.0	6.3	7.5	137	87	
5.5	27.0	6.3	7.5	137	87	
6.0	27.0	6.3	7.5	137	87	
6.5	27.0	6.3	7.5	137	87	
7.0	26.9	6.3	7.5	138	88	
7.5	26.9	6.3	7.5	138	88	
8.0	26.9	6.2	7.5	138	88	
8.5	26.9	6.1	7.5	138	88	
9.0	26.9	6.1	7.4	138	88	

Table 36. Indian Lake chemical water quality parameter data collected in deep basin #4 (August 31, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.8	0.180	0.025	<0.010	0.042	<0.10	<0.10	<0.7	16	41
5.0	0.9	<0.10	0.030	<0.010	0.041	<0.10	<0.10	<0.7		38
9.5	1.1	0.230	0.190	0.038	0.230	<0.10	<0.10	<0.7		37

Table 37. Indian Lake physical water quality parameter data collected in deep basin #1 (October 13, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	17.2	8.5	7.6	140	89	1.0
0.5	17.1	8.4	7.6	139	88	
1.0	17.1	8.4	7.7	140	89	
1.2	17.1	8.4	7.7	140	89	

Table 38. Indian Lake chemical water quality parameter data collected in deep basin #1 (October 13, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
1.0	1.2	<0.10	0.031	<0.010	0.042	<0.10	<0.10	14	16	41

Table 39. Indian Lake physical water quality parameter data collected in deep basin #2 (October 13, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	18.9	8.0	7.7	139	89	1.1
0.5	18.8	7.9	7.5	139	89	
1.0	18.8	7.9	7.5	139	89	
1.5	18.8	7.8	7.5	139	89	
2.0	18.8	8.0	7.5	139	89	
2.5	18.8	8.0	7.5	139	89	
3.0	18.7	7.9	7.5	139	89	
3.5	18.7	7.9	7.5	139	89	
4.0	18.7	7.7	7.5	139	89	
4.5	18.5	7.6	7.5	139	89	
5.0	18.5	7.5	7.5	139	89	

Table 40. Indian Lake chemical water quality parameter data collected in deep basin #2 (October 13, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	1.1	<0.10	0.037	<0.010	0.037	<0.10	<0.10	14	15	42
2.5	0.5	<0.10	0.036	<0.010	0.030	<0.10	<0.10	14		42
5.1	<0.5	<0.10	0.031	<0.010	0.026	<0.10	<0.10	14		37

Table 41. Indian Lake physical water quality parameter data collected in deep basin #3 (October 13, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	18.4	8.7	7.7	139	89	1.4
0.5	18.4	7.2	7.5	139	89	
1.0	18.4	7.2	7.5	139	89	
1.5	18.4	7.2	7.5	139	89	
2.0	18.3	7.2	7.4	139	89	
2.5	18.3	7.2	7.4	139	89	
3.0	18.3	7.1	7.4	139	89	
3.5	18.3	7.1	7.4	139	89	
4.0	18.3	7.1	7.4	139	89	
4.5	18.3	7.1	7.4	139	89	
5.0	18.3	7.1	7.4	139	89	
5.5	18.3	7.1	7.4	139	89	
6.0	18.3	7.1	7.4	139	89	
6.5	18.3	7.1	7.4	139	89	
7.0	18.3	7.0	7.4	139	89	

Table 42. Indian Lake chemical water quality parameter data collected in deep basin #3 (October 13, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.6	<0.10	0.031	<0.010	0.050	<0.10	<0.10	13	21	41
4.0	0.6	<0.10	0.043	<0.010	0.045	<0.10	<0.10	14		41
7.7	0.8	<0.10	0.041	0.013	0.058	<0.10	<0.10	14		38

Table 43. Indian Lake physical water quality parameter data collected in deep basin #4 (October 13, 2022).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (m)
0	19.1	7.9	7.8	139	89	1.0
0.5	19.1	7.3	7.5	139	89	
1.0	19.1	7.1	7.5	139	89	
1.5	19.1	6.9	7.4	139	89	
2.0	18.8	6.8	7.4	139	89	
2.5	18.8	6.8	7.4	139	89	
3.0	18.8	6.8	7.4	139	89	
3.5	18.8	6.7	7.4	139	89	
4.0	18.8	6.6	7.4	139	89	
4.5	18.8	6.6	7.4	139	89	
5.0	18.8	6.6	7.4	139	89	
5.5	18.8	6.6	7.4	139	89	
6.0	18.8	6.6	7.4	139	89	
6.5	18.8	6.6	7.4	139	89	
7.0	18.8	6.6	7.4	139	89	
7.5	18.8	6.6	7.4	139	89	
8.0	18.8	6.6	7.4	139	89	
8.5	18.8	6.6	7.4	139	89	

Table 44. Indian Lake chemical water quality parameter data collected in deep basin #4 (October 13, 2022).

Depth (m)	TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	DIC (mg/L)	Chl-a (µg/L)	Talk (mg/L)
0	0.8	<0.10	0.037	<0.010	0.070	<0.10	<0.10	12	16	42
5.0	0.8	<0.10	0.044	<0.010	0.079	<0.10	<0.10	14		41
9.5	0.8	<0.10	0.039	<0.010	0.078	<0.10	<0.10	14		37

Table 45. Post LFA March descriptive statistics for Indian Lake water quality parameters (March 2022).

Water Quality Parameter	Year 1 March, 2022 Means ± SD
Water temp (°C)	7.4±0.3
pH (S.U.)	7.8±0.1
Dissolved oxygen (mg/L)	11.7±0.9
Conductivity (mS/cm)	160±41
Total dissolved solids (mg/L)	109±24
Secchi transparency (m)	0.7±1.0
Chlorophyll-a (µg/L)	7.8±1.5
Total Kjeldahl nitrogen (mg/L)	0.8±0.2
Total inorganic nitrogen (mg/L)	0.192±0.0
Ammonia nitrogen (mg/L)	0.192±0.0
Nitrate nitrogen (mg/L)	0.100±0.0
Nitrite nitrogen (mg/L)	0.100±0.0
Total phosphorus (mg/L)	0.037±0.0
Ortho-Phosphorus (mg/L)	0.023±0.0
Dissolved inorganic carbon (mg/L)	4.2±0.8

Table 46. Pre and Post LFA descriptive statistics for Indian Lake water quality parameters (August 16, 2021 and August 31, 2022).

Parameter	Baseline August 16, 2021 Means ± SD	Year 1 August 31, 2022 Means ± SD
Water temp (°C)	24.7±4.2	27.2±0.3
pH (S.U.)	7.7±0.5	7.8±0.3
Dissolved oxygen (mg/L)	5.7±3.0	7.4±1.0
Conductivity (mS/cm)	155±14	137±0.8
Total dissolved solids (mg/L)	99±7.8	88±0.6
Secchi transparency (m)	0.9±0.2	0.9±0.2
Chlorophyll-a (µg/L)	9.5±1.9	16±0.8
Total Kjeldahl nitrogen (mg/L)	4.1±6.5	0.9±0.2
Total inorganic nitrogen (mg/L)	0.413±0.6	0.121±0.0
Ammonia nitrogen (mg/L)	0.413±0.0	0.121±0.0
Nitrate nitrogen (mg/L)	0.100±0.0	0.100±0.0
Nitrite nitrogen (mg/L)	0.100±0.0	0.100±0.0
Total phosphorus (mg/L)	0.096±0.1	0.048±0.1
Ortho-Phosphorus (mg/L)	0.052±0.1	0.013±0.0
Dissolved inorganic carbon (mg/L)	9.6±1.2	0.7±0.0

Table 47. Pre and Post LFA descriptive statistics for Indian Lake water quality parameters (October 22, 2021 and October 13, 2022).

Parameter	Baseline October 22, 2021 Means ± SD	Year 1 October 13, 2022 Means ± SD
Water temp (°C)	18.0±0.7	18.5±0.5
pH (S.U.)	7.6±0.1	7.5±0.1
Dissolved oxygen (mg/L)	6.0±1.7	7.3±0.6
Conductivity (mS/cm)	213±29	139±0.2
Total dissolved solids (mg/L)	135±19	89±0.1
Secchi transparency (m)	0.2±0.0	1.1±0.2
Chlorophyll-a (μg/L)	3.0±0.0	17±2.7
Total Kjeldahl nitrogen (mg/L)	0.9±0.2	0.8±0.2
Total inorganic nitrogen (mg/L)	0.226±0.1	0.100±0.0
Ammonia nitrogen (mg/L)	0.226±0.1	0.100±0.0
Nitrate nitrogen (mg/L)	0.100±0.0	0.100±0.0
Nitrite nitrogen (mg/L)	0.100±0.0	0.100±0.0
Total phosphorus (mg/L)	0.055±0.1	0.037±0.0
Ortho-Phosphorus (mg/L)	0.010±0.0	0.010±0.0
Dissolved inorganic carbon (mg/L)	7.7±1.2	13.7±0.7

Indian Lake Tributaries and Drain Data

RLS identified a total of 5 key water courses (drains) that enter the lake at various points. RLS was able to collect a flowing water sample for Sites T1 and T2 during the August 16, 2021 sampling event; however, more samples will be needed over time and RLS may provide a Board member with sampling kits to send in to RLS as predicting rainfall timing can be difficult and the data relies on actively flowing waters. Determination of all nutrient sources is critical for reducing incoming loads over time. The drains had higher mean TKN and conductivity than the ambient lake conditions and thus are likely to allow for increases in these two parameters over time.

Table 48. Indian Lake physical water quality parameter data collected in drain site T1 (August 16, 2021).

Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)
23.8	7.7	8.1	318	204

Table 49. Indian Lake chemical water quality parameter data collected in drain site T1 (August 16, 2021).

TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	Talk (mg/L)
0.8	<0.10	0.044	<0.010	<0.010	<0.10	<0.10	61

Table 50. Indian Lake physical water quality parameter data collected in drain site T2 (August 16, 2021).

Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)
23.1	8.0	8.0	298	181

Table 51. Indian Lake chemical water quality parameter data collected in drain site T2 (August 16, 2021).

TKN (mg/L)	TIN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NH_3 (mg/L)	NO_2- (mg/L)	NO_3- (mg/L)	Talk (mg/L)
2.0	<0.10	0.020	<0.010	0.034	<0.10	<0.10	150

5.0 INDIAN LAKE CONCLUSIONS & FUTURE RECOMMENDATIONS

The following section discusses the overall efficacy of the LFA system with bioaugmentation and also the current and ongoing lake health challenges that should be addressed through the indicated Best Management Practices (BMP's). Some of the discussed BMP's are more critical than others and this is clarified based on need.

5.1 Indian Lake LFA Efficacy

The LFA system in Indian Lake has resulted in significant water quality improvements over the past year. The data collected to date were analyzed for means and standard deviations and also for statistical significance using an independent samples *t* test of significance. Based on these analyses, the following conclusions can be made:

1. The mean Indian Lake water temperatures have slightly increased in August and October of each year due to LFA, but this finding is statistically insignificant.
2. The mean Indian Lake pH has increased in August but declined in October after LFA, but this finding is statistically insignificant.
3. The mean Indian Lake dissolved oxygen concentration has increased in both August and October after LFA and this result is significant.
4. The mean Indian Lake specific conductivity has declined in both August and October after LFA, and this result is statistically significant.
5. The mean Indian Lake total dissolved solids have declined in both August and October after LFA, and this result is statistically significant.
6. The mean Indian Lake Secchi transparency remained similar in August but significantly increased in October after LFA.
7. The mean Indian Lake chlorophyll-a concentration increased in both August and October after LFA, and this result is statistically significant.
8. The mean Indian Lake total Kjeldahl nitrogen declined in both August and October after LFA, but this result is statistically insignificant.
9. The mean Indian Lake total inorganic nitrogen declined in both August and October after LFA, and this result is statistically significant.
10. The mean Indian Lake ammonia nitrogen declined in both August and October after LFA, and this result is statistically significant.
11. The mean Indian Lake total phosphorus declined in both August and October after LFA, and this result is statistically significant.
12. The mean Indian Lake ortho-phosphorus declined in both August and October after LFA, and this result is statistically significant.

13. The mean Indian Lake dissolved inorganic carbon decreased in August but increased in October after LFA and this results is statistically significant.

Indian Lake 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. The high nutrients have also led to increased blue-green algal blooms that secrete toxins such as microcystins that can become a public and pet health hazard and result in lake advisories. These algae also reduce light to all 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 some nutrients such as nitrogen 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 in addition to LFA.

Improvements would include the assurance that all areas around the lake are vegetated at all times and with proper erosion stabilization techniques. 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.

Continued use of whole lake laminar flow aeration (LFA) is recommended for the lake basin to continuously mix the water and result in increased clarity, dissolved oxygen, and hopefully reduced algal blooms over time as well as reduced nutrients such as phosphorus and nitrogen as determined in 2022. 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 is recommended to increase breakdown of organic muck from constant decay of algal cells to reduce accumulation of organic matter in the lake and create a competitive environment for the microbes to reduce HAB's by resource limitation.

A professional limnologist and Certified Lake Professional from RLS should perform a GPS-guided whole-lake survey each summer to monitor the growth and distribution of all invasives and nuisance aquatic vegetation growth to determine if the goal of increasing submersed aquatic vegetation is occurring. RLS also recommends expanded testing of algal toxins to determine if toxins other than microcystins are a present threat.

A complete list of all current recommended lake restoration methods to significantly improve Indian Lake over time can be found in Table 52 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. RLS can provide approximate costs for each of these items upon request and would be available to accomplish them in 2023 and in future years if requested.

Table 52. List of Indian Lake proposed restoration methods with primary and secondary goals and locations for implementation.

Proposed Improvement Method	Primary Goal	Secondary Goal	Where to Implement
Laminar flow (LFA) aeration system	Increase DO, reduce blue-green algae, increase water clarity	Reduce nutrients in the water column and internal loading of TP	Entire lake as retrofitted
Bioaugmentation with beneficial microbes and enzymes	To create competition for HAB's by introducing favorable bacteria	To reduce HAB's over time	Entire lake via inlets
Algal monitoring & expanded toxin testing	To determine prevalence of HAB's and possible toxins	To determine if HAB's are declining with time	Lake sites as previously sampled for consistency
Erosion survey	Determine areas around the lake where erosion is contributing solids to lake	Reduce solids in lake and associated nutrients	Entire lake
Aquatic vegetation survey	Determine how much SAV is present and biodiversity	Determine total % cover each year to measure increases over time	Entire lake
Lake Water Quality Analyses as in 2021-2022	To generate trends in parameters with time and determine significant results from LFA	Determine if any changes are needed in the LFA system or bioaugmentation	N=4 lake basins as previously sampled.
Lake-Wide Septic Improvement Program	To determine areas of vulnerability and make recommendations for system improvements	To reduce nutrients to lake.	Entire lake shoreline
Drain CSA Monitoring and BMP Determination	Develop ongoing sampling protocol of drains and determine CSA's and make BMP recommendations upstream	To reduce nutrients and solids to the lake, especially during heavy storm events.	At the N=5 key drain sites and any TBD CSA's.

5.2 Aquatic Herbicides and Algaecides

The use of aquatic chemical herbicides is regulated by the state regulatory authority and requires a permit. Aquatic herbicides are generally applied via an airboat or skiff equipped with mixing tanks and drop hoses (Figure 29). 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 29. A boat used to apply aquatic herbicides in inland lakes (RLS).

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 only invasives as Indian lake currently lacks enough submersed aquatic vegetation. Algaecides should only be used on green filamentous algal blooms since many treatments can exacerbate blue-green algae blooms.

Aquatic herbicides should be used very sparingly in Indian Lake and should only be used on invasive species as a major ongoing goal is to significantly increase more SAV.

5.3 Indian Lake Beach Management Methods

The use of benthic barrier mats (Figure 30) or Weed Rollers (Figure 31) have been used to reduce weed growth in small areas such as in beach areas and around docks and also to create a muck-free swim area. 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 Indian Lake and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth if it becomes prevalent in future years.

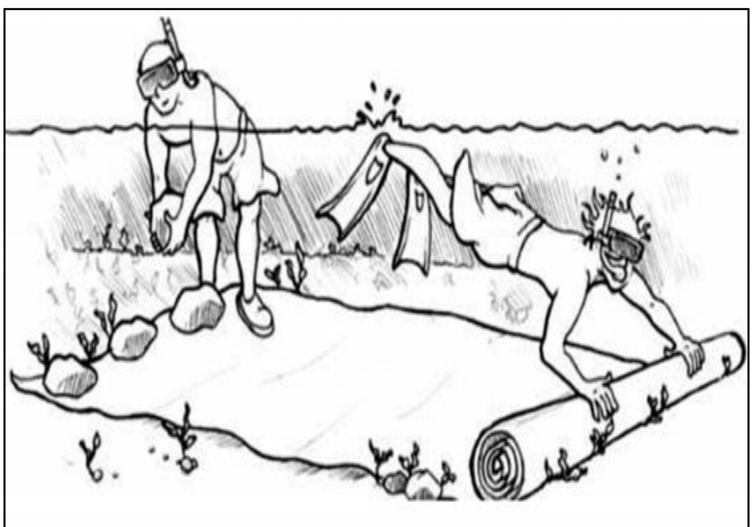


Figure 30. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.

Figure 31. A Weed Roller.

5.4 Nutrient Inactivation Consideration

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 Indian Lake 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) have demonstrated 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. If HAB's do not decline with P reduction from CSA's and septic systems, then a product such as Phoslock® may be combined with LFA.

5.5 Indian Lake Erosion Control and Shoreline Survey:

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, and vegetative cover.

Fetch, the distance across a body of water to produce a wind driven wave, also impacts the degree of possible erosion with longer fetches associated with larger wave heights and force. 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. The Indian Lake ecosystem is highly vulnerable to erosion.

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. RLS highly recommends a shoreline erosion survey be conducted by RLS certified erosion professionals in 2023.

5.6 Determination of Indian Lake Critical Source Areas (CSA's):

A large immediate watershed such will always allow for increased transport of pollutants, nutrients, or soils to a lake and is a major reason for the observed water clarity impairments of Indian Lake. Responsible management of Indian Lake water quality is dependent upon within-lake (i.e., LFA, bioaugmentation, etc.) and external (i.e., watershed BMP's) improvement methods. To address the sources of nutrient and sediment inputs to Indian Lake, recommendations for the minimization of non-point source pollutants to the lake are possible through determination of Critical Source Areas (CSA's).

Critical Source Areas (CSA's) are defined as the most probable pollutant source(s) and are 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, the Missouri Department of Natural Resources (MDNR), Natural Resources Conservation Services (NRCS), or other relevant stakeholders. These sites are 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.

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).

Excess nutrients have caused critical water quality issues such as the inundation of lakes with nutrients, decreases in water clarity and dissolved oxygen, increased HAB’s and 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).

5.7 Proper Maintenance of Indian Lake Septic Systems

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 Missouri 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 32).

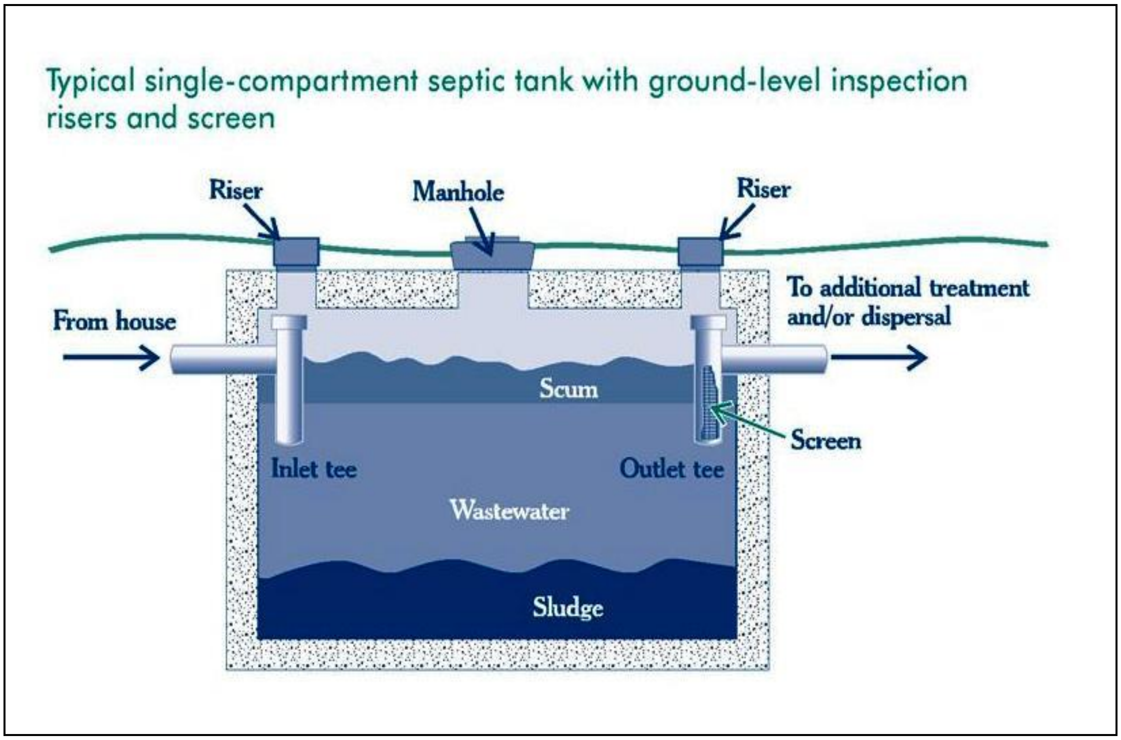


Figure 32. Diagram of essential septic tank components (US EPA).

On ideal soil types, microbes in the soil are able to decompose nutrients and reduce the probability of groundwater contamination. However, many lakes 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.

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.

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, 1980) 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 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 us 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 recommended that each septic tank be inspected every 1-2 years and pumped every 1-3 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.

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.

5.8 Best Management Practices (BMPs) for Indian Lake Riparians

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 Indian Lake ecosystem. 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 (such as many on Indian Lake)
2) Development of a vegetation buffer zone 25-30 feet from the land-water interface with approximately 60-80% of the shoreline bordered with vegetation
3) Limiting boat traffic and boat size to reduce wave energy and thus erosion potential
4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion
5) Using only native genotype plants (those native to 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 with native emergents 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 33 demonstrates a lakefront property with poor management of the shoreline.

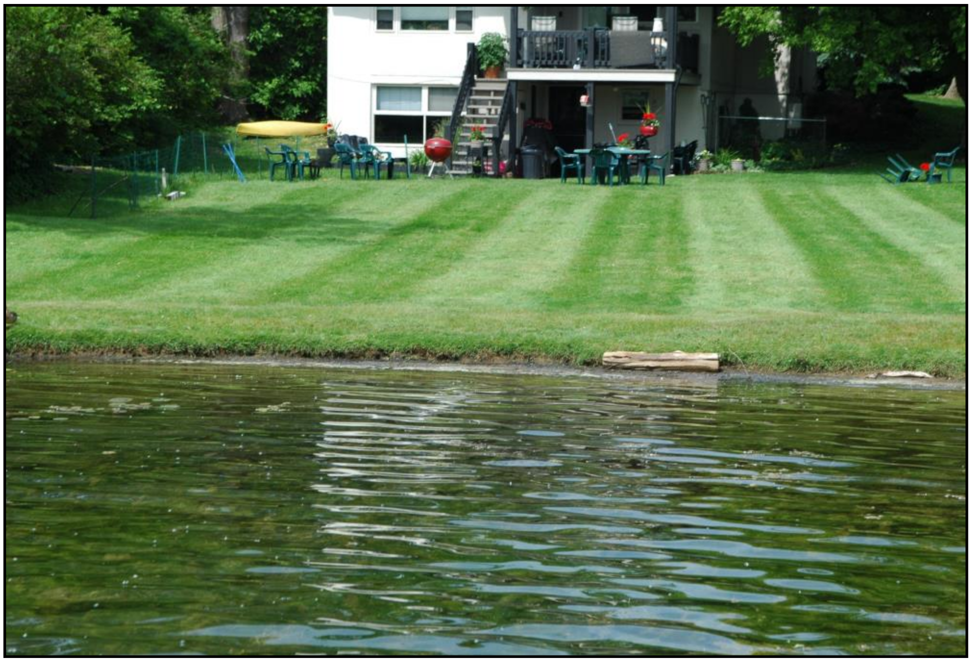


Figure 33. An example of poor shoreline management with no vegetation buffer present. ©RLS

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.

6.0 SCIENTIFIC REFERENCES

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.

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

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 macrophyte 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.

Dodds, W.K. 2002. Freshwater Ecology: Concepts and Environmental Applications. Academic Press. 569 pgs.

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.

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.

Granéli, W., M. Lindell, and L. Tranvik. Photo-oxidative production of dissolved inorganic carbon in lakes of different humic content. *Limnol. Oceanogr*. 41(4): 698-706.

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

Hutchinson, G.E. 1938. On the relation between the oxygen deficit and productivity and typology of lakes. Int. Rev. Ges-amten. *Hydrobiologia* 36:336-355.

Jermalowicz-Jones, J.L. 2009-2022. Evaluation studies of laminar flow aeration efficacy on various water quality parameters in Michigan inland lakes. *Unpublished data.*

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.

Ji, X., J.M.H. Verspagen, M. Stomp, and J. Huisman. 2017. Competition between cyanobacteria and green algae at low versus elevated CO2: who will win and why? *J. Exp. Bot* 68(14):3815-3828.

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.

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

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

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.

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.

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.

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.

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.

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.

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.

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.

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.

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. 1980. Movement of phosphorus from a septic system drain Field. *Water, Air, and Soil Pollution* 13:113-123.

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.

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

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.

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