Determination of the Seasonal Efficacy of Laminar Flow Aeration as a Treatment for Aquatic Vegetation Growth, Organic Matter Accumulation, and Sediment Nutrients in Indian Lake, Cass County, Michigan

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February, 2011

1.0 EXECUTIVE SUMMARY

Indian Lake is located in Sections 30 and 31 of Silver Creek Township (T.5S, R.16W) in Cass County, Michigan. The lake surface area is approximately 499 acres (Michigan Department of Natural Resources, 2001) and may be classified as a eutrophic aquatic ecosystem with a central deep basin and a moderate-sized littoral zone. Indian Lake has a maximum depth of 20.8 feet. The lake bottom consists primarily of sandy substrate, along with marl and organic matter deposits. Indian Lake has a lake perimeter of approximately 4.65 miles (Lakeshore Environmental, Inc., 2009) and a fetch of 1.41 miles and thus is capable of producing large waves during high wind events.

Sediments have accumulated within the lake in high amounts, especially at the north, northwest, and south areas of the lake. These areas, along with the shorelines along the west shore of the lake, have become laden with thick deposits of organic matter and detritus deposits from agricultural and riparian land use activities within the watershed which have deposited sediments from the land to these areas. There is an inlet at the north end of the lake and an outlet with a dam structure at the southeast portion of the lake. Significant loads of sediment enter the lake from the inlet during high rain events and this issue will be addressed as a component of the new watershed management program. The sediments in certain areas of the lake are thick and an imminent threat to the health of the Indian Lake ecosystem and impact recreation and property values. The Indian Lake Improvement Association has worked with Lakeshore Environmental, Inc. to assess the efficacy of a laminar flow aeration system on multiple water quality parameters such as dissolved oxygen, water column and sediment nutrients, sediment thickness, and aquatic vegetation and algal community composition. Previous research has demonstrated that aeration with the addition of microbes can reduce the quantity of organic matter in the sediments and result in increased water depth, increase dissolved oxygen levels, and help to control excessive algae and aquatic plant growth.

During June and October of 2010, these parameters were measured in three major areas of the lake with the use of various water sampling devices and SCUBA divers. A microbe-only region was established at the northern portion of the lake, followed by a control region (no microbes or aeration) at the west shore, and the diffuser plus microbe (treatment) section at the south basin which occupies nearly 88 acres of surface area. Sediment thickness in GPS marked areas of the control and microbe-only region did not significantly decline between June and October; however, there was an average decline of 1.3 feet of sediment in the diffuser plus microbe section. This data demonstrates that the diffusers work in synchrony with the microbes to effectively reduce sediment depth. The microbes feed on the organic matter and their metabolism is enhanced with oxygen supplied by the diffusers.

Fair comparisons of nutrient levels among seasons require that all parameters be measured again in June and October of 2011 and compared to the 2010 results. This data will then clarify which treatment differences are due to seasonality or laminar flow.

A reduction in the relative abundance of Eurasian Watermilfoil and blue-green algae in the diffuser plus microbes site was noted by the October sampling period. This is particularly convincing since no herbicide treatments occurred in the south basin during the 2010 study and thus declines in milfoil are not a result of herbicides.

Is recommended that the current bioaugmentation system which consists of laminar (non-turbulent) flow aeration and microbes (aerobic bacteria) be continued for the biodegradation of thick sediments in the South Basin. Sediment organic matter and nutrients should be regularly measured, but conclusions on the efficacy of bioaugmentation on reduction be made only after a substantial amount of sediment has been biodegraded since lower sediment layers likely contain high amounts of these sediment nutrients and organic content. Water quality data in the vicinity of the South Basin should also be collected to determine the efficacy of the laminar flow technology.

In addition to internal sediment loads, a comprehensive program for the minimization of non-point source (NPS) pollutants such as sediments to the lake is being developed and will follow in subsequent reports. A community involvement component for this portion of lake protection will be utilized to develop sustainable protection program for Indian Lake.

2.0 LAKE SEDIMENT BACKGROUND INFORMATION

2.1 Introductory Concepts

The following terms provide a more thorough understanding of the forthcoming lake management recommendations for sediment reduction within Indian Lake. A basic knowledge of sedimentary processes is necessary to understand the complexities involved and how management techniques are applicable to the current condition of Indian Lake. Although laboratory analyses are used to determine the composition and nutrient concentrations in the lake sediment, it must be realized that characteristics of Indian Lake sediments likely change with time due to dynamic wind and lake energy processes which redistribute sediments among the entire lake basin over time. The origin of the sediments at the South Basin cannot be determined as a single source, but rather a result of inputs from multiple areas around the lake. The majority of the sediments likely arise from watershed inputs due to agricultural activities and transport of sediments to the inlet which consequently enters the lake after a rain event. A study conducted on Austin Lake (Kalamazoo County, MI) by Straw et al., (1978) estimated that approximately 1 inch of sediment accumulates every two years throughout much of the lake and may be higher in the South Basin.

2.1.1 Lake Sediment Composition and Biogeochemistry

Lake sediments originate from external (allochthonus) and internal (autochthonous) sources within a lake system. External sources include materials such as pollen, terrestrial vegetation inputs, and organic matter that enter the lake from the drainage basin (immediate watershed) and metals and particulates from the atmosphere. The majority of those substances settle at the lake bottom, but may be resuspended during high energy events which may result in redistribution of the sediments. Internal sources of sediment are produced from the decay of organic materials such as aquatic vegetation, phytoplankton (algae), zooplankton, and other higher organisms. Lake sediments also contain a bulk density (mineral) component which consists of little organic matter that originates from the lake drainage basin. The less consolidated or flocculent component of sediment is derived from internal sources and is generally much higher in organic matter content than external sources. However, some external inputs from wetlands or marshes can also be high in organic matter content. In general, coarse sediments tend to accumulate near shoreline areas and finer silts deposit in the deeper basins. In lake systems with an abundant microbial community, the organic fraction is usually degraded as an energy source for the microbes, resulting in a reduction of the organic matter content of lake sediments.

The majority of sediment within the Indian Lake South Basin is highly organic (mean = 49.1%; Lakeshore Environmental, Inc., 2010). Most of these sediments are likely high in ammonia nitrogen (NH_3+) which is only converted to NO_3-, NO_2-, NO, and finally N_2 (gas) in the presence of oxygen. Nitrogen in the sediments is derived from multiple sources including the conversion of NO_2- to N_2 gas and referred to as denitrification. Nitrogen fixation is the conversion of N_2 gas to organic nitrogen which is usually conducted by cyanobacteria such as *Azotobacter* sp. Ammonification is the transformation of organic nitrogen to ammonia NH_3+. The release of NH_3+ under anoxic conditions follows the accumulation of NH_3+ in sediments where nitrification cannot occur and NH_3+ assimilation by anaerobic microbes declines.

Unfortunately, the sediments in the South Basin of Indian Lake are anoxic (lacking in oxygen) and this essential conversion cannot occur. The imminent accumulation of NH_3+ then results in toxicity to aquatic organisms (Camargo et al., 2005; Beutel, 2006). Beutel (2006) found that NH_3+ release rates in anoxic sediment were > 15 mg N m^{-2} day^{-1}, but were nearly absent in oxic (oxygenated) conditions. The majority of rooted aquatic plants are able to oxidize the rhizosphere and overcome anoxic conditions as a method of compromised growth (Bodelier et al., 1996). Additionally, the low oxygen levels at the sediment allow release of phosphorus into the water column and reduce the oxidation-reduction potential which results in the formation of black hydrogen sulfide (H_2S) sediments. A study conducted by Ramco in 1993 on Austin Lake (Kalamazoo County, MI), utilized a Biological Activity Reaction Test (BART) to determine the degree of activity by various bacteria such as Iron and Sulfate metabolism microbes, slime-forming bacteria, fluorescing pseudomonads, cyanobacteria, and total aerobes. Although the current study did not measure these parameters, it is useful information to assess the pre-existing microbial flora in anticipation of bioaugmentation methods. The result of their study indicated that the numbers of aggressive aerobic bacteria increased with an increase in aeration relative to the control region which was not aerated. The BART test indicated higher activity of sulfate-reducing bacteria, slime-forming bacteria, Iron-related bacteria, fluorescing pseudomonads, and total aerobes in the barge and tube-aerated sites than in the control (non-aerated) site. Such data suggests a strong synergy between bioaugmentation and aeration which may be adequately utilized to decompose organic matter in the sediments.

Phosphorus cycling occurs between the sediments and overlying water and is significantly influenced by wind action and resuspension of particulate matter in lakes (Krogerus and Ekholm, 2003). The sediments in the South Basin of Indian Lake contain a mean of 881 ± 157 mg kg^{-1} of total phosphorus, which is high. Thus, under anoxic conditions, release of phosphorus from lake sediments contributes to internal nutrient loading and can cause intense algal blooms and degradations in water quality. Phosphorus enters a lake system from the immediate watershed and from smaller particulate contributions from the atmosphere.

2.1.2 Lake Sediment Functions

The majority of inland lake sediment originates from glacial material that was deposited in lake basins nearly 8,000 years ago (Straw et al., 1978). Lake sediments may function as a rooting medium and source of nutrients for rooted aquatic vegetation. In addition, lake sediments are active components of the biogeochemical cycles present in aquatic ecosystems in that they recycle nutrients and organic matter via microbial metabolism. In general, lake sediments with coarse particle size are associated with higher water clarity, while those with smaller particle size such as silts and clays are usually correlated with increased turbidity. Sediments with large particle size may inhibit rooted aquatic plant growth through mechanical impedance, whereas sediments with smaller particle sizes tend to favor rooted vegetation growth unless those sediments are highly flocculent and rooting is not possible. Sediments may also receive oxygen from rooted aquatic vegetation plant roots. A study by Bodelier et al. (1996) determined that the emergent macrophyte, *Glyceria maxima* utilized root aerenchymatous tissue to oxidize an anoxic (no oxygen) portion of lake sediment which encouraged ammonia-oxidizing bacteria. In general, sediments in lake systems are highly heterogeneous and are derived from glacial and anthropogenic (man-induced) activities over time. Sediments have been a large source of siliceous diatoms and other macrobiota which form the food chain base for higher organisms that feed on benthic biota (life).

2.1.3 Impairments Caused by Lake Sediments

The accumulation of lake sediment in the Indian Lake South Basin causes limitations in navigational activities in near shore areas due to low freeboard which is the distance between the water surface at lake level and the beginning of the lake sediment. Boats may easily contact the lake bottom and resuspend sediments which results in degradation of water quality or damage to boat components. The release of high nutrient content from the sediments under low oxygen has negative impacts on aquatic biota and can lead to further degradation of water quality over time if not reduced. Most of the excess sediments within Indian Lake have entered the lake from the immediate watershed.

A watershed may be defined as an area of land that drains to a common point and is influenced by surface water and groundwater resources that are impacted from land use activities. In general, a large watershed of a particular lake possesses more opportunities for pollutants to enter the system and alter water quality and ecological communities. In addition, watersheds that contain abundant development and industrial sites are more vulnerable to water quality degradation since the fate of pollutant transport may be increased and negatively affect surface waters and groundwater. 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 one non-aerated lake which was attributed to substantial reduction of sediment loading from the surrounding catchment. The topography of the land surrounding a lake may make it vulnerable to nutrient inputs and consequential loading over time. The topography of the land and the morphometry of the lake dictate the ultimate fate transport of pollutants and nutrients into the lake from a particular watershed. 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.

3.0 INDIAN LAKE PHYSICAL & WATERSHED CHARACTERISTICS

3.1 The Indian Lake Basin

Indian Lake is located in Sections 30 and 31 of Silver Creek Township (T.5S, R.16W) in Cass County, Michigan (Figure 1). The lake surface area is approximately 499 acres (Michigan Department of Natural Resources, 2001) and may be classified as a eutrophic aquatic ecosystem with a central deep basin and a moderate-sized littoral zone. Indian Lake has a maximum depth of 20.8 feet. The lake bottom consists primarily of sandy substrate, along with marl and organic matter deposits. Indian Lake has a lake perimeter of approximately 4.65 miles (Lakeshore Environmental, Inc., 2009) and a fetch of 1.41 miles and is capable of producing large waves during high wind events.

The shorelines along with the shorelines along the west and south shores of the lake have become laden with thick deposits of organic matter and detritus deposits from agricultural land use activities within the watershed which that deposited sediments from the land. There is an inlet at the north end of the lake and an outlet with a dam structure at the southeast portion of the lake. The inlet will be a large focus of the forthcoming NPS reduction program for Indian Lake.

Figure 1. Location map of Indian Lake, Cass County, Michigan.

3.2 Indian Lake Extended and Immediate Watershed

Indian Lake is located within the St. Joseph River extended watershed which is approximately 2,998,400 acres (approximately 4,685 mi^2) in area and includes portions of 15 counties, including Berrien, Branch, Calhoun, Cass, Hillsdale, Kalamazoo, St. Joseph, and Van Buren in Michigan, and De Kalb, Elkhart, Kosciusko, Lagrange, Noble, St. Joseph, and Steuben in Indiana (Michigan Department of Environmental Quality, 2008). The extended watershed consists of primarily agricultural lands (> 50%), followed by 25-50% forested lands.

The Indian Lake immediate watershed is the area around the lake draining directly to the lake and is approximately 5,445 acres (8.51 mi^2) in size. Additionally, the immediate watershed is approximately 10.9 times larger than the size of the lake, which indicates the presence of a moderate-sized immediate watershed. There is also one other lake within the Indian Lake immediate watershed; Brush Lake, which lies in the southernmost portion of the immediate watershed.

3.3 Indian Lake Land Use

The predominant land use types surrounding Indian Lake (Figure 2) are agricultural, forested, open water/wetlands, open lands, and residential and commercial lands. Much of the forested land has been fragmented due to agricultural development, which is the dominant land use activity in the Indian Lake immediate watershed. The majority of the Indian Lake shoreline is developed with residential properties, and thus may have a significant impact on water quality. A shoreline development factor (SDF) is a ratio assigned to a lake to describe the degree of shoreline irregularity compared to the lake surface area. Lakes with a perfectly circular shoreline have an SDF of 1.0. Lakes with higher SDF values (> 1.0) are more irregular and may accommodate greater shoreline development. The SDF of Indian Lake is 1.5 and thus may contain substantially more development than a lake of similar surface area with a perfectly circular shoreline.

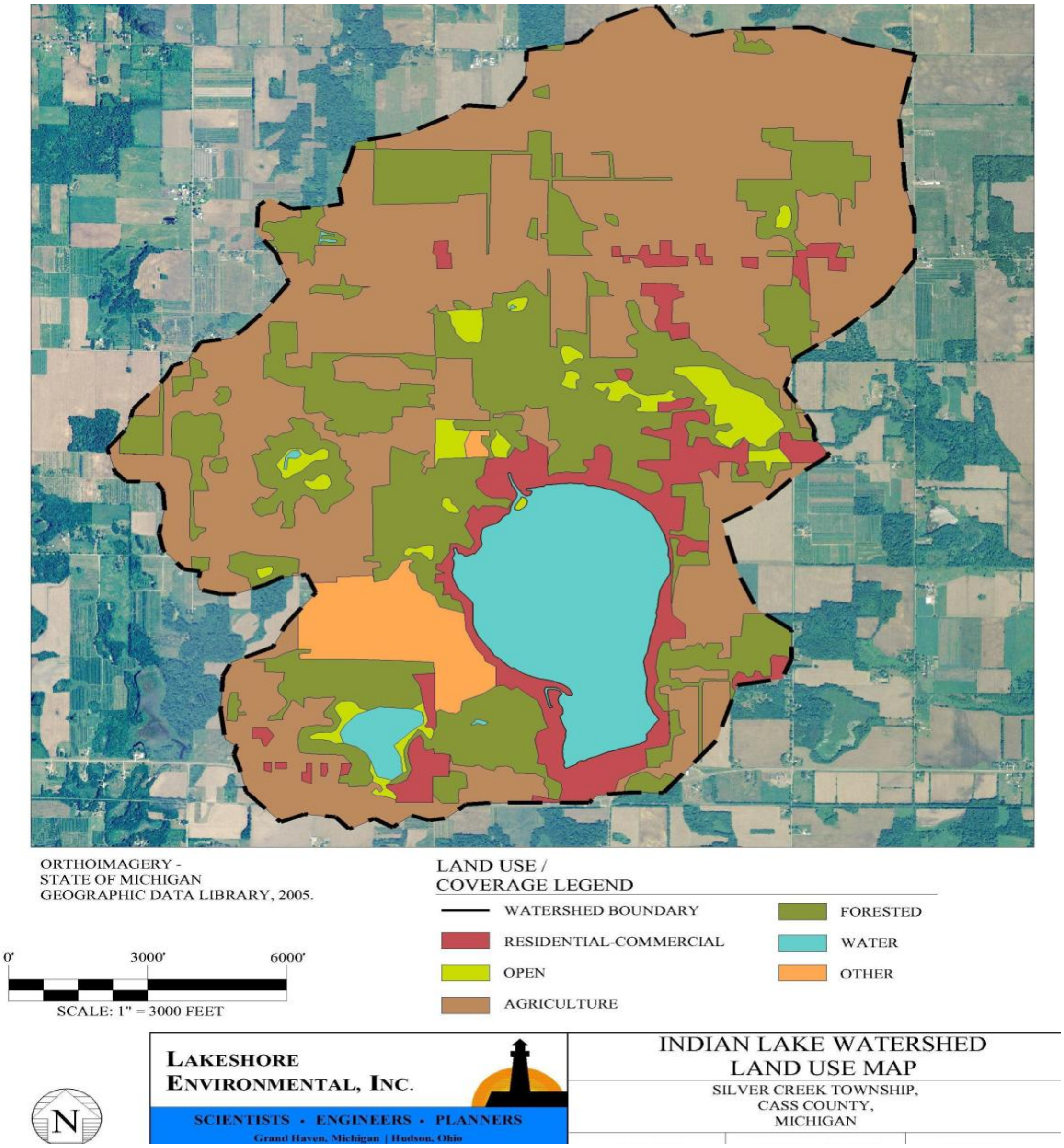

Figure 2. Photographic representation of land use types around Indian Lake, Cass County, Michigan.

3.4 Indian Lake Shoreline Soils

The five major soil series types immediately surrounding Indian Lake may have impacts on the water quality of the lake and may also dictate the particular land use activities associated with a location. Data from the United States Department of Agriculture and Natural Resources Conservation Service, (1977) was used to create Table 1 and demonstrates the precise soil types and locations around Indian Lake. There are five major classes of soils that are found in large quantities around the Indian Lake shoreline and include the Gilford Sandy Loams, Kalamazoo Loams, Oshtemo Sandy Loams, Udipsamments, Udorthents, and the Riddles Sandy Loams. All of the Loamy series are well drained soils and are thus not prone to saturation or ponding. The Udipsamments are very deep soils that are also well drained. Such soils are located at the southernmost region of Indian Lake. In areas around the lake with slopes > 6%, surface runoff [due to erosion] may be a factor in nutrient contributions from the land and thus every effort to implement low impact development (LID) techniques for construction of pervious surfaces close to the lake should be followed. In addition, land and sediment erosion is a considerable factor for water quality impairment in areas where land slopes exceed 6%. Thus, in many areas of the lake where slope ranges between 12-35%, erosion is a concern.

USDA-NRCS Soil Series	***Indian Lake Location***	***Prominent Soil Type Characteristics***
Gilford Sandy Loam	Majority of shoreline	Well drained soils; moderate to high permeability
Kalamazoo Loam; 12-18% Slope	East shore	Well drained soils; moderate to high permeability; erodible
Oshtemo Sandy Loam; 2-6% Slope;	Northwest shore	Well drained soils; moderate to high permeability
Udipsamments, Udorthents, nearly level	South shore	Very deep, well-drained soils; high permeability
Riddles Fine Sandy Loam; 18-35% slope	South shore	Well drained sands; moderate to rapid permeability; erodible

Table 1. Indian Lake Shoreline Soil Types (USDA-NRCS data, 1977).

4.0 INDIAN LAKE SOUTH BASIN WATER AND SEDIMENT DATA

The quality of water is highly variable among Michigan 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. 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 considered eutrophic due to its moderate water clarity, but elevated chlorophyll-*a*, water column, and sediment nutrients.

4.1 Water Quality Parameters

Water quality parameters such as dissolved oxygen, water temperature, conductivity, pH, oxidative reduction potential, water column total phosphorus and total kjeldahl nitrogen, sediment total phosphorus and organic matter all respond to changes in water quality and consequently serve as indicators of water quality change. These parameters are discussed below along with water quality data specific to Indian Lake (Tables 2-4 and 8-10). Sediment nutrients are generally more consistent with time, but can be several orders of magnitude higher than water column concentrations (Tables 5-7 and 11-13). Sediments are usually highly heterogeneous among sites and exhibit strong variability based on site-specific characteristics. Locations for water quality and sediment sampling are represented in Figure 3. Each parameter described above was measured at 10 sampling locations in each of the control, microbe-only, and diffuser plus microbe experimental sites on June 11, 2010 and October 16, 2010.

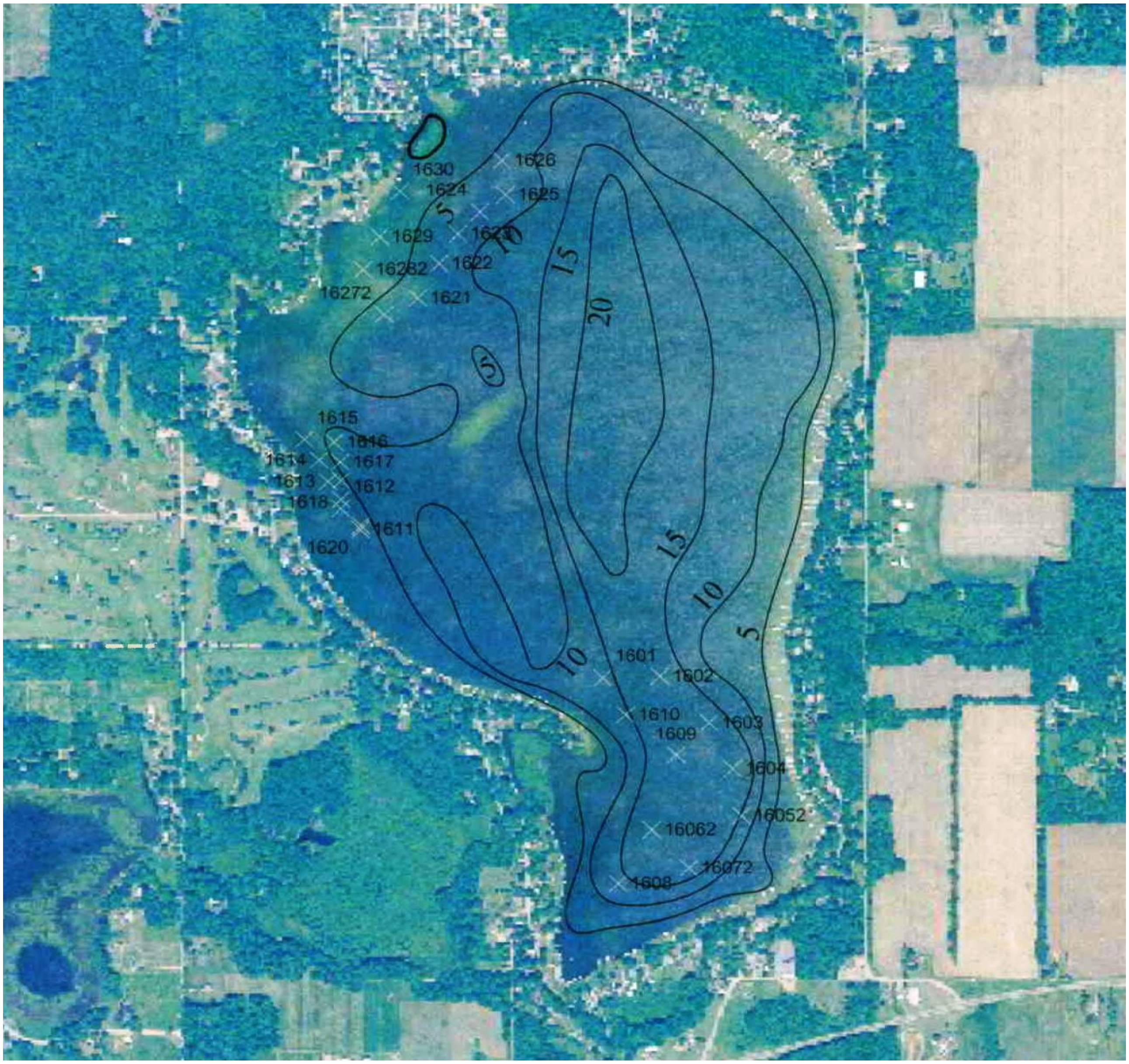

Figure 3. Sampling locations of all treatment sites-control (west shore), microbe-only (north shore), and diffuser plus microbe (south basin).

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^{-1} to sustain a healthy warm-water fishery. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. Dissolved oxygen is measured in milligrams per liter (mg L^{-1}) with the use of a dissolved oxygen meter and/or through the use of Winkler titration methods. The dissolved oxygen concentrations in Indian Lake were plentiful at depths during both sampling periods but declines sharply at the sediment interface. Values ranged between 7.4-9.1 mg L^{-1} of dissolved oxygen and were significantly different among sites. This may be due to the fact that the South Basin is shallow and is well-mixed with exposure to the atmosphere which increases these levels regardless of seasonality. During summer months, dissolved oxygen at the surface is generally higher due to the exchange of oxygen from the atmosphere with the lake surface, whereas dissolved oxygen is lower at the lake bottom due to decreased contact with the atmosphere and increased biochemical oxygen demand (BOD) from microbial activity. The observed decline in dissolved oxygen in sediments may cause increased release rates of phosphorus (P) from the lake bottom.

4.1.2 Water Temperature

The water temperature of lakes varies within and among seasons and is nearly uniform with depth under winter ice cover because lake mixing is reduced when waters are not exposed to wind. When the upper layers of water begin to warm in the spring after ice-off, the colder, dense layers remain at the bottom. This process results in a “thermocline” that acts as a transition layer between warmer and colder water layers. During the fall season, the upper layers begin to cool and become denser than the warmer layers, causing an inversion known as “fall turnover”. In general, shallow lakes such as

Indian Lake will not stratify while deeper lakes may experience single or multiple turnover cycles. Water temperature is measured in degrees Celsius (ºC) or degrees Fahrenheit (ºF) with the use of a submersible thermometer. The mid-November water temperatures of Austin Lake demonstrated the lack of a thermocline between the surface and a "middle depth", since the lake was sampled during a nearly isothermic period. Water temperatures were significantly lower in the South Basin during the June sampling period due to the greater depths. There were no significant differences in water temperatures among sites during the study.

4.1.3 Conductivity

Conductivity is a measure of the amount of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases as the amount of dissolved minerals and salts in a lake increases, and also increases as water temperature increases. Conductivity is measured in microsiemens per centimeter ($\mu S\ cm^{-1}$) with the use of a conductivity probe and meter. Conductivity values for Indian Lake ranged between 240-313 $\mu S\ cm^{-1}$. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) in 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. Values were higher in June for the microbe and diffuser sites but this cannot be attributed to diffuser effect since the system was not yet in operation during the June sampling.

4.1.4 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 $mg\ L^{-1}$ of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to higher release rates of P from lake sediments under low oxygen (anoxic) conditions. TP concentrations for all sampling sites (based on the n = 30 total sampling locations) in June 2010 ranged between 0.021-0.039 mg L^{-1} with the highest values at the diffuser site. TP concentrations from October 2010 ranged between 0.041-0.051 mg L^{-1} and were highest at the diffuser site due to high concentrations of organic matter in that region.

4.1.5 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3^+), and organic nitrogen forms in freshwater systems. Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e. burning of fossil fuels), wastewater sources from developed areas (i.e. runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen (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. Lakes with a mean TKN value of 0.66 mg L^{-1} may be classified as oligotrophic, those with a mean TKN value of 0.75 mg L^{-1} may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg L^{-1} may be classified as eutrophic. Indian Lake contains highly variable values for TKN (= 0.53 – 1.04 mg L^{-1}), with higher values noted during June and the highest recording of 1.04 mg L-1 noted for the diffuser site in October. High TKN values in the sediment pore water are also associated with high concentrations of organic matter.

4.1.6 pH

pH is the measure of acidity or basicity of water. The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 6.5 to 9.5. Acidic lakes (pH < 7) are rare in Michigan and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC). pH is measured with a pH electrode and pH-meter in Standard Units (S.U). The pH of Indian Lake water ranged from 8.1 – 9.0 S.U during the 2010 study. The pH of lakes is generally dependent upon submersed aquatic plant growth and underlying geological features. From a limnological perspective, Indian Lake is considered “slightly basic” on the pH scale.

4.1.7 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. Secchi disk transparency is measured in feet (ft) or meters (m) by lowering the disk over the shaded side of a boat around noon and taking the mean of the measurements of disappearance and reappearance of the disk. Elevated Secchi transparency readings allow for more aquatic plant and algae growth. Eutrophic systems generally have Secchi disk transparency measurements less than 7.5 feet due to turbidity caused by excessive planktonic algae growth. The Secchi transparency of Indian Lake ranged between 4.0-6.0 feet. This transparency is adequate to allow abundant growth of algae and aquatic plants in the majority of the littoral zone of the lake. 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. There were not significant differences in Secchi transparency among sites.

4.1.8 Oxidative Reduction Potential

The oxidation-reduction potential (E_h) of lake water describes the effectiveness of certain atoms to serve as potential oxidizers and indicates the degree of reductants present within the water. In general, the Eh level (measured in millivolts) decreases in anoxic (low oxygen) waters. Low E_h values are therefore indicative of reducing environments where sulfates (if present in the lake water) may be reduced to hydrogen sulfide (H_2S). Decomposition by microorganisms in the hypolimnion may also cause the E_h value to decline with depth during periods of thermal stratification. The E_h (ORP) values for Indian Lake ranged between 25.0-390.0 with lowest values recoded during June of 2010. All values collected at the sediment interface had negative values. The cause of the two observed negative mid-depth ORP values in unclear and warrants further investigation. There were no significant differences in ORP among sites.

4.1.9 Sediment Total Phosphorus

Sediment Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the lake sediment. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. The TP concentrations in lake sediments are often up to several times higher than those in the water column since phosphorus tends to adsorb onto sediment particles and sediments thus act as a “sink” or reservoir of nutrients. TP concentrations are usually higher at increased depths due to higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Sediment TP is measured in milligrams per kilogram (mg kg^{-1}) with EPA method 6010B. The mean sediment TP concentration for Indian Lake South Basin sediments was 881 ± 157 mg kg^{-1} in June and 939 ± 185 mg kg^{-1} in October. Mean values for the microbe-only site were 338 ± 209 mg kg^{-1} in June and 405 ±107 mg kg^{-1}in October. Mean values for the control region were 286 ±147 mg kg^{-1} in June and 241 ± 99 mg kg^{-1} in October. These values were substantially higher than ones previously reported for White Lake (Muskegon County, Michigan) in 2005 with a mean of 60.4 ± 18.6 mg kg^{-1}

(Jermalowicz-Jones, MS thesis, *unpublished data*). Values for the diffuser site are likely higher due to the high organic content and correlations are being assessed. A study by Krogerus and Ekholm (2003) measured the release rates of P from sediment in shallow, open agriculturally impacted lakes and found that the mean daily rate of gross sedimentation was 0.04-0.18 g m^{-2} day^{-1} of phosphorus.

4.1.10 Sediment Organic Matter

Organic matter (OM) contains a high amount of carbon which is derived from biota such as decayed plant and animal matter. Detritus is the term for all dead organic matter which is different than living organic and inorganic matter. OM may be autochthonous or allochthonous in nature where it originates from within the system or external to the system, respectively. Sediment OM is measured with the ASTM D2974 method and is usually expressed in a percentage (%) of total bulk volume. OM content was highest at the diffuser sites with a mean of 49.1 ± 9.4 % in June and 47.4 ± 7.7% in October. OM content in the microbe-only region was 18.5 ± 9.7 % in June and 23.2 ± 8.7 % in October. Values for the control region were 24.3 ± 6.2% in June and 20.7 ± 2.2% in October. It is critical that these values be compared to 2011 data in order to assess diffuser efficacy in the reduction of OM relative to potential seasonal effects. In contrast, sediments collected from similar depths in White Lake (Muskegon County, Michigan) had mean organic matter values of < 0.8% (Jermalowicz-Jones, MS thesis, *unpublished data*). Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present. There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then ferment to alcohol, CO_2, or CH_4. Second, proteins may be proteolyzed to amino acids, deaminated to NH_3+, nitrified to NO_2- or NO_3-, and denitrified to N_2 gas.

4.1.11 Aquatic Vegetation

Aquatic plants (macrophytes) are an essential lake component in that they serve as suitable habitat and food for macroinvertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (if in the rooted growth form), and contribute to the cycling of nutrients such as phosphorus and nitrogen upon decay. In addition, decaying aquatic plants contribute organic matter to lake sediments which further supports healthy growth of successive aquatic plant communities that are necessary for a balanced aquatic ecosystem. An overabundance of aquatic vegetation may cause organic matter to accumulate on the lake bottom faster than it can break down. Aquatic plants generally consist of rooted submersed, free-floating submersed, floating-leaved, and emergent growth forms. The emergent growth form (i.e. Cattails, Native Loosestrife) is critical for the diversity of insects onshore and for the health of nearby wetlands. Submersed aquatic plants can be rooted in the lake sediment (i.e. Milfoils, Pondweeds), or free-floating in the water column (i.e. Coontail). There is evidence that the diversity of submersed aquatic macrophytes can greatly influence the diversity of macroinvertebrates associated with aquatic plants of different structural morphologies (Parsons and Matthews, 1995). Therefore, it is possible that declines in the biodiversity and abundance of submersed aquatic plant species and associated macroinvertebrates could negatively impact the fisheries of inland lakes. Alternatively, the overabundance of aquatic vegetation can compromise recreational activities, aesthetics, and property values.

Exotic aquatic plants (macrophytes) are not native to a particular site, but are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially if the lake has public access sites), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem. Eurasian is an exotic aquatic macrophyte first documented in the United States in the 1880’s (Reed 1997), although other reports (Couch and

Nelson 1985) suggest it was first found in the 1940's. *M. spicatum* has since spread to thousands of inland lakes in various states through the use of boats and trailers, waterfowl, seed dispersal, and intentional introduction for fish habitat. *M. spicatum* is a major threat to the ecological balance of an aquatic ecosystem through causation of significant declines in favorable native vegetation within lakes (Madsen et al. 1991), and may limit light from native aquatic plant species (Newroth 1985; Aiken et al. 1979). Additionally, *M. spicatum* can alter the macroinvertebrate populations associated with native plants of certain structural architecture (Newroth 1985).

Aquatic plant species relative abundance was assessed along a 100 foot long radius around each diffuser site and around each of the individual sampling sites in the control and microbe-only region. The results of the plant surveys are displayed in Figures 4 and 6 for both October and June 2010 sampling dates.

4.1.12 Algal Genera Composition

Algal genera from composite water samples collected from all sampling sites on June 11, 2010 and October 16, 2010 were analyzed under a compound bright field microscope. The genera present included the Chlorophyta (green algae): *Chlorella* sp., *Gleocystis* sp., *Protococcus* sp., *Chroococcus* sp., and *Ulothrix* sp.; The Cyanophyta (blue-green algae): *Microcystis* sp., *Nostoc* sp., *Oscillatoria* sp., and *Gleocapsa* sp.; The Bascillariophyta (diatoms): *Navicula* sp., *Synedra* sp., and *Melosira* sp. Also present was the Chrysophyte, *Dinobryon* sp. Graphical representations of this data are shown in Figures 5 and 7 for both October and June 2010 sampling dates. The abundance of blue-green algae was lowest at the diffuser sites during both sampling periods.

Blue-green algae such as *Microcystis* sp and *Oscillatoria* sp. are capable of producing microtoxins (Rinehart et al. 1994) that can cause neurologic or hepatic (liver) dysfunction in animals or humans if ingested in large quantities. Blue-green blooms are usually visible as a bluish tinted surface “scum layer” on lake waters when they are a threat and these areas should be avoided when obvious surface layer blooms are present.

Water Column Descriptive Statistic	***Water Depth ft***	***Water Temp. °F***	***pH S.U.***	***ORP mV***	***Diss. Oxygen mg L***$^{-1}$	***Total Phos mg L***$^{-1}$	***Tot. Nitr. mg L***$^{-1}$	***Secchi Trans. ft***	***Conduc. µS cm***$^{-1}$
Mean ± SD	16.3 ± 2.7	60.8 ± 0.1	9.0 ± 0.4	384 ± 2.2	8.7 ± 0.4	0.051 ± 0.021	1.04 ± 0.96	5.2 ± 0.4	241 ± 0.4
Max	19.4	60.9	9.1	388	9.0	0.100	3.70	6.0	242
Min	10.0	60.6	8.8	382	8.0	0.033	0.50	4.5	241

Table 2. Indian Lake mean water quality parameter data collected over South Basin (**diffuser and microbe treatment site**) on October 16, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation.

Water Column Descriptive Statistic	***Water Depth ft***	***Water Temp. °F***	***pH S.U.***	***ORP mV***	***Diss. Oxygen mg L***$^{-1}$	***Total Phos mg L***$^{-1}$	***Tot. Nitr. mg L***$^{-1}$	***Secchi Trans. ft***	***Conduc. µS cm***$^{-1}$
Mean ± SD	6.95 ± 1.6	59.5 ± 0.4	8.1 ± 0.2	388 ± 1.0	9.1 ± 0.3	0.041 ± 0.025	0.78 ± 0.65	5.2 ± 0.4	241 ± 0.4
Max	9.9	60.3	8.7	389	9.5	0.110	2.60	6.0	242
Min	5.3	59.2	7.9	386	8.8	0.027	0.50	4.5	241

Table 3. Indian Lake mean water quality parameter data collected in the **microbe-only treatment site** on October 16, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation

Water Column Descriptive Statistic	*Water Depth ft*	*Water Temp. °F*	*pH S.U.*	*ORP mV*	*Diss. Oxygen mg L^{-1}*	*Total Phos mg L^{-1}*	*Tot. Nitr. mg L^{-1}*	*Secchi Trans. ft*	*Conduc. µS cm^{-1}*
Mean ± SD	5.9 ± 0.5	60.8 ± 0.1	8.7 ± 0.1	384 ± 3.0	8.9 ± 0.5	0.046 ± 0.037	0.53 ± 0.052	5.3 ± 0.5	240 ± 1.1
Max	6.7	60.9	8.7	390	9.5	0.150	0.63	6.0	241
Min	5.1	60.6	8.5	380	7.9	0.029	0.50	4.5	238

Table 4. Indian Lake mean water quality parameter data collected in the **control site** on October16, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation.

Sediment Descriptive Statistic	*Sediment Depth feet*	*Sediment TP mg kg^{-1}*	*Sediment Organic Matter %*
Mean ± SD	8.4 ± 1.1	939 ± 185	47.4 ± 7.7
Max	9.5	1,300	66
Min	6.0	620	34

Table 5. Indian Lake mean sediment parameter data collected over South Basin (**diffuser and microbe treatment site**) on October 16, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation.

Sediment Descriptive Statistic	***Sediment Depth feet***	***Sediment TP mg kg $^{-1}$***	***Sediment Organic Matter %***
Mean ± SD	5.6 ± 4.0	405 ± 107	23.2 ± 8.7
Max	10.0	600	44
Min	1.0	120	14

Table 6. Indian Lake mean sediment parameter data collected in the **microbe-only treatment site** on October 16, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation

Sediment Descriptive Statistic	***Sediment Depth feet***	***Sediment TP mg kg $^{-1}$***	***Sediment Organic Matter %***
Mean ± SD	8.1 ± 2.1	241 ± 99	20.7 ± 2.2
Max	10.0	510	28
Min	3.0	140	19

Table 7. Indian Lake mean sediment parameter data collected in the **control site** on October16, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation.

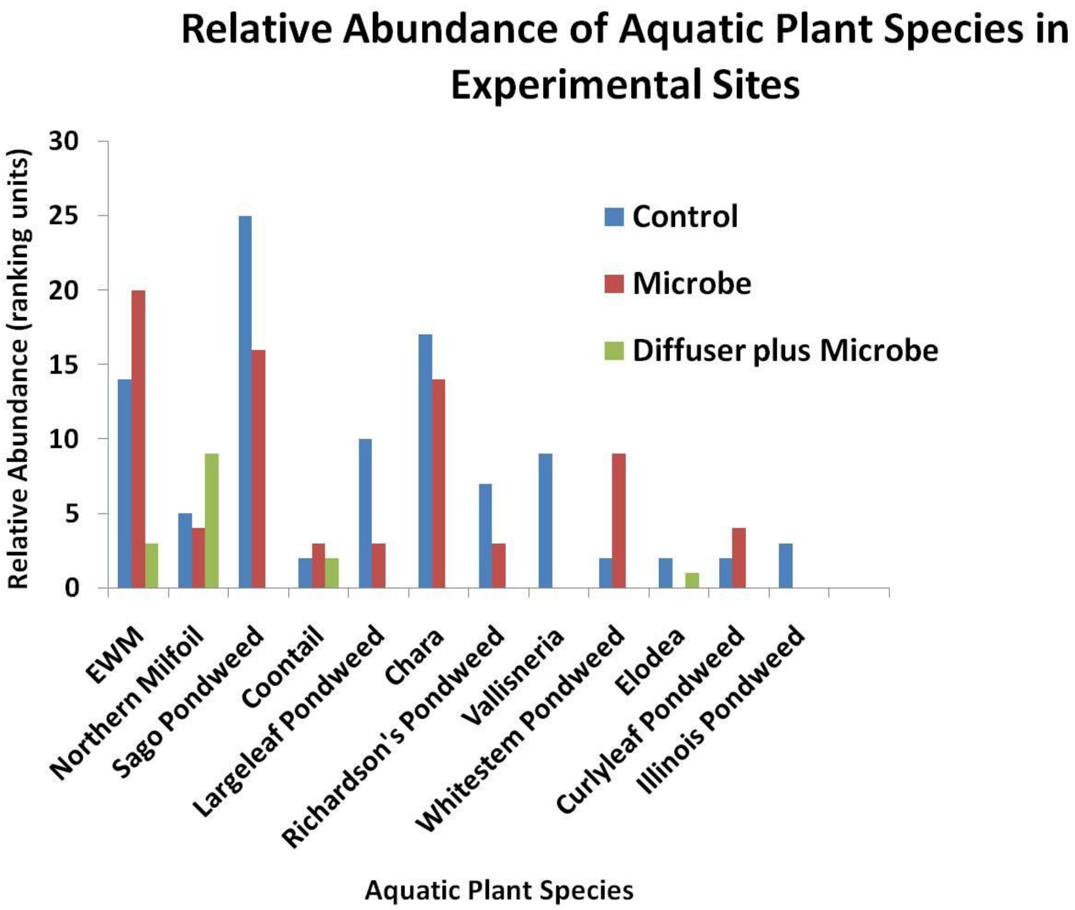

Figure 4. Graphical representation of the relative abundance of aquatic vegetation in Indian Lake South Basin experimental sites (October, 2010).

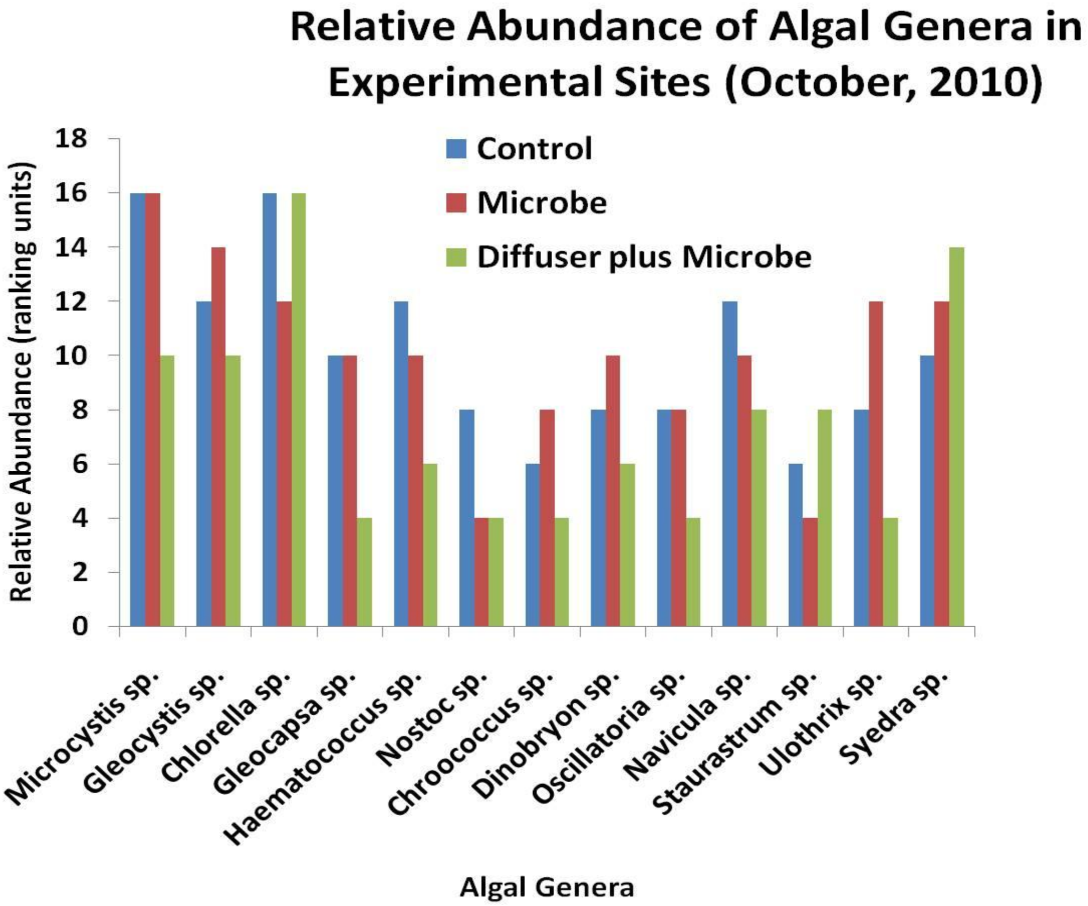

Figure 5. Graphical representation of the relative abundance of algal genera in Indian Lake South Basin experimental sites (October, 2010).

Water Column Descriptive Statistic	*Water Depth ft*	*Water Temp. °F*	*pH S.U.*	*ORP mV*	*Diss. Oxygen mg L^{-1}*	*Total Phos mg L^{-1}*	*Tot. Nitr. mg L^{-1}*	*Secchi Trans. ft*	*Conduc µS cm^{-1}*
Mean ± SD	16.3 ± 2.7	64.0 ± 5.3	8.5 ± 0.1	36.2 ± 6.4	7.4 ± 0.3	0.039 ± 0.021	0.948 ± 0.279	5.0 ± 0.2	313 ± 1.1
Max	19.4	73.2	8.6	41.4	7.9	0.076	1.40	5.0	315
Min	10.0	58.5	8.3	25	7.0	0.020	0.64	4.5	312

Table 8. Indian Lake mean water quality parameter data collected over South Basin (**diffuser and microbe treatment site**) on June 11, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation.

Water Column Descriptive Statistic	*Water Depth ft*	*Water Temp. °F*	*pH S.U.*	*ORP mV*	*Diss. Oxygen mg L^{-1}*	*Total Phos mg L^{-1}*	*Tot. Nitr. mg L^{-1}*	*Secchi Trans. ft*	*Conduc. µS cm^{-1}*
Mean ± SD	6.95 ± 1.6	76.6 ± 0.5	8.5 ± 0.1	45.8 ±4.7	8.1 ± 0.1	0.021 ± 0.006	0.97 ± 0.04	4.5 ± 0.4	313 ± 0.0
Max	9.9	77.2	8.7	50.0	8.3	0.030	1.00	5.0	313
Min	5.3	75.9	8.4	40.5	7.9	0.010	0.00	4.0	313

Table 9. Indian Lake mean water quality parameter data collected in the **microbe-only treatment site** on June 11, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation

Water Column Descriptive Statistic	*Water Depth ft*	*Water Temp. °F*	*pH S.U.*	*ORP mV*	*Diss. Oxygen mg L^{-1}*	*Total Phos mg L^{-1}*	*Tot. Nitr. mg L^{-1}*	*Secchi Trans. ft*	*Cond µS cm^{-1}*
Mean ± SD	5.9 ± 0.5	75.6 ± 0.5	8.6 ± 0.2	63.1 ± 13.8	7.9 ± 0.2	0.026 ± 0.006	0.82 ± 0.10	4.8 ± 0.3	240 ± 1.1
Max	6.7	76.1	8.7	78.1	7.9	0.040	0.98	5.0	241
Min	5.1	74.5	8.2	36.8	7.4	0.017	0.63	4.5	238

Table 10. Indian Lake mean water quality parameter data collected in the **control site** on June 11, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation.

Sediment Descriptive Statistic	*Sediment Depth feet*	*Sediment TP mg kg^{-1}*	*Sediment Organic Matter %*
Mean ± SD	9.7 ± 0.1	881 ± 157	49.1 ± 9.4
Max	10.0	1,000	69
Min	7.0	630	42

Table 11. Indian Lake mean sediment parameter data collected over South Basin (**diffuser and microbe treatment site**) on June 11, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation.

Sediment Descriptive Statistic	*Sediment Depth feet*	*Sediment TP mg kg $^{-1}$*	*Sediment Organic Matter %*
Mean ± SD	5.7 ± 4.0	338 ± 209	18.5 ± 9.7
Max	10.0	650	29
Min	1.0	23	7.6

Table 12. Indian Lake mean sediment parameter data collected in the **microbe-only treatment site** on June 11, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation

Sediment Descriptive Statistic	*Sediment Depth feet*	*Sediment TP mg kg $^{-1}$*	*Sediment Organic Matter %*
Mean ± SD	8.0 ± 2.1	286 ± 147	24.3 ± 6.2
Max	10.0	480	33
Min	3.0	110	14

Table 13. Indian Lake mean sediment parameter data collected in the **control site** on June 11, 2010. Means based on n=10 sampling locations per treatment site. SD denotes standard deviation.

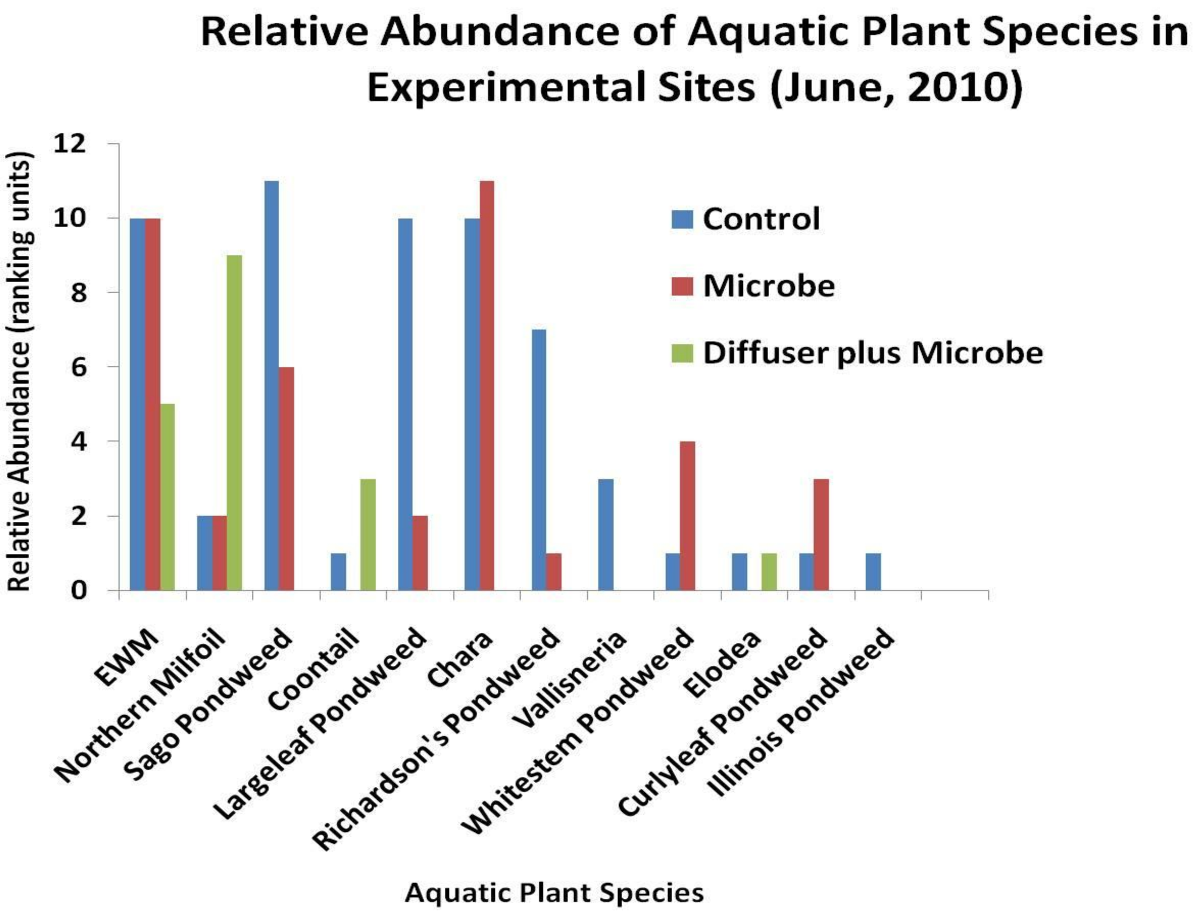

Figure 6. Graphical representation of the relative abundance of aquatic vegetation in Indian Lake South Basin experimental sites (June, 2010).

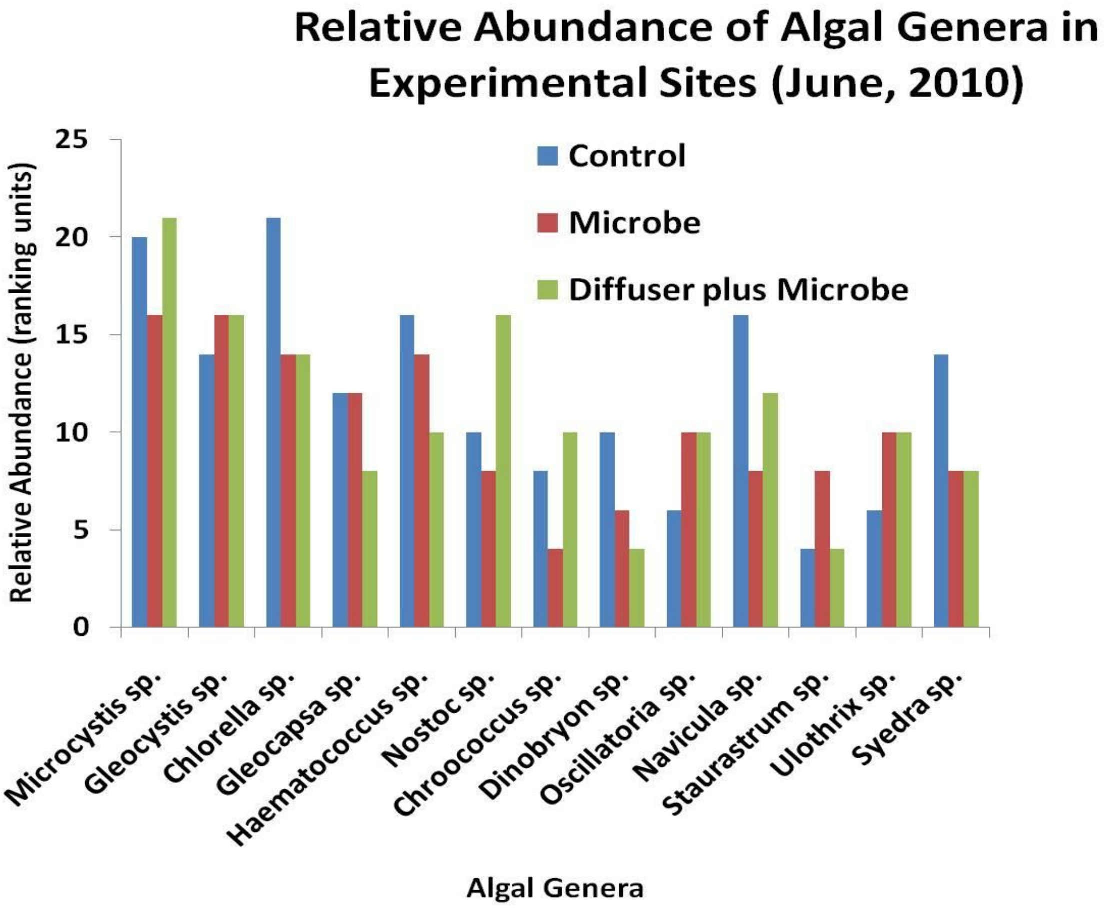

Figure 7. Graphical representation of the relative abundance of algal genera in Indian Lake South Basin experimental sites (June, 2010).

5.0 INDIAN LAKE SEDIMENTATION REDUCTION METHODS

The use of laminar flow aeration and implementation of a non-point source (NPS) pollution prevention program are recommended to reduce sediment inputs to Indian Lake through the control of beach and shoreline erosion and nutrient loading from the immediate watershed. The increased developmental pressures and usage of aquatic ecosystems necessitate inland lake management practices to restore balance within the Indian Lake watershed. Lake management components involve within-lake (basin) and around-lake (watershed) solutions to protect and restore complex aquatic ecosystems.

5.1 Laminar Flow Aeration

A laminar flow aeration system utilizes diffusers which are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help purge the lake water of benthic carbon dioxide (CO_2), which is a primary nutrient necessary aquatic plant photosynthetic growth and productivity and is also a byproduct of microbial metabolism. Other gasses such as H_2S are also purged from the sediments. In addition to the placement of the diffuser units, concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also implemented. Beutel (2006) found that lake oxygenation eliminates release of NH_3+ from sediments through oxygenation of the sediment-water interface. Allen (2009) demonstrated that NH_3+ oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry wt day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt day^{-1} in controls. Although this is a relatively new area of research, recent case studies have shown promise on the positive impacts of laminar flow aeration systems on aquatic ecosystem management with respect to organic matter degradation and resultant increase in water depth, and rooted aquatic plant management in eutrophic ecosystems (Lakeshore Environmental, Inc., 2010). Toetz (1981) found evidence of a decline in *Microcystis* algae (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. Their study was limited to one sediment core per lake and given the high degree of heterogeneous sediments in inland lakes may not have accurately represented the conditions present throughout much of the lake bottom. The philosophy and science behind the laminar flow aeration system is to reduce the organic matter layer in the sediment so that a significant amount of nutrient is removed from the sediments and excessive sediments are reduced to yield a greater water depth.

5.1.1 The Laminar Flow System

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

5.1.2 Benefits and Limitations of Laminar Flow Systems

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. The current study of Indian Lake by Lakeshore Environmental, Inc. indicated a significant reduction of organic sediments in bioaugmented/aerated regions, as well as a decline in the relative proportion of blue-green algae and the presence of the rooted, submersed, exotic aquatic plant, Eurasian Watermilfoil (*Myriophyllum spicatum*). A study by Turcotte et al. (1988) analyzed the impacts of bioaugmentation on the growth of *M. spicatum* and found that during two four-month studies, the growth and re-generation of this plant was reduced significantly with little change in external nutrient loading. Currently, it is unknown whether the reduction of organic matter for rooting medium or the availability of nutrients for sustained growth is the critical growth limitation factor and these possibilities are being researched. A reduction of *M. spicatum* is desirable for protection of native plant biodiversity, recreation, water quality, and reduction of nutrients such as nitrogen and phosphorus upon decay (Ogwada et al., 1984).

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

The Laminar Flow Aeration system has some limitations including the inability to degrade mineral sediments, the requirement of a constant Phase I electrical energy source to power the diffusers and unpredictable response by various species of rooted aquatic plants. In other systems installed within Michigan during 2009-2010, it was observed that Curly-Leaf Pondweed did not show a marked decline in biomass relative to *M. spicatum* (J. Tucci, *personal communication*). Thus, the main objective of laminar flow system use should be related primarily to sediment and water quality parameters and secondarily for aquatic plant control.

5.1.3 Design of Indian Lake South Basin Laminar Flow System

The laminar flow aeration design for the Indian Lake South Basin consists of eleven (12-inch diameter ceramic) aeration diffusers and one 7.5 Vane compressor (in a fiberglass cabinet with cooling fans), 1400 feet of PVC piping, 5,500 feet of self-sinking airline, and bacteria and enzymes. The system has been engineered or retrofitted to circulate the entire water volume of the South Basin (Figure 8).

Figure 8. Laminar Flow system design for Indian Lake South Basin designed by Clean-Flo (2010).

5.2 Indian Lake Watershed Management

Responsible management of Indian Lake water quality is dependent upon within-lake (i.e laminar flow, aquatic plant treatments, etc.) and external (i.e. watershed) improvement methods. The watershed surrounding the lake is moderate in size and contains high amounts of soil that eventually may enter the lake and become sediments. Based on recent sediment measurements, much of these soils are high in organic matter which requires adequate oxygen on the lake bottom and microbial populations to be biodegraded. The following recommendations should be included in a comprehensive program to reduce sediment loads to Indian Lake.

5.2.1 Possible Sources of Non-Point Source (NPS) Pollution to Indian Lake

Non-point source (NPS) pollutants are diffuse and have many potential sources to inland lakes such as the construction of impervious surfaces (i.e. paved roads and walkways, houses). If construction areas are less than one acre in size, they are not regulated for NPS pollution. Thus, it is recommended that construction activities on the lake shore be minimized and kept at least 100 feet from the shoreline to reduce surface runoff potential. This is especially important in areas around the east and south shores where erodible soils are prevalent. Wetland areas around Indian Lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat. Increased erosion may lead to increased turbidity and nutrient loading to the lake as well as high sedimentation rates. Seawalls should consist of emergent vegetation (cattails, reeds, tall grasses), and rip-rap (stone, rock), to provide nutrient filtration, soil stabilization, and favorable habitat for lakeshore organisms that are critical to the ecological balance of the Indian Lake ecosystem.

6.0 CONCLUSIONS AND FURTHER RECOMMENDATIONS

It is highly recommended that the members of the Indian Lake Improvement Association and the riparians around the lake continue to implement the laminar flow technology in the South Basin of the lake to ensure that lake bottom sediments receive adequate oxygen and additional microbes can biodegrade the excessive organic matter that is present in certain areas of the lake. Lake circulation patterns may transport problematic sediment loads to many areas throughout the lake over time and create issues with water quality, recreational activities, and even property values. Lakes are sizeable yet sensitive systems that have thresholds for every known environmental parameter and scientists are now beginning to discover that those thresholds vary considerably among lakes throughout the nation. If nutrient thresholds are exceeded, a water body such as Indian Lake may convert rapidly from a balanced ecosystem with aquatic vegetation to one that is dominated by toxin-producing blue-green algae (such as *Microcystis*). The objective of the laminar flow system is to prevent many thresholds (such as nutrient, dissolved oxygen, sedimentation) from being exceeded and resulting in consequential water quality degradation.

6.1 Recommendations for the Indian Lake Improvement Association, Silver Creek Township, and Indian Lake riparians

Every lake improvement project should offer solutions that are ecologically sound, practical, and economically feasible. Since funds for the suggested management improvements and oversight are limited, it is suggested that the current Special Assessment District (SAD) under P.A. 188 of 1954, as amended, be utilized to continuously fund the suggested improvements. The SAD should include all riparian properties around the Indian Lake and back lot properties which would derive benefit from the intended aeration improvements (i.e. those with deeded or dedicated access or easements). Under P.A. 188 of 1954, it is critical that the SAD be equitable to properties within each particular category.

Continued monitoring is continuously recommended to assess the water quality status for years after implementation to reassess water quality improvements from management techniques.

Scientists from Lakeshore Environmental, Inc. will be working with local township officials to develop a sustainable program for the detection of NPS pollutants within the immediate watershed of Indian Lake and assist the community with alternatives for Best Management Practice (BMP) implementation. This program will be critical for the future health of Indian Lake since a lack of NPS prevention would result in inundation of the existing laminar flow system and further water quality degradation. It may be desirable given the observed laminar flow benefits that the system be utilized throughout the entire lake. The 2011 data set will allow for that determination to assist in the long-term lake management goals of the Indian Lake Improvement Association.

Furthermore, a professional limnologist should perform regular assessments of the installed laminar flow system as an unbiased investigator. The use of GPS technology will allow the limnologist to repeatedly sample specific locations over time so that accurate assessments of the laminar flow system efficacy can be determined. Furthermore, an educational newsletter which contains pertinent information regarding the pilot project in the South Basin should continue to be distributed to all riparians around the lake so that the technology is understood and accepted as a new component of the Indian Lake ecosystem. The newsletter should contain educational tips for residents to recognize and prevent areas of nutrient and sediment transport to the lake as efforts to reduce non-point source pollutants and improve the water quality of Indian Lake.

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