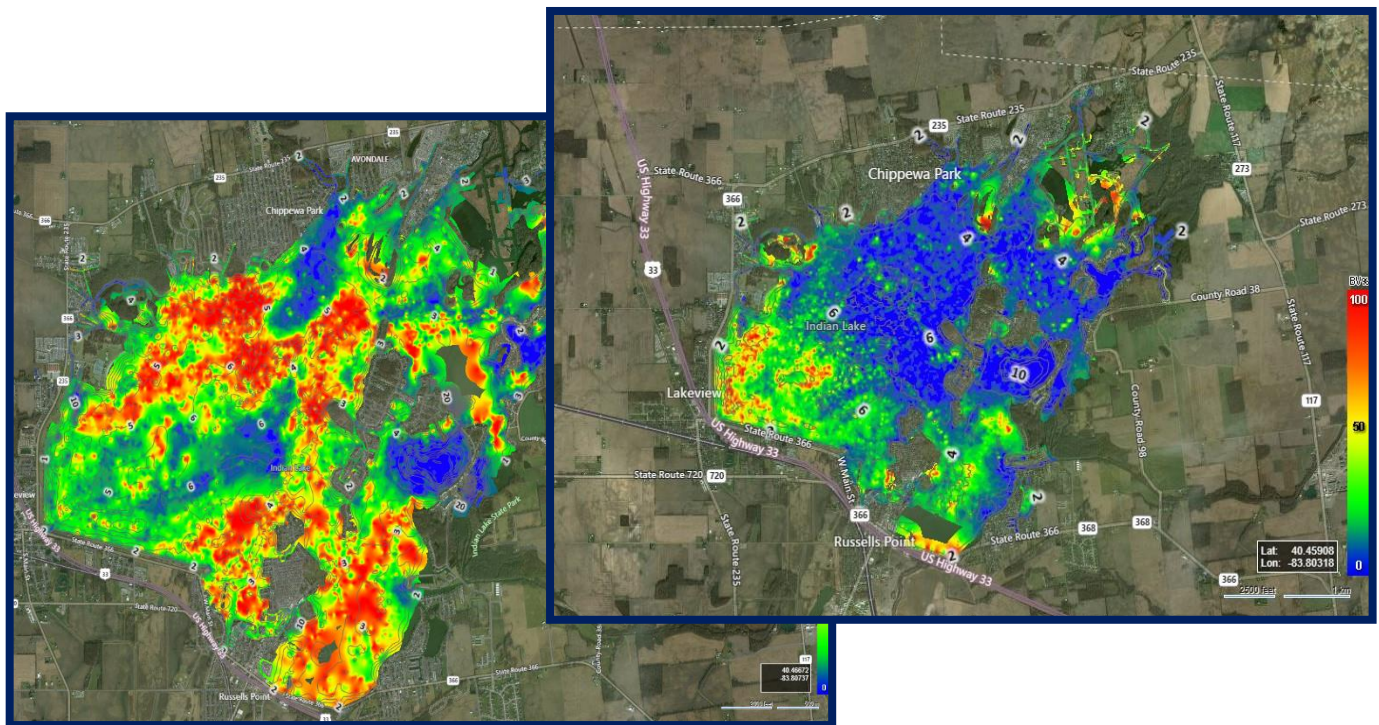




# Indian Lake 2023 Annual Progress Report Logan County, Ohio



Provided for: The Ohio Department of Natural Resources (ODNR)

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# Indian Lake 2023 Annual Progress Report Logan County, Ohio

October, 2023

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## 1.0 EXECUTIVE SUMMARY

In 2022, the Indian Lake Watershed Project (ILWP) with the support of the Logan County Board of Commissioners, requested that Restorative Lake Sciences (RLS) create a first comprehensive Indian Lake Management Plan. The purpose of this plan was to provide guidance on additional improvements to the current conditions of Indian Lake and allow for an adaptive process that was amended with restoration activities in 2023 while RLS worked closely with the Ohio Department of Natural Resources (ODNR) Department of State Parks and Watercraft and Aqua Doc as well as in collaboration with partners such as the ILWP. This continually amended plan will allow for the co-development of a local program for lake citizens to become involved in assisting with lake data collection and real-time monitoring of the lake. These elements would result in a sustainable lake that would be more resilient to negative impacts in an effort to improve the current hyper-eutrophic condition for a more ecologically balanced lake.

### *Indian Lake Physical Characteristics:*

Indian Lake is located in Logan County and is a man-made impoundment or reservoir. The lake is comprised of 5,104 acres (RLS, 2022). The lake has a dam spillway located in the south region which drains into the Great Miami River. There are five areas of water influx to the lake which include the North Fork of the Upper Great Miami River, South Fork of the Upper Great Miami River, Cherokee Mans Run, Blackhawk Creek, and Van Horn Creek. The mean depth of the lake is approximately 4.5 feet, and the maximum depth is approximately 16.0 feet (RLS, 2022 bathymetric scan data). The lake has a shoreline length of 41.2 miles without the islands and 67.9 miles including the islands. The lake possesses numerous islands and canals.

Indian Lake has an approximate water volume of 20,686.24 acre-feet (RLS, 2022 bathymetric data). The water volume previously determined by the Ohio EPA in 1973, was approximately 46,280 acre-feet (US EPA National Eutrophication Survey, 1973). Thus, the water volume of Indian Lake has significantly declined (~45%) likely due to excessive siltation as evidenced by recently collected total suspended solids data and changes in bathymetric lake depth contours. The mean depth reported by the Ohio EPA was 7.5 feet in 1973. Thus, the mean depth has declined by 3.0 feet as of 2022.

Indian Lake is identified as a drainage lake since tributaries entering the lake contribute significant water quantities. The Ohio EPA estimated that the mean hydraulic retention time was approximately 275 days. This is the approximate amount of time that water remains in Indian Lake. Water flows from the dam Spillway to the Great Miami River and then into the Ohio River and Mississippi River prior to exiting at the Gulf of Mexico.

There are 447 publicly owned lakes in the State of Ohio (Ohio DNR, 1980). The Ohio EPA determined that 16.6% of all assessed lakes and 60.3% of all assessed lakes were considered hyper-eutrophic and eutrophic, respectively (Ohio Water Resource Inventory, 1996). Only three lakes (0.7% of total lakes) were found to be over 5,000 acres in the State of Ohio. The 1996 report also mentions Indian Lake is an Ohio DNR canal lake as well as present within an agricultural watershed. Furthermore, all state waters are protected as potential public water supplies. For this reason, protection of Indian Lake water quality with focus on reducing toxic cyanobacteria is critical for protection of human health as well as ecological balance.

Indian Lake is a targeted lake by the Ohio EPA for non-point source pollution and thus restoration of Indian Lake must extend beyond removal of invasive species such as Eurasian Watermilfoil.

A detailed study of Indian Lake by the Ohio EPA in 1973 made the following conclusions:

1. The lake is eutrophic (now classified as hyper-eutrophic)
2. Macrophytes (aquatic plants) were common in nearshore areas only
3. Algal blooms occurred as late as October
4. The lake was phosphorus-limited in May and August and nitrogen-limited in October
5. Septic systems were estimated to contribute only 4.2% of nutrients reaching the lake
6. Major lake pollution sources were attributed to over-development and sewage bypassing during sewer overflows (Younger, 1975).
7. Approximately 94% of total phosphorus inputs to Indian Lake are from nonpoint pollution sources (NPS)
8. The tributaries contributed 89.6% of total phosphorus loads to Indian Lake in 1973 but the phosphorus losses to the Great Miami River at the outlet were higher.

### ***2023 Indian Lake Aquatic Vegetation Data:***

The ODNR began monitoring the lake conditions which included water temperature, clarity, color, and the presence of all aquatic vegetation beginning February 2, 2023 with additional evaluations on Meach 8, 2023, March 15, 2023, March 22, 2023, March 29, 2023, April 5, 2023 and April 16, 2023. Water clarity ranged from 6 inches to 2 feet and water temperatures ranged from 37-58°F. The last evaluation preceded the lake treatments that required water temperatures of at least 55°F for optimum efficacy.

Based on the 2023 whole-lake aquatic vegetation surveys in April and July, Indian Lake contained a total of four invasive aquatic plant species including approximately 1,100 acres of Eurasian Watermilfoil (*Myriophyllum spicatum*) and three and twelve locations where the invasive emergent aquatic plants Common Reed (*Phragmites australis*) and Purple Loosestrife (*Lythrum salicaria*) were found, respectively. In 2022, there were approximately 1,900 acres of invasive watermilfoil. The April, 2023 survey found approximately 1,821 Acres of invasive submersed Curly-leaf Pondweed (*Potamogeton crispus*). The July, 2023 survey determined the presence of less than 1 acre of Curly-leaf Pondweed and approximately 20.7 acres of Eurasian Watermilfoil.

Mechanical harvesting by the ODNR began on April 27, 2023 to remove dense areas of Curly-leaf Pondweed where milfoil was not present. The goal was to remove as much Curly-leaf Pondweed as possible to avoid additional herbicide treatment and to remove the plants prior to turion formation to reduce future colorizations. Care was taken to avoid cutting untreated milfoil to avoid fragmentation. The targeted ProcettaCOR® systemic aquatic herbicide treatments began from Aqua Doc on May 10, 2023 when weather conditions were ideal and were divided into zones to allow for slow decay of the plants and prevent dissolved oxygen depletion in the water column. This approach allowed for staggered application of harvesting in areas of dense Curly-leaf Pondweed while other areas of Eurasian Watermilfoil were treated and allowed to decay prior to being harvested of dead biomass. This process continued throughout the summer months with later removal of dense Coontail and Pithophora algae and floating debris by ODNR and contracted harvesters. This approach proved to be a great success with adequate native aquatic plant biomass remaining and algal blooms present but not the only form of primary production. Once the nutrients in the lake are reduced, much less algal growth is expected in the future.

RLS did find one specimen of a new invasive, Water Pennywort (*Hydrocotyle* sp.) in the lake basin and discarded the sample. No other plants of this genus were found during the whole-lake survey, but vigilance is needed for the spring, 2024 survey.

In addition to the GPS Point-Intercept lake survey, a whole-lake scan of the aquatic vegetation in Indian Lake was conducted on April 16-20, 2023 and July 17-20, 2023 with a WAAS-enabled Lowrance HDS 9® GPS equipped with variable frequency transducers. This data included sounding points which were then uploaded into a cloud software program to reveal maps that displayed depth contours, sediment hardness, and aquatic vegetation biovolume.

Results from the most recent July 16-20, 2023 aquatic vegetation survey revealed that Indian Lake contained 10 native submersed, 6 native floating-leaved, and 7 native emergent aquatic plant species, for a total of 23 native aquatic macrophyte species. This represents a highly diverse aquatic ecosystem with 2 more native species present than in 2022. The dominant native aquatic plants in the main part of the lake included the native rootless Coontail (79.4% of the sampling locations), and the submersed Sago Pondweed (20.5% of the sampling locations).

The 1973 Indian Lake EPA evaluation noted that macrophytes were common in nearshore shallow areas but did not mention the presence of macrophytes throughout the open waters. This may indicate that the previous state of Indian Lake was more dominated by algae and not as much by aquatic vegetation. Since the current quantities of aquatic vegetation are quite high, management of these plants must be highly selective and should not remove too much biomass as the lake may revert back to an algal-dominant state. Scheffer et *al.*, (2001) discussed alternate stable states and the difficulty associated with reverting a lake back to the more favorable and less turbid condition.

Additionally, the low water clarity is limiting the growth of lower-growing and favorable native submersed aquatic plants and thus Coontail, a native, should only be removed when dense.

The management of submersed invasive aquatic plants is necessary in Indian Lake due to accelerated growth, spread, and distribution. Additionally, highly selective management of the native rootless aquatic plant Coontail is also recommended in areas of “common” and “dense” level densities. It is imperative to realize that this plant does serve a critical function in the Indian Lake ecosystem in that it allows the lake to remain in a macrophyte (aquatic plant) dominated state, especially once the Eurasian Watermilfoil is significantly reduced. Removal of too much Coontail may allow for the lake to regress back to an algal-dominant state as it was in 1973. It is important not to remove too much Coontail due the following scientific findings:

1. Coontail reduces phytoplankton development (Mjelde and Faafng, 2003); however, *Microcystis* algae can have toxic effects on the ability of Coontail to tolerate biotic stress (Ujvarosi et *al.*, 2019).
2. Coontail improves water quality by reducing turbidity, total phosphorus, ammonia nitrogen, and chlorophyll-a with an ideal coverage of 20% (Yanran et *al.*, 2012).
3. Coontail is linked to an abundance of macroinvertebrates relative to EWM (Bogut et *al.*, 2010)

The August 2022 aquatic vegetation survey determined that approximately 3,560 acres of Coontail were present with 741 acres of dense Coontail. In April of 2023, there were approximately 278 acres of dense Coontail. The July 2023 survey determined a total of 2,950 acres of Coontail. The density of that Coontail will be determined in spring of 2024 for possible removal of dense areas only. A healthy and balanced aquatic ecosystem will always have at least 33% cover of native aquatic vegetation. Coontail currently occupies approximately 58% of the lake area and thus removal should be targeted to remove not less than 33% of the total cover. Significant reductions in Coontail have occurred since August of 2022.

With the substantial reduction in Eurasian Watermilfoil, removal of additional Coontail should be limited to allow for ample vegetation considering the low relative abundance of other native aquatic plants.

### ***Indian Lake Water Quality Data:***

A total of N=6 water quality sampling locations were sampled on August 19, 2022, April 22, 2023 and July 21, 2023 for the physical water quality parameters including water temperature, dissolved oxygen, pH, conductivity, total dissolved solids, and Secchi transparency. Chemical water quality parameters included total and ortho-phosphorus, total Kjeldahl and inorganic nitrogen, total suspended solids, and chlorophyll-*a*. A total of N=20 sediment samples were collected throughout the lake basin and analyzed for percentage of organic carbon. Table 1 below displays the mean August measurements and concentrations of various water quality parameters collected by the Ohio EPA in summer of 1973 and RLS in the summer of 2022-2023. Based on this data comparison, there has been a decline in total Kjeldahl nitrogen and chlorophyll-*a*, which is favorable. The spike in phosphorus in July of 2023 was likely due to decay of large quantities of submersed aquatic plants which was required for treatment.

Previously, RLS recommended that a whole-lake erosion survey be conducted as numerous areas in the canals and around the islands had significant erosion. This can contribute large amount of nutrients that fuel algal growth and also reduce water clarity. In addition, RLS recommends strategic dredging of very shallow areas where recreation and navigation are impaired.

Lastly, RLS recommends that the ILWP work to reduce all nutrient sources to Indian Lake by targeting detection of key Critical Source Areas (CSA's). This may require collaboration with multiple partners such as the Ohio DNR, Ohio EPA, and other parties. Reduction of nutrients entering the lake is imperative for improving the lake water quality over time.

**Table 1. Comparison of Mean August 1973 (EPA) and 2022-2023 (RLS) Indian Lake summer water quality parameters. The 2022-2023 data included means  $\pm$  standard deviations.**

Water Quality Parameter	2023 July Mean	2022 August Mean	1973 August Mean
Water Temp ( $^{\circ}$ C)	25.2 $\pm$ 0.4	24.2 $\pm$ 1.3	23.8
Dissolved Oxygen (mg/L)	8.7 $\pm$ 0.3	9.4 $\pm$ 3.9	8.5
pH (S.U.)	8.7 $\pm$ 0.3	8.4 $\pm$ 0.5	8.7
Conductivity (mS/cm)	343 $\pm$ 23	322 $\pm$ 37	368
Secchi depth (ft)	1.2 $\pm$ 0.2	1.8 $\pm$ 0.8	1.3
Total Phosphorus (mg/L)	0.213 $\pm$ 0.1	0.118 $\pm$ 0.1	0.128
Ortho-Phosphorus (mg/L)	0.032 $\pm$ 0.0	0.011 $\pm$ 0.0	0.015
Total Kjeldahl Nitrogen (mg/L)	1.8 $\pm$ 0.1	2.1 $\pm$ 0.6	2.6
Total Inorganic Nitrogen (mg/L)	0.138 $\pm$ 0.1	0.105 $\pm$ 0.014	0.382
Chlorophyll- <i>a</i> ( $\mu$ g/L)	56 $\pm$ 19	36.0 $\pm$ 11.0	105

In July of 2023, RLS determined that Indian Lake was not in a phosphorus-limited state with an N:P (nitrogen to phosphorus ratio) of 8.5 based on data collected on July 21, 2023. Eurasian Watermilfoil is able to tolerate very low light conditions and Coontail is able to float near the surface due to its growth form; therefore, these two aquatic plant species have adapted to the current low light penetration conditions. The result of the overabundance of algae is lower water clarity, more cyanobacteria, and fewer favorable low-growing native aquatic plants. Based on data collected by the ILWP, the quantities of nutrients exiting the lake are higher than current mean concentrations in the lake, which is favorable. However, the quantities of total suspended solids exiting the lake are much lower and thus the lake is functioning as a “sink” for sediments which reduces water volume and depth over time.

### ***Tributary Improvements: Reduction of NPS:***

The major tributaries entering Indian Lake include: 1.) The Van Horn tributary, 2.) Blackhawk tributary, 3.) North Fork of the Great Miami River, and 4.) South Fork of the Great Miami River. The ILWP has conducted numerous water quality sampling events in recent years and should continue to do so, given the high levels of nutrients such as phosphorus and nitrogen that are still entering the lake. RLS highly recommends determination of Critical Source Areas (CSAs) that contribute directly to these tributaries and thus contribute to water quality degradation in Indian Lake. A 9-element watershed plan is currently being created for the Indian Lake extended watershed and this should result in defined CSA's and mitigation strategies.

Proper maintenance of these tributaries is important for continued reduction of nutrient and sediment loads to the lake. More Best Management Practices related to nutrient and solid inputs are offered later in this management plan report.

### ***Future Restoration Recommendations:***

It is critical to realize that some improvements to Indian Lake have already occurred relative to 1973 lake conditions; however, the lake is still hyper-eutrophic and much more needs to be implemented. Some efforts such as reduction of invasive aquatic vegetation and removal of dense areas of nuisance Coontail will yield relatively quicker results than some other recommended improvements related to water quality. It is also important for the community to have realistic expectations for Indian Lake.

The lake will never be pristine, but the degree of hyper-eutrophy can be reduced over time to yield a lake that is balanced and acceptable for recreational, navigational uses, and for enhancement of property values.

RLS has made the following overall management recommendations for the future improvement of Indian Lake:

1. Continued highly selective spot-treatments with systemic herbicides (ProcellaCOR® and/or 2,4-D) for the control of invasive Eurasian Watermilfoil. The cost of granular 2,4-D at the required effective dose may be cost prohibitive relative to ProcellaCOR®.
2. Selective removal of only dense areas of Coontail and surface mats of *Pithophora* with the use of mechanical harvesters. Care should be taken to remove milfoil with systemic herbicides first before removal with harvesters in areas where milfoil coexists with Coontail. This will reduce the risk of further fragmentation.
3. Continued water quality monitoring of the lake in the N=6 basins by RLS and the four key tributaries and Spillway by the ILWP. More data is needed over time to generate accurate trend analyses which allow for determination of BMP and lake protection method efficacies.

4. Development of an Early Detection Rapid Response (EDRR) protocol for the lake to determine how the lake will respond to new incoming invasive species. Such a plan will prevent situations that require irrational reactivity and instead promote proactivity and faster access to mitigation methodologies. RLS can work collaboratively with the ODNR in 2024 to develop this protocol.
5. If permitted, consider implementation of boat washing stations at all entry sites where boats are launched on a regular basis. This will provide lake users with a tool to protect the lake from future invasions.
6. Selective dredging of the lake in the areas prioritized in this plan. This will allow for continued acceptable and safe use of the lake. Note that canals should also be dredged when needed for similar reasons.
7. Annual pre and post lake aquatic vegetation surveys are needed to determine the efficacy of invasive species treatments and to assure minimal impacts on the desirable native aquatic plant communities.
8. A shoreline erosion survey is recommended to account for any areas immediately surrounding the lake that may unknowingly contribute solids to the lake that further reduce water clarity and add potential nutrients. In addition, it is recommended that the Indian Lake community implement Best Management Practices (BMP's) discussed in the report to reduce the nutrient and sediment loads being transported into the lake from areas that contribute these loads.
9. Indian Lake riparians are encouraged to attend regular ODNR and ILWP meetings that are held to discuss data trends and evaluate lake improvement progress. A high level of focus should be centered on invasive species awareness and nonpoint source pollution (NPS) that is responsible for nutrient and sediment loads to the lake. Additionally, riparians would be encouraged to hold an annual lake workshop. Education alone (i.e., meetings, brochures, etc.) will not adequately introduce all riparians to lake issues as many people are participatory learners. There is therefore a need to incorporate different educational strategies into this lake restoration program for a sustainable program.

## **2.0 INDIAN LAKE BATHYMETRIC MAPS AND SEDIMENT RELATIVE HARDNESS MAP DATA**

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A whole-lake bathymetric scan (depth contour mapping) of the lake was conducted in August of 2022 (Figure 1) and July of 2023 (Figure 2). These maps show that the maximum recorded depth in 2022 was around 12.0 feet with the deepest areas located in the central and east-central regions of the lake. Scan data was also recorded in April of 2023, but these maps had processing difficulties due to the presence of very dense vegetation in particular areas that would not allow for complete bottom scans.

In addition to the lake depth contour scans, whole-lake bottom sediment hardness scans were conducted in August of 2022 (Figure 3) and July of 2023 (Figure 4). The bottom hardness maps show that most of the lake bottom consists of some soft clay and consolidated sediments throughout the lake with softer sediments located mostly in the deeper waters. Tables 2-4 below show the categories of relative bottom hardness for each scanning period with 0.0-0.1 referring to the softest and least consolidated bottom and >0.4 referring to the hardest, most consolidated bottom. This scale does not mean that any of the lake contains a truly “hard” bottom but rather a bottom that is more coherent and not flocculent in relative locations.

**Table 2. Indian Lake relative hardness of the lake bottom by category or hardness and percent bottom cover of each category (relative cover); August 15-20, 2022.**

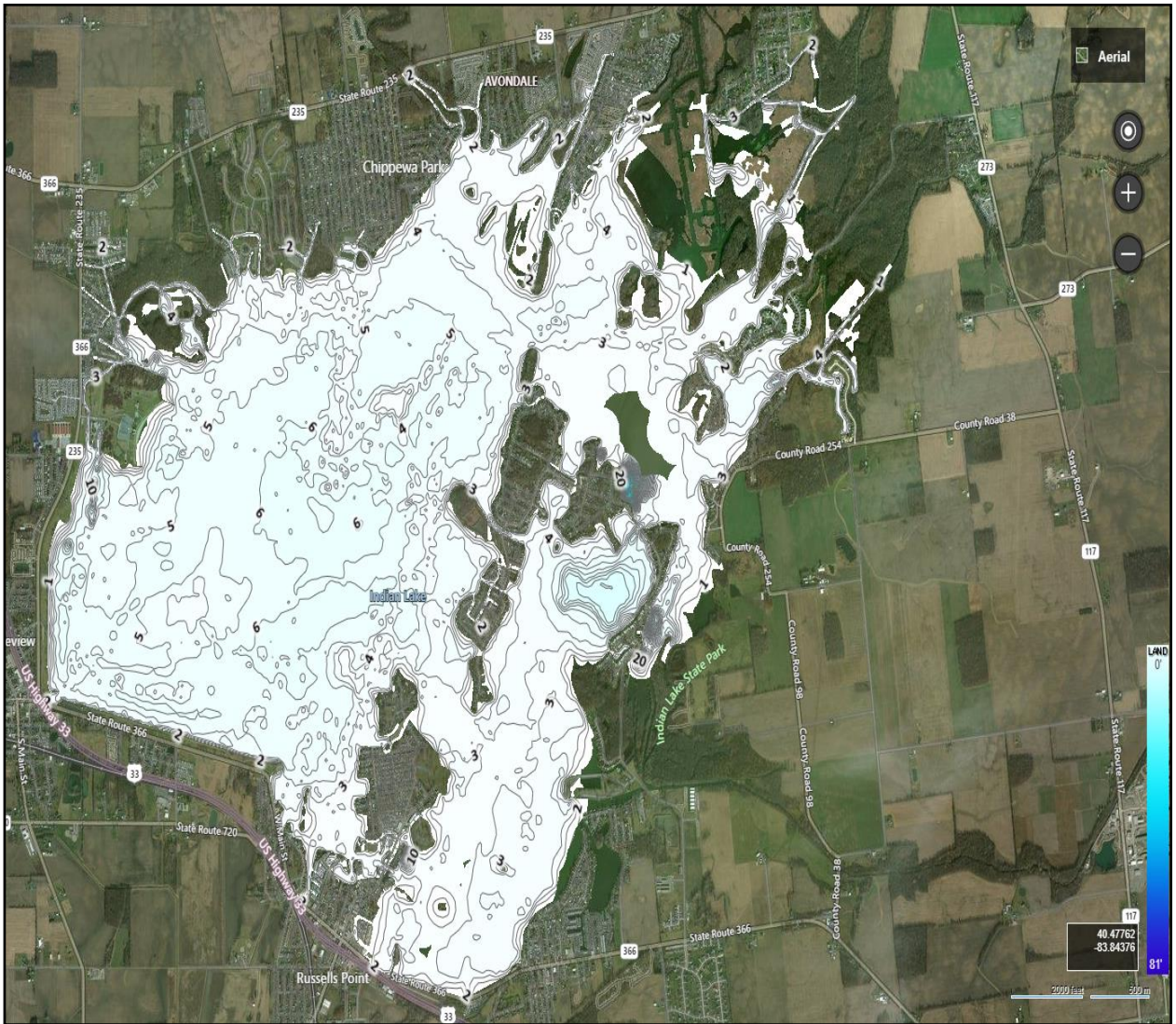
<b>Lake Bottom Relative Hardness Category</b>	<b># GPS Points in Each Category (Total =60,247)</b>	<b>% Relative Cover of Bottom by Category</b>
<b>0.0-0.1</b>	633	1.1
<b>0.1-0.2</b>	13,769	22.9
<b>0.2-0.3</b>	28,466	47.3
<b>0.3-0.4</b>	17,064	28.3
<b>&gt;0.4</b>	355	0.6

**Table 3. Indian Lake relative hardness of the lake bottom by category or hardness and percent bottom cover of each category (relative cover); April, 2023.**

<b>Lake Bottom Relative Hardness Category</b>	<b># GPS Points in Each Category (Total =76,172)</b>	<b>% Relative Cover of Bottom by Category</b>
<b>0.0-0.1</b>	670	0.9
<b>0.1-0.2</b>	31,254	41.0
<b>0.2-0.3</b>	38,557	50.6
<b>0.3-0.4</b>	5,652	7.4
<b>&gt;0.4</b>	39	0.1

**Table 4. Indian Lake relative hardness of the lake bottom by category or hardness and percent bottom cover of each category (relative cover); July, 2023.**

<b>Lake Bottom Relative Hardness Category</b>	<b># GPS Points in Each Category (Total =55,368)</b>	<b>% Relative Cover of Bottom by Category</b>
<b>0.0-0.1</b>	156	0.3
<b>0.1-0.2</b>	12,718	23.0
<b>0.2-0.3</b>	37,754	68.1
<b>0.3-0.4</b>	4,711	8.5
<b>&gt;0.4</b>	29	0.1



**Figure 1. Indian Lake Depth Contour Map, Logan County, Ohio (August 15-20, 2022).**

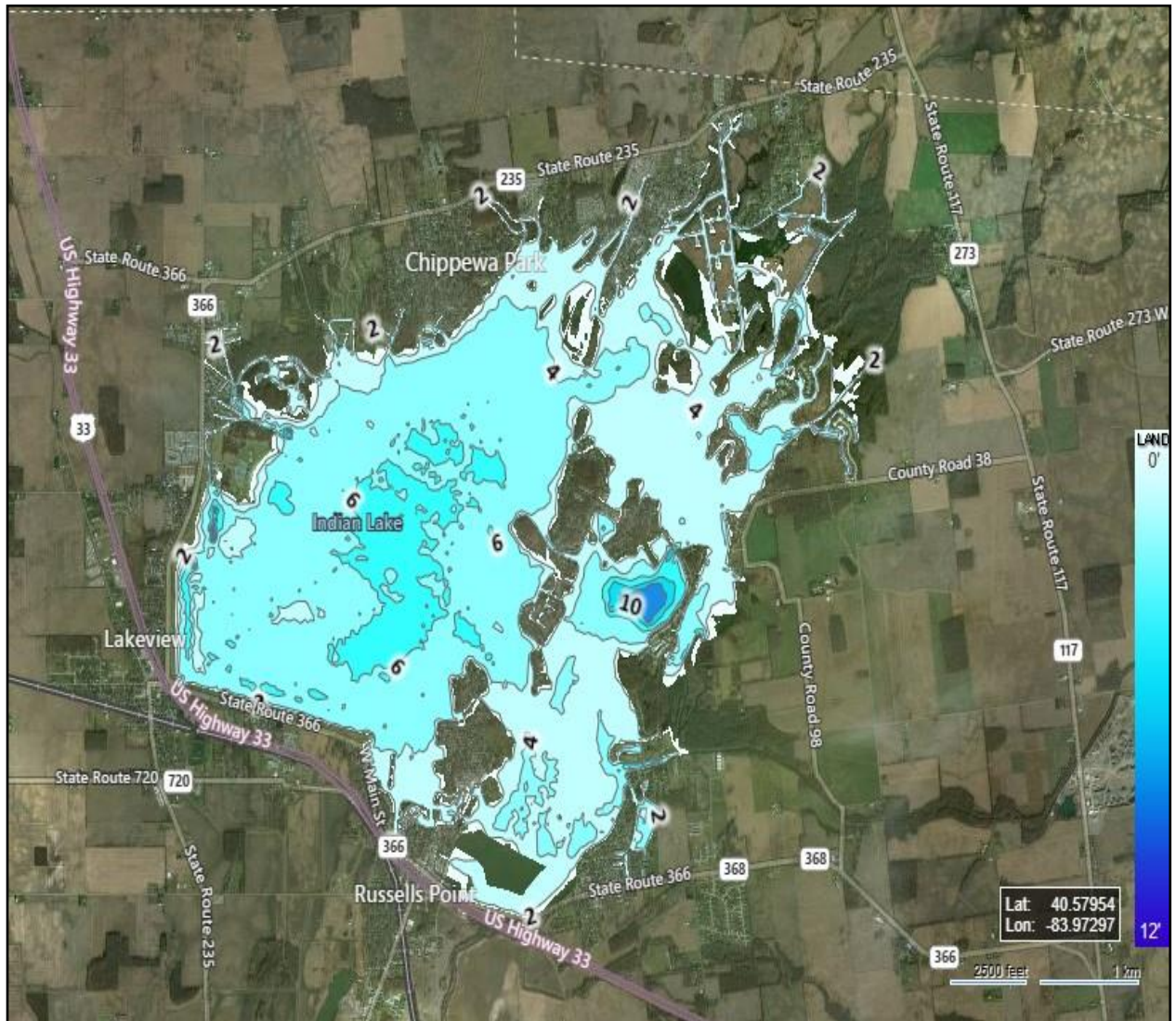
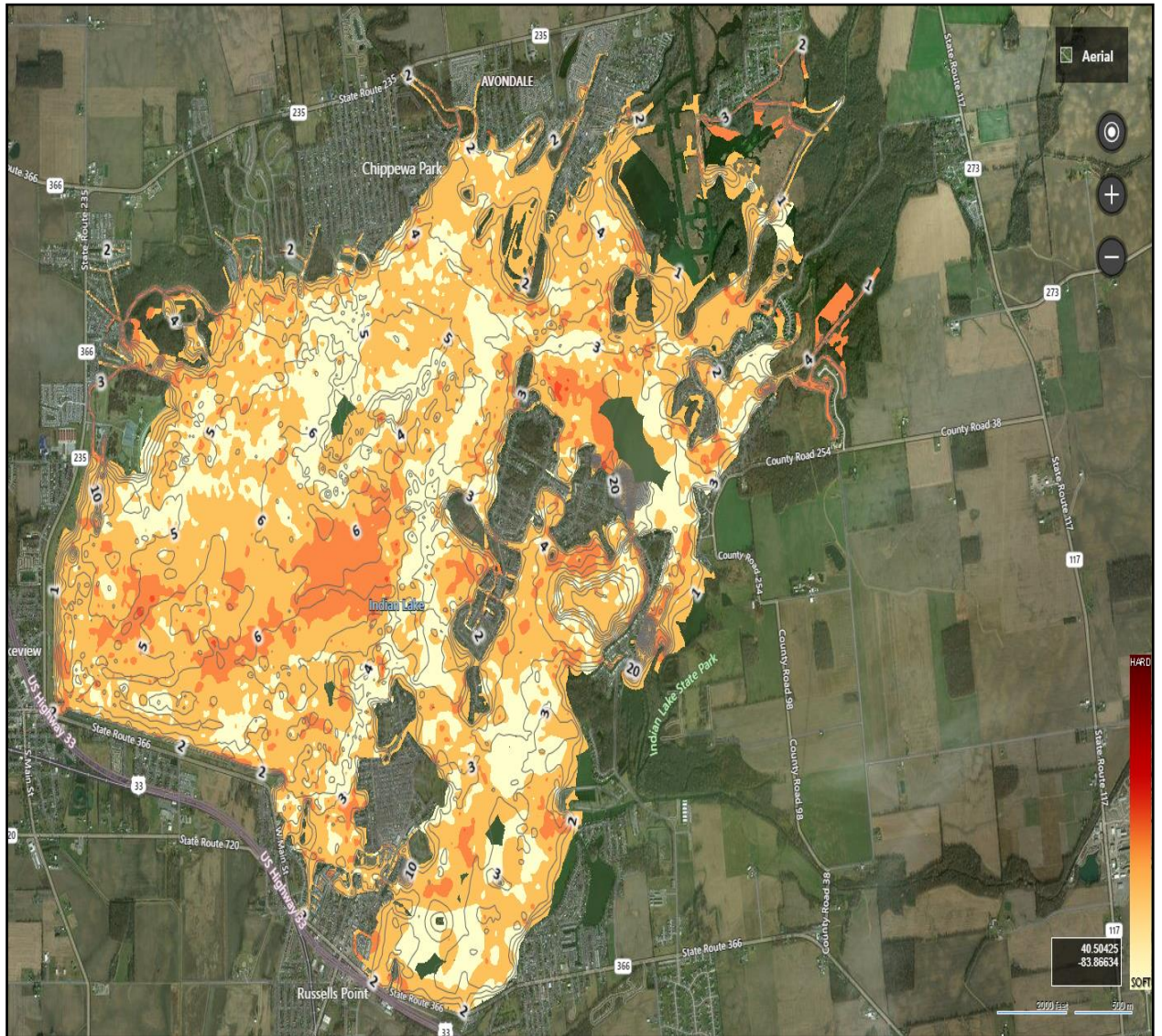
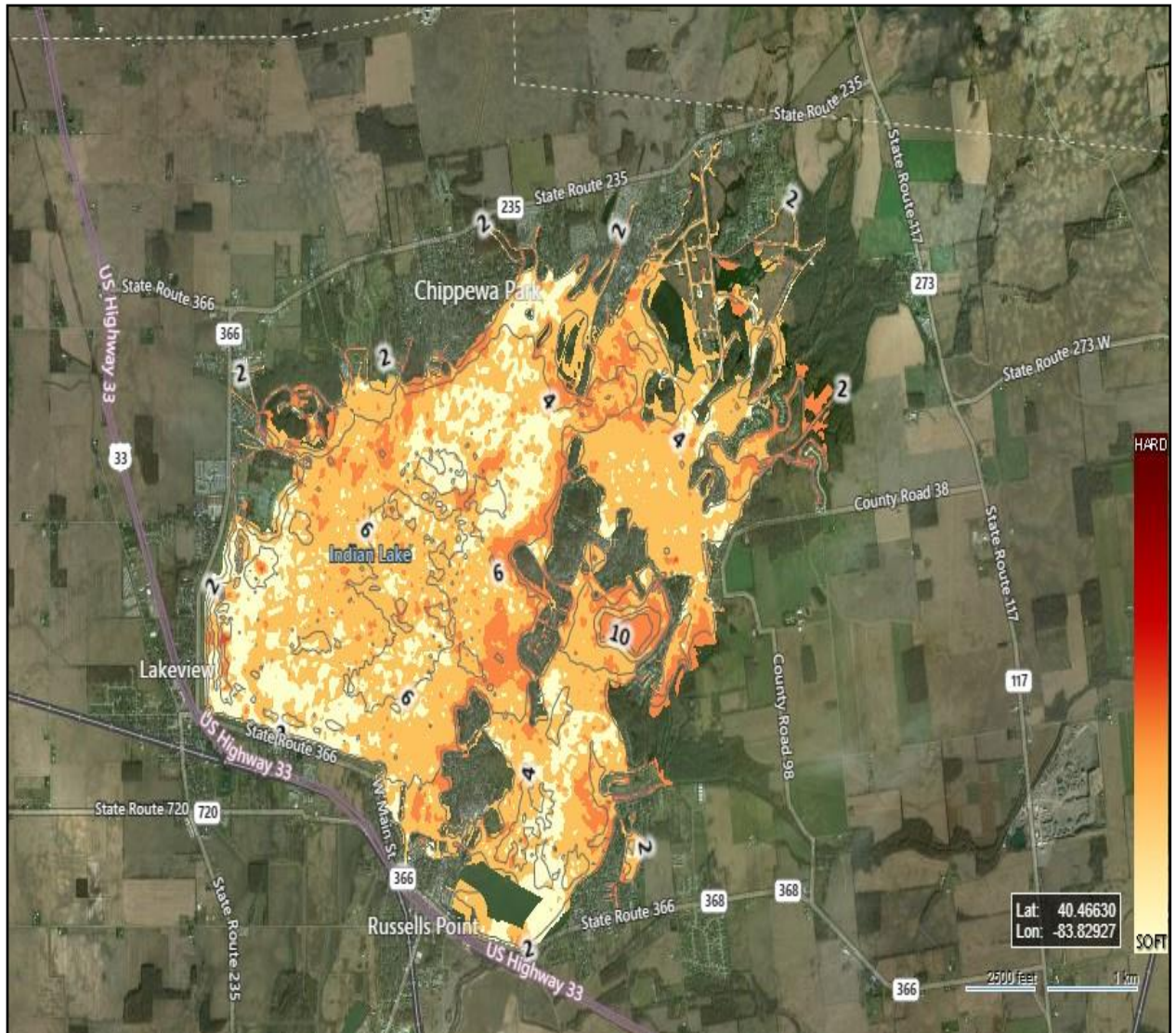


Figure 2. Indian Lake Depth Contour Map, Logan County, Ohio (July 17-20, 2023).



**Figure 3. Indian Lake Relative Sediment Hardness Map, Logan County, Ohio (August 15-20, 2022).**



**Figure 4. Indian Lake Relative Sediment Hardness Map, Logan County, Ohio (July 15-20, 2023).**

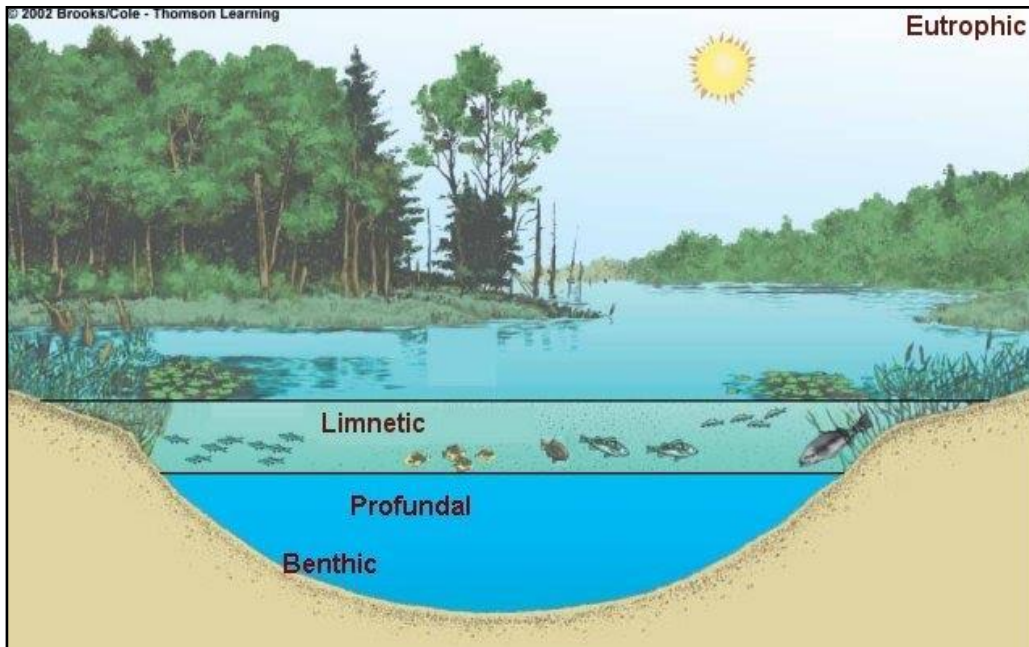
### 3.0 INDIAN LAKE BASIN WATER QUALITY DATA & RESULTS

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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. urban/shoreline development, tributary inputs, 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 5). Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a*, and low in transparency are classified as eutrophic (or hyper-eutrophic if both are very high); 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 a hyper-eutrophic (very nutrient-rich) lake due to the high nutrient concentrations, elevated chlorophyll-*a* concentrations, and low Secchi transparency (Figure 5).

**Table 5. General Lake Trophic Status Classification Table.**

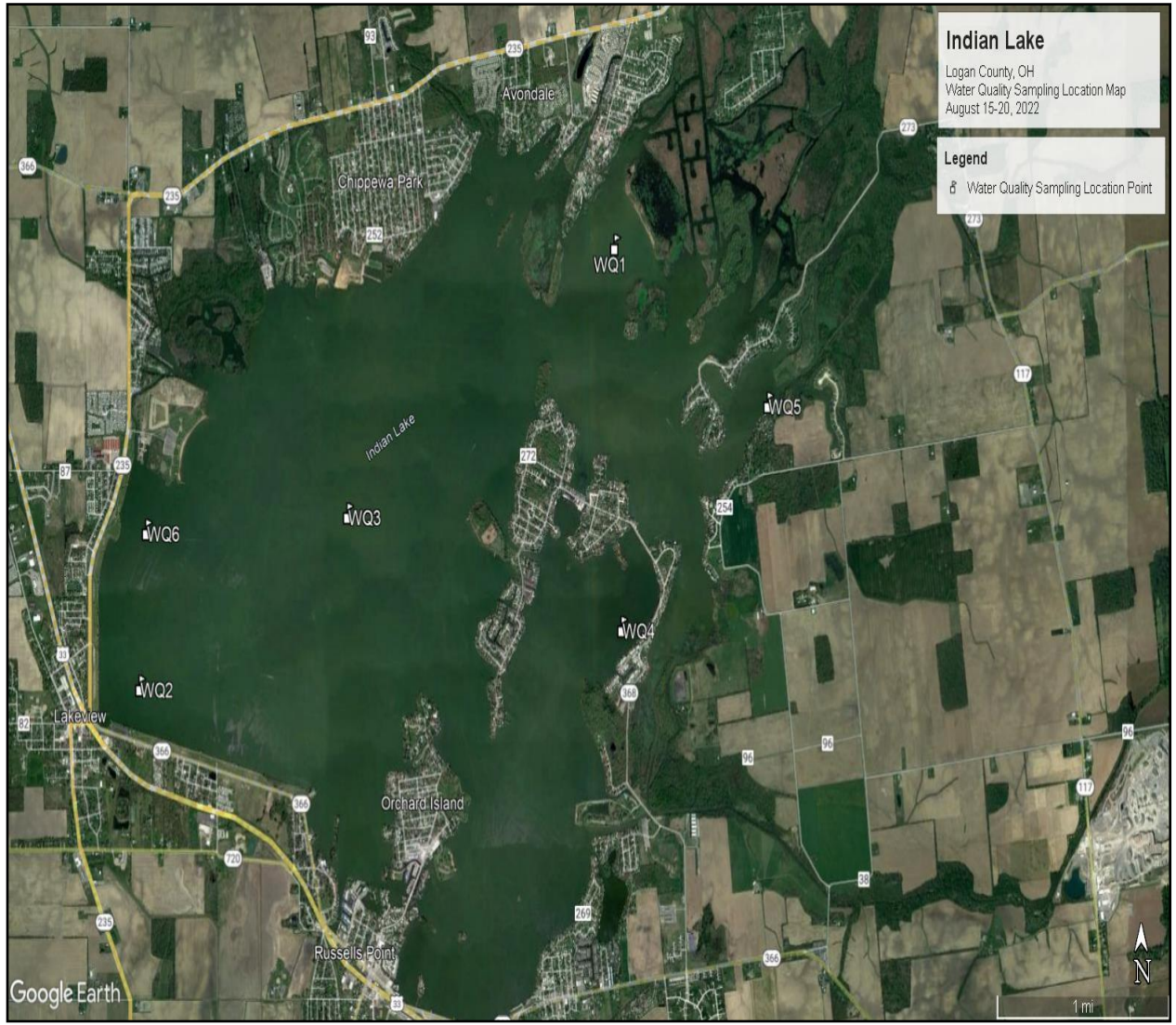
<i>Lake Trophic Status</i>	<i>Total Phosphorus (mg L<sup>-1</sup>)</i>	<i>Chlorophyll-a (µg L<sup>-1</sup>)</i>	<i>Secchi Transparency (feet)</i>
<b>Oligotrophic</b>	< 0.010	< 2.2	> 15.0
<b>Mesotrophic</b>	0.010-0.025	2.2 – 6.0	7.5 – 15.0
<b>Eutrophic</b>	> 0.025	> 6.0	< 7.5



**Figure 5. Diagram showing a eutrophic or nutrient-enriched lake ecosystem (photo adapted from Brooks/Cole Thomson learning online).**

### **3.1 Water Quality Parameters Measured**

Water quality parameters measured during this evaluation included the following parameters at N=6 water quality sampling stations: 1.) Physical water quality parameters such as dissolved oxygen (in  $\text{mg L}^{-1}$ ), water temperature (in  $^{\circ}\text{C}$ ), conductivity ( $\text{mS cm}^{-1}$ ), total dissolved solids ( $\text{mg L}^{-1}$ ), and pH (S.U), and 2.) Chemical water quality parameters such as total phosphorus and ortho-phosphorus (also known as soluble reactive phosphorus or SRP measured in  $\text{mg L}^{-1}$ ), total Kjeldahl nitrogen and total inorganic nitrogen (in  $\text{mg L}^{-1}$ ), total suspended solids (measured in  $\text{mg L}^{-1}$ ), and chlorophyll-*a* (in  $\mu\text{g L}^{-1}$ ). In addition, Secchi transparency (measured in feet) was collected at each of the N=6 sampling stations. All of these parameters respond to changes in water quality and consequently serve as indicators of change over time. Mean 2022-2023 physical and chemical water quality data for the Indian Lake basin are displayed below and are presented in Tables 6-17. A map showing the sampling locations for all water quality samples is shown below in Figure 6. In addition to water samples, a total of N=20 lake sediment samples were collected with an Ekman hand dredge and analyzed for sediment percentage of organic carbon (Table 18). A map showing the sediment sampling locations is displayed as Figure 7. All water samples and readings were collected at the N=6 locations on August 19, 2022, April 22, 2023, and July 21, 2023 with the use of a Van Dorn horizontal water sampler and calibrated Eureka Manta II® multi-meter probe with parameter electrodes, respectively. All samples were taken to a NELAP (EPA)-certified laboratory for analysis. Whenever possible, historical data comparisons were made for certain parameters that utilized similar sampling locations and methods as those used in this study.

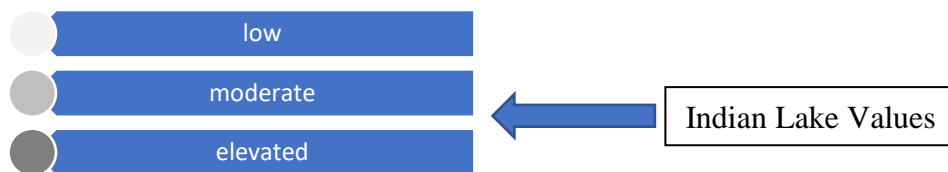


**Figure 6. Locations for water quality basin sampling in Indian Lake, Logan County, Ohio (August 19, 2022, April 22, 2023, and July 21, 2023).**



### 3.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water column. In general, dissolved oxygen levels should be greater than 5.0 mg/L 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<sup>-1</sup>) with the use of a calibrated Eureka Manta II® dissolved oxygen meter. The mean August DO measured during the 1973 EPA evaluation was 8.5 mg L<sup>-1</sup> so the recent concentrations are favorable. All concentrations were favorable in April 2023 with the cooler water temperatures. In July, 2023 only Station 2 had lower than acceptable concentrations at the bottom. Table 6 below shows the mean dissolved oxygen concentrations during 2022-2023 for all basins sampled. The bottom of the lake produces a biochemical oxygen demand (BOD) due to microbial activity attempting to break down high quantities of organic plant and algal matter, which reduces dissolved oxygen in the water column at depth. Furthermore, the lake bottom is more 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.

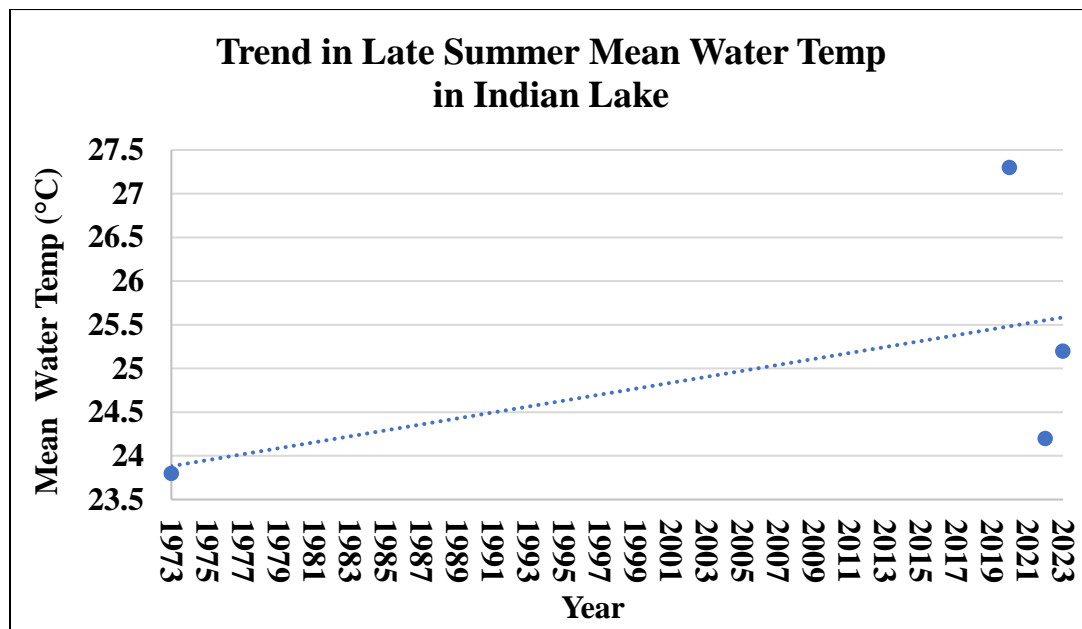


**Table 6. Mean dissolved oxygen during 2022-2023 in the Indian Lake deep basins.**

<b>August 19, 2022</b>	<b>April 22, 2023</b>	<b>July 21, 2023</b>
<b>Mean DO±SD</b>	<b>Mean DO±SD</b>	<b>Mean DO±SD</b>
9.4±3.9 mg/L	10.3±0.5 mg/L	8.7±0.3 mg/L

### 3.1.2 Water Temperature

A lake's water temperature varies within and among seasons, and is nearly uniform with depth under the winter ice cover because lake mixing is reduced when waters are not exposed to the wind. When the upper layers of water begin to warm in the spring after ice-off, the colder, dense layers remain at the bottom. This process results in a "thermocline" that acts as a transition layer between warmer and colder water layers. During the fall season, the upper layers begin to cool and become denser than the warmer layers, causing an inversion known as "fall turnover". In general, shallow lakes will not stratify and deeper lakes may experience single or multiple turnover cycles. Indian Lake water temperatures were measured in degrees Celsius (°C) with the use of a calibrated Eureka Manta II® submersible thermometer. All water temperatures of Indian Lake demonstrated weak thermoclines due to overall shallow depths. The 1973 EPA evaluation noted a mean August water temperature of 23.8°C. These water temperatures are warm but can support a warm-water fishery. Figure 8 displays the change in late summer water temperatures over time. Due to the significant data gaps in between the EPA study and current evaluation, an accurate trend cannot be developed but the mean water temperatures do appear to be increasing. The collection of more data in future years will help solidify this observation. Table 7 below shows the mean water temperatures during 2022-2023 for all basins sampled. Summer water temperatures in 2023 were slightly higher than in 2022 due to higher overall air temperatures.



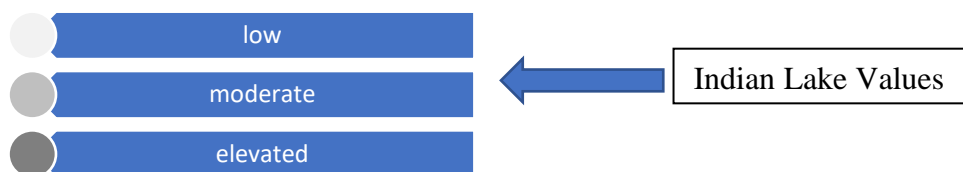
**Figure 8. Trend in August mean water temperatures in Indian Lake over time. NOTE: Due to scarce data collected at the same time with similar methods, more precise trends could not be produced and thus continued data collection is recommended (EPA and RLS data).**

**Table 7. Mean water temperatures during 2022-2023 in the Indian Lake deep basins.**

<b>August 19, 2022</b>	<b>April 22, 2023</b>	<b>July 21, 2023</b>
<b>Mean Temp±SD</b>	<b>Mean Temp±SD</b>	<b>Mean Temp±SD</b>
23.8±0.0°C	14.0±0.3°C	25.2±0.4°C

### 3.1.3 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 with water temperature and the amount of dissolved minerals and salts in a lake. Conductivity was measured in micro Siemens per centimeter ( $\mu\text{S cm}^{-1}$ ) with the use of a calibrated Eureka Manta II® conductivity probe and meter. The 1973 EPA evaluation noted a mean August value of 368  $\text{mS cm}^{-1}$ . Since these values are moderately high for an inland lake, the lake water contains ample dissolved metals and ions such as calcium, potassium, sodium, chlorides, sulfates, and carbonates. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on 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  $\text{mS/cm}$  can negatively impact aquatic life. The values were higher than normal in April of 2023 but declined to normal values by July, 2023 (Table 8). The reason for this is unclear but could be attributed to spring rains carrying more runoff and salts to the lake.



**Table 8. Mean conductivity during 2022-2023 in the Indian Lake deep basins.**

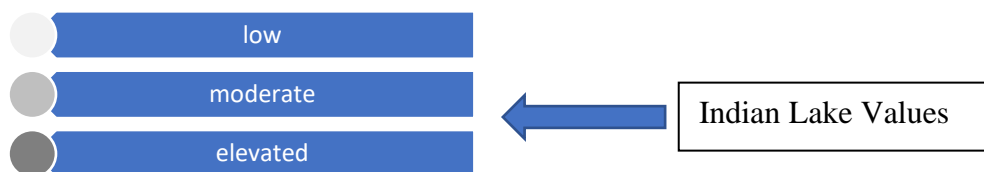
<b>August 19, 2022</b>	<b>April 22, 2023</b>	<b>July 21, 2023</b>
<b>Mean Cond±SD</b>	<b>Mean Cond±SD</b>	<b>Mean Cond±SD</b>
322±37 $\text{mS/cm}$	611±162 $\text{mS/cm}$	343±23 $\text{mS/cm}$

### 3.1.4 Total Dissolved Solids and Total Suspended Solids

There are two different types of solids that are present in lake systems. Both types vary in their forms and effects on water quality.

#### **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<sup>-1</sup>. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. Summer 2023 values were close to those during the summer of 2022 with higher values in the spring of 2023 (Table 9), presumably due to spring runoff.



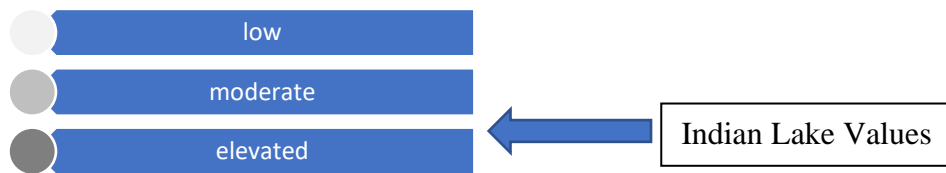
**Table 9. Mean TDS during 2022-2023 in the Indian Lake deep basins.**

<b>August 19, 2022</b>	<b>April 22, 2023</b>	<b>July 21, 2023</b>
<b>Mean TDS±SD</b>	<b>Mean TDS±SD</b>	<b>Mean TDS±SD</b>
207±21 mS/cm	394±97 mS/cm	226±21 mS/cm

### **Total Suspended Solids (TSS)**

Total suspended solids are the measure of the number of suspended particles in the water column that do not pass through a filter during analysis. Particles suspended in the water column absorb heat from the sun and raise the water temperature. This raise in water temperature also results in overall lower dissolved oxygen concentrations over time. Additionally, elevated TSS can cover fish spawning habitat and thus impact fishery reproduction. Total suspended solids were measured in  $\text{mg L}^{-1}$  and analyzed in the laboratory with Method SM 2540 D-11. The Indian Lake bottom contains many fine sediment particles (silts and clays) that are easily perturbed from winds and wave turbulence from boats and heavy rainfall events. Primary sources of TSS include erosion of soils into the lake and transference of solids to lakes from agricultural watersheds and local developments.

Spring values may be higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. Historical data on this parameter are scarce but should be collected more often to evaluate upstream watershed improvements and the impacts on water quality. TSS values in 2023 were much lower than those recorded in 2022 (Table 10) but the optimum values are under  $10 \text{ mg L}^{-1}$ .



**Table 10. Mean TSS during 2022-2023 in the Indian Lake deep basins.**

<b>August 19, 2022</b>	<b>April 22, 2023</b>	<b>July 21, 2023</b>
<b>Mean TSS<math>\pm</math>SD</b>	<b>Mean TSS<math>\pm</math>SD</b>	<b>Mean TSS<math>\pm</math>SD</b>
43 $\pm$ 52 mS/cm	19 $\pm$ 10 mS/cm	29 $\pm$ 10 mS/cm

### **3.1.5 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 inland lakes have pH values that range from 7.0 to 9.0 S.U. Acidic lakes ( $\text{pH} < 7$ ) are rare and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC). The 1973 EPA evaluation reported a mean August pH of 8.7 S.U. This range of pH is neutral to alkaline on the pH scale and is ideal for an inland lake.

pH tends to rise when abundant aquatic plants are actively growing through photosynthesis or when abundant marl deposits are present. The pH of Indian Lake water ranged from 8.4-8.7 S.U. in 2022-2023 which are ideal values for an inland lake (Table 11).

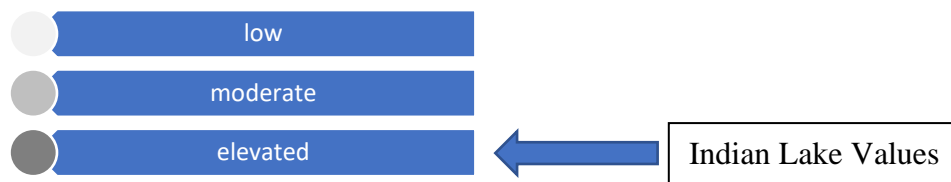
**Table 11. Mean pH during 2022-2023 in the Indian Lake deep basins.**

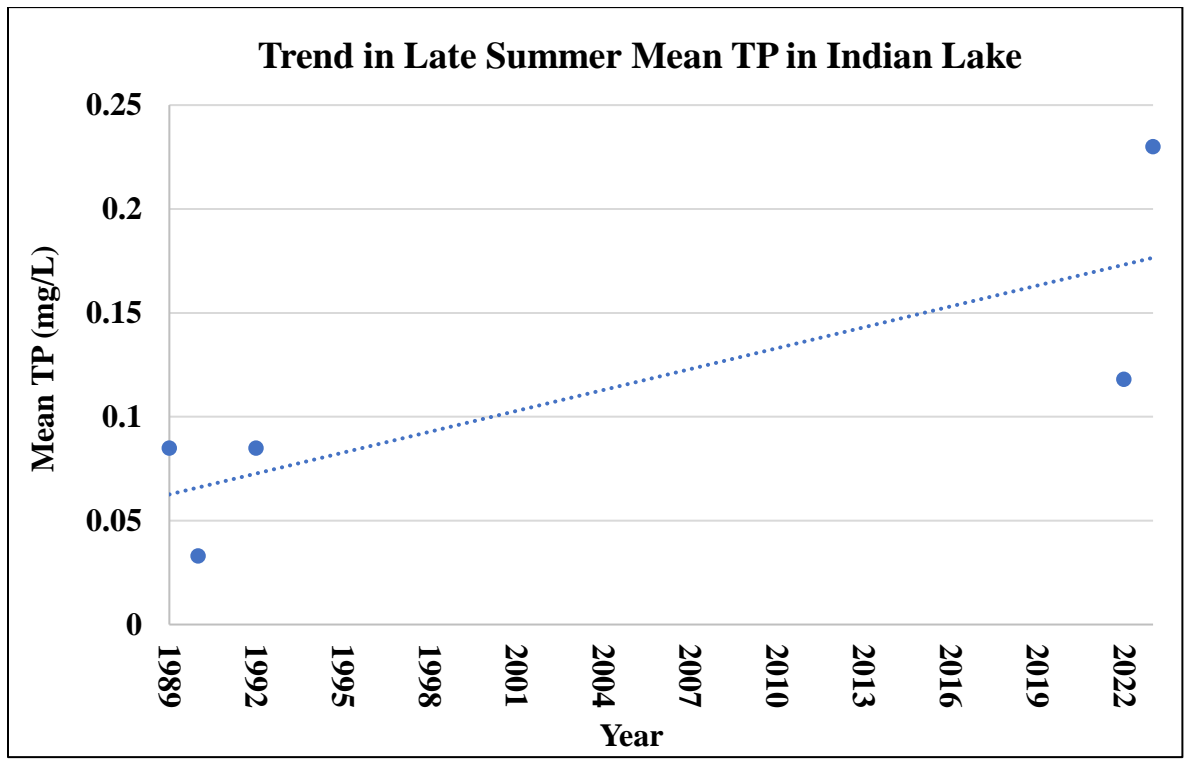
<b>August 19, 2022</b>	<b>April 22, 2023</b>	<b>July 21, 2023</b>
<b>Mean pH±SD</b>	<b>Mean pH±SD</b>	<b>Mean pH±SD</b>
8.4±0.5 mS/cm	8.5±0.1 mS/cm	8.7±0.3 mS/cm

### 3.1.6 Total Phosphorus and Ortho-Phosphorus (SRP)

#### *Total Phosphorus*

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Lakes that contain greater than 0.020-0.025 mg L<sup>-1</sup> 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<sup>-1</sup>) with the use of Method EPA 200.7 (Rev. 4.4). The 1973 EPA study noted that the mean August TP concentration was 0.128 mg L<sup>-1</sup>. TP concentrations have thus declined since 1973 likely due to immediate watershed improvements (Figure 9). The mean TP in late-July, 2023 was much higher (Table 12) and could be attributed to the decay of submersed aquatic vegetation which likely released nitrogen and phosphorus upon decay. This will take time for the water in the lake to be replaced and the concentrations to return to normal. These concentrations are still much higher than desired however, and efforts should continue to decrease them over time.





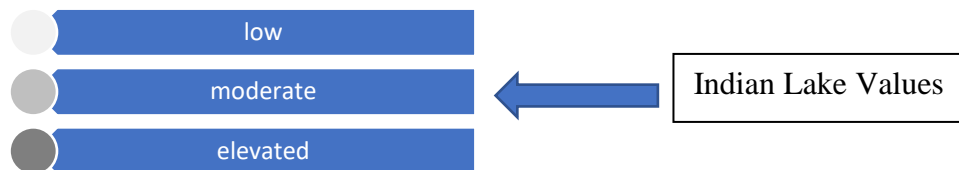
**Figure 9.** Trend in late summer mean total phosphorus concentrations (TP) in Indian Lake over time. NOTE: Due to scarce data collected at the same time with similar methods, more precise trends could not be produced (CLIP, OLMS, RLS data).

**Table 12.** Mean TP during 2022-2023 in the Indian Lake deep basins.

August 19, 2022	April 22, 2023	July 21, 2023
Mean TP±SD	Mean TP±SD	Mean TP±SD
118±0.1 µg/L	63±0.0 µg/L	213±0.1 µg/L

### *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 form of P used by all aquatic life. Previously measured August mean concentrations (EPA 1973) were around 0.015 mg L<sup>-1</sup>. As the TP increased in July, 2023 so did the SRP (Table 13) which is not surprising. A drop in SRP may also correlate with declines in chlorophyll-*a* over time.



**Table 13. Mean SRP during 2022-2023 in the Indian Lake deep basins.**

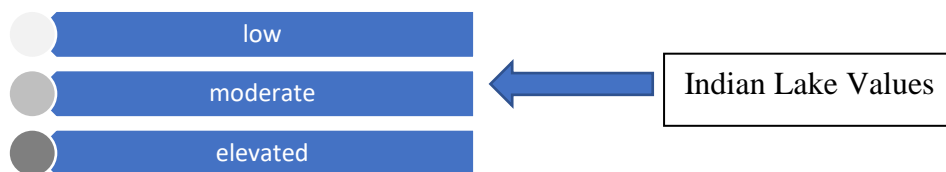
<b>August 19, 2022</b>	<b>April 22, 2023</b>	<b>July 21, 2023</b>
<b>Mean SRP±SD</b>	<b>Mean SRP±SD</b>	<b>Mean SRP±SD</b>
11.0±0.0 µg/L	11.0±0.0 µg/L	32±0.0 µg/L

### *3.1.7 Total Kjeldahl Nitrogen and Total Inorganic Nitrogen*

Total Kjeldahl nitrogen (TKN) is the sum organic nitrogen and ammonia (NH<sub>3</sub><sup>+</sup>) 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 concentrations of three different forms of nitrogen (nitrate, nitrite, and ammonia). 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 > 17), 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<sup>-1</sup> may be classified as oligotrophic, those with a mean TKN value of 0.75 mg L<sup>-1</sup> may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg L<sup>-1</sup> may be classified as eutrophic. The previously measured August TKN in 1973 by the EPA was 2.6 mg L<sup>-1</sup> and thus concentrations have declined.

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 EPA 1973 report previously noted that the lake may revert to a nitrogen limited system in the fall.

The total inorganic nitrogen (TIN) consists of nitrate (NO<sub>3</sub>-), nitrite (NO<sub>2</sub>-), and ammonia (NH<sub>3</sub>) forms of nitrogen without the organic forms of nitrogen. The previously measured 1973 August mean concentration was 0.382 mg L<sup>-1</sup> (EPA data) and thus concentrations of TIN have also declined. This was likely attributed to improvements in the immediate watershed. The TKN (Table 14) was lower overall in 2023 and the TIN (Table 15) was higher, but both are still lower than the 1973 values reported by the EPA.



**Table 14. Mean TKN during 2022-2023 in the Indian Lake deep basins.**

August 19, 2022	April 22, 2023	July 21, 2023
Mean TKN±SD	Mean TKN±SD	Mean TKN±SD
2.1±0.9 mg/L	0.9±0.3 mg/L	1.8±0.1 mg/L

**Table 15. Mean TIN during 2022-2023 in the Indian Lake deep basins.**

August 19, 2022	April 22, 2023	July 21, 2023
Mean TIN±SD	Mean TIN±SD	Mean TIN±SD
105±0.0 mg/L	120±0.0 mg/L	138±0.1 mg/L

### 3.1.8 Chlorophyll-*a* and Algae

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. High chlorophyll-*a* concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg L<sup>-1</sup> are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg L<sup>-1</sup> are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* was measured in micrograms per liter (µg L<sup>-1</sup>) with the use of Turner Designs® hand-held *in situ* fluorimeter. The chlorophyll-*a* concentrations in Indian Lake were determined by collecting a composite sample of the algae throughout the water column at the deep basin site from just above the lake bottom to the lake surface.

The 1973 August mean measured by the EPA was  $105.0 \mu\text{g L}^{-1}$  and thus concentrations have declined over time. Samples collected from June 27, 2022-September 6, 2022 (ODNR data) showed that Microcystin concentrations ranged from  $0.072\text{-}0.546 \mu\text{g L}^{-1}$ . Although these concentrations are well under the EPA recreational value maximum of  $8.0 \mu\text{g L}^{-1}$ , they are still detectable and may increase in the absence of continued and selective improvements. RLS recommends a more detailed panel of cyanobacterial toxins that detects the concentrations of Anatoxin-a, Cylindrospermopsis, Microcystin-LA, Microcystin-LF, Microcystin-LR, Microcystin-LY, Microcystin-RR, Microcystin-YR, and Nodularin. This would allow for definitive concentration determination of possible toxins by other cyanobacteria species.

Algal genera from a composite water sample collected from the deep basins of Indian Lake were analyzed under a Zeiss® compound brightfield microscope and with the use of a Sedgewick rafter counting cell chamber. The genera present in 2022-2023 are displayed in Table 16 below along with cell count data. The aforementioned species indicate a problematic composition in that the dominant algal genera were in the cyanobacteria. Although not all cyanobacteria may emit toxins, they are the least palatable algal communities for zooplankton that serve as critical fish food. Figure 10 displays the change in mean August chlorophyll-*a* over time (EPA, CLIP, OLMS, and RLS data). Table 17 displays the mean chlorophyll-*a* concentrations in 2022 and 2023 with increases in 2023.

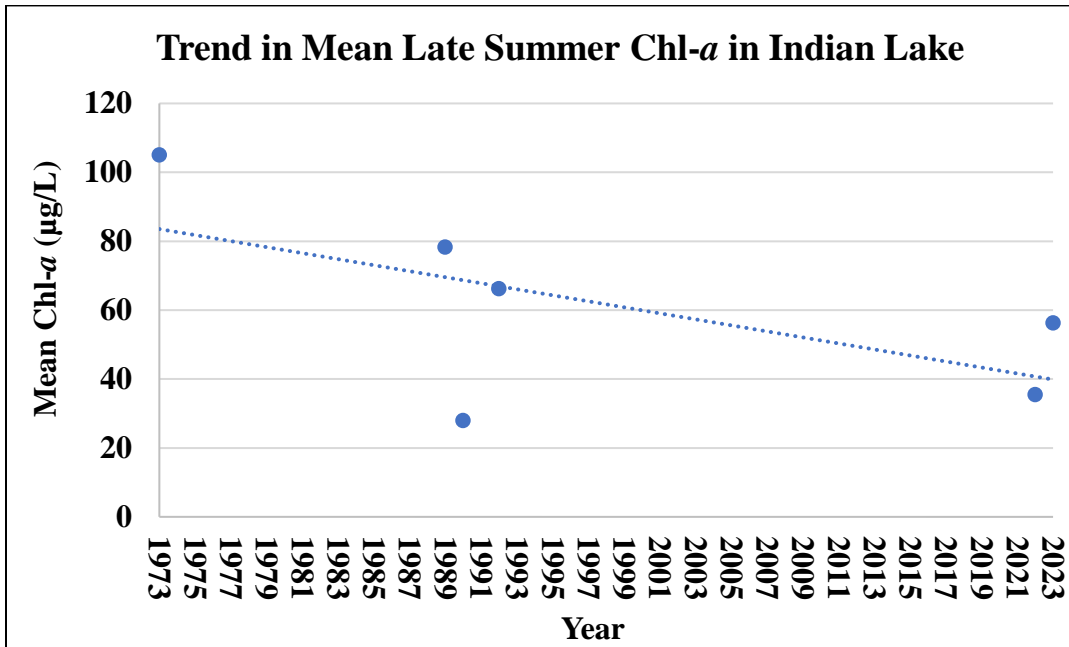
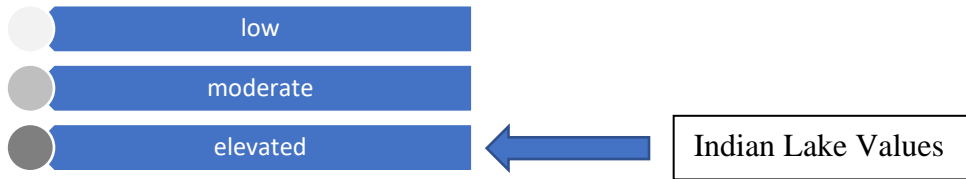
**Table 16. Algal genera and cell counts for 2022-2023 Indian Lake summer water samples.**

Algal Genera	August 2022 (cells/ml)	July 2023 (cells/ml)
<i>Mougeotia</i> sp.	3	15
<i>Ankistrodesmus</i> sp.	2	9
<i>Chlorella</i> sp.	8	25
<i>Pithophora</i> sp.	9	6
<i>Anabaenopsis</i> sp.	200	10
<i>Microcystis</i> sp.	13,000	24,000
<i>Merismopedia</i> sp.	2	0
<i>Pediastrum</i> sp.	0	5
<i>Lyngbya</i> sp.	2	0
<i>Oscillatoria</i> sp.	100	3
<i>Nitzschia</i> sp.	1	14
<i>Synedra</i> sp.	4	8

In addition to the planktonic algal forms present in Indian Lake, there were also dense filamentous algae noted on the lake in the form of mats referred to as *Pithophora* (Figure 11). *Pithophora* is a filamentous green algae that thrives in shallow and low flowing waters. It has irregularly branched filaments with swollen reproductive akinetes. The alga produces gas bubbles and thus remains buoyant on the surface but may sink to the lake bottom during intense wave activity and then float back to the surface. This alga is representative of highly nutrient-enriched waters and is difficult to control but was harvested in 2023 with only small areas in the canals remaining (Figure 12).

Figure 13 displays a recent cyanobacteria bloom that occurred on the surface near the north shore of Indian Lake. These blooms should be monitored and tested for algal toxicity concentrations. There is growing scientific evidence that cyanobacteria growth may be exacerbated by increasing global carbon dioxide (CO<sub>2</sub>) concentrations (Ji et al., 2020). Loftin et al., (2008) classified heavy cyanobacterial blooms as having cell counts between 20,000-100,000 cells per milliliter.

The Ohio EPA has been monitoring harmful algal blooms on Indian Lake using satellite imagery from NOAA-NOS Copernicus Sentinel 3b. Updates can be found on the following website: <http://publicapps.odh.ohio.gov/beachguardpublic>. Images during late summer of 2023 displayed an increasing area of HAB's present. A protocol is in place by the ODNR, Ohio EPA, and the Department of Health for toxicity sampling of water in the open basin and nearshore areas where scums are present to determine possible beach area closings in the future. Figure 14 shows a 2023 microscopic image taken by RLS that shows prominent blue-green algae, *Microcystis* colonies present in the water samples. Figure 15 displays a microscopic image of another genera of blue-green algae, *Anabaenopsis* sp also found in Indian Lake water samples.



**Figure 10. Trend in August mean chlorophyll-a in Indian Lake over time. NOTE: Due to scarce data collected at the same time with similar methods, more precise trends could not be produced (EPA, CLIP, OLMS, RLS data).**

**Table 17. Mean Chl-a during 2022-2023 in the Indian Lake deep basins.**

August 19, 2022	April 22, 2023	July 21, 2023
Mean Chla±SD	Mean Chla±SD	Mean Chla±SD
36.0±11 µg/L	54±25 mg/L	56±19 mg/L



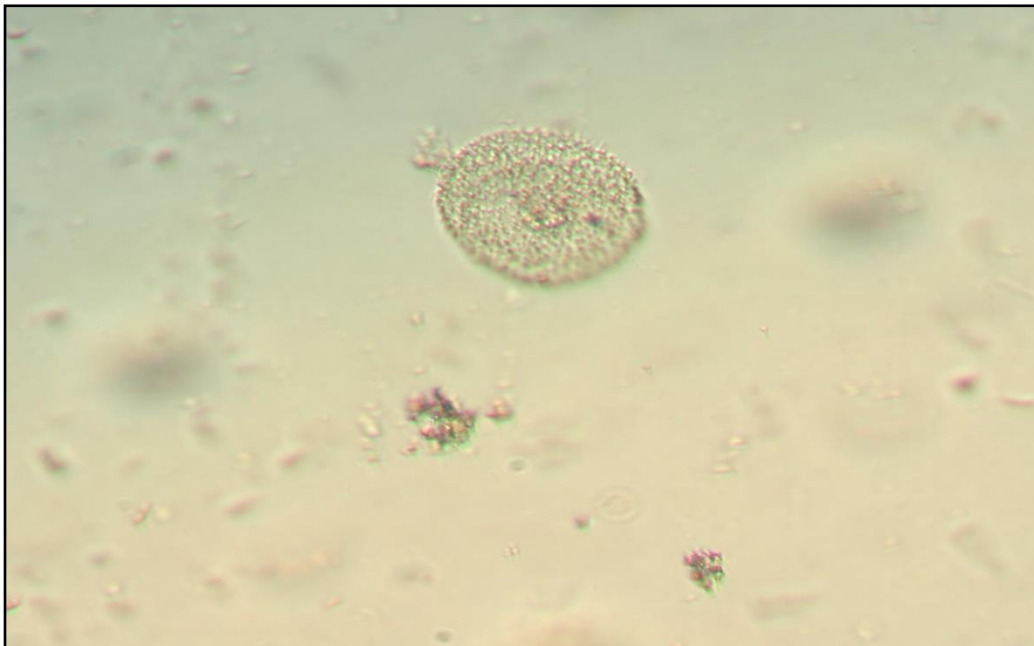
**Figure 11. Dense filamentous *Pithophora* algae on the surface of Indian Lake (August 19, 2022).**



**Figure 12. Photo showing Indian Lake *Pithophora* remnants with some dissolved blue-green algae in the water column (July 21, 2023).**



**Figure 13.** A prominent blue-green algae bloom at the north shore of Indian Lake (September, 2022; photo courtesy of Dustin Wickersham).



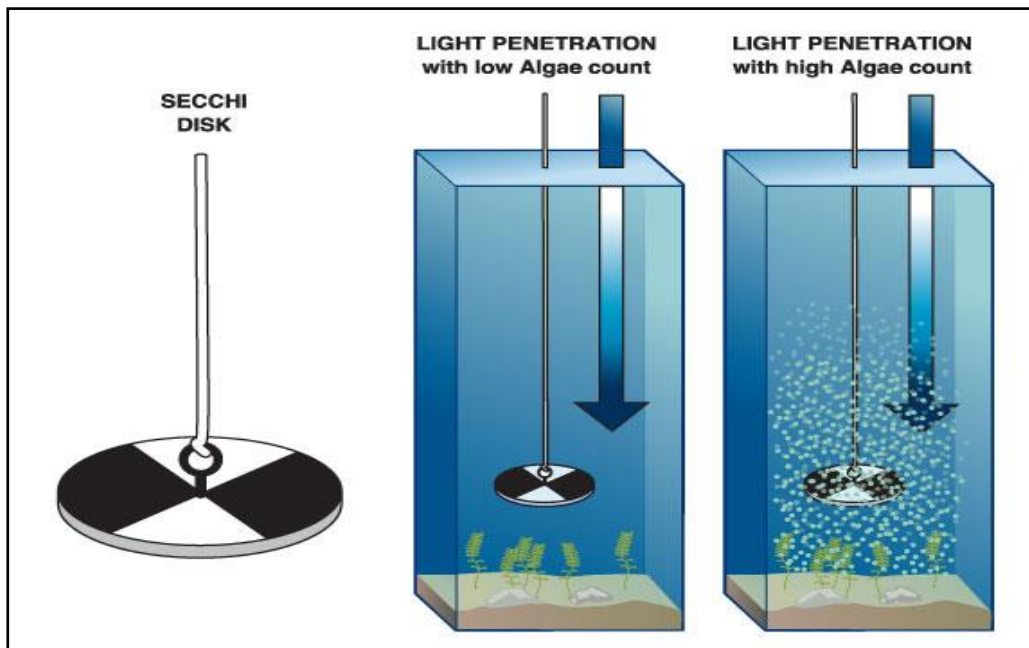
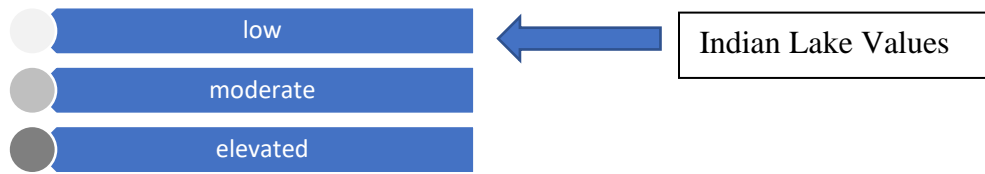
**Figure 14.** Microscopic image of the blue-green alga *Microcystis* in a July 21, 2023 water sample analyzed by RLS.



**Figure 15. Microscopic image of the blue-green alga *Anabaenopsis* sp. in a July, 2023 water sample analyzed by RLS.**

### ***3.1.9 Secchi Transparency***

Secchi transparency is a measure of the clarity or transparency of lake water and was measured with the use of an 8-inch diameter standardized Secchi disk. Secchi disk transparency is measured in feet (ft.) or meters (m) by lowering the disk over the shaded side of a boat around noon and taking the mean of the measurements of disappearance and reappearance of the disk (Figure 16). 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. A historical mean measured by the EPA in 1973 was 1.3 feet and thus water clarity has improved since 1973. These measurements are indicative of low water clarity. Measurements were collected during calm conditions. This transparency indicates a high quantity of suspended particles and algae throughout the water column which would result in lower water clarity. Secchi transparency is variable and depends on the amount of suspended particles in the water (often due to windy conditions of lake water mixing) and the amount of sunlight present at the time of measurement. A hedonic study conducted by Michael *et al.*, (1996) determined that a 1.0 meter improvement in water clarity increased average lakefront property values from \$11-\$200 per square foot. Table 18 displays the mean Secchi transparency in 2022-2023 with stable values in 2022 and spring of 2023 but a reduction by July of 2023 due to the observed increase in planktonic algae. Figure 17 shows the change in Secchi transparency over time.



**Figure 16. Measurement of water transparency with a Secchi disk.**

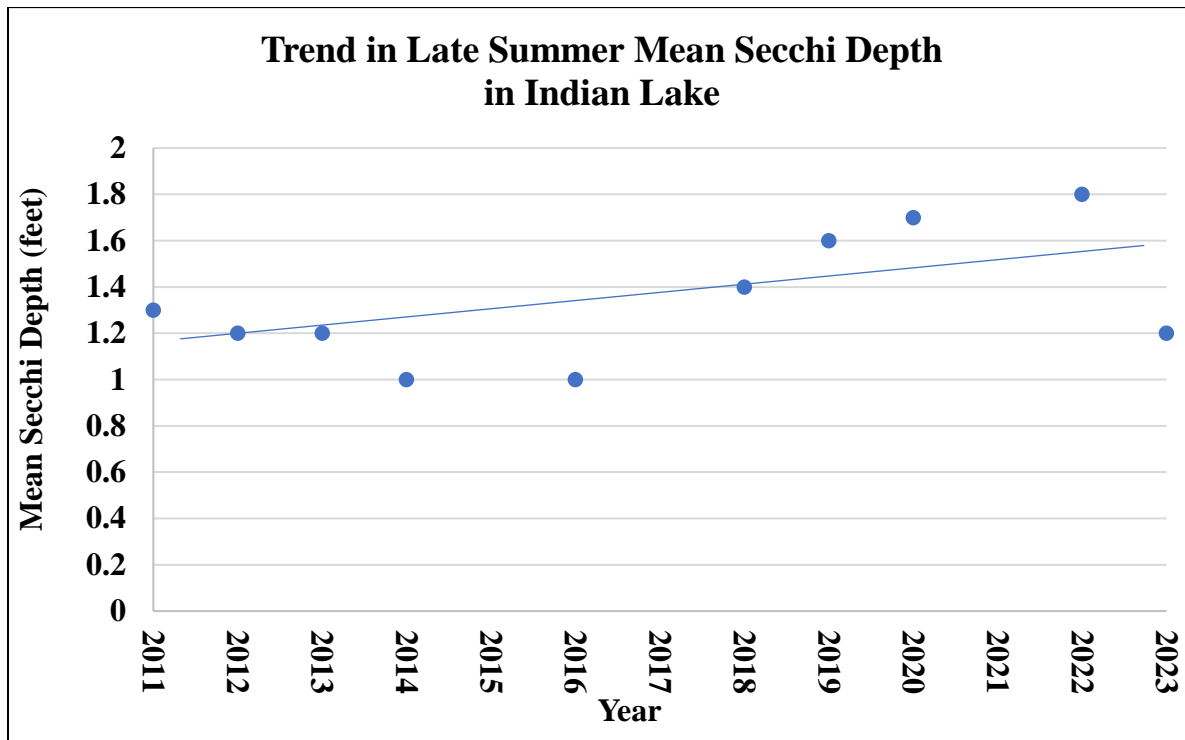


Figure 17. Trend in summer mean Secchi depth (transparency) in Indian Lake over time. NOTE: Due to scarce data collected between 2011-2022, more definitive long-term trends prior to 2011 could not be created (CLIP, OLMS, RLS data).

Table 18. Indian Lake Secchi transparency data collected at N=6 locations (August 19, 2022, April 22, 2023, and July 21, 2023).

Sampling Location	August 19, 2022	April 22, 2023	July 21, 2023
WQ 1	1.3	1.7	1.0
WQ 2	2.1	3.4	1.4
WQ 3	3.3	1.8	1.3
WQ 4	1.2	1.3	0.8
WQ 5	1.2	0.7	0.9
WQ 6	1.8	1.9	1.3
MEAN±SD	1.8±0.8	1.8±0.9	1.2±0.2

### ***3.1.10 Sediment Organic Carbon***

Organic carbon (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 carbon by total bulk volume. The range of organic matter for the Indian Lake sediments was between 1.5-14.0% in 2022 and 0.5-8.0% in 2023, which indicates a moderately low quantity of organic matter in Indian Lake sediments. It is interesting that the percentage of organic matter declined in 2023 given the large amount of aquatic vegetation that decayed. This may be attributed to adequate dissolved oxygen concentrations at the lake bottom that are able to stimulate aerobic microbes to naturally decompose the vegetation.

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. Table 19 below displays the percentage of organic carbon for N=20 lake sediment samples collected throughout the Indian Lake basin in 2022 and 2023. Although there is a slight decline in OM in 2023 relative to 2022, this number is likely not statistically different given the calculated standard deviations.

**Table 19. Indian Lake sediment organic carbon data collected at N=20 locations (August 19, 2022 and July 21, 2023)**

<i>Sampling Location</i>	<i>2022 Sediment Organic Carbon (%)</i>	<i>2023 Sediment Organic Carbon (%)</i>
S1	13.0	7.8
S2	12.0	7.7
S3	7.6	2.7
S4	13.0	8.0
S5	14.0	7.0
S6	13.0	7.9
S7	14.0	7.5
S8	12.0	7.1
S9	11.0	5.2
S10	13.0	8.0
S11	12.0	7.4
S12	11.0	7.3
S13	11.0	5.9
S14	1.5	1.1
S15	4.0	4.8
S16	11.0	6.2
S17	14.0	7.3
S18	9.4	0.5
S19	12.0	6.7
S20	12.0	5.9
<b>MEAN</b>	<b>11.0</b>	<b>6.1</b>
<b>STD DEV</b>	<b>3.3</b>	<b>2.2</b>

## 4.0 INDIAN LAKE AQUATIC VEGETATION DATA & RESULTS

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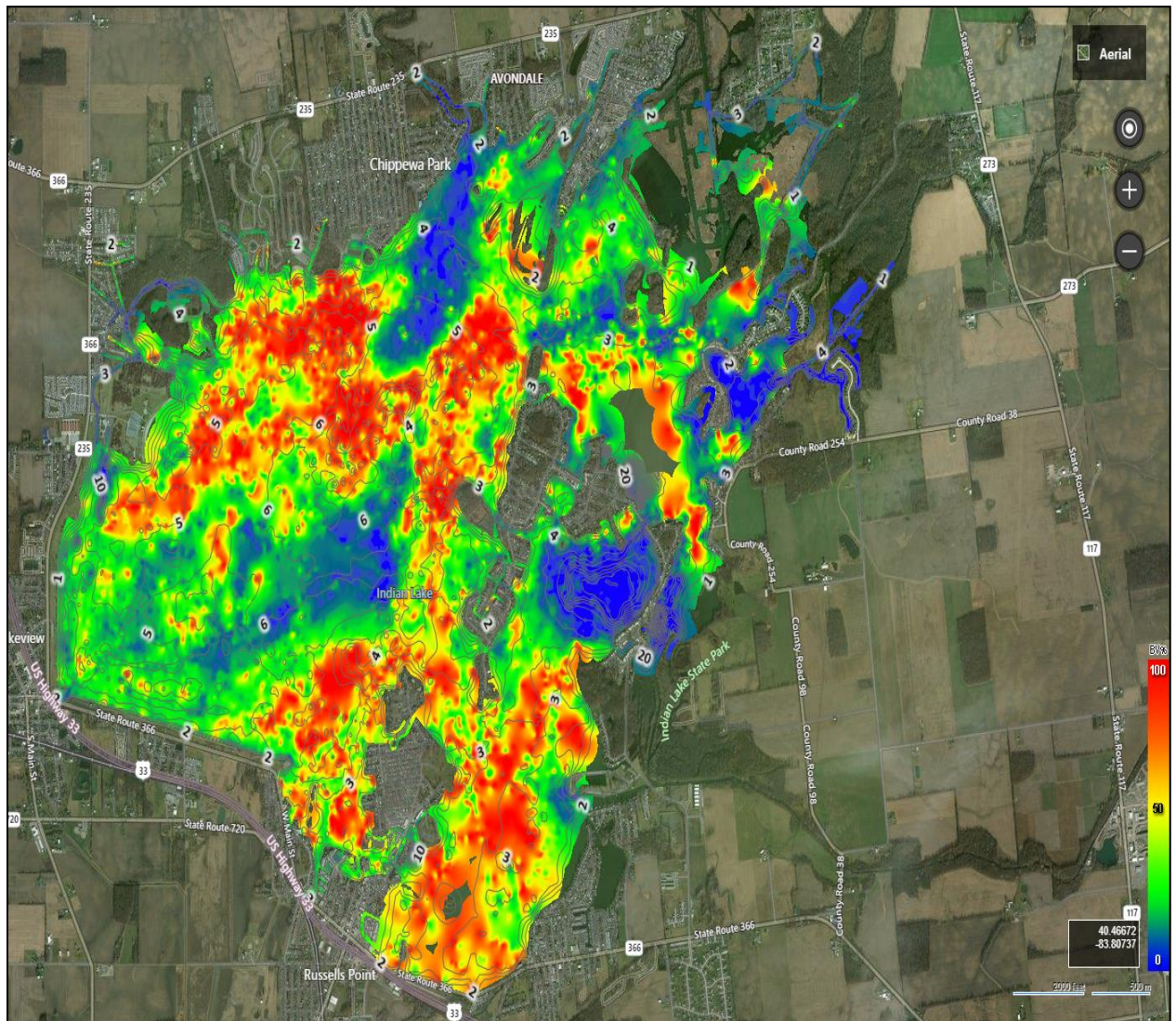
Aquatic plants (macrophytes) are an essential component in the littoral zones of most lakes in that they serve as suitable habitat and food for macroinvertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (in the rooted growth form), and contribute to the cycling of nutrients such as phosphorus and nitrogen upon decay. In addition, decaying aquatic plants contribute organic matter to lake sediments which further supports healthy growth of successive aquatic plant communities that are necessary for a balanced aquatic ecosystem. An overabundance of aquatic vegetation may cause organic matter to accumulate on the lake bottom faster than it can break down. Aquatic plants generally consist of rooted submersed, free-floating submersed, floating-leaved, and emergent growth forms. The emergent growth form (i.e., cattails, native loosestrife) is critical for the diversity of insects onshore and for the health of nearby wetlands. Submersed aquatic plants can be rooted in the lake sediment (i.e., milfoils, pondweeds), or free-floating in the water column (i.e., Coontail). Nonetheless, there is evidence that the diversity of submersed aquatic macrophytes can greatly influence the diversity of macroinvertebrates associated with aquatic plants of different structural morphologies (Parsons and Matthews, 1995). Therefore, it is possible that declines in the biodiversity and abundance of submersed aquatic plant species and associated macroinvertebrates, could negatively impact the fisheries of inland lakes. Alternatively, the overabundance of aquatic vegetation can compromise recreational activities, aesthetics, and property values. Indian Lake has a great biodiversity of native aquatic plants; however, the high density of Coontail and invasive Eurasian Watermilfoil are limiting space for successful germination and growth other native submersed aquatic plants. Additionally, the low water clarity is also limiting the growth of lower-growing and favorable native submersed aquatic plants.

A whole-lake scan of the aquatic vegetation in Indian Lake was conducted on August 15-20, 2022, April 16-20, 2023 and July 17-20, 2023, with a WAAS-enabled Lowrance HDS 9® GPS with variable frequency transducer. This data included numerous data points which were uploaded into a cloud software program to reveal maps that displayed depth contours, sediment hardness, and aquatic vegetation biovolume (Figures 18-20). On these scan maps, the color blue refers to areas that lack vegetation. The color green refers to low-lying vegetation. The colors red/orange refer to tall-growing vegetation that can also include floating-leaved vegetation. There are many areas around the littoral (shallow) zone of the lake that contain low-growing plants like *Elodea*. For this reason, the scans are conducted in conjunction with a whole lake GPS Point Intercept survey to account for individual species identification of all aquatic plants in the lake. Table 20 shows the biovolume categories by plant cover on August 15-20, 2022, April 16-20, 2023 and July 17-20, 2023,

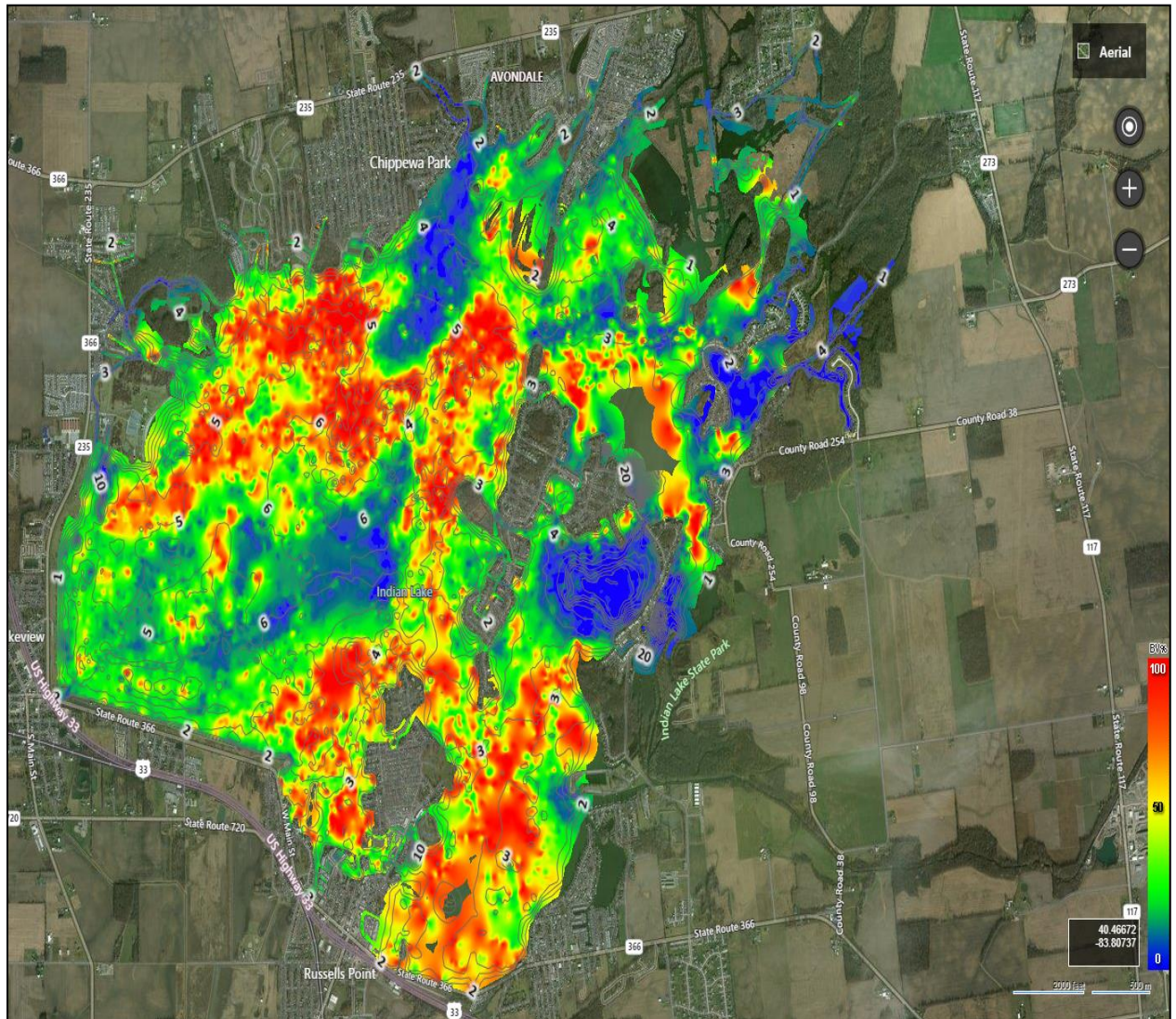
The GPS Point Intercept survey is sometimes used with an Aquatic Vegetation Assessment Site (AVAS) Survey method to assess the relative abundance of submersed, floating-leaved, and emergent aquatic vegetation within and around the littoral zones of inland lakes. With this survey method, the littoral zone areas of the lakes are divided into lakeshore sections approximately 100 - 300 feet in length. Each AVAS segment is sampled using visual observation, dependent on water clarity, and weighted rake tows to verify species identification.

The species of aquatic macrophytes present and density of each macrophyte are recorded onto an AVAS data sheet. Each separate plant species found in each AVAS segment is recorded along with an estimate of each plant density. Each macrophyte species corresponds to an assigned number. There are designated density codes for the aquatic vegetation surveys, where a = found (occupying < 2% of the surface area of the lake), b = sparse (occupying 2-20% of the surface area of the lake), c = common, (occupying 21-60% of the surface area of the lake), and d = dense (occupying > 60% of the surface area of the lake). In addition to the particular species observed (via assigned numbers), density information above was used to estimate the percent cumulative coverage of each species within the AVAS site. If shallow areas were present in the open waters of the lakes, then individual AVAS segments were sampled at those locations to assess the macrophyte communities in offshore locations. This is particularly important since exotics often expand in shallow island areas located offshore in many lakes.

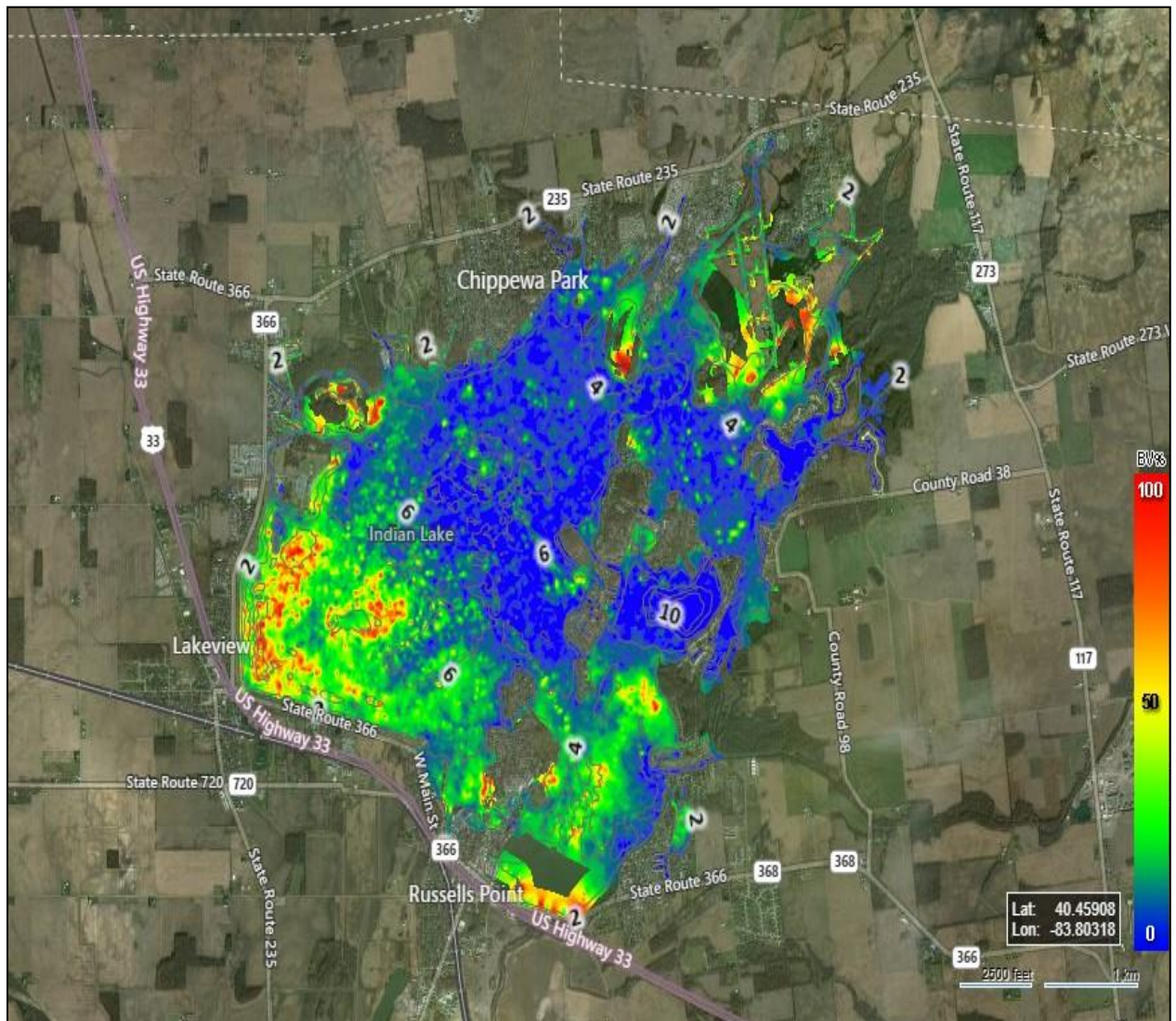
The GPS Point-Intercept/AVAS survey of Indian Lake was conducted on August 15-20, 2022, April 16-20, 2023 and July 17-20, 2023, and consisted of 2,934 sampling locations around the littoral zone (Figure 21). Data were placed in a table showing the relative abundance of each aquatic plant species found and a resultant calculation showing the frequency of each plant and cumulative cover.



**Figure 18. Aquatic plant biovolume of all aquatic plants in Indian Lake, Logan County, Ohio (August 15-20, 2022). Note: Red color denotes high-growing aquatic plants, green color denotes low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.**



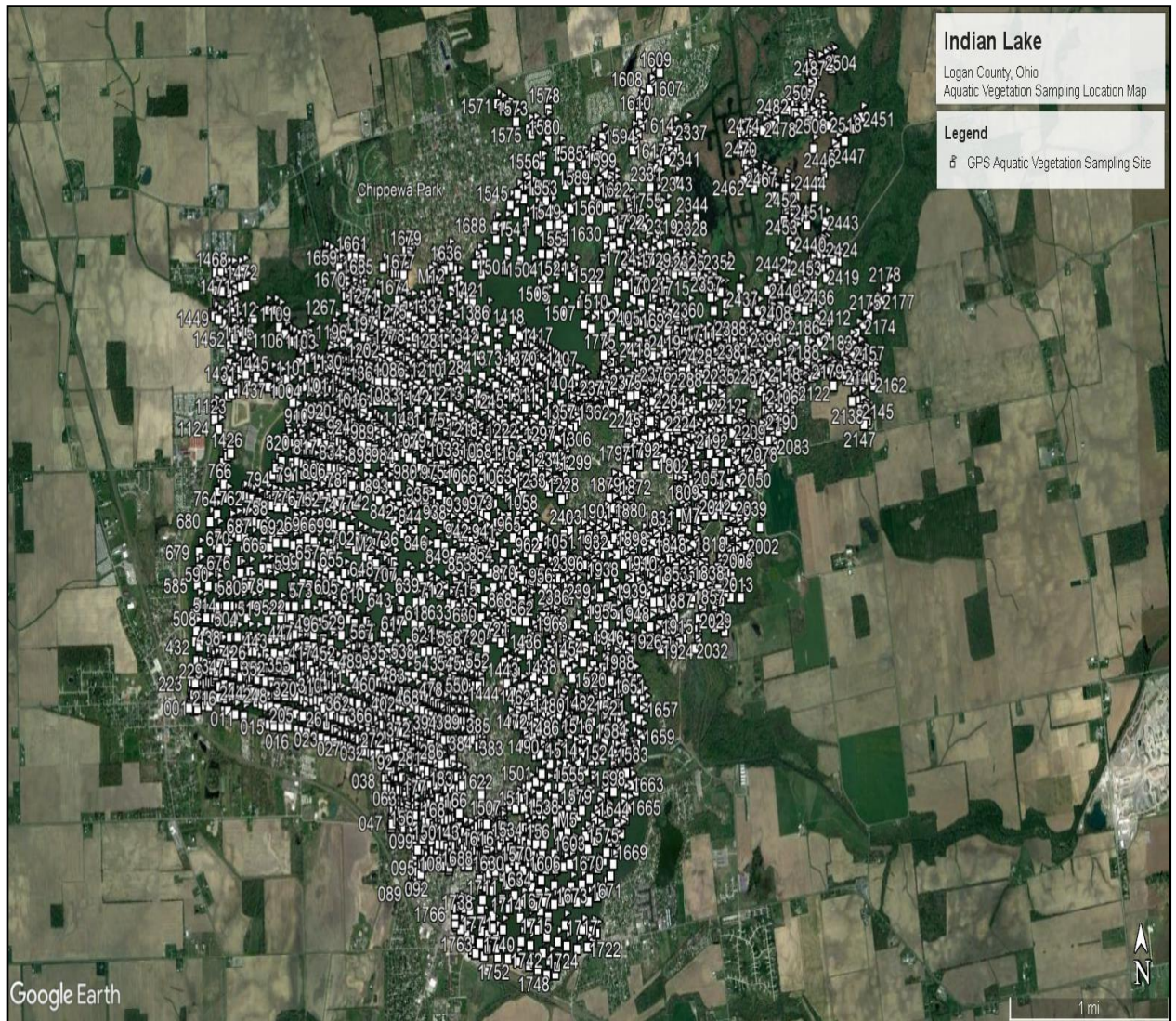
**Figure 19. Aquatic plant biovolume of all aquatic plants in Indian Lake, Logan County, Ohio (April 16-20, 2023). Note: Red color denotes high-growing aquatic plants, green color denotes low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.**



**Figure 20. Aquatic plant biovolume of all aquatic plants in Indian Lake, Logan County, Ohio (July 17-20, 2023). Note: Red color denotes high-growing aquatic plants, green color denotes low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.**

**Table 20. Indian Lake aquatic vegetation biovolume by category percent cover of each category (relative cover on August 15-20, 2022, April 16-20, 2023 and July 17-20, 2023).**

<b>Biovolume Cover Category</b>	<b>August 15-20, 2022</b>	<b>April 16-20, 2023</b>	<b>July 17-20, 2023</b>
<b>0-20%</b>	58.2	67.1	81.5
<b>20-40%</b>	17.8	19.5	10.6
<b>40-60%</b>	7.9	7.5	3.3
<b>60-80%</b>	1.5	0.5	0.4
<b>80-100%</b>	14.6	5.4	4.3



**Figure 21. Aquatic vegetation sampling locations in Indian Lake (August 15-20, 2022, April 16-20, 2023 and July 17-20, 2023).**

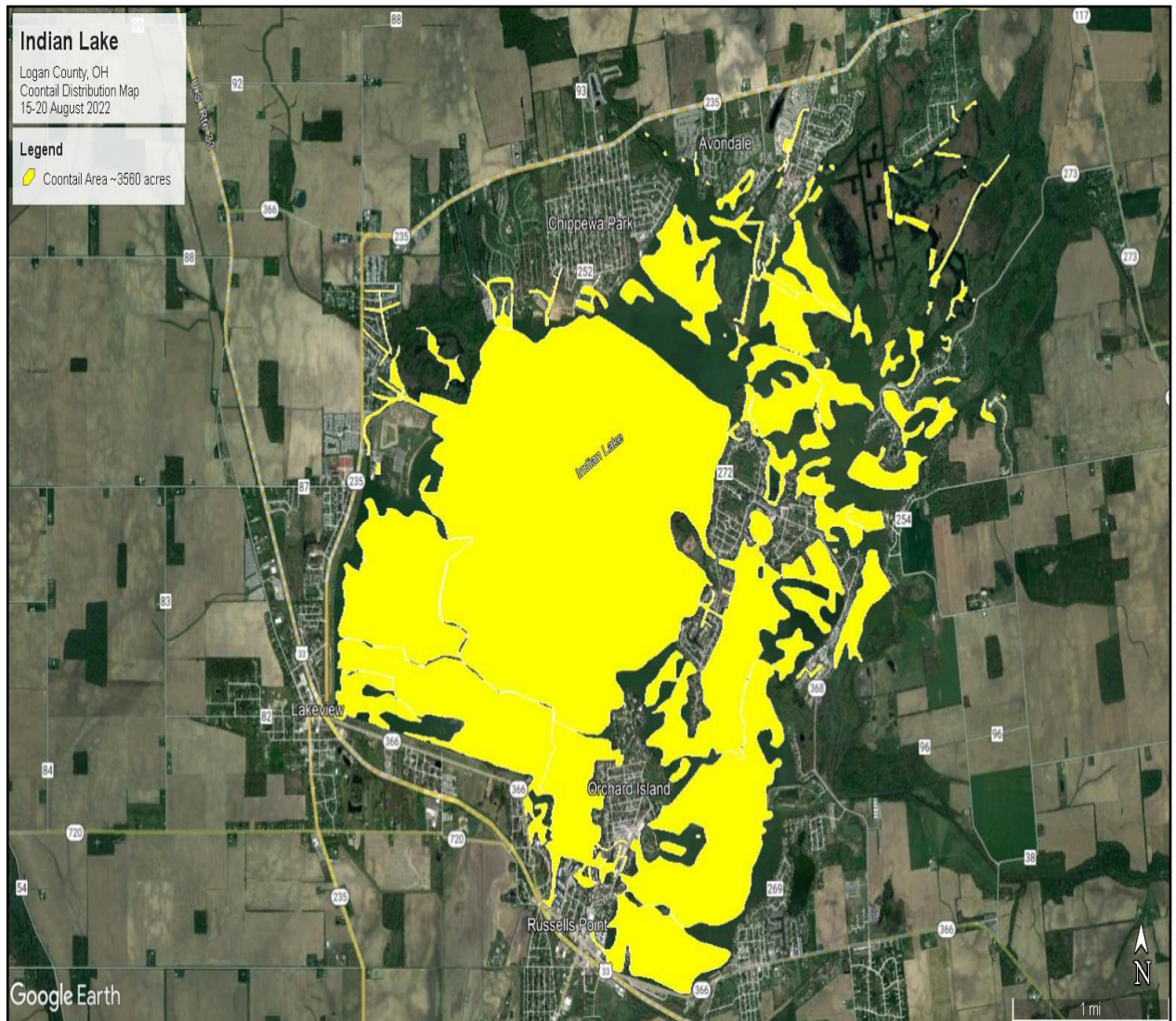
#### **4.1 Indian Lake Native Aquatic Macrophytes**

There are hundreds of native aquatic plant species in the waters of the United States. The most diverse native genera include the Potamogetonaceae (pondweeds) and the Haloragaceae (milfoils). Native aquatic plants may grow to nuisance levels in lakes with abundant nutrients (both water column and sediment) such as phosphorus, and in sites with high water transparency. The diversity of native aquatic plants is essential for the balance of aquatic ecosystems, because each plant harbors different macroinvertebrate communities and varies in fish habitat structure.

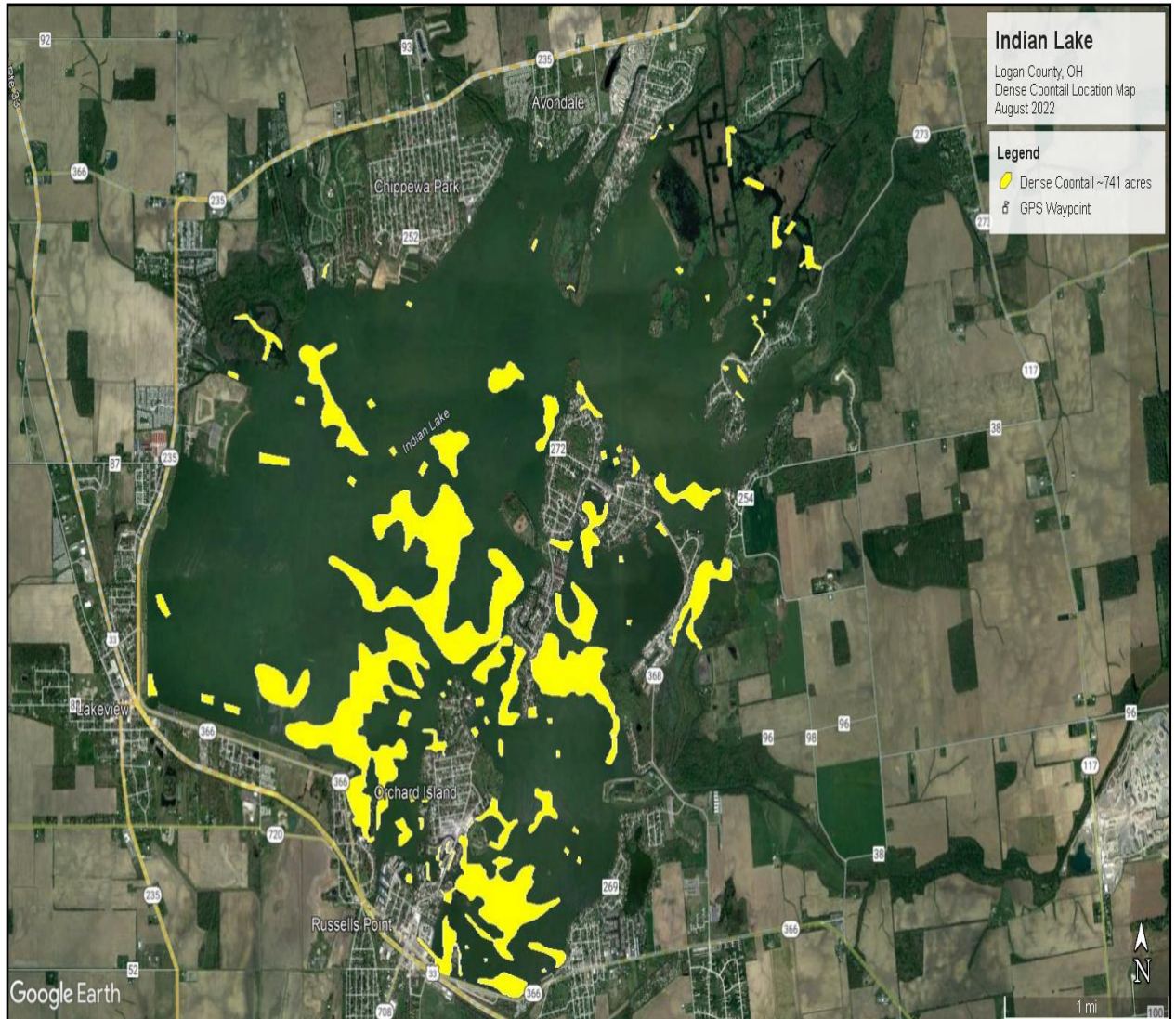
In 2023, Indian Lake contained 10 native submersed, 6 native floating-leaved, and 6 native emergent aquatic plant species, for a total of 23 native aquatic macrophyte species (Tables 21-26). Photos of all native aquatic plants are shown below in Figures 26-48. The emergent macrophytes are found along the shoreline of the lake, including the canals. Additionally, the lower-growing species were found in the littoral zone near the lake bottom and the higher-growing pondweeds were present in the deeper waters where they are somewhat protected from wave action. There were some large areas of water lilies and Lotus plants. These floating-leaved species should not be removed as they provide critical nursery habitat for fish and other wildlife and thus are an integral component of the Indian Lake ecosystem.

The dominant aquatic plants in the main part of the lake included the native rootless Coontail (79.4% of the sampling locations and the submersed Sago Pondweed (20.5% of the sampling locations). Duckweed was also common and is common in lakes with high nitrogen concentrations as it can uptake large quantities for sustained growth (Cedergreen and Madsen, 2002). Although there was a favorable presence of native pondweeds, they were sparse in comparison to the rootless submersed aquatic plant species. This indicates that Indian Lake nutrients are highly available in the water column as well as in the sediments where Eurasian Watermilfoil grows as a rooted plant. Indian Lake contains a favorable biodiversity of native aquatic vegetation for a lake of its size and thus protection of all native aquatic plant species is critical for the lake ecosystem.

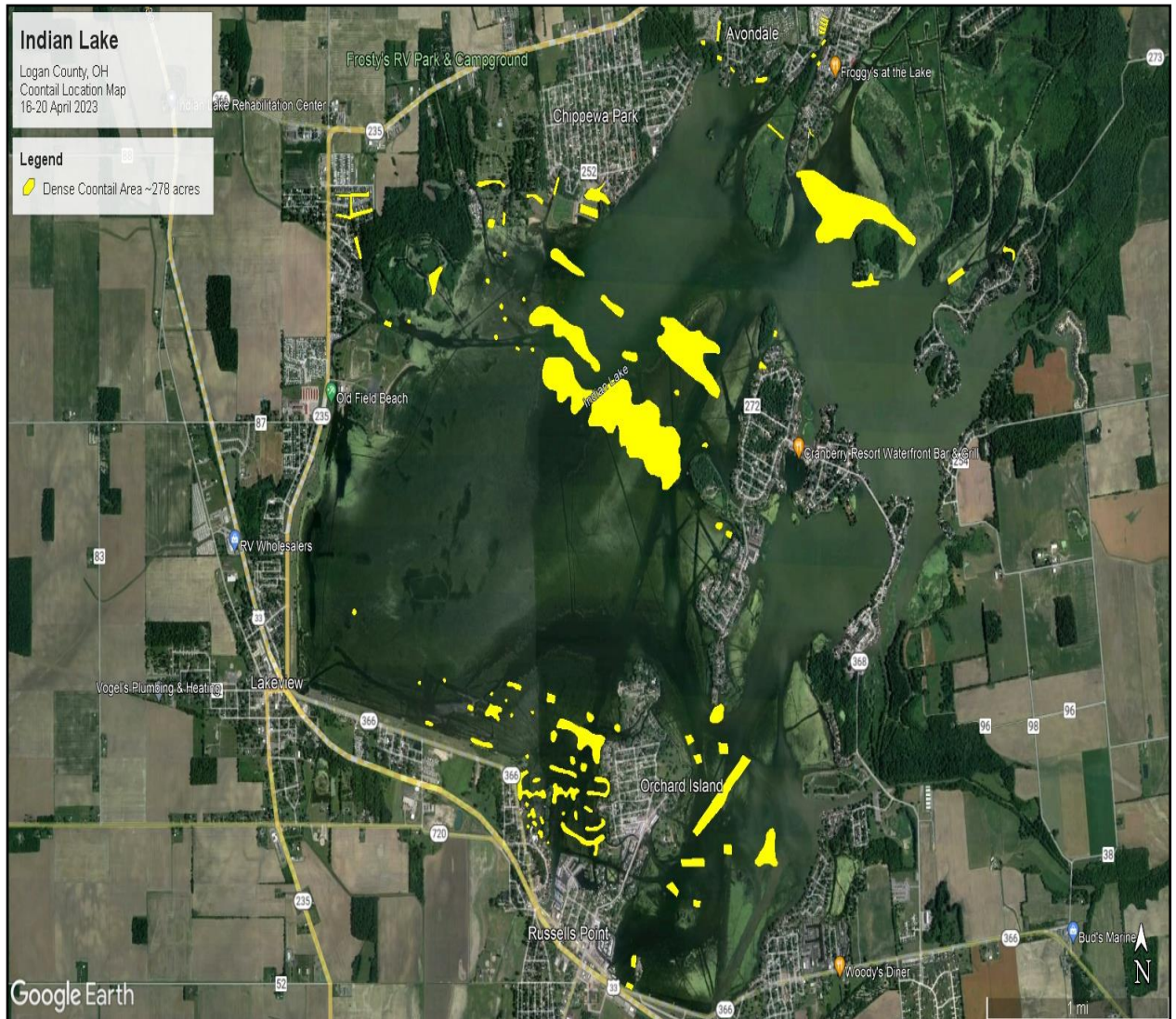
The 1973 Indian Lake EPA evaluation noted that macrophytes were common in nearshore shallow areas but did not mention the presence of macrophytes throughout the open waters. This may indicate that the previous state of Indian Lake was more dominated by algae and not as much by aquatic vegetation. Since the current quantities of aquatic vegetation are quite high, management of these plants must be highly selective and should not result in the removal of too much biomass as the lake may revert back to an algal-dominant state.



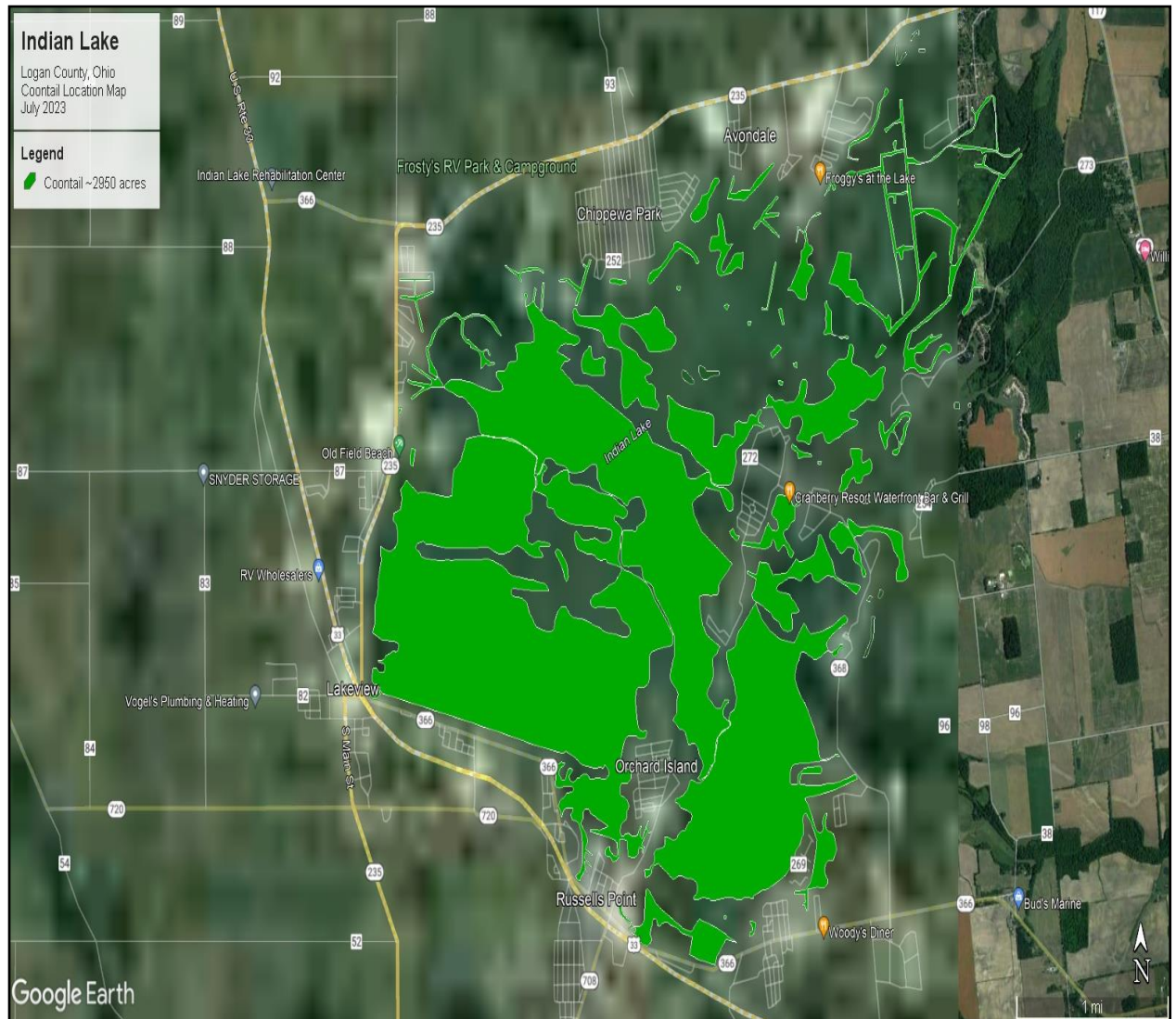
**Figure 22. Distribution of the native aquatic plant, Coontail, throughout Indian Lake, Logan County, Ohio (August 15-20, 2022).**



**Figure 23. Distribution of only common and dense areas of the native aquatic plant, Coontail, throughout Indian Lake (August 15-20, 2022). NOTE: These areas should be prioritized for removal through mechanical harvesting. Also note that removal of Coontail in the smaller polygon areas may not be recommended.**



**Figure 24. Distribution of only common and dense areas of the native aquatic plant, Coontail, throughout Indian Lake (April 16-20, 2023). NOTE: These areas should be prioritized for removal through mechanical harvesting. Also note that removal of Coontail in the smaller polygon areas may not be recommended.**



**Figure 25. Distribution of all areas of the native aquatic plant, Coontail, throughout Indian Lake (July 17-20, 2023). NOTE: Only dense areas should be prioritized for removal through mechanical harvesting in 2024 and these maps will be created by RLS after a spring, 2024 survey.**

**Table 21. Indian Lake native aquatic plant frequency (August 15-20, 2022).**

<i>Native Aquatic Plant Species Name</i>	<i>Native Aquatic Plant Common Name</i>	<i>Indian Lake Frequency</i>	<i>Native Aquatic Plant Growth Habit</i>
<i>Chara vulgaris</i>	Muskgrass	0.1	Submersed, Rooted
<i>Potamogeton pusillus</i>	Small-leaf Pondweed	0.1	Submersed, Rooted
<i>Stuckenia pectinata</i>	Sago Pondweed	11.6	Submersed, Rooted
<i>Potamogeton natans</i>	Floating-leaf Pondweed	0.1	Submersed, Rooted
<i>Potamogeton gramineus</i>	Variable-leaf Pondweed	0.3	Submersed, Rooted
<i>Zosterella dubia</i>	Water Stargrass	0.4	Submersed, Rooted
<i>Vallisneria americana</i>	Wild Celery	0.03	Submersed, Rooted
<i>Ceratophyllum demersum</i>	Coontail	73.9	Submersed, Non-Rooted
<i>Elodea canadensis</i>	Common Waterweed	5.9	Submersed, Rooted
<i>Utricularia vulgaris</i>	Bladderwort	0.03	Submersed, Non-Rooted
<i>Potamogeton guadalupensis</i>	Southern Naiad	0.03	Submersed, Rooted
<i>Nymphaea odorata</i>	White Waterlily	2.0	Floating-Leaved
<i>Nuphar variegata</i>	Yellow Waterlily	10.7	Floating-Leaved
<i>Lemna minor</i>	Duckweed	30.3	Floating-Leaved
<i>Nelumbo lutea</i>	Lotus	0.3	Floating-leaved
<i>Schoenoplectus acutus</i>	Bulrushes	0.2	Emergent
<i>Typha latifolia</i>	Cattails	7.9	Emergent
<i>Pontedaria cordata</i>	Pickerelweed	0.03	Emergent
<i>Decodon verticillata</i>	Swamp Loosestrife	3.0	Emergent
<i>Iris pseudacorus</i>	Yellow Iris	0.2	Emergent
<i>Cephalanthus occidentalis</i>	Buttonbush	0.03	Emergent

**Table 22. Indian Lake native aquatic plant relative abundance (August 15-20, 2022).**

<i>Native Aquatic Plant Species Name</i>	<i>Native Aquatic Plant Common Name</i>	<i>“a” level</i>	<i>“b” level</i>	<i>“c” level</i>	<i>“d” level</i>
<i>Chara vulgaris</i>	Muskgrass	2	0	0	0
<i>Potamogeton pusillus</i>	Small-leaf Pondweed	1	1	0	0
<i>Stuckenia pectinata</i>	Sago Pondweed	233	99	6	1
<i>Potamogeton natans</i>	Floating-leaf Pondweed	3	0	0	0
<i>Potamogeton gramineus</i>	Variable-leaf Pondweed	9	0	0	0
<i>Zosterella dubia</i>	Water Stargrass	12	1	0	0
<i>Vallisneria americana</i>	Wild Celery	1	0	0	0
<i>Ceratophyllum demersum</i>	Coontail	771	667	316	415
<i>Elodea canadensis</i>	Common Waterweed	107	52	11	2
<i>Utricularia vulgaris</i>	Bladderwort	1	0	0	0
<i>Potamogeton guadalupensis</i>	Southern Naiad	1	0	0	0
<i>Nymphaea odorata</i>	White Waterlily	24	15	12	7
<i>Nuphar variegata</i>	Yellow Waterlily	35	61	32	187
<i>Lemna minor</i>	Duckweed	433	227	110	119
<i>Nelumbo lutea</i>	Lotus	1	6	2	0
<i>Schoenoplectus acutus</i>	Bulrushes	3	2	0	0
<i>Typha latifolia</i>	Cattails	174	50	4	5
<i>Pontedaria cordata</i>	Pickerelweed	1	0	0	0
<i>Decodon verticillata</i>	Swamp Loosestrife	17	24	6	40
<i>Iris pseudacorus</i>	Yellow Iris	1	4	0	0
<i>Cephalanthus occidentalis</i>	Buttonbush	1	0	0	0

**Table 23. Indian Lake native aquatic plant relative abundance (April 16-20, 2023).**

<i>Native Aquatic Plant Species Name</i>	<i>Native Aquatic Plant Common Name</i>	<i>“a” level</i>	<i>“b” level</i>	<i>“c” level</i>	<i>“d” level</i>
<i>Chara vulgaris</i>	Muskgrass	1	1	0	0
<i>Potamogeton pusillus</i>	Small-leaf Pondweed	5	2	0	0
<i>Stuckenia pectinata</i>	Sago Pondweed	8	1	0	0
<i>Potamogeton</i> spp.	Thread-leaved Pondweed	2	0	0	0
<i>Ceratophyllum demersum</i>	Coontail	762	525	305	101
<i>Elodea canadensis</i>	Common Waterweed	10	3	1	0
<i>Utricularia vulgaris</i>	Bladderwort	1	0	0	0
<i>Najas guadalupensis</i>	Southern Naiad	2	0	0	0
<i>Najas flexilis</i>	Slender Naiad	1	2	0	0
<i>Myriophyllum sibiricum</i>	Northern Watermilfoil	2	1	0	0
<i>Nymphaea odorata</i>	White Waterlily	70	40	0	0
<i>Nuphar variegata</i>	Yellow Waterlily	10	32	28	100
<i>Brasenia schreberi</i>	Watershield	1	0	0	0
<i>Lemna minor</i>	Duckweed	26	1	0	0
<i>Wolffia</i>	Watermeal	8	2	0	0
<i>Nelumbo lutea</i>	Lotus	5	1	0	0
<i>Pontedaria cordata</i>	Pickerelweed	1	0	0	0
<i>Polygonum amphibium</i>	Water Smartweed	1	0	0	0
<i>Schoenoplectus acutus</i>	Bulrushes	1	0	0	0
<i>Typha latifolia</i>	Cattails	20	19	9	18
<i>Decodon verticillata</i>	Swamp Loosestrife	18	42	16	17
<i>Iris pseudacorus</i>	Yellow Iris	4	0	0	0
<i>Cephalanthus occidentalis</i>	Buttonbush	1	1	0	0

**Table 24. Indian Lake native aquatic plant frequency (April 16-20, 2023).**

<i>Native Aquatic Plant Species Name</i>	<i>Native Aquatic Plant Common Name</i>	<i>Indian Lake Frequency</i>	<i>Native Aquatic Plant Growth Habit</i>
<i>Chara vulgaris</i>	Muskgrass	0.1	Submersed, Rooted
<i>Potamogeton pusillus</i>	Small-leaf Pondweed	0.2	Submersed, Rooted
<i>Stuckenia pectinata</i>	Sago Pondweed	0.3	Submersed, Rooted
<i>Potamogeton</i> spp.	Thread-leaved Pondweed	0.1	Submersed, Rooted
<i>Ceratophyllum demersum</i>	Coontail	57.7	Submersed, Non-Rooted
<i>Elodea canadensis</i>	Common Waterweed	0.5	Submersed, Rooted
<i>Utricularia vulgaris</i>	Bladderwort	0.03	Submersed, Non-Rooted
<i>Najas guadalupensis</i>	Southern Naiad	0.1	Submersed, Rooted
<i>Najas flexilis</i>	Slender Naiad	0.1	Submersed, Rooted
<i>Myriophyllum sibiricum</i>	Northern Watermilfoil	0.1	Submersed, Rooted
<i>Nymphaea odorata</i>	White Waterlily	3.7	Floating-Leaved
<i>Nuphar variegata</i>	Yellow Waterlily	12.7	Floating-Leaved
<i>Brasenia schreberi</i>	Watershield	0.1	Floating-Leaved
<i>Lemna minor</i>	Duckweed	0.9	Floating-Leaved
<i>Wolffia</i> sp.	Watermeal	0.3	Floating-Leaved
<i>Nelumbo lutea</i>	Lotus	0.2	Floating-leaved
<i>Pontedaria cordata</i>	Pickerelweed	0.1	Emergent
<i>Polygonum amphibium</i>	Water Smartweed	0.1	Emergent
<i>Schoenoplectus acutus</i>	Bullrushes	0.1	Emergent
<i>Typha latifolia</i>	Cattails	2.2	Emergent
<i>Decodon verticillata</i>	Swamp Loosestrife	3.2	Emergent
<i>Iris pseudacorus</i>	Yellow Iris	0.1	Emergent
<i>Cephalanthus occidentalis</i>	Buttonbush	0.1	Emergent

**Table 25. Indian Lake native aquatic plant relative abundance (July 17-20, 2023).**

<i>Native Aquatic Plant Species Name</i>	<i>Native Aquatic Plant Common Name</i>	<i>“a” level</i>	<i>“b” level</i>	<i>“c” level</i>	<i>“d” level</i>
<i>Chara vulgaris</i>	Muskgrass	2	2	0	0
<i>Potamogeton pusillus</i>	Small-leaf Pondweed	39	16	0	0
<i>Stuckenia pectinata</i>	Sago Pondweed	309	185	81	27
<i>Potamogeton</i> spp.	Thread-leaved Pondweed	32	8	0	0
<i>Ceratophyllum demersum</i>	Coontail	1043	819	321	147
<i>Elodea canadensis</i>	Common Waterweed	107	52	11	2
<i>Utricularia vulgaris</i>	Bladderwort	1	1	0	0
<i>Najas guadalupensis</i>	Southern Naiad	1	0	0	0
<i>Najas flexilis</i>	Slender Naiad	4	1	1	0
<i>Myriophyllum sibiricum</i>	Northern Watermilfoil	1	1	0	0
<i>Nymphaea odorata</i>	White Waterlily	78	50	3	0
<i>Nuphar variegata</i>	Yellow Waterlily	29	120	83	141
<i>Brasenia schreberi</i>	Watershield	2	0	0	0
<i>Lemna minor</i>	Duckweed	295	143	46	27
<i>Wolffia</i>	Watermeal	9	16	0	0
<i>Nelumbo lutea</i>	Lotus	7	2	0	0
<i>Pontedaria cordata</i>	Pickerelweed	1	1	0	0
<i>Polygonum amphibium</i>	Water Smartweed	4	0	0	0
<i>Schoenoplectus acutus</i>	Bullrushes	1	0	0	0
<i>Typha latifolia</i>	Cattails	21	23	12	20
<i>Decodon verticillata</i>	Swamp Loosestrife	20	49	20	20
<i>Iris pseudacorus</i>	Yellow Iris	5	0	0	0
<i>Cephalanthus occidentalis</i>	Buttonbush	1	0	0	0

**Table 26. Indian Lake native aquatic plant frequency (July 17-20, 2023).**

<i>Native Aquatic Plant Species Name</i>	<i>Native Aquatic Plant Common Name</i>	<i>Indian Lake Frequency</i>	<i>Native Aquatic Plant Growth Habit</i>
<i>Chara vulgaris</i>	Muskgrass	0.1	Submersed, Rooted
<i>Potamogeton pusillus</i>	Small-leaf Pondweed	1.9	Submersed, Rooted
<i>Stuckenia pectinata</i>	Sago Pondweed	20.5	Submersed, Rooted
<i>Potamogeton</i> spp.	Thread-leaved Pondweed	1.4	Submersed, Rooted
<i>Ceratophyllum demersum</i>	Coontail	79.4	Submersed, Non-Rooted
<i>Elodea canadensis</i>	Common Waterweed	5.9	Submersed, Rooted
<i>Utricularia vulgaris</i>	Bladderwort	0.1	Submersed, Non-Rooted
<i>Najas guadalupensis</i>	Southern Naiad	0.03	Submersed, Rooted
<i>Najas flexilis</i>	Slender Naiad	0.6	Submersed, Rooted
<i>Myriophyllum sibiricum</i>	Northern Watermilfoil	0.1	Submersed, Rooted
<i>Nymphaea odorata</i>	White Waterlily	4.5	Floating-Leaved
<i>Nuphar variegata</i>	Yellow Waterlily	12.7	Floating-Leaved
<i>Brasenia schreberi</i>	Watershield	0.1	Floating-Leaved
<i>Lemna minor</i>	Duckweed	17.4	Floating-Leaved
<i>Wolffia</i> sp.	Watermeal	0.9	Floating-Leaved
<i>Nelumbo lutea</i>	Lotus	0.3	Floating-leaved
<i>Pontedaria cordata</i>	Pickerelweed	0.1	Emergent
<i>Polygonum amphibium</i>	Water Smartweed	0.1	Emergent
<i>Schoenoplectus acutus</i>	Bullrushes	0.03	Emergent
<i>Typha latifolia</i>	Cattails	2.6	Emergent
<i>Decodon verticillata</i>	Swamp Loosestrife	3.7	Emergent
<i>Iris pseudacorus</i>	Yellow Iris	0.2	Emergent
<i>Cephalanthus occidentalis</i>	Buttonbush	0.03	Emergent



**Figure 26. Chara  
(Muskgrass) ©RLS**



**Figure 27. Small-leaf  
Pondweed ©RLS**



**Figure 28. Sago  
Pondweed ©RLS**



**Figure 29. Thread-leaf  
Pondweed ©RLS**



**Figure 30. Coontail  
©RLS**



**Figure 31. Common  
Waterweed ©RLS**



**Figure 32. Bladderwort**  
©RLS



**Figure 33. Southern Naiad**  
©RLS



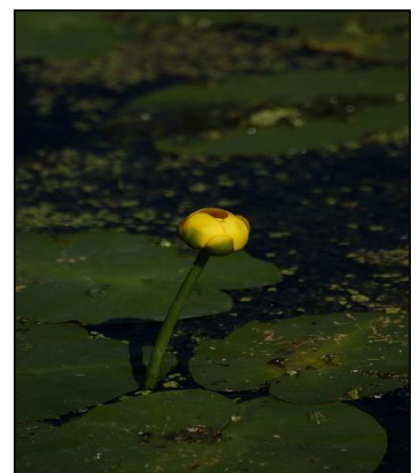
**Figure 34. Slender Naiad**  
©RLS



**Figure 35. Northern Watermilfoil**  
©RLS



**Figure 36. White Waterlily**  
©RLS



**Figure 37. Yellow Waterlily**  
©RLS



**Figure 38. Watershield**  
©RLS



**Figure 39. Duckweed**  
©RLS



**Figure 40. Watermeal**



**Figure 41. Lotus** ©RLS



**Figure 42. Pickerelweed**  
©RLS



**Figure 43. Water  
Smartweed** ©RLS



**Figure 44. Bulrushes**  
©RLS



**Figure 45. Cattails**  
©RLS



**Figure 46. Swamp  
Loosestrife** ©RLS



**Figure 47. Yellow Iris**  
©RLS



**Figure 48. Buttonbush**  
©RLS

## 4.2 Indian Lake Exotic Aquatic Macrophytes

Exotic aquatic plants (macrophytes) are not native to a particular site and are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially if the lake has public access sites), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem. Eurasian Watermilfoil (*Myriophyllum spicatum*; Figure 49) is an exotic aquatic macrophyte first documented in the United States in the 1880's (Reed 1997), although other reports (Couch and Nelson 1985) suggest it was first found in the 1940's. In recent years, this species has hybridized with native milfoil species to form hybrid species. Eurasian Watermilfoil has since spread to thousands of inland lakes in various states through the use of boats and trailers, waterfowl, seed dispersal, and intentional introduction for fish habitat. Eurasian Watermilfoil is a major threat to the ecological balance of an aquatic ecosystem through causation of significant declines in favorable native vegetation within lakes (Madsen et al. 1991), in that it forms dense canopies and may limit light from reaching native aquatic plant species (Newroth 1985; Aiken et al. 1979). Additionally, Eurasian Watermilfoil can alter the macroinvertebrate populations associated with particular native plants of certain structural architecture (Newroth 1985).

Hybrid watermilfoil (*Myriophyllum spicatum* var. *sibiricum*) is an exotic aquatic macrophyte that is a serious problem in many inland lakes. A similar watermilfoil species that is considered to be exotic by some scientists (*Myriophyllum heterophyllum*) in New Hampshire was found to have significant impacts on waterfront property values (Halstead et al., 2003). Moody and Les (2007) were among the first to determine a means of genotypic and phenotypic identification of the hybrid watermilfoil variant and further warned of the potential difficulties in the management of hybrids relative to the parental genotypes. It is commonly known that hybrid vigor is likely due to increased ecological tolerances relative to parental genotypes (Anderson 1948), which would give hybrid watermilfoil a distinct advantage to earlier growth, faster growth rates, and increased robustness in harsh environmental conditions. In regards to impacts on native vegetation, hybrid watermilfoil possesses a faster growth rate than Eurasian watermilfoil or other plants and thus may effectively displace other vegetation (Les and Philbrick 1993; Vilá et al. 2000).

Furthermore, the required dose of herbicides for successful control of the hybrid watermilfoil is likely to be higher since there is much more water volume at greater depths it can occupy and also due to the fact that hybrid watermilfoil has shown increased tolerance to traditionally used doses of systemic aquatic herbicides. There has been significant scientific debate in the aquatic plant management community regarding the required doses for effective control of hybrid watermilfoil.

On August 20, 2022 a total of N=20 stems of Eurasian Watermilfoil were collected in Indian Lake by RLS and submitted to the laboratory at Montana State University (U.S.A.) Plant fragments were dried with silica gel once they arrived to the Thum lab at Montana State University. Once the plants had dried, DNA identifications were then performed on each of the 20 plants. Eighteen out of the 20 plants were found to be a widespread pure Eurasian Watermilfoil (*Myriophyllum spicatum*) with two plants unsuitable for testing.

Approximately 1,900 acres of Eurasian Watermilfoil were found in Indian Lake during the August 15-20, 2022 survey and 1,122 acres were found during the April 16-20, 2023 survey. Targeted ProcellaCOR® aquatic herbicide treatments at a dose of 2.2 PDUs during the spring/summer of 2023 resulted in only 20.7 acres of watermilfoil remaining during the July 17-20 survey, which is a highly favorable outcome. Figures 50-52 below display the distribution of milfoil throughout Indian Lake in 2022-2023.

A detailed spring, 2024 survey will determine how much watermilfoil should be removed with treatments in 2024. As previously noted, Eurasian Watermilfoil growth in Indian Lake is capable of producing dense surface canopies in shallow areas which would include the majority of the area in Indian Lake. Exotic aquatic plant species that have been found in Indian Lake are shown in tables 27-29 below and discussions of key invasives also follow below.



**Figure 49. Eurasian Watermilfoil plant with seed head and lateral branches (©RLS).**

**Table 27. Indian Lake exotic aquatic plant species (August 15-20, 2022).**

<i>Exotic Aquatic Plant Species</i>	<i>Exotic Aquatic Plant Common Name</i>	<i>Exotic Aquatic Plant Growth Habit</i>	<i>Abundance in or around Indian Lake</i>
<i>Myriophyllum sibiricum</i>	Eurasian Watermilfoil	Rooted, Submersed	~1,900 acres
<i>Potamogeton crispus</i>	Curly-leaf Pondweed	Rooted, Submersed	1 location
<i>Lythrum salicaria</i>	Purple Loosestrife	Emergent	12 locations
<i>Phragmites australis</i>	Giant Reed	Emergent	3 locations

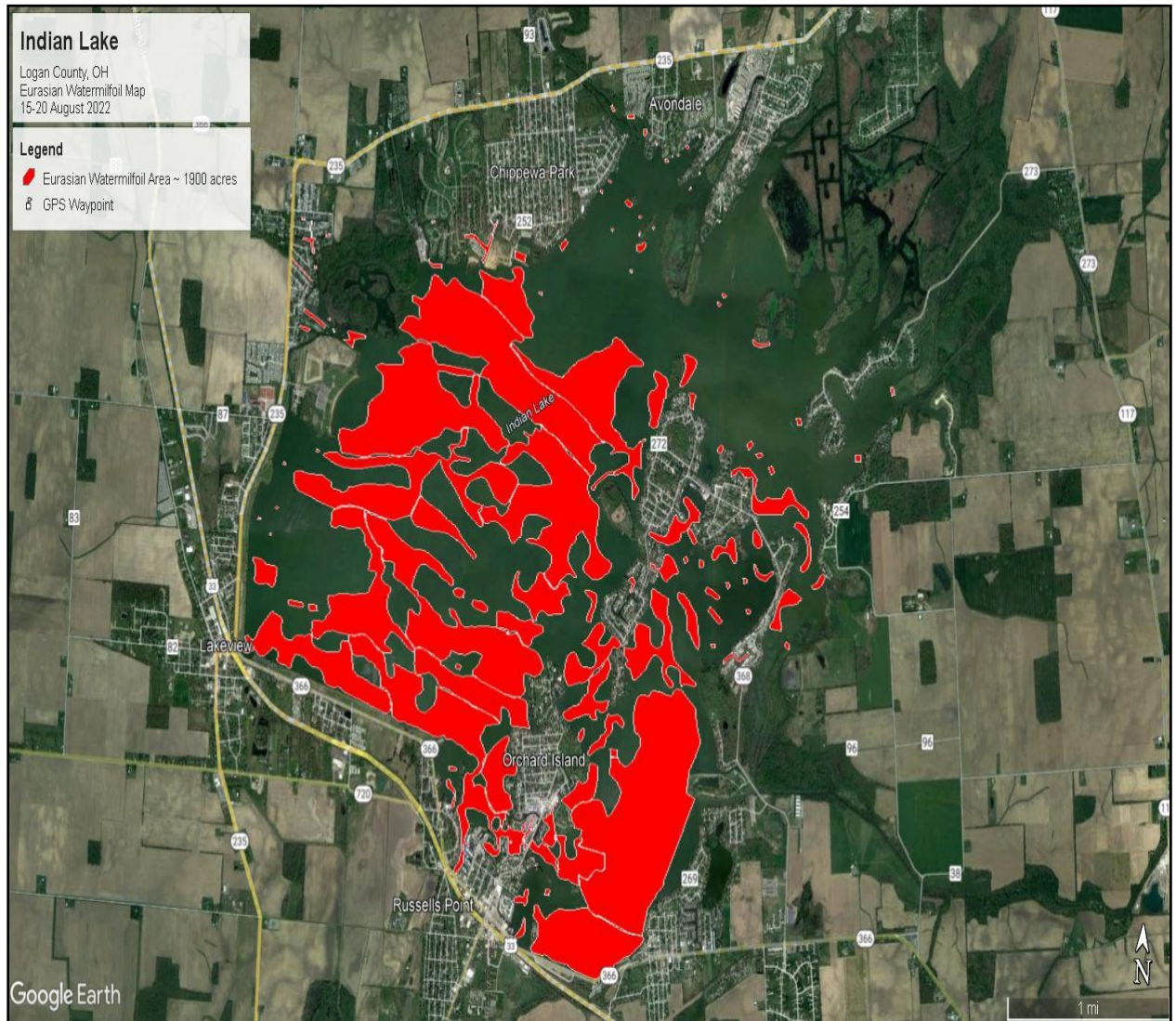
Note: The location(s) of Curly-leaf Pondweed has/have been reported to be much higher earlier in the season and thus this plant should be watched. Turion seed pods are best removed with mechanical harvesting.

**Table 28. Indian Lake exotic aquatic plant species (April 16-20, 2023).**

<i>Exotic Aquatic Plant Species</i>	<i>Exotic Aquatic Plant Common Name</i>	<i>Exotic Aquatic Plant Growth Habit</i>	<i>Abundance in or around Indian Lake</i>
<i>Myriophyllum sibiricum</i>	Eurasian Watermilfoil	Rooted, Submersed	1,122 Acres
<i>Potamogeton crispus</i>	Curly-leaf Pondweed	Rooted, Submersed	1,821 Acres
<i>Lythrum salicaria</i>	Purple Loosestrife	Emergent	12 locations
<i>Phragmites australis</i>	Giant Reed	Emergent	3 locations

**Table 29. Indian Lake exotic aquatic plant species (July 17-20, 2023).**

<i>Exotic Aquatic Plant Species</i>	<i>Exotic Aquatic Plant Common Name</i>	<i>Exotic Aquatic Plant Growth Habit</i>	<i>Abundance in or around Indian Lake</i>
<i>Myriophyllum sibiricum</i>	Eurasian Watermilfoil	Rooted, Submersed	20.7 Acres
<i>Potamogeton crispus</i>	Curly-leaf Pondweed	Rooted, Submersed	<1.0 Acre
<i>Lythrum salicaria</i>	Purple Loosestrife	Emergent	12 locations
<i>Phragmites australis</i>	Giant Reed	Emergent	3 locations



**Figure 50. EWM distribution in Indian Lake, Logan County, Ohio (August 15-20, 2022).**





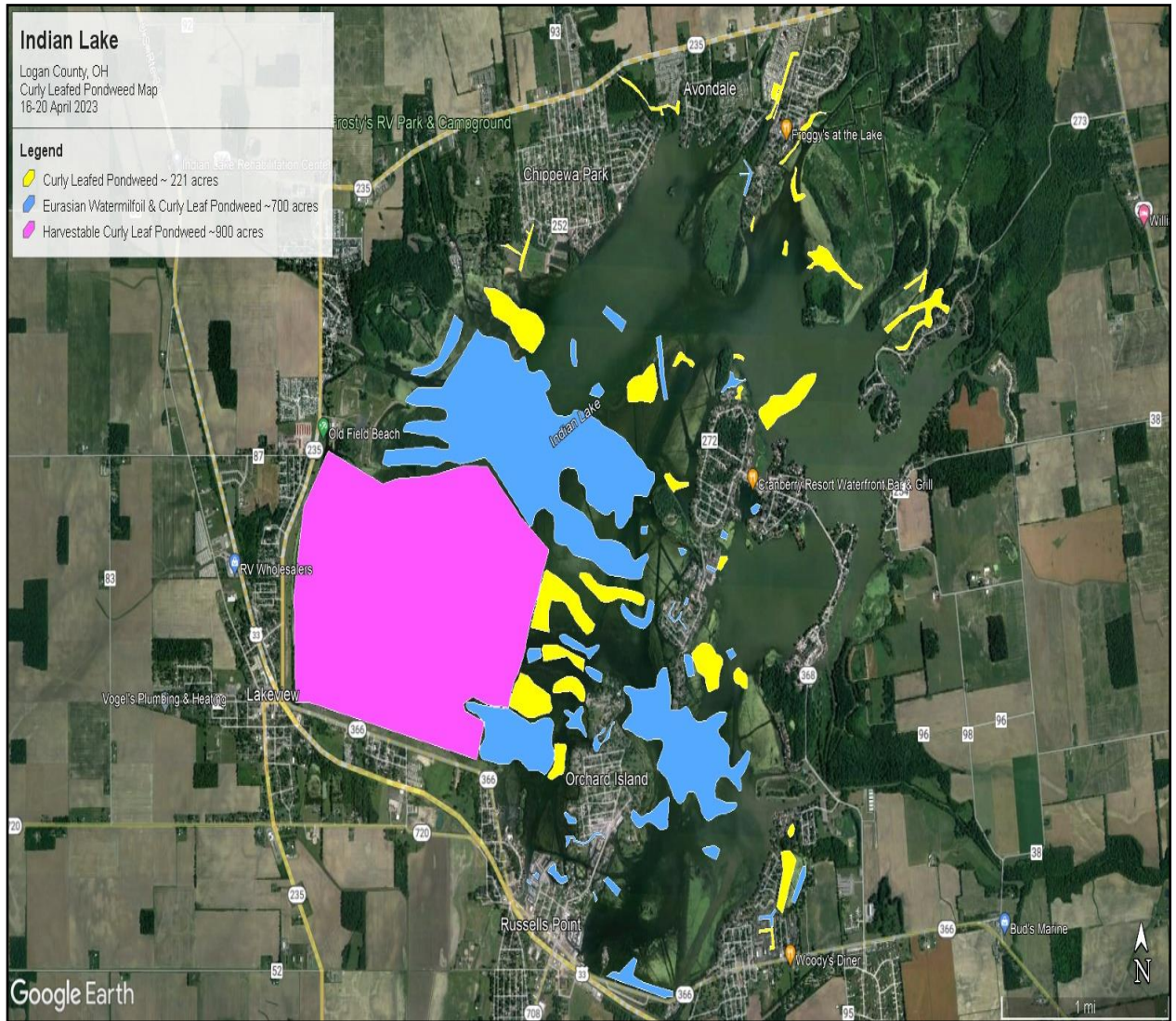
Curly-leaf Pondweed (*Potamogeton crispus*; Figure 53) is an exotic, submersed, rooted aquatic plant that was introduced into the United States in 1807 but was abundant by the early 1900's. It is easily distinguished from other native pondweeds by its wavy leaf margins. It grows early in the spring and as a result may prevent other favorable native aquatic species from germinating. The plant reproduces by the formation of fruiting structures called turions (Figure 54). The plant does not reproduce by fragmentation as milfoil does; however, the turions may be deposited in the lake sediment and germinate in following seasons. Fortunately, the plant naturally declines around mid-July in most lakes and thus is not likely to be prolific throughout an entire growing season. Curly-leaf Pondweed is a pioneering aquatic plant species and specializes in colonizing disturbed habitats. It is highly invasive in aquatic ecosystems with low biodiversity and unique sediment characteristics. It was present in Indian Lake but was not abundant at the time of the August 2022 survey. The April 2023 survey determined that approximately 1,821 acres of Curly-leaf Pondweed were present (Figure 55). Since it is also invasive, it was harvested due to its heavy presence during the spring and summer of 2023. Management for future invasions could include mechanical harvesting to remove the turion seed pods. The July, 2023 survey determined that the only significant remaining quantities of the pondweed were present in the canals and occupied less than 1 acre overall.



**Figure 53. Curly-leaf Pondweed (*Potamogeton crispus* L.).**



**Figure 54.** A turion (seed pod) from Curly-leaf Pondweed in Indian Lake (RLS, April, 2023).



**Figure 55. CLP distribution in Indian Lake, Logan County, Ohio (April 16-20, 2023). Note: The only locations in July of 2023 that had CLP were the canals and thus a map was not created.**

The Common Reed (*Phragmites australis*; Figure 56) is an imminent threat to the surface area and shallows of the lake since it may grow submersed in water depths of  $\geq$  two meters (Herrick and Wolf, 2005), thereby drying up wetland habitat and reducing lake surface area. In addition, large, dense stands of *Phragmites* accumulate sediments, reduce habitat variability, and impede natural water flow (Wang et al., 2006). This plant was found in three locations around Indian Lake and should be manually removed.



**Figure 56. Common Reed (*Phragmites australis*).**

Purple Loosestrife (*Lythrum salicaria*; Figure 57) is an invasive (exotic) emergent aquatic plant that inhabits wetlands and shoreline areas and was found in thirty locations around the shoreline of Indian Lake. *L. salicaria* has showy magenta-colored flowers that bloom in mid-July and terminate in late September. The seeds are highly resistant to tough environmental conditions and may reside in the ground for extended periods of time. It exhibits rigorous growth and may out-compete other favorable native emergents such as Cattails (*Typha latifolia*) or native Swamp Loosestrife (*Decodon verticillatus*) and thus reduce the biological diversity of localized ecosystems. The plant is spreading rapidly across the United States and is converting diverse wetland habitats to monocultures with substantially lower biological diversity. Lake residents should be educated about its invasiveness and threat to the health of the Indian Lake ecosystem. This plant may be removed by hand pulling or using a shovel to remove the roots and then discarding the plant into the garbage if it is discovered to avoid further infestation. If the plant is not promptly removed by hand, it could dominate in wetland areas and require larger-scale systemic herbicide treatments. Figure 58 shows the distribution of *Phragmites* and Purple Loosestrife, the two invasive emergent aquatic plants found along the shoreline Indian Lake.



**Figure 57. Purple Loosestrife (*Lythrum salicaria* L.).**



## 5.0 INDIAN LAKE IMPROVEMENT & RESTORATION METHODS

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Lake improvement and restoration methods are needed for the current and future health and ecological balance of Indian Lake. Such improvements consist of strategies to reduce invasive aquatic plants, reduce the transport of invasive species, reduction of nuisance algae (both dense *Pithophora* and cyanobacteria), improvements in water clarity, reductions in lake sedimentation and nutrient transport, community education, and proper immediate watershed management. The following sections discuss feasible options that offer useful and effective methods for improving the overall condition of Indian Lake. It is critical to realize that some improvements to Indian Lake have already occurred relative to 1973 lake conditions; however, the lake is still hyper-eutrophic and much more needs to be implemented. Some efforts such as reduction in invasive aquatic vegetation and removal of dense areas of nuisance Coontail will yield relatively quicker results than some other recommended improvements related to water quality. It is also important for the community to have realistic expectations for Indian Lake. The lake will never be pristine, but the degree of hyper-eutrophy can be reduced over time to yield a lake that is balanced and acceptable for recreational, navigational uses and for enhancement of property values. Thus, the ultimate goals of a Lake Management Plan (LMP) such as this are to increase water quality, increase favorable wildlife habitat and aquatic plant and animal biodiversity, optimize recreational use, and protect property values. Regardless of the management goals, all management decisions must be site-specific and should consider the socio-economic, scientific, and environmental components of the LMP such as within this LMP.

### 5.1 Indian Lake Aquatic Plant Management

The management of submersed invasive aquatic plants is necessary in Indian Lake due to accelerated growth, spread, and distribution. Additionally, highly selective management of the native rootless aquatic plant Coontail is also recommended in areas of “c” and “d” level densities. It is imperative to realize that this plant does serve a critical function in the Indian Lake ecosystem in that it allows the lake to remain in a macrophyte (aquatic plant) dominated state, especially once the Eurasian Watermilfoil is significantly reduced. Removal of too much Coontail may allow for the lake to regress back to an algal-dominant state as it was in 1973. It is important not to remove too much Coontail due the following scientific findings:

1. Coontail reduces phytoplankton development (Mjelde and Faafng, 2003); however, *Microcystis* algae can have toxic effects on the ability of Coontail to tolerate biotic stress (Ujvarosi et al., 2019).
2. Coontail improves water quality by reducing turbidity, total phosphorus, ammonia nitrogen, and chlorophyll-a with an ideal coverage of 20% (Yanran et al., 2012).
3. Coontail is linked to an abundance of macroinvertebrates relative to EWM (Bogut et al., 2010)

Management options should be environmentally and ecologically-sound and financially feasible. Options for control of aquatic plants are limited yet are capable of achieving strong results when used properly. Implementation of more growth of favorable native aquatic plants (especially the low growing native plants) in Indian Lake to provide for a healthier lake is recommended though this may require significant increases in water clarity along with reductions in invasive plant cover. All aquatic vegetation should be managed with solutions that will yield the longest-term results. A detailed Early Detection Rapid Response (EDRR) protocol is recommended for Indian Lake for each invasive species that could enter the lake in the future. RLS can assist the ODNR with development of this in 2024. The following sections detail invasive species prevention and community education.

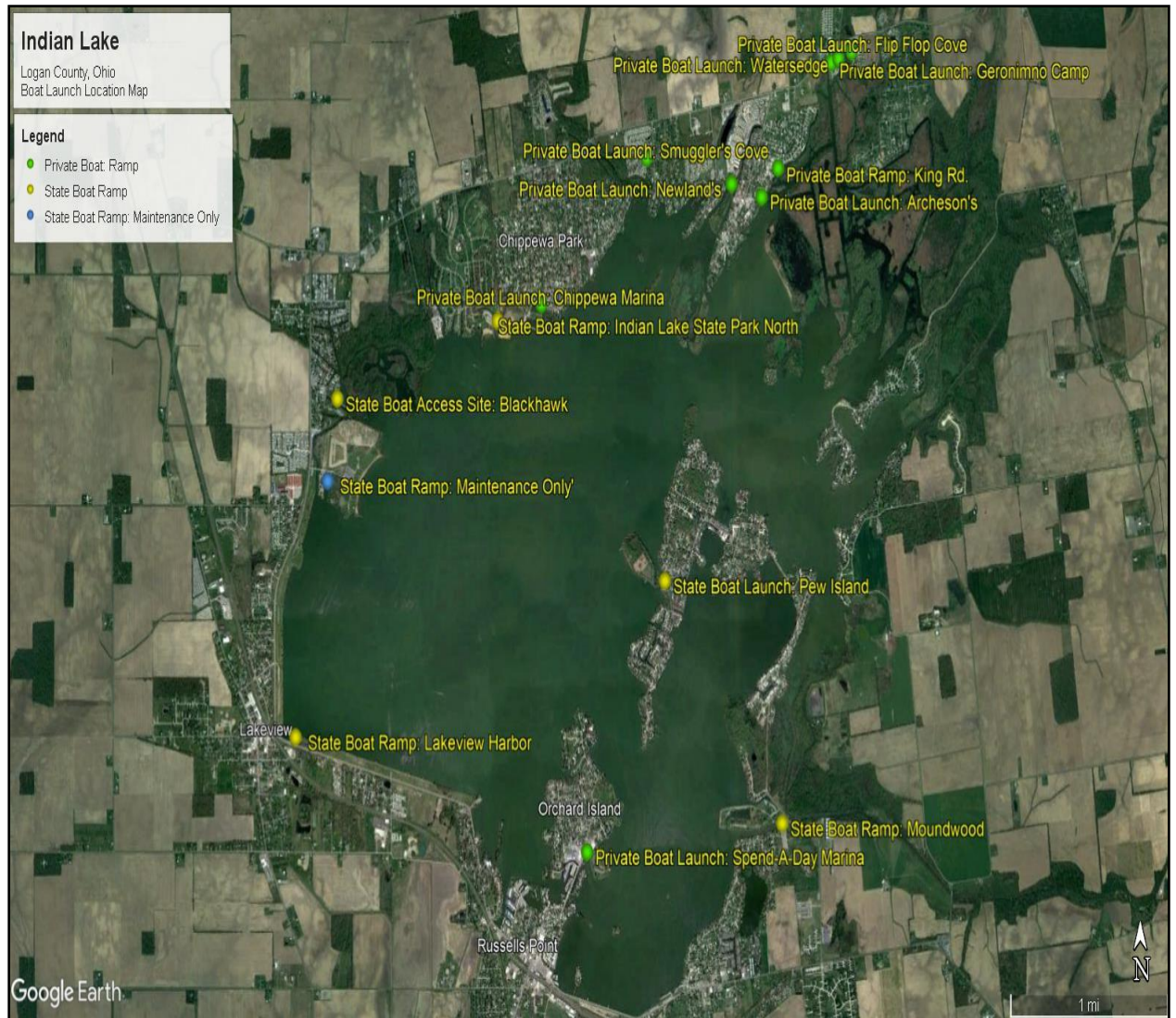
### ***5.1.1 Aquatic Invasive Species Prevention***

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

The first ingredient to successful prevention of unwanted transfers of exotic species to Indian Lake is awareness and education. The majority of the exotic species of concern have been listed in this report. Other exotic species on the move could be introduced to the riparians around Indian Lake through a local community educational workshop or other educational events and should be included in an EDRR document. RLS noted the abundance of AIS signage at local public access sites and still recommends a boat washing station if permitted (Figure 59). Ideally, AIS signs should be placed at all access sites listed in Figure 60 below.



**Figure 59.** A public boat washing station for boat access sites.



**Figure 60. Boat launch access entry locations around Indian Lake, Logan County, Ohio.**

The recommended prevention protocols for further introduction of invasive species includes steam-washing all boats, boat trailers, jet-skis, and floaters prior to placing them into Indian Lake. Fishing poles, lures, and other equipment used in other lakes (and especially the Great Lakes) should also be thoroughly steam-washed before use in Indian Lake. Additionally, all solid construction materials (if recycled from other lakes) must also be steam-washed. Boat transom wells must always be steam-washed and emptied prior to entry into the lake. Excessive waterfowl should also be discouraged from the lake since they are a natural transportation vector of invasive microscopic larvae.

During the July 16-20, 2023 whole-lake survey, RLS found one location in the center of the lake that contained the invasive species *Hydrocotyle* sp., or Water Pennywort (Figure 61). This plant is capable of spreading throughout the lake with particular suitability for the canals. RLS immediately discarded this plant specimen (Figure 62) and did not find any other specimens during the entire lake survey. Vigilance is needed however and supports the need for whole-lake inventories each season to prepare for an EDRR protocol if a new invasive species is found. If this or any other rare invasive species is found in the lake, a GPS coordinate should be taken, and the plant should be discarded and not placed back into the lake.



**Figure 61. Invasive *Hydrocotyle* from Indian Lake (©RLS, 2023).**



**Figure 62. Discarded *Hydrocotyle* in Indian Lake (RLS, 2023).**

### ***5.1.2 Aquatic Herbicides, Algaecides, and Applications***

The use of aquatic chemical herbicides is regulated and requires a permit with application by a licensed aquatic herbicide applicator. Aquatic herbicides are generally applied via an airboat or skiff equipped with mixing tanks and drop hoses (Figure 63). 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.

Contact herbicides such as diquat, flumioxazin, and hydrothol cause damage to leaf and stem structures; whereas systemic herbicides are assimilated by the plant roots and are lethal to the entire plant. Wherever possible, it is preferred to use a systemic herbicide for longer-lasting aquatic plant control of invasives. In Indian Lake, the use of contact herbicides (such as diquat and flumioxazin) would be highly discouraged since those offer short-term control of plants and are most commonly used on nuisance native aquatic plant species. Most native aquatic plants within Indian Lake are very sparse and should all be protected. Coontail should be managed with mechanical means only in dense areas and not with the use of contact herbicides. Coontail is more effectively controlled through mechanical removal.

Algaecides such as copper sulfate should also be avoided on Indian Lake. Copper accumulates in lake sediments and bio-persists over time. It is harmful to sediment biota and can be released into the water column with sediment perturbations. Planktonic algae in the water column are best reduced with nutrient reductions from the watershed and possible use of nutrient inactivation methods. Treatment of blue-green algal blooms with copper is highly discouraged as this can make the algae population aggressively rebound. Dense, surface-matted algae such as *Pithophora* could best be removed with mechanical harvesters. These mats are so dense that not all copper would reach the entire mat and result in the mat disappearance.

Systemic herbicides such as 2, 4-D and triclopyr are two systemic herbicides that have been used for a long time to treat milfoil that occurs in a scattered distribution. Fluridone (trade name, SONAR<sup>®</sup>) is a systemic whole-lake herbicide treatment that is applied to the entire lake volume in the spring and is used for extensive infestations. The objective of a fluridone treatment is to selectively control the growth of milfoil in order to allow other native aquatic plants to germinate and create a more diverse aquatic plant community. Fluridone would be recommended for Indian Lake but there are many unknowns relative to lake inflow rates, degree of organic complexation, and need for subsequent post-treatment re-applications with currently undetermined concentration needs. Triclopyr exists in the liquid and granular form, but all liquid would not be recommended in Indian Lake due to the high energy dynamics present in the lake (i.e., wave activity, boats, wind), and also the granular form is lightweight and may drift. Granular 2,4-D (trade names Navigate<sup>®</sup>, Sculpin G<sup>®</sup>) are possible systemic granular herbicides that have demonstrated efficacy on numerous lakes. In recent years, a new aquatic herbicide called ProcellaCOR<sup>®</sup> has been used with great efficacy in longer-term control of Eurasian Watermilfoil. ProcellaCOR<sup>®</sup> was used in Indian Lake in July-August of 2022 on a total of 500 acres of milfoil present in Indian Lake. Evaluation of the efficacy of these treatments were conducted in April, 2023 with no milfoil present in those treatment areas.

If an additional herbicide is recommended for the milfoil along with ProcellaCOR<sup>®</sup>, then use of 2,4-D would be recommended. The dose of 2,4-D most likely to be effective would be around 200 pounds per acre (200#/acre).

Prior to the 2023 spring/summer Indian Lake herbicide treatments, RLS collaborated with the ODNR and Aqua Docs to decide on a treatment protocol. The selected protocol consisted of the determination of treatment zones to allow for adequate uptake of the ProcellaCOR<sup>®</sup> product at 2.2 PDUs and allow for individual areas of dense biomass to decay slowly to reduce the possibility of oxygen depletion throughout the whole lake (Figure 64). This process was able to prevent oxygen depletion throughout the season and allow for the re-colonization of favorable, low-growing native aquatic plants.



**Figure 63. A boat used to apply aquatic herbicides in inland lakes (©RLS).**



Mechanical harvesting is usually not recommended for the removal of Eurasian Watermilfoil since the plant may fragment when cut and re-grow on the lake bottom. Additionally, it is often not practical for very large lakes, given the long transfer times to offload harvested vegetation. Fortunately, Indian Lake utilizes a few offload/transfer sites with multiple harvesting machines to reduce this transfer time and increase removal efficacy. Mechanical harvesting should be a long-term method of managing both surface *Pithophora* mats and dense areas of Coontail.



**Figure 65. A mechanical harvester used to remove aquatic plants in Indian Lake (©RLS).**

#### **5.1.4 Diver Assisted Suction Harvesting (DASH)**

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 66) involves hand removal of individual plants by a SCUBA diver in selected areas of lake bottom with the use of a hand-operated suction hose. Samples are dewatered on land or removed via fabric bags to an offsite location. This method is costly on a large scale and so it is used on a spot-removal basis or in canals.

Because this activity may cause re-suspension of sediments (Nayar et al., 2007), increased turbidity and reduced clarity of the water can occur. Permitting requirements typically include the use of a turbidity curtain that reduce the transport of solids to locations outside of treatment areas and also help define areas where intensive aquatic vegetation removal efforts are being implemented. This method could have practical applications for areas of dense vegetation in canals where harvesting is limited by depth or area.



**Figure 66. A DASH boat used for aquatic plant removal (©RLS).**

## 5.2 Indian Lake Water Quality Improvements

In addition to lake improvement methods that improve the aquatic plant communities through prevention and selective control of invasive aquatic plant species, there are methods to improve the water quality within the lake basin. Such improvements consist of possible nutrient inactivation, dredging, continued watershed improvements, and community education. A survey of approximately 485 riparians that represented five lakes in Kalamazoo County, Michigan, USA, was conducted in 2002 by Lemberg *et al.* (2002) and revealed that the most important benefit of lakefront ownership was the vista. This value may be quite substantial for the Indian Lake community.

### 5.2.1 Indian Lake Erosion, Sediment Control, and Dredging

In addition to the proposed protection of native aquatic plants and control of invasives in Indian Lake, it is recommended that BMP's be implemented to improve the lake's water quality relative to sedimentation. Best Management Practices (BMPs) are land management practices that treat, prevent, or reduce water pollution. Structural BMPs are physical improvements that require construction during installation. Examples of structural BMPs include check dams, detention basins, and rock riprap. BMPs that utilize plants to stabilize soils, filter runoff, or slow water velocity are categorized as Vegetative BMPs. Managerial BMPs involve changing operating procedures to lessen water quality impairments. Conservation tillage and adoption of ordinances are examples of these types of BMPs. For inland lakes, the emphasis should be on BMPs that are designed to reduce storm water volume, peak flows, and/or nonpoint source pollution through proper storm water management and erosion control practices. Below is a summary of BMPs that are designed to meet these requirements. Identifying opportunities for implementation of BMPs is based on several factors including stakeholder willingness/preferences, cost, time, and effectiveness of specific management options. 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 (those > 6%).
- 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. Osborne and Wiley (1988) emphasize the importance of maintaining a healthy vegetation buffer zone around a water body to protect it from land use activities that contribute nutrient and sediment loads.
- 3) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion.
- 4) Planting only native genotype plants (those native to Indian Lake or the region) around the lake since they are most likely to establish and thrive than those not acclimated to growing in the area soils. A local horticultural supply center would likely have a list of these species.

- 5) 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.
- 6) Any wetland areas around Indian Lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat. This would include areas with dense floating-leaved vegetation such as lily pads.
- 7) Erosion of soils into the water may lead to increased turbidity and nutrient loading to the lake. Seawalls should consist of rip-rap (stone, rock), rather than metal or concrete, due to the fact that rip-rap offers a more favorable habitat for lakeshore organisms, which are critical to the ecological balance of the lake ecosystem. Rip-rap should be installed in front of areas where metal seawalls are currently in use. The rip-rap should extend into the water to create a presence of microhabitats for enhanced biodiversity of the aquatic organisms within Indian Lake. The emergent aquatic plant bulrushes present on Indian Lake offer some satisfactory stabilization of shoreline sediments and assists in the minimization of sediment release into the lake. All other emergent aquatic plants such as Cattails and Swamp Loosestrife should also be preserved. Figure 67 below displays a shoreline in a canal with significant erosion. There are many areas around Indian Lake that have visible erosion, and most are found in the canals or around islands.
- 8) Discourage the use of wake boats in the lake as they have been determined by the Michigan Department of Natural Resources (MDNR) to produce 1.7-17 times the wave energy created by other boats of similar size. These boats also make contact with the lake bottom further contributing to suspension of sediments in the water column.
- 9) A detailed shoreline erosion survey is recommended to determine all possible sources of soil transport to Indian Lake during heavy rainfall events.



**Figure 67. Shoreline erosion on an Indian Lake canal (July, 2023).**

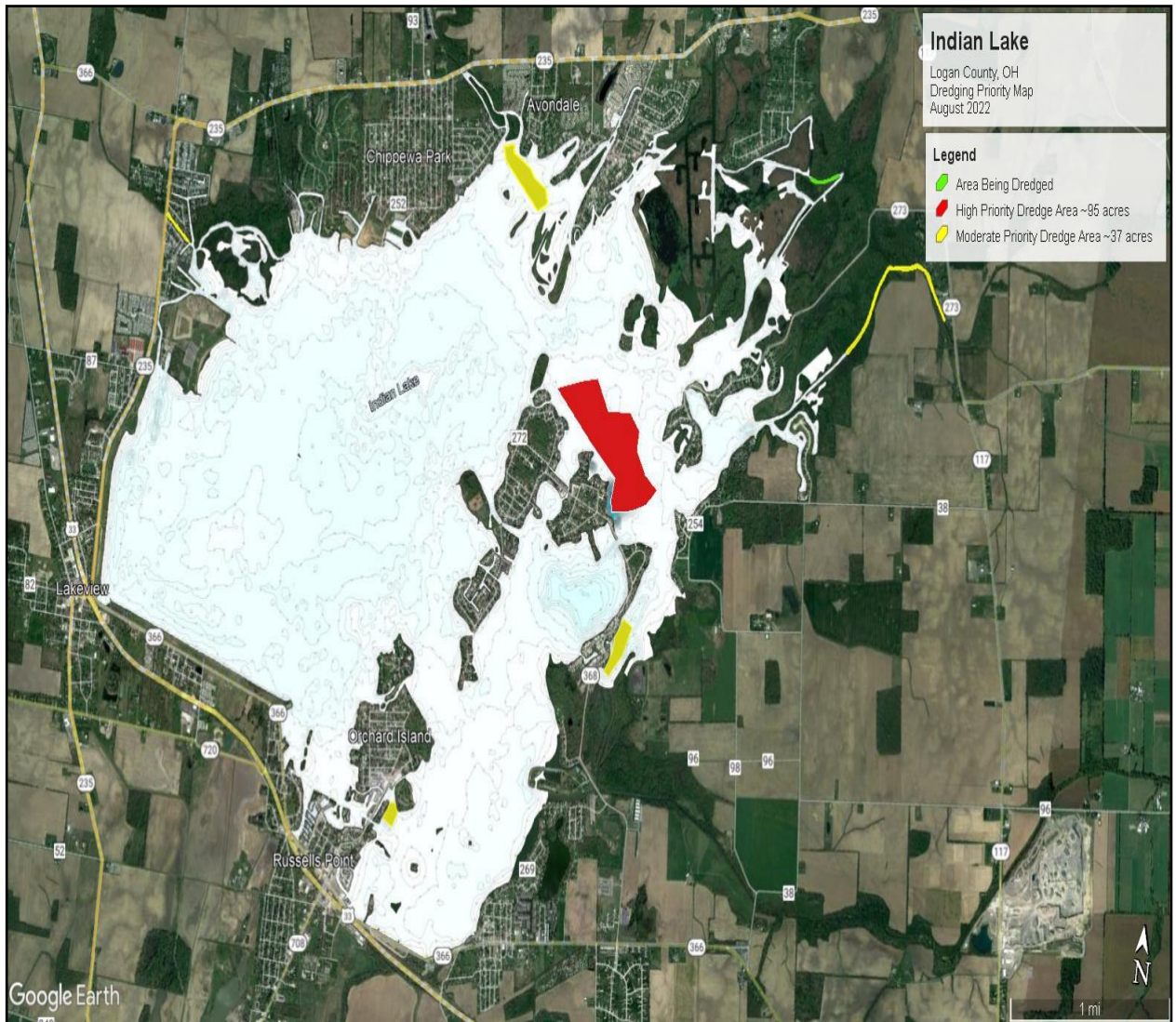
***Dredging for Removal of Indian Lake Excess Sediments:***

Dredging is a lake management option used to remove accumulated lake sediments to increase accessibility for navigation and recreational activities. Dredging is subject to permitting by the U.S. Army Corps of Engineers (USACE), and Ohio department of Natural Resources (ODNR). The two major types of dredging include hydraulic and mechanical methods. A mechanical dredge usually utilizes a backhoe and requires that the disposal site be adjacent to the lake. In contrast, a hydraulic dredge removes sediments in an aqueous slurry and the wetted sediments are transported through a hose to a confined disposal facility (CDF) or along the shores of Indian Lake. If the latter sites are utilized for disposal of dredged spoils, care must be taken to assure that these soils will not be transferred back into the lake during heavy storm events.

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

Dredge spoils cannot usually be emptied into wetland habitats; therefore, a large upland area is needed for lake areas that are surrounded by wetland habitats. Furthermore, this activity may cause re-suspension of sediments (Nayar et al., 2007) which may lead to increased turbidity and reduced clarity of the water. In addition, proposed sediment for removal must usually be tested for metal contaminants before being stored in a CDF.

Dredging is a very costly operation with an average dredging cost of \$30-50 per cubic yard. Dredging has been used extensively in the past on Indian Lake and should be considered in prioritized areas. RLS recommends the areas in Figure 68 be dredged in the future to allow for continued navigation as these areas have demonstrated very shallow depths and suspension of sediments with normal boating activities. Some of these areas were dredged in 2023 with measurable success. Dredging may also be needed in the future for canals or additional shallow areas prone to siltation. All impacts that larger scale dredging may have on the lake ecology should also be investigated.



**Figure 68.** A prioritized dredging map based on critically shallow depths (RLS data, 2022), and previously submitted data from the ILWP on recorded sediment thickness.

### 5.2.2 *Indian Lake Nutrient Source Control*

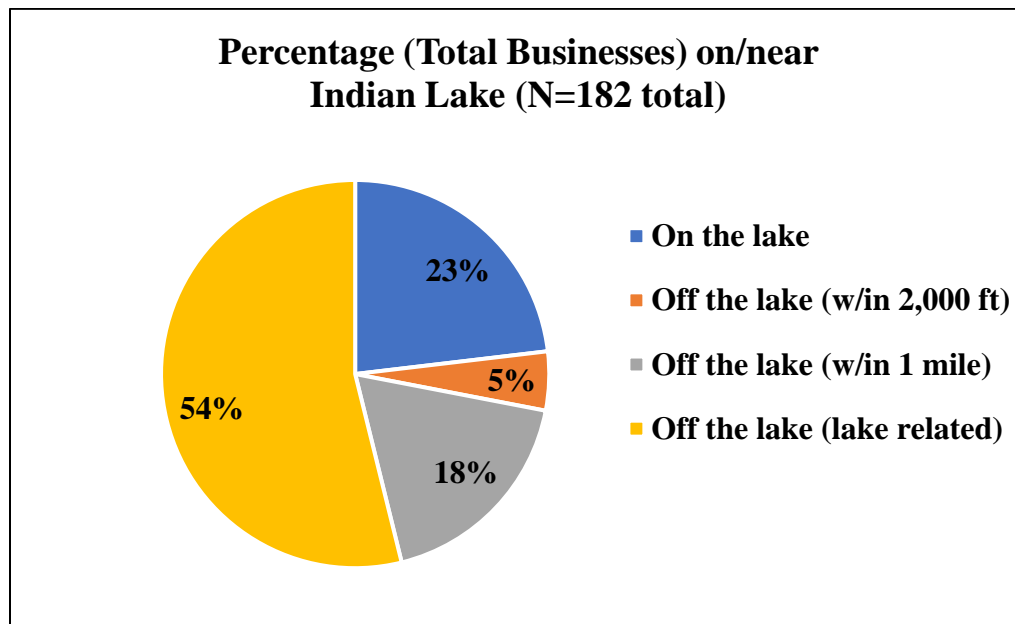
Additional inputs of phosphorus to the lake are likely to create more algal and aquatic plant growth. This defines a P-limited aquatic ecosystem. Accordingly, RLS recommends the following procedures to protect the water quality of Indian Lake:

- 1) 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. Education of riparians on this issue is important as is understanding what they may use for fertilizers and where they are purchased. Whenever possible, water lawns with lake water to recycle water and reduce nutrients in the lake.
- 2) Preserve riparian vegetation buffers around the lake (such as those that consist of Cattails, Bulrushes), since they act as a filter to catch nutrients and pollutants that occur on land and may run off into the 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. Valuable information can be found on the Michigan Natural Shoreline Partnership website at: [www.mishorelinepartnership.org](http://www.mishorelinepartnership.org)
- 3) 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 dissolved and utilized by aquatic vegetation and algae.
- 4) Assure all areas that drain into the lake from the surrounding land are vegetated and that no fertilizers are used in areas with saturated soils.
- 5) Never dump any solvents, chemicals, or debris into the lake. These can all harm fish, wildlife, and humans.
- 6) Never dump leaves or chemicals into storm drains as these often lead to waterways.
- 7) Allow trees to grow near the shoreline for erosion control but be sure to rake away leaves in the fall. Do not rake leaves into the lake and instead dispose of leaves as yard waste.
- 8) Do not feed any waterfowl. Although this is enjoyable, they have plenty of food in the lake and their feces are all high in nutrients and bacteria. A large population of cormorants was noted during this evaluation period.

- 9) Do not allow any rubber from water balloons, firework debris, plastic, Styrofoam, or food containers to enter the lake. Most of this will require hundreds of years to break down and is harmful to the lake.
- 10) Be a responsible lake steward! Attend lake meetings and learn about issues on the Indian Lake Watershed Project website at: <https://www.indianlakewatershedproject.com>

### 5.2.3 Indian Lake Community Education Program

A sustainable lake improvement/restoration program will include the riparians around the lake since their daily activities can have a marked impact on the lake progress and health. The following sections are intended to facilitate engagement of riparians who can be effective lake stewards for sustained lake improvements. Even without a scientific background, individual riparians can learn about basic lake and watershed principles and how they can make a difference with simple BMP's and other lake improvement methods. Additionally, inclusion of all local businesses proximate to the lake should be invited to participate since they contribute to the economic capital of the area. Figure 69 below demonstrates the classifications of local businesses around and proximate to Indian Lake. Nearly a quarter of these businesses are directly on the lake.



**Figure 69.** A pie chart displaying the percentages of local businesses on or proximate to Indian Lake (data from the Indian Lake Chamber of Commerce).

## **Why Citizen Involvement is Recommended**

An outside expert or group of experts (such as RLS) is often contacted to recommend a lake management or restoration program and to educate the public about issues and possible solutions. These experts are not a part of the daily contact with the lake itself and cannot police the community for various poor practices or problems. Experts may be in contact with the lake multiple times per year, but the residents have the most contact time with the lake. This makes riparians the optimum investigators for changes in and around the lake. Once riparians around the lake realize a specific impairment in the lake and how it affects their well-being, property values, etc., they bond with the lake in a constructive manner. Social scientists refer to this connection as a link between natural capital (the lake and surroundings) and human capital (the knowledge and skills of people in a community). In other words, these two capitals are not mutually exclusive once a person has interacted with an environment (lake). Thus, riparians have both the capacity to degrade water quality and improve water quality. Jermalowicz-Jones (2017) found that human capital and cultural capital are the largest drivers of implementation for lake management plans. The Indian Lake community likely contains a high degree of these two forms of capital, and this could be evaluated for better certainty.

## **How the Indian Lake Community Can Participate in Lake Improvements**

Indian Lake riparians are encouraged to attend regular ILWP meetings that are held to discuss data trends and evaluate lake improvement progress. A high level of focus should be centered on invasive species awareness and nonpoint source pollution (NPS) that is responsible for nutrient and sediment loads to the lake. Additionally, riparians are encouraged to hold an annual lake workshop. Education alone (i.e., meetings, brochures, etc.) will not adequately introduce all riparians to lake issues as many people are participatory learners. There is therefore a need to incorporate different educational strategies into this lake restoration program. RLS proposes development of an annual lake workshop where new data is presented (including post-BMP implementation data) to the public and new research information is disseminated. Riparian BMP's would be openly discussed with attendants. Critical information dissemination would include handouts at the workshop with modernized lake maps, water quality graphs, and other updated lake information. Also recommended would be water quality sampling demonstrations along with key Indian Lake biota present in the lake available for learning.

## 6.0 INDIAN LAKE RESTORATION CONCLUSIONS & RECOMMENDATIONS

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Indian Lake is facing significant issues such as water quality impairments, including inputs of nutrients and sediments from surrounding tributaries and developments, and excessive algae growth and nuisance invasive aquatic vegetation growth that all lead to a decline in lake health and recreational uses. Fishery spawning habitat may become impaired by the addition of sediments to the lake and the increased biochemical oxygen demand (BOD) is resulting in a seasonal decline in dissolved oxygen with depth in some areas of the lake. Previous studies of the lake (EPA 1973) demonstrate that significant progress has been made, especially since formation of the Indian Lake Sanitary Sewer District in the 1930's which preceded numerous local additions that now comprise the Logan County Water Pollution Control District. These improvements have reduced nutrients over time, but these loads still need to be reduced.

The high nutrients have also led to increased algal concentrations (chlorophyll-*a*) which reduces light to all aquatic plants and favors an algal-dominated state. The result of the overabundance of algae is lower water clarity, more cyanobacteria, and fewer favorable low-growing native aquatic plants. The quantities of nutrients exiting the lake are higher than current mean concentrations in the lake, which is favorable. However, the quantities of total suspended solids exiting the lake are much lower and thus the lake is functioning as a "sink" for sediments which reduce water volume and depth over time. Improvements to reduce solids include the assurance that all areas around the lake are vegetated at all times and with proper erosion stabilization techniques. A whole lake shoreline erosion survey is recommended in 2024. RLS has recommended dredging of one high priority area and five moderate priority areas for dredging based on excessive sedimentation and interference with navigation and recreation in those areas. Thus, selective implementation of dredging 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.

Furthermore, an independent professional limnologist/aquatic botanist should perform regular GPS-guided whole-lake surveys each spring and summer/early fall to monitor the growth and distribution of all invasives and nuisance aquatic vegetation growth prior to and after treatments to determine treatment efficacy. Continuous monitoring of the lake for potential influxes of other exotic aquatic plant genera (i.e., *Hydrilla*) that could also significantly disrupt the ecological stability of Indian Lake is critical. Currently, Indian Lake has a scarcity of native aquatic vegetation (even with the high biodiversity) and thus management efforts on the control of natives should be restricted only to dense Coontail and *Pithophora* algal mats with the mechanical harvesting method.

The 2023 aquatic vegetation management season was highly successful with under 21 acres of EWM remaining throughout the lake, including the canals. Seed bank germination is still possible in 2024 and beyond and thus continued whole-lake inventories are needed. RLS recommends budgeting for around half of the original infestation for milfoil control even though a sustained reduction is expected which would significantly reduce cost relative to 2023. RLS recommends continued collaboration with the ODNR and Aqua Doc for each significant lake-wide treatment.

RLS recommends that the public regularly access harmful algal bloom (HAB) data from NOAA-NOS, Copernicus Sentinel 3b which is provided to the Ohio EPA and shows real-time imaging of HAB concentrations within Indian Lake. When a strong bloom is present on the lake, RLS additionally recommends algal toxin testing to determine the types and concentrations of all algal toxins present.

A complete list of recommended lake improvement methods for a comprehensive Indian Lake management plan can be found in Table 30 below. It is important to coordinate these methods with objectives so that baseline conditions can be compared to post-treatment/management conditions once the methods have been implemented.

**Table 30. List of Indian Lake proposed improvement methods with primary and secondary goals and locations for implementation.**

<b>Proposed Improvement Method</b>	<b>Primary Goal</b>	<b>Secondary Goal</b>	<b>Where to Implement</b>
<b>Systemic herbicide spot-treatments for EWM in lake</b>	Reduce EWM throughout lake; reduce herbicide use over time	Improve probability of successful native aquatic plant growth	Entire lake where EWM present
<b>Mechanical removal of “c” and “d” level Coontail</b>	Reduce areas of dense Coontail where navigation is impaired	Maintain enough Coontail to provide a macrophyte-dominate lake state	Only in areas of high density as determined in 2024 and with follow-up surveys
<b>Water quality monitoring of lake and tributaries</b>	Monitor lake health over time and determine incoming loads	Use long-term and current data to drive management decisions relative to BMP’s	Lake basins monitored in 2022-2024 and major tributaries
<b>Development of Early Detection Rapid Response (EDRR) Protocol for new invasives</b>	Generate a clear strategy for dealing with new invasives that may be found in the lake	Allow for less long-term spread of any new invasives with early detection	Entire lake
<b>Boat launch washing stations if permitted</b>	To reduce entry of invasives into Indian Lake	To reduce exit of invasives from Indian Lake	At ALL public access sites noted in this report.
<b>Dredging of lake sediments in shallow areas</b>	To improve recreation/navigation abilities in areas with shallow depth and excess siltation	To remove sediment associated nutrients from the lake	Only in key areas with severe impairments (see priority map)
<b>Annual lake surveys pre- and post-treatment</b>	To determine efficacy of herbicide treatments on invasives	To determine ability of native aquatic vegetation biodiversity to recover post-management implementation	Entire lake
<b>Shoreline erosion inventory</b>	To determine individual properties that need shoreline erosion stabilization practices	Reduce associated solids and nutrients that enter lake	Lake-wide; Entire shoreline
<b>Riparian/Community Education</b>	To raise awareness of lake issues and	Long-term sustainability requires	Entire lake community and those

	empower all to participate in lake protection	ongoing awareness and action	who frequent the lake; may also include relevant stakeholders (ODNR, ILWP)
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