Indiana Lake Water Quality Assessment Report
For 2023-2024

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Acknowledgments

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Cover: Crooked Lake, Whitley County. September 2015

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INDIANA CLEAN LAKES PROGRAM

The Indiana Clean Lakes Program was created in 1989 as a program within the Indiana Department of Environmental Management's (IDEM) Office of Water Management. The program is administered through a grant to Indiana University's School of Public and Environmental Affairs (SPEA) in Bloomington. The Indiana Clean Lakes Program is a comprehensive, statewide public lake management program having five components:

1. Public information and education
2. Technical assistance
3. Volunteer lake monitoring
4. Lake water quality assessment
5. Coordination with other state and federal lake programs.

This document is a summary of lake water quality assessment (LWQA) results for 2023 to 2024.

Lake Water Quality Assessment

The goals of the LWQA include: (a) identifying water quality trends in individual lakes, (b) identifying lakes that need special management, and (c) tracking water quality improvements due to industrial discharge and runoff reduction programs (Jones 1996).

This program only samples public lakes that generally have boat trailer access from a public right-of-way. Public lakes are defined as those that have navigable inlets or outlets, or those that exist on or adjacent to public land. Sampling occurs in late June, July, and August of each year to coincide with the period of thermal stratification and the period of poorest annual water quality in lakes (Figure 1). Most Indiana lakes with maximum depths of 16 to 23 feet (5–7 m) or greater undergo thermal stratification during the summer. The warming of lake surface water by sunlight and higher air temperatures cause the water to become less dense. The less dense water will then rise above the cold, denser water at the lake’s bottom. Summer wind and waves may not be strong enough to overcome the density differences between the surface and bottom waters and ***thermal stratification*** occurs. In a stratified lake, the surface waters (***epilimnion***) circulate and are well mixed throughout the summer while the bottom waters (***hypolimnion***) may stagnate because they are isolated from the surface. Thus, water characteristics in the epilimnion and hypolimnion of a given lake may be considerably different during stratification.

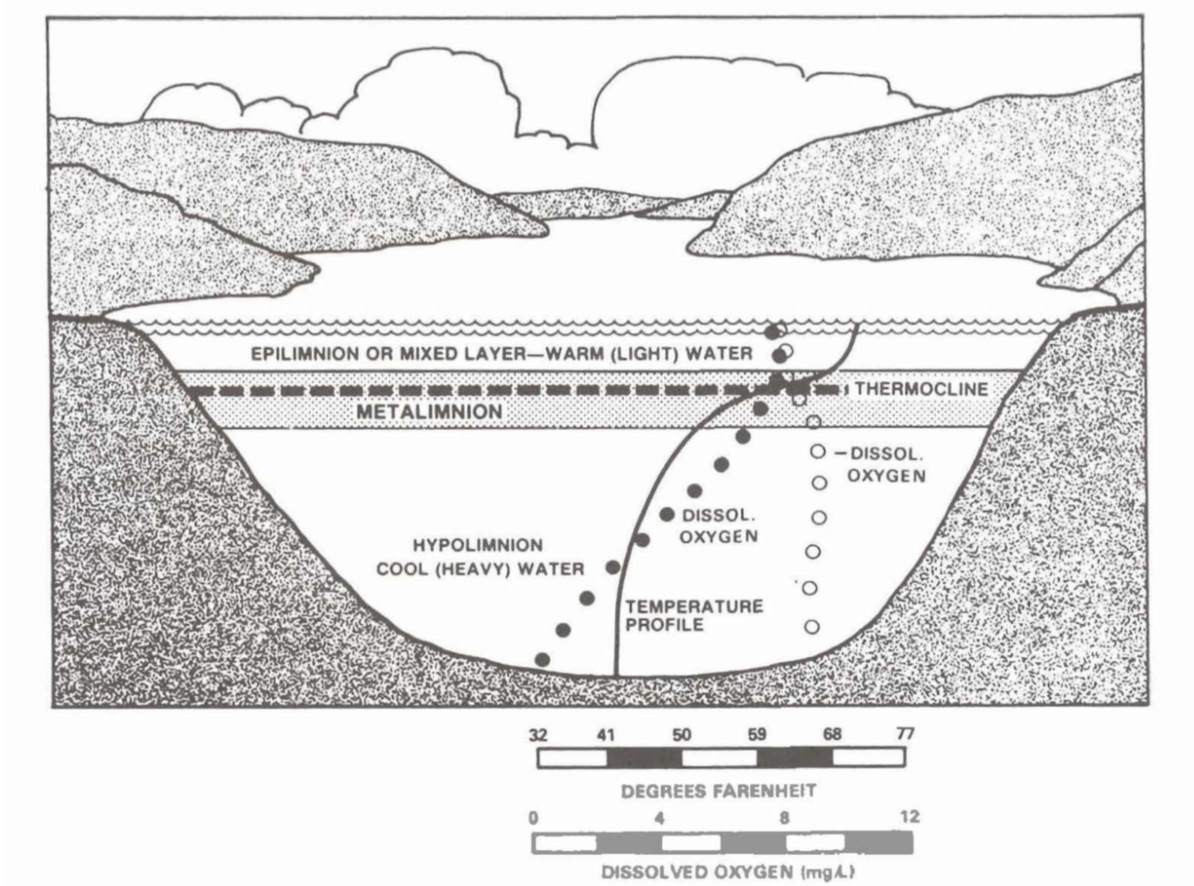

Figure 1 Cross-section of a lake experiencing summer thermal stratification. Adapted from Olem and Flock (1990).

To account for potential differences between the epilimnion and hypolimnion of stratified lakes, water samples are collected from the top two meters of the surface and from one to two meters above the bottom. In addition, dissolved oxygen and temperature are measured at one-meter intervals from the surface to the bottom of each lake.

Lakes were randomized and selected from our list of all public lakes and impoundments having a) a minimum surface area of 5 acres, and b) a usable boat ramp. This process was similar to that used by the United States Environmental Protection Agency (USEPA) in the National Lakes Assessment (NLA) of 2007, 2012, and 2017. The resulting list contained a total of 160lakes and impoundments. We randomize the candidate lake list each survey year. We sampled lakes from this list beginning with the first lake at the top and working downward until we had sampled 80 lakes each survey year, repeating the randomization for the next year. Using this sampling scheme, our 2023-2024 results should be statistically significant for the entire state and we could then better discuss lake water quality in Indiana.

The 160 lakes in our randomized pool are a small fraction of the 1475 lakes, reservoirs, and ponds in our master lake list for Indiana. However, many of these other lakes are private, smaller than 5 acres in surface area, and/or have no usable boat ramp. While the randomized sampling scheme allows us to gain a better understanding of Indiana lake quality each year, it is possible that the sampling frequency for any given lake would create long gaps between individual lake surveys.

Water Quality Parameters Included in Lake Assessments

Monitoring lakes requires many different parameters to be sampled. The parameters analyzed in this assessment include:

pH

pH is the measure of the acidity of a solution of water. The pH scale commonly ranges from 0 to 14 (Figure 2). The scale is not linear but rather logarithmic. For example, a solution with a pH of 6.0 is ten times more acidic than a solution with a pH of 7.0. Pure water is said to be neutral, with a pH of 7.0. Water with a pH below 7.0 is considered acidic while water with pH greater than 7.0 is considered basic or alkaline. The pH of most natural waters in Indiana is between 6.5 and 8.0. However, acidic deposition may cause lower pH in susceptible waters and high phytoplankton productivity (which consumes CO_2, a weak acid) can result in pH values exceeding 9.0.

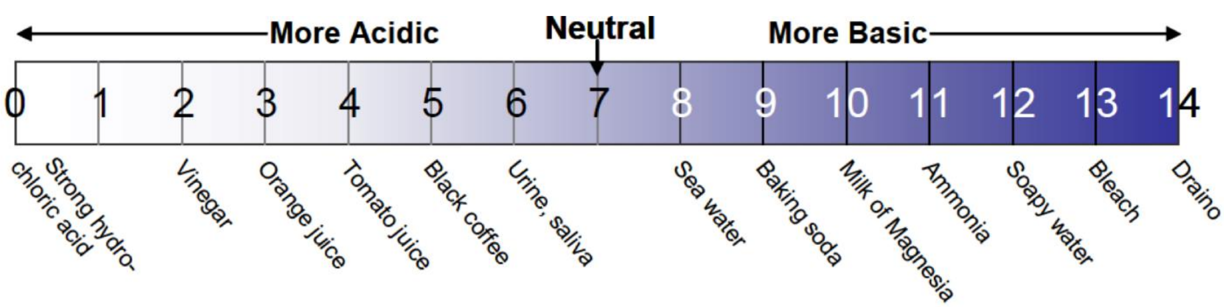

Figure 2 The pH scale compared with common solutions. Source: Addy et al. (2004).

Conductivity

Conductivity is a numerical expression of an aqueous solution's capacity to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, valence, relative concentrations, and on the temperature of the liquid (APHA 2023). Solutions of most inorganic acids, bases, and salts are relatively good conductors. Conductivities of natural lakes in Indiana generally range from 50 to 1,000 µmhos/cm, but the conductivity of old coal mine lakes can be as high as 3,000 µmhos/cm. In contrast, the conductivity of distilled water is less than 1 µmhos/cm. As conductivity is the inverse of resistance, the unit of conductance is the mho, or in low-conductivity natural waters, the micromho (µmhos).

Acid Neutralizing Capacity

Acid neutralizing capacity (ANC) is the sum total of components in the water that tend to elevate the pH to the alkaline side of neutrality, and is expressed commonly as milligrams per liter as calcium carbonate (mg/L as $CaCO_3$). ANC is a measure of the *buffering capacity* (ability to resist changes in pH) of the water, and since pH has a direct effect on organisms as well as an indirect effect on the toxicity of certain pollutants in the water, the buffering capacity is important to water quality. Commonly occurring materials in water that increase alkalinity are carbonates, bicarbonates, phosphates, and hydroxides. Limestone bedrock and thick deposits of glacial till are good sources of carbonate buffering. Lakes within such areas are usually well-buffered.

Phosphorus

Phosphorus is an essential plant nutrient and most often controls aquatic plant (algae and macrophyte) growth in freshwater. It is found in fertilizers, human and animal wastes, and yard waste. There is no atmospheric (vapor) form of phosphorus. Because there are few natural sources of phosphorus and the lack of an atmospheric cycle, phosphorus is often a *limiting nutrient* in aquatic systems. This means that the relative scarcity of phosphorus may limit the ultimate growth and production of algae and rooted aquatic plants. Therefore, management efforts often focus on reducing phosphorus input to a receiving waterway because: (a) it can be managed, and (b) reducing phosphorus can reduce algae production. Two common forms of phosphorus are:

> ***Soluble reactive phosphorus (SRP)*** – SRP is dissolved phosphorus readily usable by algae. SRP is often found in very low concentrations in phosphorus-limited systems where the phosphorus is tied up in the algae and cycled very rapidly. Sources of SRP include fertilizers, animal wastes, and septic systems.
>
> ***Total phosphorus (TP)*** – TP includes dissolved and particulate forms of phosphorus. TP concentrations greater than 0.03 mg/L (or 30g/L) can cause algal blooms in lakes and reservoirs.

Nitrogen

Nitrogen is an essential plant nutrient found in fertilizers, human and animal wastes, yard waste, and the air. About 80 percent of the atmosphere is nitrogen gas. Nitrogen gas diffuses into water where it can be "fixed" (converted) by blue-green algae to ammonia for algal use. Nitrogen can also enter lakes and streams as inorganic nitrogen and ammonia. Because nitrogen can enter aquatic systems in many forms, there is an abundant supply of available nitrogen in these systems. The three common forms of nitrogen are:

> ***Nitrate (NO_3^-)*** – Nitrate is an oxidized form of dissolved nitrogen that is converted to ammonia by algae under anoxic (low or no oxygen) conditions. It is found in streams and runoff when dissolved oxygen is present, usually in the surface waters.

Ammonia (NH_4^+) – Ammonia is a form of dissolved nitrogen that is readily used by algae. It is the reduced form of nitrogen and is found in water where dissolved oxygen is lacking such as in a eutrophic hypolimnion. Important sources of ammonia include fertilizers and animal manure. In addition, ammonia is produced as a by-product by bacteria as dead plant and animal matter are decomposed.

Organic Nitrogen (Org-N) – Organic nitrogen includes nitrogen found in plant and animal materials and may be in dissolved or particulate form. Organic nitrogen is determined by analyzing samples for total nitrogen (TN) and subtracting the non-organic species of ammonia and nitrate.

Light Transmission

Light transmission is used to determine the amount of the lake that is photosynthetically active. We use a light meter (photocell) to determine the *rate* at which light transmission is diminished in the water column to 1% of the surface level. The 1% light level is considered the lower limit of algal growth in lakes and this area is referred to as the *euphotic zone*.

Dissolved Oxygen

Dissolved oxygen (DO) is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. DO enters water by diffusion from the atmosphere and as a by-product of photosynthesis by algae and plants. The concentration of DO in epilimnetic waters continually equilibrates with the concentration of atmospheric oxygen to maintain 100 percent DO saturation. Excessive algae growth can over-saturate (greater than 100 percent saturation) the water with DO when the rate of photosynthesis is greater than the rate of oxygen diffusion to the atmosphere. Hypolimnetic DO concentration is typically low as there is no mechanism to replace oxygen that is consumed by respiration and decomposition. Fish need at least 3-5 mg/L of DO to survive.

Secchi Disk Transparency

Secchi disk transparency is the depth to which a black and white Secchi disk can be seen in lake water that indicates water clarity. Water clarity, is affected by two primary factors: algae and suspended particulate matter. Particulates (soil or dead leaves) come from runoff or sediments already on the lake bottom. Erosion from construction, agricultural, and riverbanks all lead to increased sediment. Bottom sediments can be resuspended by bottom-feeding fish, boats, or strong winds.

Plankton

Plankton include phytoplankton and zooplankton. They are the base of the aquatic food chain (Figure 3).

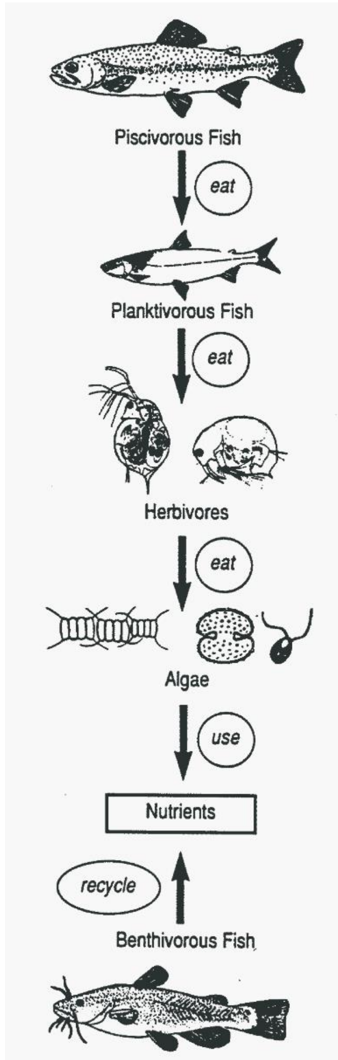

Figure 3 A simplified aquatic food chain.

The phytoplankton are organized taxonomically largely by color. Important phyla (groups) include: Cyanobacteria (blue-green algae), Chlorophyta (green algae), Chrysophyta (yellow-brown algae), and Bacillariophyta (diatoms). Cyanobacteria can out compete other algae, produce toxins, and produce taste and odder issues.

Chlorophyll-a

The plant pigments of algae consist of the chlorophylls (green color) and carotenoids (yellow color). Chlorophyll-a is the most dominant chlorophyll pigment in green algae (Chlorophyta) but is only one of several pigments in cyanobacteria (Cyanophyta), yellow-brown algae

(Chrysophyta), and others. Despite this, chlorophyll-a is used as a direct estimate of algal biomass although it might underestimate the production of algae that contain multiple pigments.

LAKE CLASSIFICATION

There are many factors that influence the condition of a lake including physical dimensions (*morphometry)*, nutrient concentrations, oxygen availability, temperature, light, and fish species. To simplify the analysis of lakes, there are a variety of lake classifications that are used. Lake classifications serve to aid in the decision-making process, in prioritizing, and in creating public awareness. Lakes can be classified based on their origin, thermal stratification regime, or by trophic status.

Lake Origin Classification

Hutchinson (1957) classified lakes according to how they were formed which resulted in 76 different classifications; the following are several important lake types in Indiana.

Glacial Lakes

As the glacier ice sheets moved south and then receded some 10,000 to 12,000 years ago, they created several types of lakes including scour lakes and kettle lakes. **Scour lakes** were formed when the sheet moved over the land creating a groove in the surface of the earth which later filled with meltwater. **Kettle lakes** were formed when large chunks of ice, deposited by the retreating glacier, left depressions in the thick deposits of *till* (sand and gravel ground up by the glacier) that covered the landscape. When the ice blocks melted the depressions filled in with water and lakes were formed. Most lakes in Indiana are kettle lakes including Lake Tippecanoe, the deepest lake (123 feet), and Lake Wawasee, the largest glacial lake (3,410 acres). Glacial lakes in Indiana are primarily in the north and are found between the western Valparaiso Morainal Area and the eastern Steuben Morainal Area where the Lake Michigan, Saginaw, and Erie lobes occurred (Figure 4). Glacial lakes are thus limited to this part of the state.

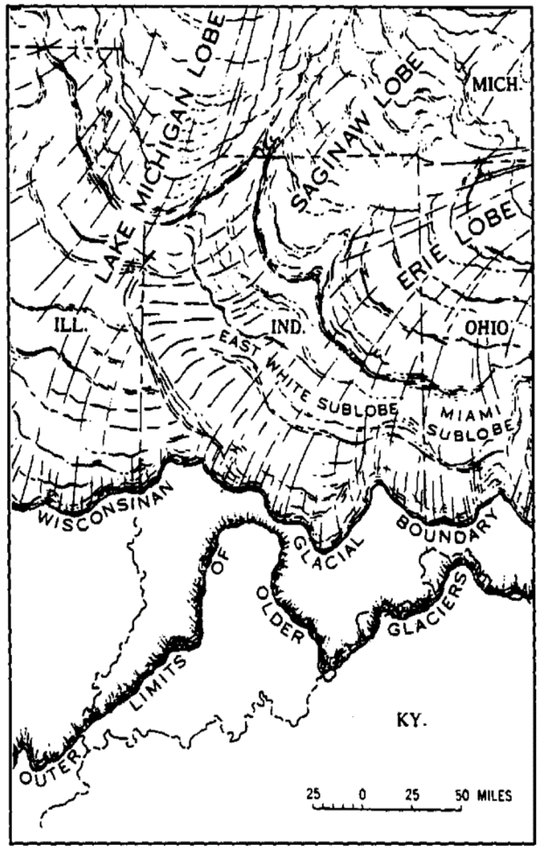

Figure 4 The Lake Michigan, Saginaw, and Erie lobes of the most recent glacial episode affecting northern Indiana.

Solution Lakes

Solution lakes form when water collects in basins formed by the solution of limestone found in regions of karst topography. These lakes tend to be circular and are primarily found in the Mitchell Plain of southern Indiana.

Oxbow Lakes

Oxbow lakes are formed from former river channels that have been isolated from the original river channel due to deposition of sedimentation or erosion. Oxbow lakes can be found throughout the state of Indiana.

Artificial Lakes

Artificial lakes are created by humans due to excavation of a site or to damming a stream or river. Artificial lakes include ponds, strip pits, borrow pits, quarries, and reservoirs (Jones 1996). Reservoirs, also called impoundments, are typically elongated with many branches representing the tributaries of the former stream or river. Strip pits are coal mine lakes found in southwestern Indiana where coal mines are located. Many coal mine lakes formed when water filled the final cut excavated during surface mining. Borrow pits were originally excavated as a source of fill dirt for highway and other large construction projects. For our purposes, we aggregated strip pits, borrow pits, and quarry pits into a singular classification, surface mine lakes (SML).

Trophic Classification

Trophic state is an indication of a lake's nutritional level or biological productivity. The following definitions are used to describe the trophic state of a lake:

> *Oligotrophic* **-** lakes with clear waters, low nutrient levels (total phosphorus < 6 µg/L), supports few algae, hypolimnion has dissolved oxygen, and can support salmonids (trout and salmon).
>
> *Mesotrophic* - water is less clear, moderate nutrient levels (total phosphorus 10-30 µg/L), support healthy populations of algae, less dissolved oxygen in the hypolimnion, and lack of salmonids.
>
> *Eutrophic* **-** water transparency is less than 2 meters, high concentrations of nutrients (total phosphorus > 35 µg/L), abundant algae and weeds, lack of dissolved oxygen in the hypolimnion during the summer.
>
> *Hypereutrophic* **-** water transparency less than 1 meter, extremely high concentrations of nutrients (total phosphorus > 80 µg/L), thick algal scum, dense weeds.

Eutrophication is the biological response observed in a lake caused by increased nutrients, organic material, and/or silt (Cooke et al. 1993). Nutrients enter the lake through runoff or through eroded soils to which they are attached. Increased nutrient concentrations stimulate the growth of aquatic plants. Sediments and plants accumulate at the bottom of the lake decreasing the mean depth of the lake. The filling-in of a lake is a natural process that usually occurs over thousands of years. However, this natural process can be accelerated by human activities such as increased watershed erosion and increased nutrient loss from the land. Thus, ***cultural eutrophication*** can degrade a lake in as little as a few decades.

Although it is widely known that nutrients, especially phosphorus, are responsible for increased productivity, the concentration of nutrients alone cannot determine the trophic state of a lake. Other factors such as the presence of algae and plants aid in the determination of the trophic status, and other factors such as light and temperature impact the growth of algae and plants.

Trophic State Indices

Due to the complex nature and variability of water quality data, a trophic state index (TSI) is used to aid in the evaluation of water quality data. A TSI assigns a numerical value to different levels of standard water quality measurements. The sum of these points for all parameters in the TSI represents the standardized trophic status of a lake that can be compared in different years or can be compared to other lakes. When using a TSI for comparison, it is important to not disregard other data collected as these results may help in explaining other differences between lakes. As with any index, when the data are reduced to a single number for a comparison some information is lost.

The Carlson Trophic State Index

The Carlson Trophic State Index, developed by Carlson (1977) is the most widely used TSI in the United States (Figure 5). Carlson used mathematical equations developed from the relationships observed between summer measurements of Secchi disk transparency, total phosphorus, and chlorophyll-a in north temperate lakes. With Carlson's TSI, one parameter, Secchi disk transparency, total phosphorus, or chlorophyll-a, can be used to yield a TSI value for that lake. One parameter can also be used to predict the value of the other parameters. Values for the Carlson's TSI range from 0 to 100 and each increase of 10 trophic points represents a doubling of algal biomass.

Not all lakes exhibit the same relationship between Secchi disk transparency, total phosphorus, and chlorophyll-a that Carlson's lakes show. However, in these cases Carlson's TSI gives valuable insight into the functioning of a particular lake.

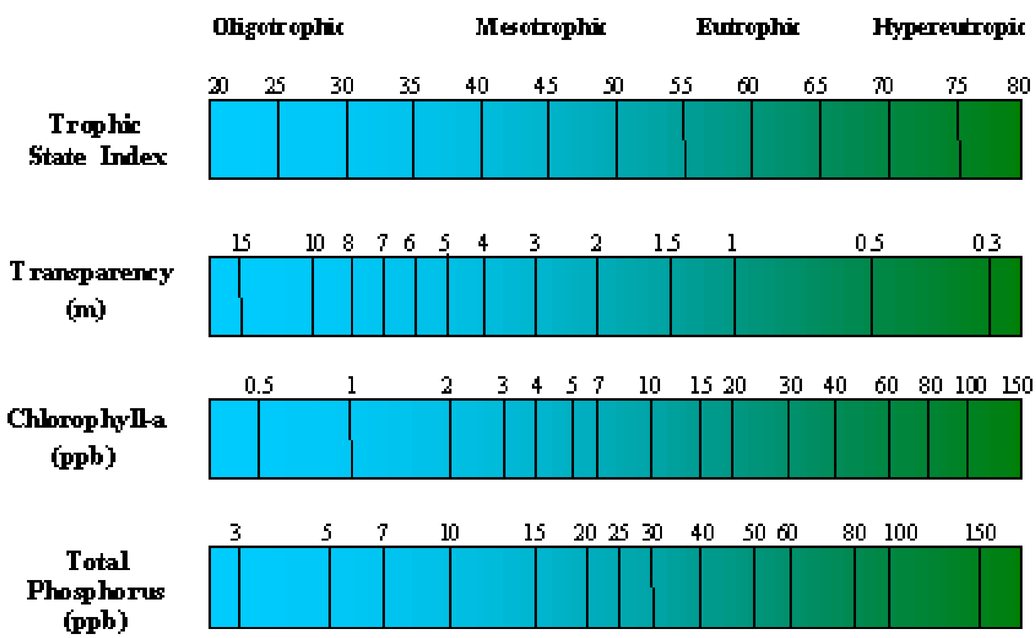

Figure 5 The Carlson Trophic State Index.

Ecoregion Descriptions

Lakes are connected to their watershed through soil types, land slope, and land use. These relationships can be expanded to a larger scale, known as ecoregions, that incorporate this relationship across a larger geographic area. Omernik and Gallant (1988) defined ecoregions in the Midwest through the examination of land use, soils, and potential natural vegetation. Ecoregions have similar ecological properties and can influence lake water quality characteristics. Six ecoregions are present in Indiana (Figure 6). Descriptions of the ecoregions are as follows:

Central Corn Belt Plains (#54): Ecoregion 54 covers 46,000 square miles of Indiana and Illinois. This ecoregion is primarily cultivated for feed crops, only 5 percent of the area is woodland. Crops and livestock are responsible for the nonpoint source pollution in this region.

Eastern Corn Belt Plains (#55): Ecoregion 55 covers 31,800 square miles of Indiana, Ohio, and Michigan. Hardwood forests can thrive in this area; 75 percent of the land is used for crop production. Few natural lakes or reservoirs are located in this area.

Southern Michigan/Northern Indiana Till Plain (#56): Ecoregion 56 covers 25,800 square miles of Michigan and Indiana. Oak-hickory forests are the dominant vegetation in this area; however, 25 percent of this area is urbanized.

Huron/Erie Lake plain (#57): Ecoregion 57 covers 11,000 square miles of Indiana, Ohio, and Michigan. This area used to be occupied by forested wetlands; however, the primary use is now farming and 10 percent of this region is urbanized. There are no lakes in this region that could be assessed by the present study.

Interior Plateau (#71): Ecoregion 71 covers 56,000 square miles from Indiana and Ohio down to Alabama. Land is used for pasture, livestock, and crops. Woodlands and forests remain in this area. There are many quarries and coal mines in this area; however, there are few natural lakes.

Interior River Lowland (#72): Ecoregion 72 covers 29,000 square miles in Indiana, Kentucky, Illinois, and Missouri. One third of this area is maintained as oak-hickory forest; other land uses include pasture, livestock, crops, timber, and coal mines. Water quality disturbances come from livestock, crops, and surface mining.

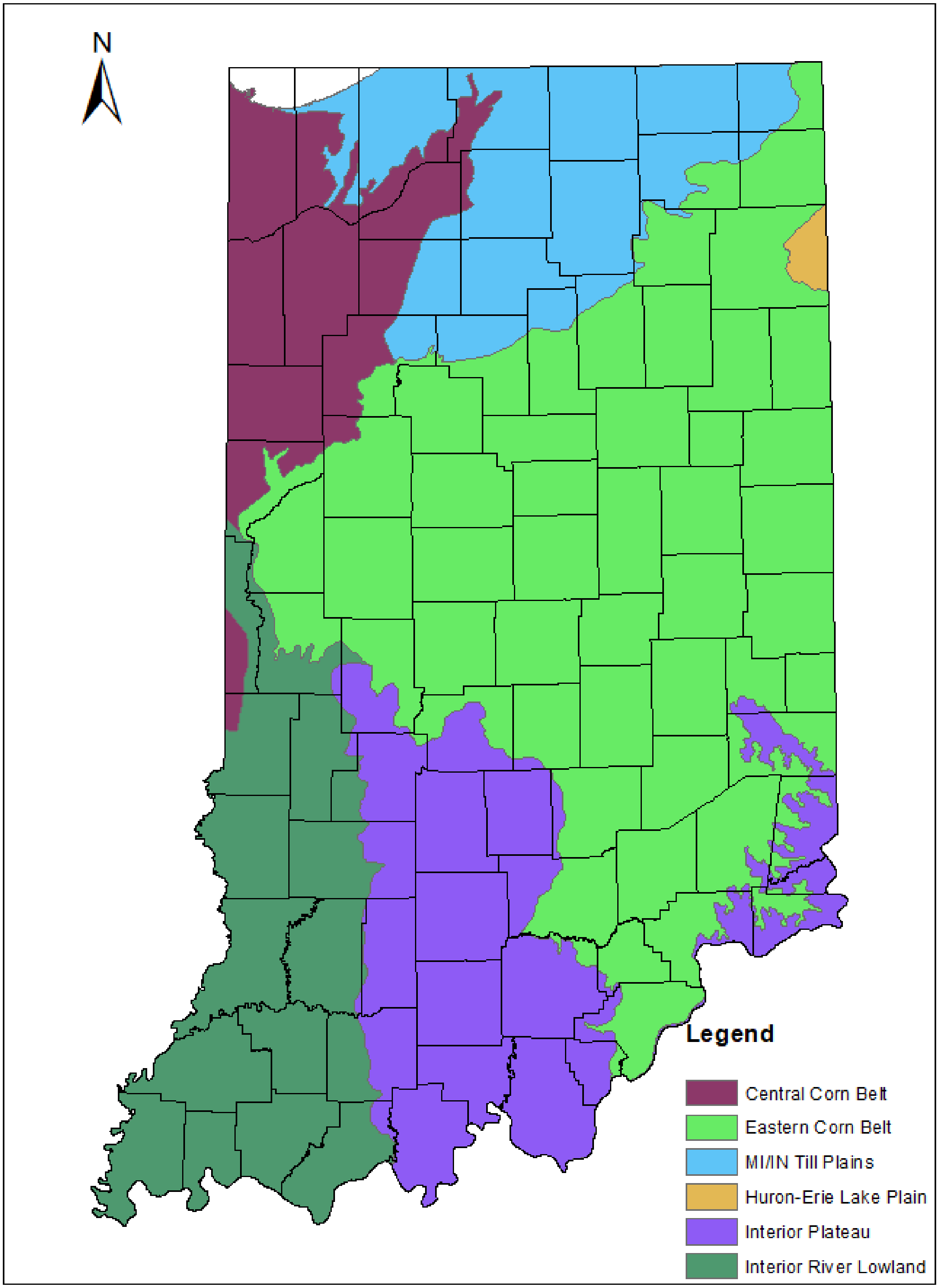

Figure 6 Ecoregions of Indiana.

METHODS

Field Procedures

Water samples are collected from the epilimnion and hypolimnion. Epilimnetic water samples are collected using a 2-meter integrated sampler. Hypolimnion samples are collected at least one meter from the bottom of the lake using a VanDoren sampler. Water samples are collected for soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate (NO_3^-), ammonia (NH_4^+), and total nitrogen (TN). SRP is filtered in the field using a 47 µm membrane filter. TP nitrate/ammonia, and TN are preserved with sulfuric acid (H_2SO_4) resulting in a pH of the sample between 1 and 2.

Dissolved oxygen (DO), temperature, conductivity, and pH are measured using an In-Situ multi-parameter sonde. Measurements are taken at 1-meter intervals through the water column to the lake bottom.

Secchi disk transparency is measured by lowering a black and white disk through the water column until it is no longer visible. Light penetration is measured with a LiCor Spherical Quantum Sensor.

Phytoplankton are collected using a 2-meter integrated sampler. Phytoplankton samples are preserved with glutaraldehyde. Zooplankton are collected with a tow net through the whole water column, utilizing an 80-micron mesh on the net and bucket. Zooplankton samples were preserved with 95% ethyl alcohol.

Chlorophyll-a is collected with an integrated sampler that reaches a 2-m depth. The sample is filtered with Whatman GF/F filter paper and sample volume filtered is recorded.

Lab Procedures

SRP is determined using an ascorbic acid method and then measured colormetrically on a spectrophotometer (APHA 2023).

NO_3^- is analyzed using the cadmium reduction method (Seal Method EPA-126-C Revision 2, U.S. EPA Method 353.2). NH_4^+ is processed the salicylate and hypochlorite method (Seal Method EPA-150-C Revision 1, U.S. EPA Method 350.1 Rev. 2.0) using discrete analysis. TN samples are digested in an alkaline persulfate solution then processed as nitrite-nitrate using the cadmium reduction method.

TP samples are digested in an alkaline persulfate solution releasing particulate bound phosphorus and analyzed using the ascorbic acid method.

Zooplankton analysis is done by transferring one milliliter of sample to a Sedgwick-Rafter Cell for identification and enumeration. The entire cell is scanned, and all zooplankton counted.

Phytoplankton samples are analyzed using an Imaging FlowCytobot (IFCB) that is an automated submersible imaging flow cytometer, manufactured by McLane Research Laboratories, that generates high-resolution images of suspended particles in water. PhycoTech, Inc. uses the IFCB as a benchtop application to capture algal images for identification. The IFCB can reliably capture particulates between 8 and 250 µm (average phytoplankton ~ 50 µm). The general process of analysis includes sample injection, image processing, and classification. Classification of algal images uses a random forest model developed and trained by Dr. Ann St. Amand and can accurately identify algal images to genus and species (70-80% accuracy). However, classification to functional group is more accurate and allows for sufficient assessment of ecological conditions in a waterbody.

1. ***Natural Unit density (NU/L)*** – this is the historic unit used for many years to quantify plankton in Indiana lakes. A natural unit represents a single organism, regardless of whether the organism is single-celled or a multi-celled colonial form. The size range of natural units may be several orders of magnitude (100 – 1000x).

2. ***Cell density (cells/mL)*** – Counting and recording at the cell level is preferred by phycologists and limnologists today. Each phytoplankton cell can live and reproduce independently of other cells, even in those taxa that aggregate in colonies. Public health warnings regarding toxigenic cyanobacteria are determined, in part, by cell densities.

3. ***Blue-green dominance (%)*** – This valuable variable is the percentage of a plankton population that is dominated by cyanobacteria. Since cyanobacteria are more likely to become a nuisance in aquatic systems, this simple indicator is still useful. Caution is necessary in interpreting this metric because dominance by cyanobacteria in a lake with a low density of phytoplankton does not necessarily indicate a problem in that lake.

Chlorophyll-*a* filters are frozen then filters are ground, and chlorophyll-a is extracted using 90% aqueous acetone and measured using a spectrophotometer. Samples are corrected for pheophytin pigments with dilute acid.

All sampling techniques and laboratory analytical methods were performed in accordance with procedures in APHA (2023). Details can be found in the Quality Assurance Protection Plan (QAPP).

Data analysis was done using R. For dot plots all data is shown including outliers. For box plots outliers were removed using the 1.5 times interquartile range rule.

RESULTS

Information about the lakes sampled from 2023 to 2024 is included in Appendix A and B. Raw data for all lakes assessed will be available on the Indiana Clean Lakes Program website at: www.clp.indiana.edu.

Lakes Assessed

We assessed a total of 160 lakes during this two-year period, 80 each year from 2023-2024 (Figure 7).

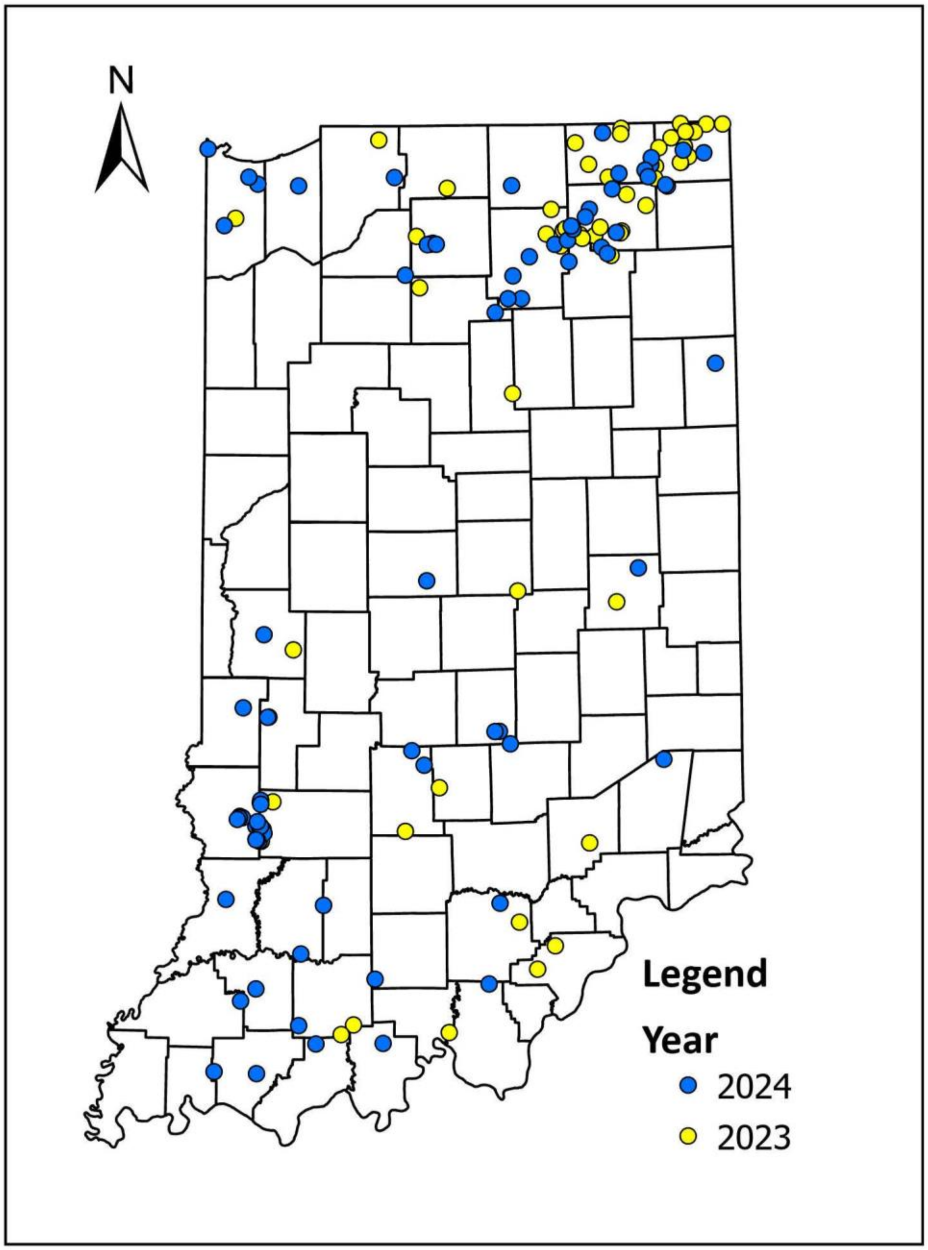

Figure 7 Lakes assessed from 20232- 2024.

Lake surface area ranged from 0.7 hectares (Cottonwood) to 4,350 hectares (Monroe Lake), with a median surface area of 14 ha (Figure 8). Six lakes had surface areas greater than 500 ha, while 76 percent (n = 122) of all lakes sampled were under 50 ha.

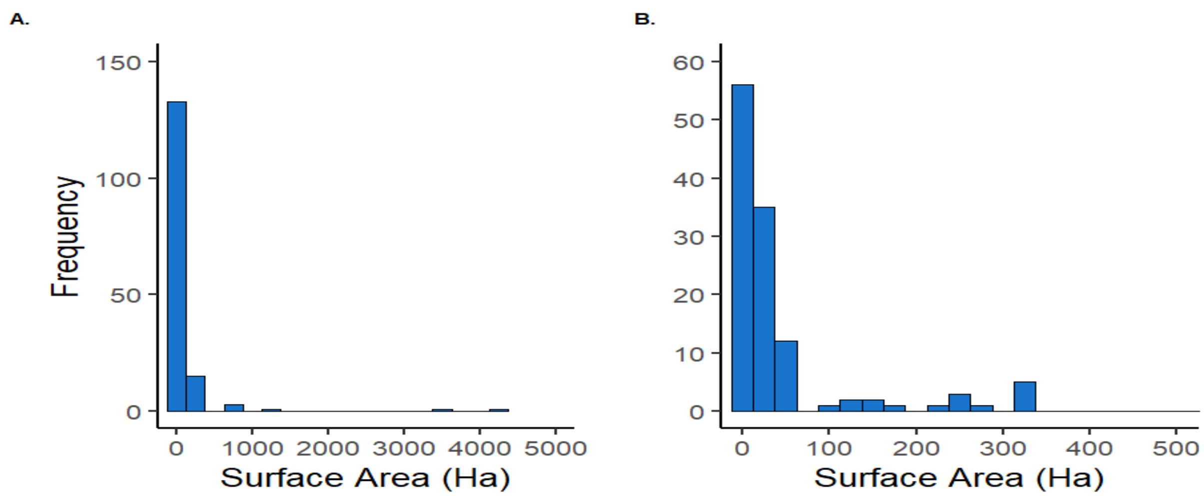

Figure 8 Surface area distribution for (A) all 160 lakes sampled in 2023 and 2024, and (B) the distribution of lakes under 500 hectares.

Maximum depth ranged from 1.5 meters (Mollenkramer Reservoir) to 37 meters (Tippecanoe Lake), with a median of 8.8 meters (Figure 9). Natural lakes had the deepest median maximum depth (10.7 meters), followed by surface mine lakes (7.6 meters) and impoundments (6.4 meters).

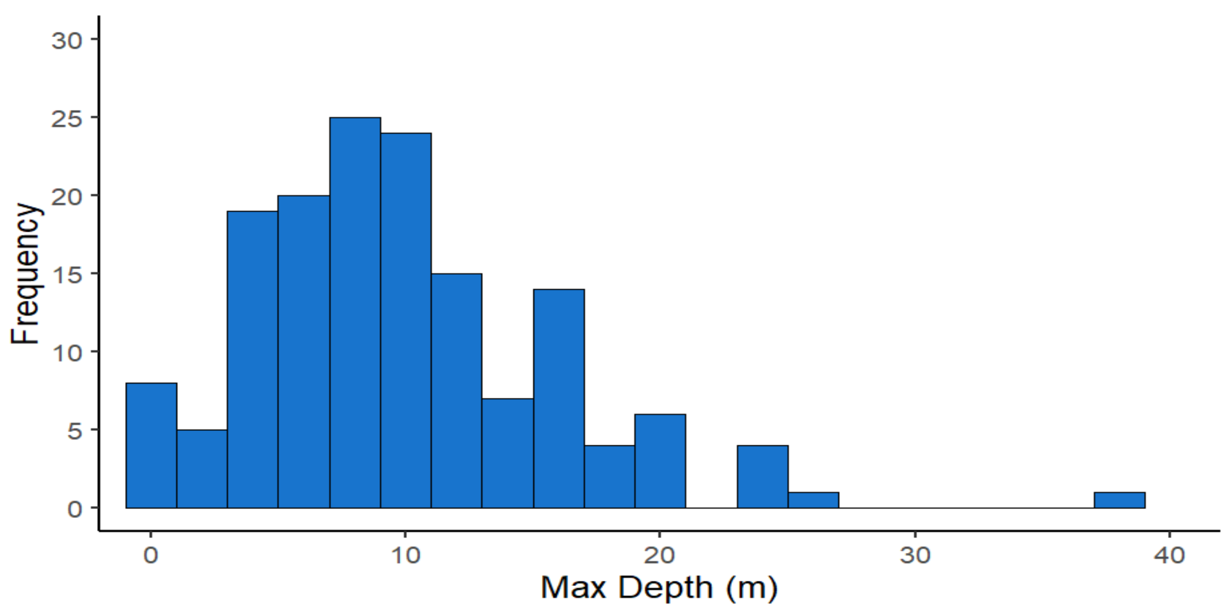

Figure 9 Maximum depth distribution for 160 lakes sampled from 2023 and 2024.

Water Characteristics

pH, Conductivity, and Alkalinity

Epilimnetic pH ranged from 6.52 to 9.56 for all lakes sampled. Oak Lake had the lowest epilimnetic pH of 6.52 and Bobcat Lake – both surface mine lakes – had the highest epilimnetic pH of 9.62 (Figure 10). Median epilimnetic pH for all lakes was 8.19. Hypolimnetic pH was comparable to epilimnetic pH, with a median hypolimnetic pH of 7.19. Goose Lake had the lowest hypolimnetic pH of 6.18 and Mallard Lake had the highest hypolimnetic pH of 9.38.

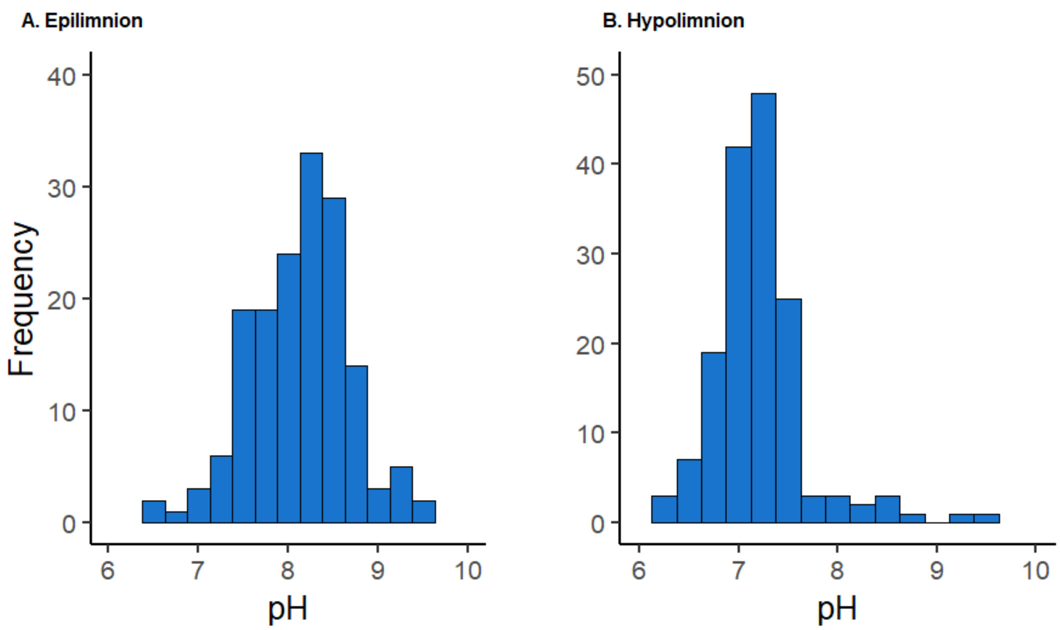

Figure 10 pH distribution for 320 lakes sampled in 2023 and 2024 by (A) epilimnion and (B) hypolimnion.

Median epilimnetic and hypolimnetic values were comparable for both conductivity and acid neutralizing capacity (ANC) (Figure 11). Minimum epilimnetic and hypolimnetic conductivity values were 40 µmhos/cm and 118 µmhos/cm, respectively. Maximum hypolimnetic conductivity was higher than maximum epilimnetic conductivity, with values of 2,708 and 8,380 µmhos/cm, respectively. These values come from surface mine lakes in Greene and Sullivan County. Median epilimnetic conductivity was 391 µmhos/cm compared to 507 for hypolimnetic samples.

The median ANC concentration for epilimnetic samples was 131 mg $CaCO_3$/L and 180 mg $CaCO_3$/L for hypolimnetic samples. Yellow Creek Lake (289 mg $CaCO_3$/L) and Airline Lake (1,966 mg $CaCO_3$/L) represented the maximum values for both epilimnion and hypolimnion.

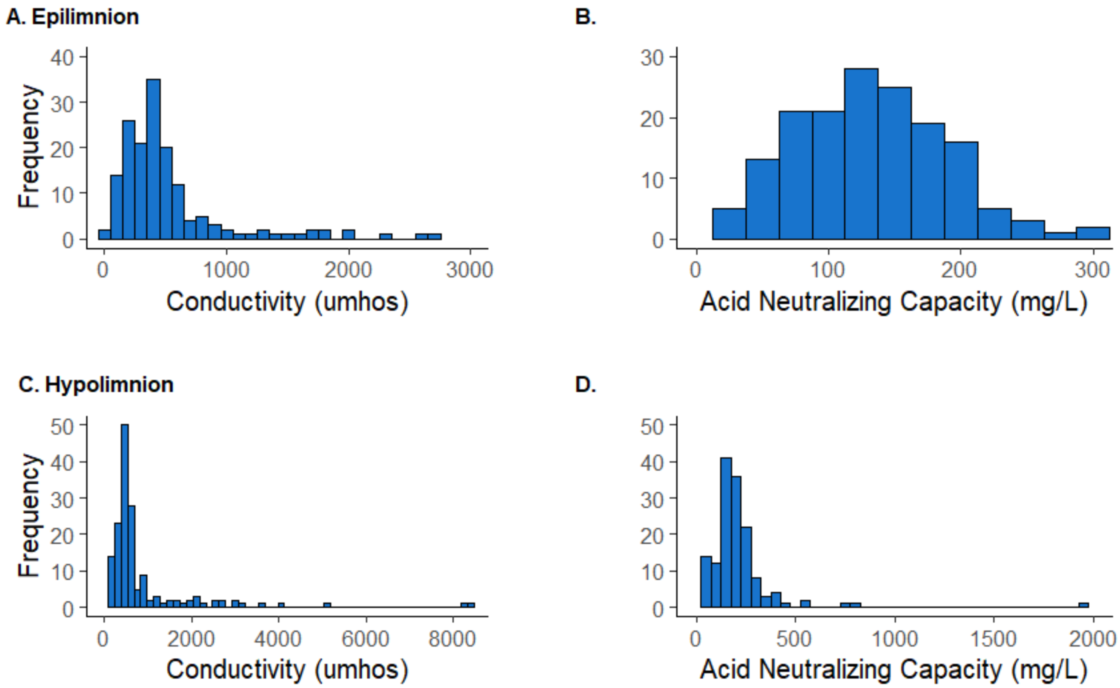

Figure 11 Conductivity and alkalinity distribution for 160 lakes sampled in 2023 and 2024 by (A) epilimnetic conductivity, (B) epilimnetic acid neutralizing capacity (ANC), (C) hypolimnetic conductivity, and (D) hypolimnetic ANC.

SRP and TP

Epilimnetic soluble reactive phosphorus (SRP) concentrations were generally low across all lakes, with a median concentration of 0.004 mg/L (Figure 12). Four lakes (2.5 percent) were at or below the method detection limit of 0.002 mg/L. However, Mollenkramer Lake in Ripley County had an SRP concentration of 0.114 mg/L. Hypolimentic SRP were higher than epilimnetic samples, with a median concentration of 0.069 mg/L. No hypolimnetic SRP values were at or below the method detection limit. Airline Lake had the highest concentration of 4.100 mg/L.

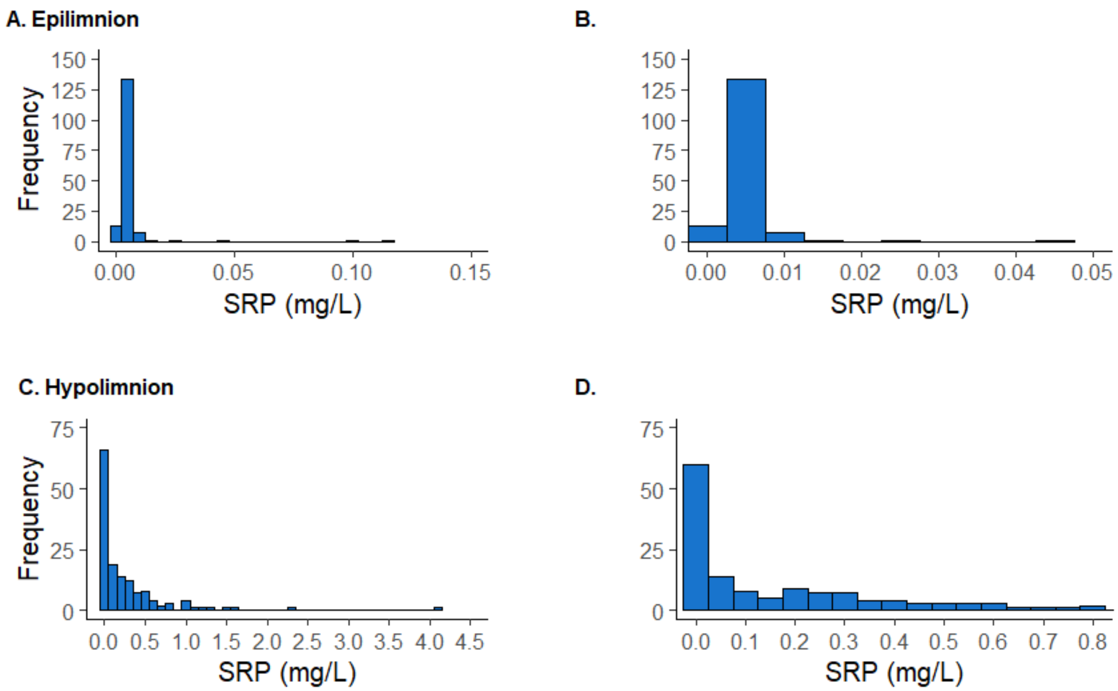

Figure 12 Soluble reactive phosphorus (SRP) distribution for 160 lakes sampled in 2023 and 2024 by (A) total distribution of epilimnetic SRP concentrations, (B) epilimnetic SRP concentrations under 0.05 mg/L, (C) all hypolimnetic SRP concentrations, and (D) hypolimnetic SRP concentrations under 0.80 mg/L.

Epilimnetic total phosphorus (TP) concentrations were lower compared to hypolimnetic samples, with median concentrations of 0.031 and 0.147 mg/L, respectively (Figure 13). Mollenkramer Lake (Ripley County) had the highest epilimnetic TP concentration of 0.446 mg/L and Airline Lake had the highest hypolimnetic concentration of 4.395mg/L.

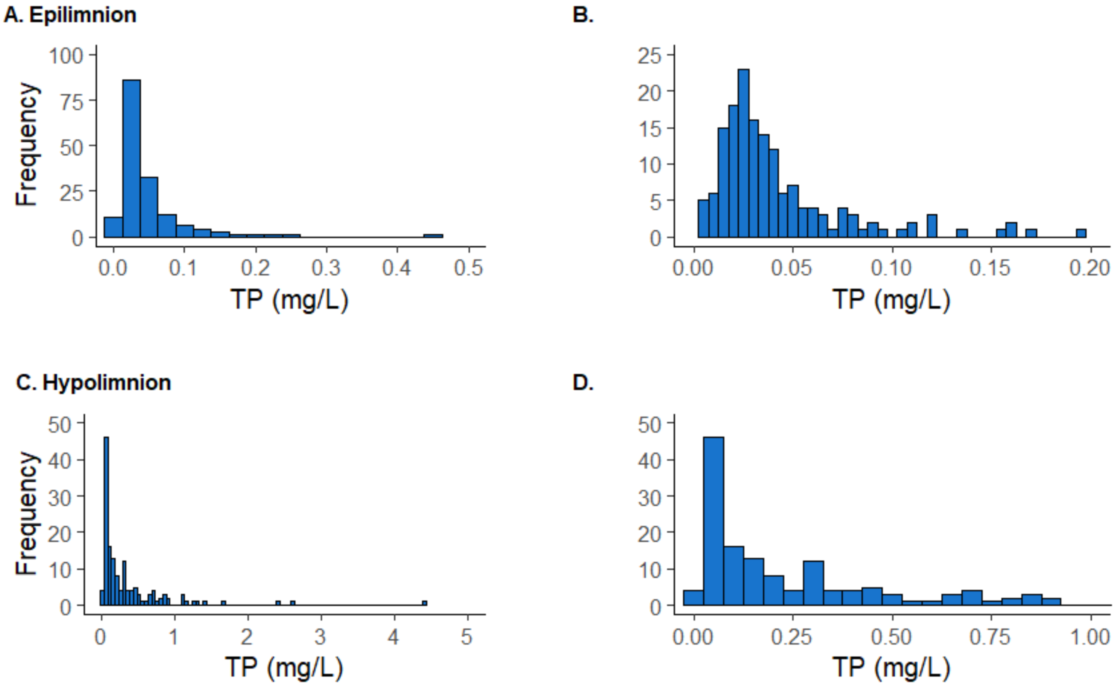

Figure 13 Total phosphorus (TP) distribution for 160 lakes sampled in 2023 and 2024 by (A) the total distribution of epilimnetic TP concentrations, (B) epilimnetic TP concentrations under 0.20 mg/L, (C) all hypolimnetic TP concentrations, and (D) hypolimnetic TP concentrations, and (D) hypolimnetic TP concentrations under 1.00 mg/L.

NO_3-N, NH_3-N, and Org-N

Nitrate-nitrogen median epilimnetic and hypolimnetic concentrations were similar, with concentrations of 0.027 and 0.032 mg/L, respectively (Figure 14). For the lakes sampled, 3 percent (5 lakes) had epilimnetic nitrate-nitrogen concentrations below the method detection limit of 0.007 mg/L, and 5.6 percent (9 lakes) had hypolimnetic concentrations below the method detection limit.

Ammonia-nitrogen concentrations were higher in the hypolimnion than the epilimnion (Figure 14). The median epilimnetic ammonia-nitrogen concentration was 0.064 mg/L, with 6.9 percent of lakes sampled below the method detection limit of 0.005 mg/L. In contrast, the median hypolimnetic concentration was 1.319 mg/L with only 2.5 percent of lakes below the method detection limit. Eagle Lake in Noble county had the highest hypolimnic concentration of 10.806 mg/L.

The median epilimnetic organic-nitrogen concentration was 0.0.574 mg/L (Figure 14). While Yellow Creek Lake had the highest epilimnetic organic-nitrogen concentration of 4.356 mg/L, organic-nitrogen concentrations across the 160 lakes were more normally distributed compared to nitrate-nitrogen and ammonia-nitrogen.

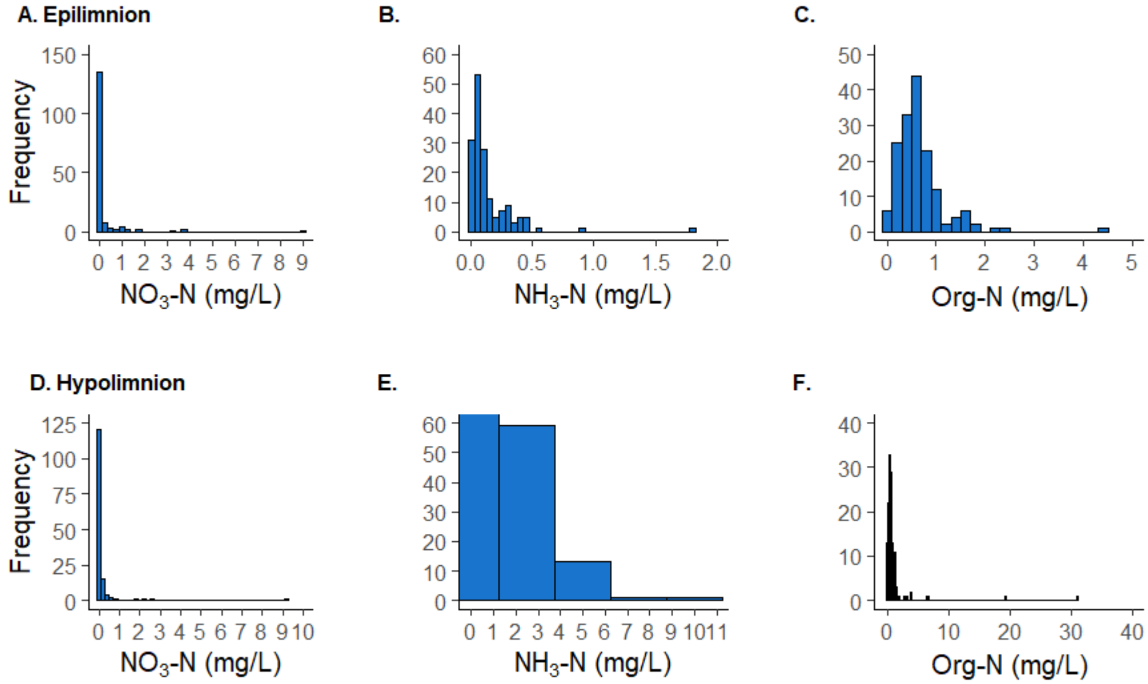

Figure 14 Nitrate-nitrogen (NO3-N), ammonia-nitrogen (NH3-N), and organic-nitrogen (Org-N) distributions for 160 lakes sampled in 2023 and 2024 by (A) epilimnetic NO3-N, (B) epilimnetic NH3-N, (C) epilimnetic Org-N, (D) hypolimnetic NO3-N, (E) hypolimnetic NH3-N, and (F) hypolimnetic Org-N.

Chlorophyll-a and Phytoplankton

Chlorophyll-a concentrations ranged from 0.512 ug/L (Daredevil Pit, Clay County) to 559.95µg/L (Yellow Creek Lake, Elkhart County), with a median concentration of 8.256 µg/L. Chlorophyll-a concentrations were highest in impoundments with a mean concentration of 38.246 µg/L, compared to 26.056 µg/L for natural lakes and 13.555 µg/L for surface mine lakes (Figure 15). Hypereutrophic lakes had the highest mean chlorophyll-a concentration of 100.147 µg/L, followed by eutrophic lakes (23.577 µg/L), mesotrophic lakes (4.718 µg/L), and oligotrophic lakes (1.820 µg/L) (Figure 16).

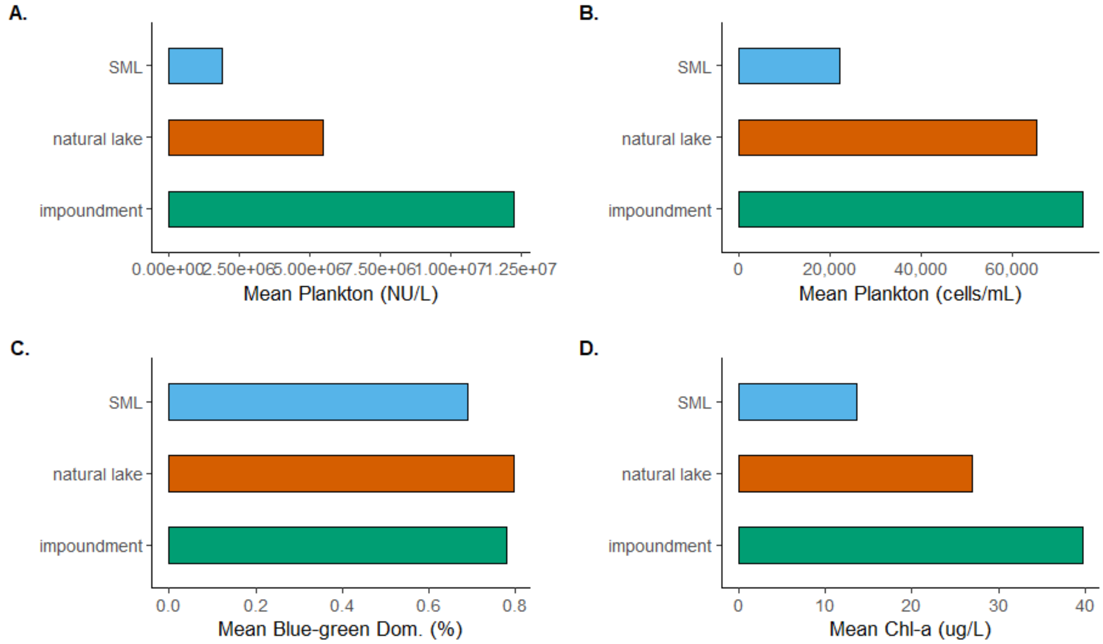

Figure 15 Distribution of (A) mean plankton natural units, (B) mean plankton cells, (C) mean blue-green cell dominance, and (D) mean chlorophyll-a concentration by lake type for 160 lakes sampled in 2023 and 2024.

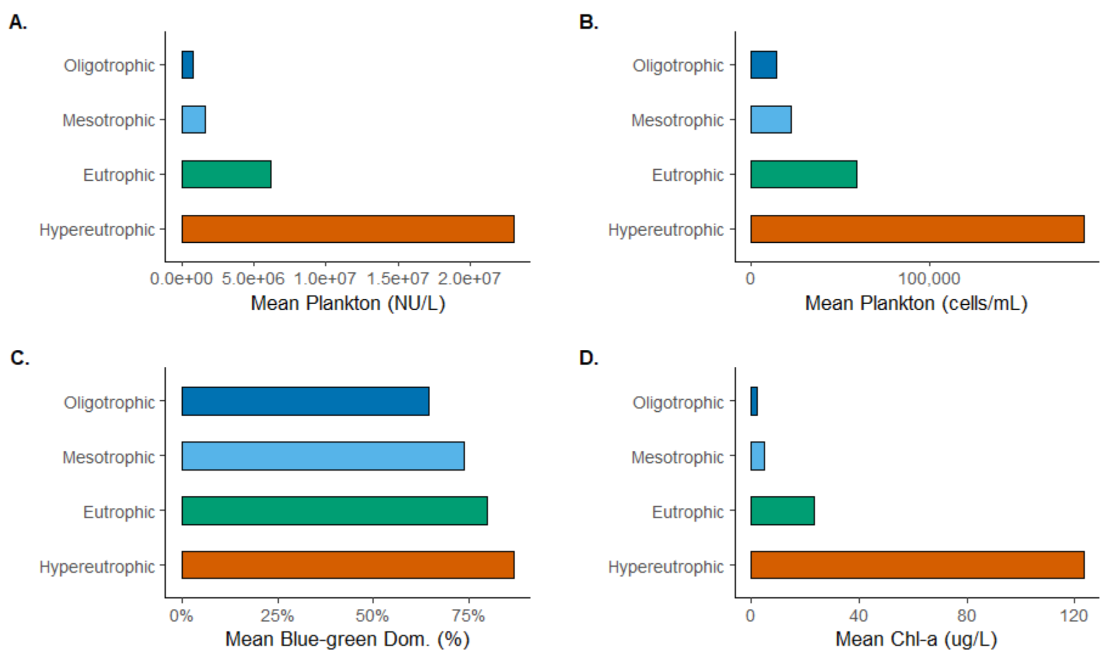

Figure 16 Distribution of (A) mean plankton natural units, (B) mean plankton cells, (C) mean blue-green cell dominance, and (D) mean chlorophyll-a concentration by lake type for 160 lakes sampled in 2023 and 2024.

Mean phytoplankton cell concentration was 56,317 cells/mL. Only Cedar Lake in Lake County's concentration exceeded 1 million cells/mL. Phytoplankton cell concentrations followed similar trends to chlorophyll-a in terms of lake type and trophic state. Mean cell concentrations were incrementally highest for impoundments (75,461 cells/mL), followed by natural lakes (65,169 cells/mL), and then surface mine lakes (22,114 cells/mL). Hypereutrophic lakes had the highest phytoplankton cell concentration, with a mean concentration of 1196,447 cells/mL. The mean cell concentration for eutrophic lakes was 59,180 cells/mL. Mesotrophic and oligotrophic lakes had the lowest mean cell concentrations of 21,825 and 13,870 cells/mL, respectively.

Cyanobacteria (commonly called blue-green algae) were most dominant in impoundments, accounting for a mean of 61 percent of all algal cells, followed by natural lakes with a mean of 55 percent, then surface mine lakes with a mean of 40 percent of all cells being cyanobacteria. Cyanobacteria dominance correlated with trophic classification showing a mean decrease with decreasing trophic class. Hypereutrophic lakes had the highest mean cyanobacteria dominance of 87 percent, eutrophic lakes 80 percent, mesotrophic 74 percent, and oligotrophic 65 percent, respectively.

Secchi Disk Transparency and Trophic State

Median Secchi depth for all lakes sampled was 1.6 meters (Figure 17). Impoundments have the lowest median Secchi depth of 1.14 meters, whereas surface mine lakes had a median Secchi depth of 2.2 meters. These trends followed for the overall lowest and highest Secchi depths. Wyandotte Lake (an impoundment) had a Secchi depth of only 0.15 meters and Daredevil Pit Lake in Clay County (a surface mine lake) had the maximum Secchi depth of 7.4 meters. Falling in the middle, natural lakes had a median Secchi depth of 1.6 meters.

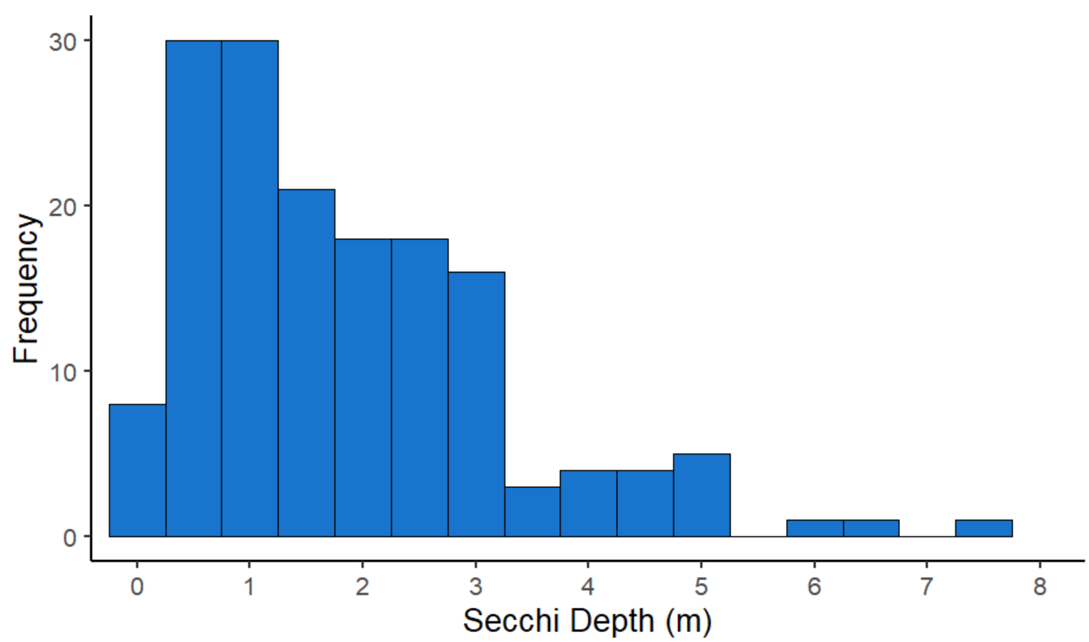

Figure 17 Secchi depth distribution for 160 lakes sampled in 2023 and 2024.

Eutrophic lakes were the most common based on TSI [chl-a], accounting for 41 percent of all lakes sampled (Figure 18). Mesotrophic lakes accounted for 33 percent of lakes sampled. Only 12 percent of lakes sampled were hypereutrophic.

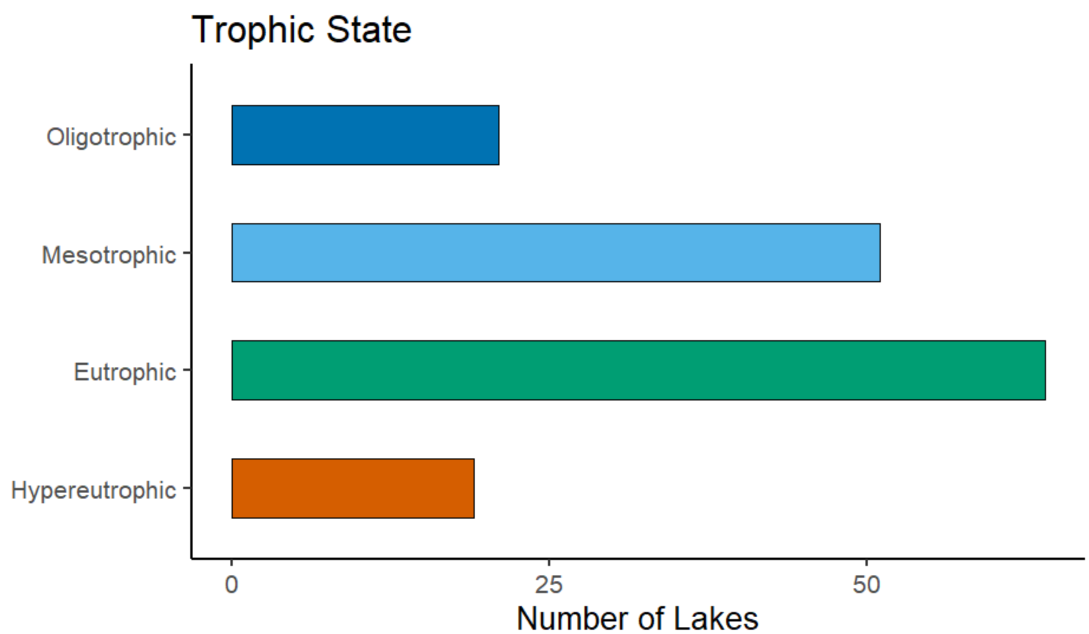

Figure 18 Number of lakes sampled in 2023 and 2024 (n = 160) by Carlson TSI[chl-a].

While TSI [chl-a] is reported consistently throughout this report as the best indicator of eutrophication, the relationship between TSI [chl-a] and TSI [TP] is important to assess (Figure 19). Approximately 45 percent of the lakes sampled in 2023 and 2024 fall below the predicted one to one relationship (red line in Figure 19) between chlorophyll-a and total phosphorus according to Carlson (1977). The 45 percent that fall below the predicted relationship indicates that a high percentage of Indiana lakes have non algal bound phosphorus, likely a result of sediment bound phosphorus.

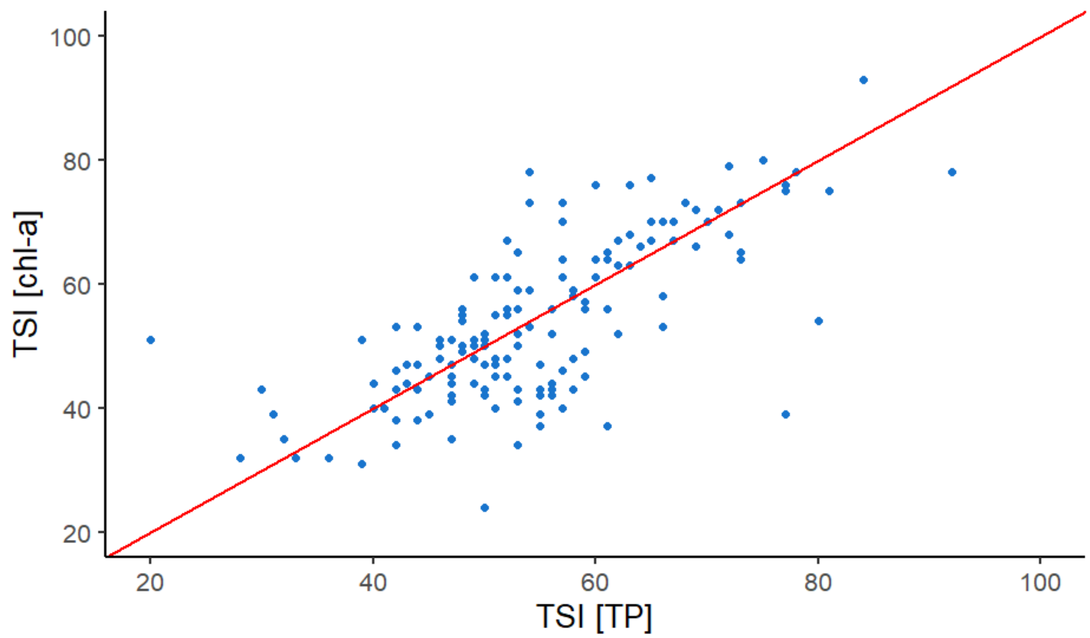

Figure 19 Carlson TSI[TP] plotted against Carlson TSI[chl-a] for 160 lakes sampled in 2023 and 2024. The red line indicates the predicted relationship between TSI[TP] and TSI[chl-a].

Spatial Patterns

The 160 lakes sampled in 2023 and 2024 were in 5 of the 6 ecoregions in Indiana (Figure 20). The Huron-Erie Lake Plain (Ecoregion 57) was the only ecoregion without a lake sampled. Most lakes sampled were in northeastern Indiana, with 50 percent occurring in the Southern Michigan/Northern Indiana Till Plain (Ecoregion 56).

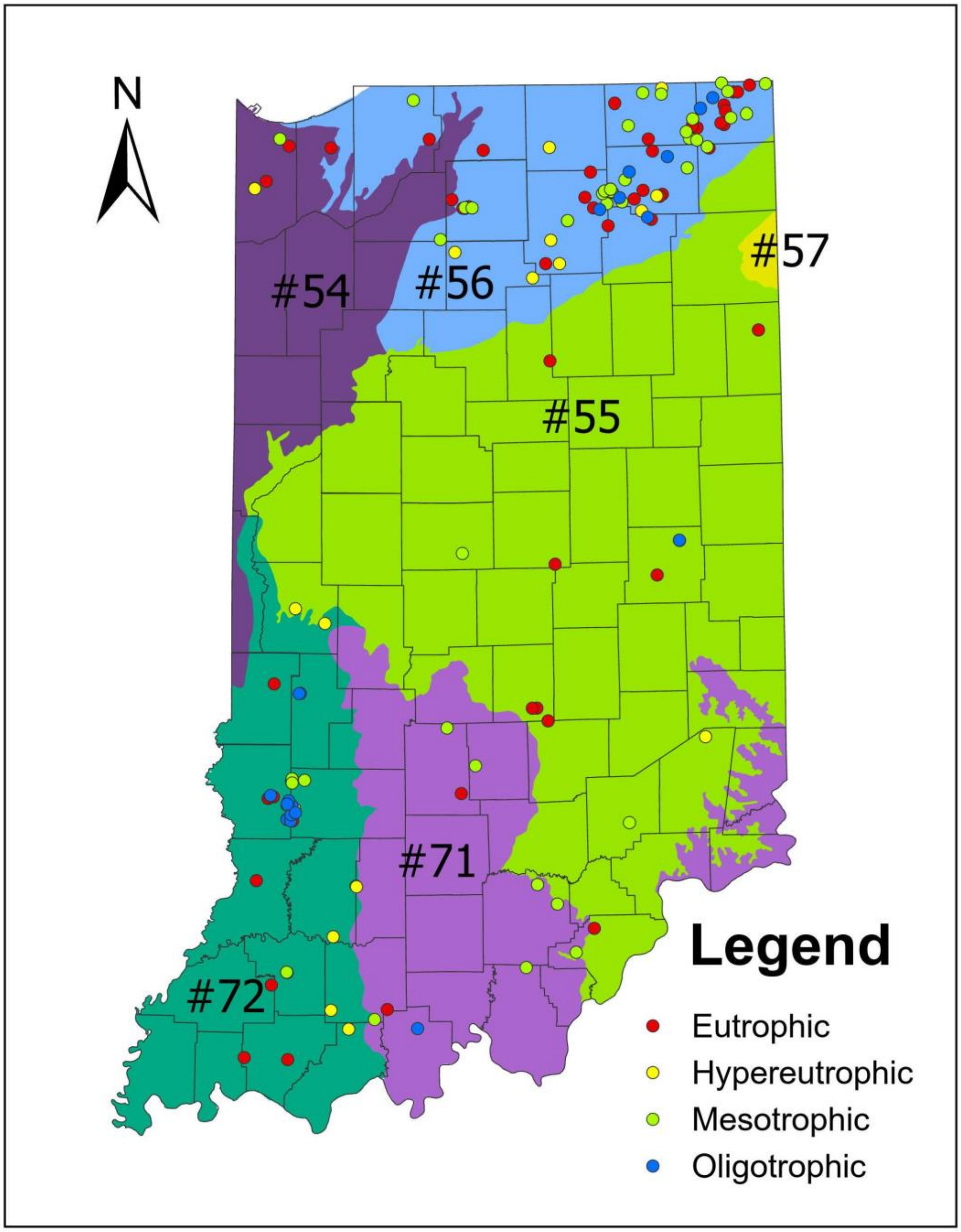

Figure 20 Location of lakes in 2023 and 2024 (n = 160) by Carlson TSI [chl-a] overlain on Indiana ecoregions (represented by color and corresponding number).

The Central Corn Belt Plains (Ecoregion 54) and the Eastern Corn Belt Plains (Ecoregion 55) had the highest median chlorophyll-a concentrations of 16.068 ug/L and 11.691 ug/L, respectively (Figure 21). The Interior Plateau (Ecoregion 71) had the lowest median chlorophyll-a concentration of 5.676 ug/L.

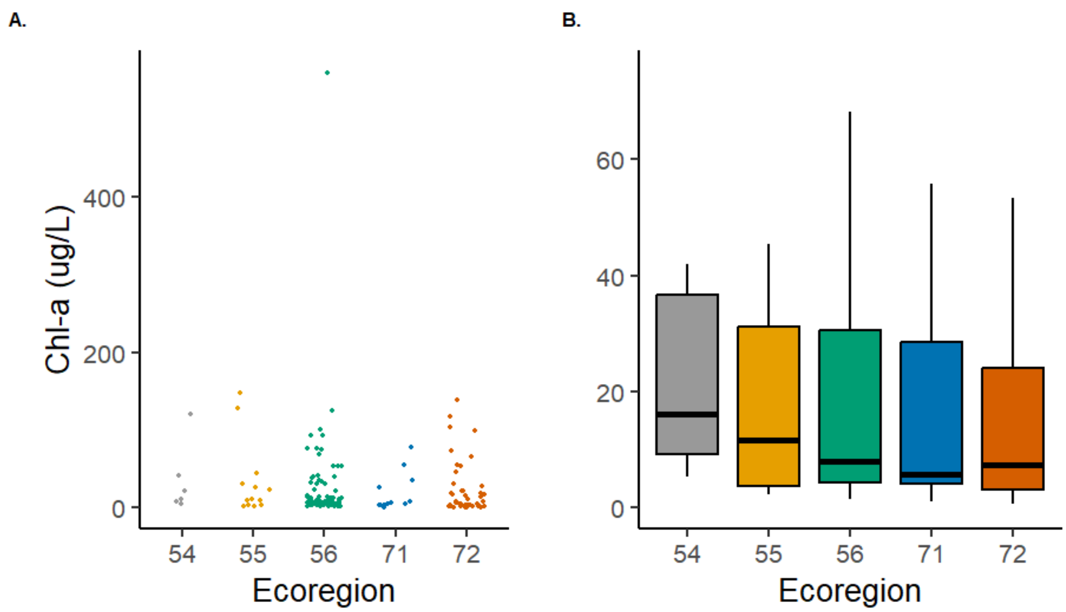

Figure 21 Chloropyll-a (chl-a) distribution by ecoregion for 160 lakes sampled in 2023 and 2024. Figure (A) illustrates the total distribution by a dot plot and (B) illustrates the same distribution with a box pot.

Total phosphorus concentrations followed similar spatial patterns to that of chlorophyll-a concentrations (Figure 22). Ecoregion 54, 55, and 72 had higher median TP concentrations compared to that of Ecoregion 56 and 71. Median TP concentration was highest in Ecoregion 54 with a concentration of 0.057 mg/L, and Ecoregion 71 had the lowest median concentration of 0.023 mg/L.

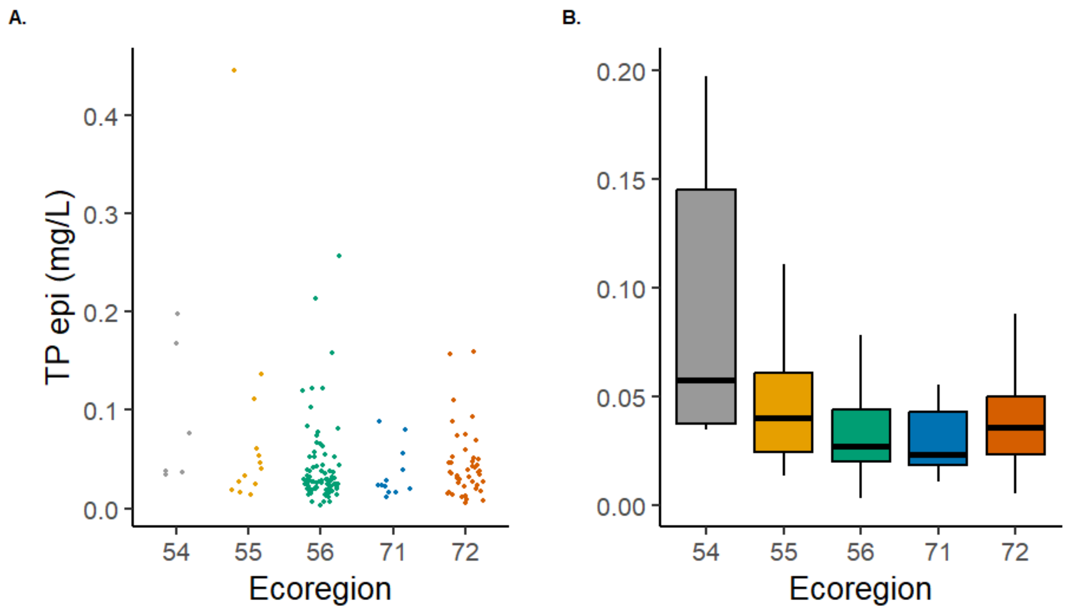

Figure 22 Total phosphorus (TP) distribution by ecoregion for 160 lakes sampled in 2023 and 2024 by the (A) total TP distribution via dot plot and the (B) TP distribution via box plot.

Median Secchi depths were highest in Ecoregion 72 (3.24 meters) and 71 (1.72 meters) (Figure 23). Ecoregion 55 had the lowest median Secchi depth of 1.15 meters. Daredevil Lake in Ecoregion 72 had the deepest Secchi depth, the highest overall value of 7.4. Most of the lakes in ecoregion 72 are surface mine lakes and have the highest Secchi depth transparencies.

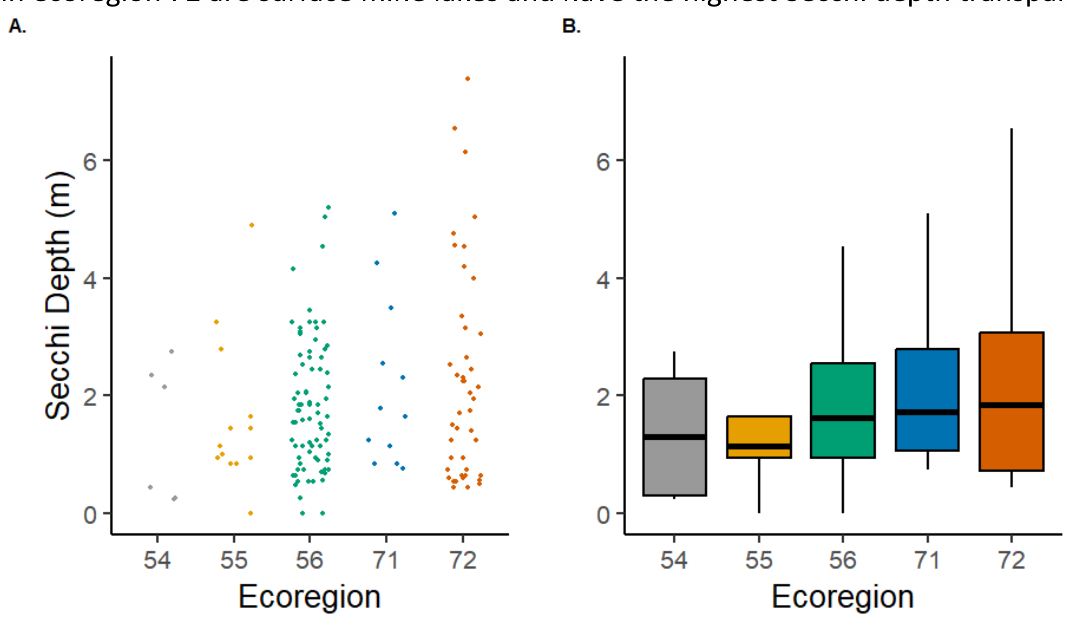

Figure 23 Secchi depth distribution by ecoregion for 160 lakes sampled in 2023 and 2024 by the (A) total Secchi depth distribution via dot plot and (B) Secchi depth distribution via box plot.

TSI [chl-a] median values followed similar trends across ecoregions with chlorophyll-a and total phosphorus (Figure 24). Median TSI [chl-a] values were highest in Ecoregion 54 and 55, both of which were above the bottom limit of the eutrophic classification of 51. Ecoregion 71 had the lowest median TSI [chl-a] value of 47.5.

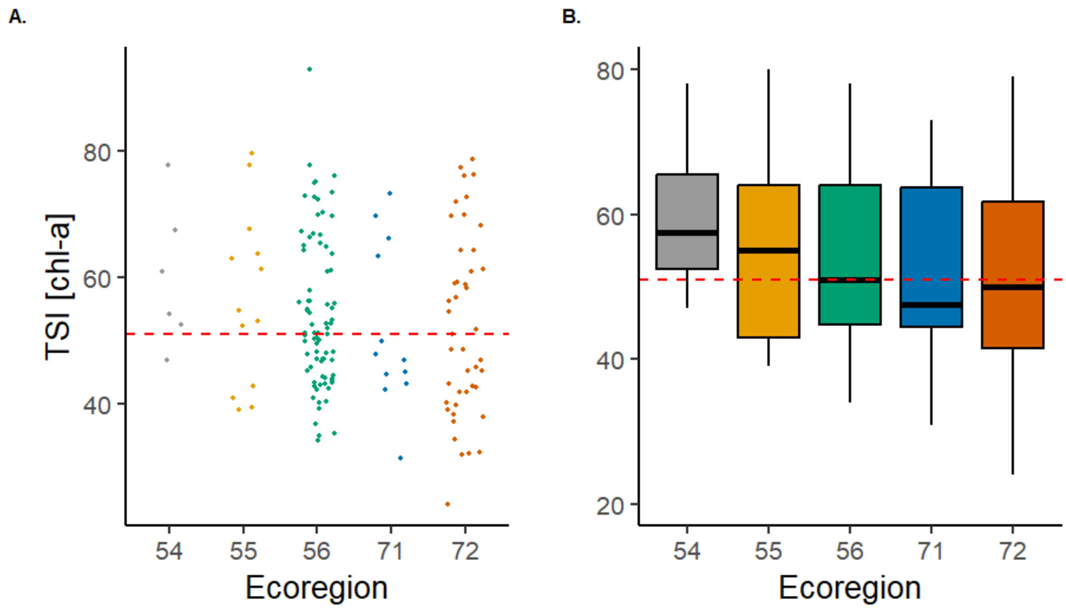

Figure 24 Carlson TSI [chl-a] distribution by ecoregion for 160 lakes sampled in 2023 and 2024. Figure (A) illustrates the total distribution by a dot plot and (B) illustrates the same distribution with a dox plot. The dashed line indicates the TSI break between eutrophic and mesotrophic.

Lake Type Characteristics

Natural lakes represented the most common lake type sampled during the project, accounting for 52 percent of all lakes sampled. Impoundments, or reservoirs, represented 23 percent of lakes sampled, and 25 percent of lakes were surface mine lakes.

Impoundments had the highest median surface area of all lake types, but the lowest median maximum depth (Figure 25, Figure 26). Impoundments also had the largest variation in surface area from 1 to 4,350 hectares. While the median surface area of natural lakes was less than the median for impoundments, natural lakes were the deepest of the three lake types. The median surface area and maximum depth for natural lakes was 24.69 hectares and 11 meters, respectively. Median surface area for surface mine lakes was the smallest of the three lake types, with a value of 3.04 hectares. Surface mine lakes were generally deeper than impoundments but shallower compared to natural lakes, with a median maximum depth of 7.6 meters. The largest lake sampled was Monroe Lake (Monroe County) and Tippecanoe Lake (Kosciusko County) was the deepest lake sampled.

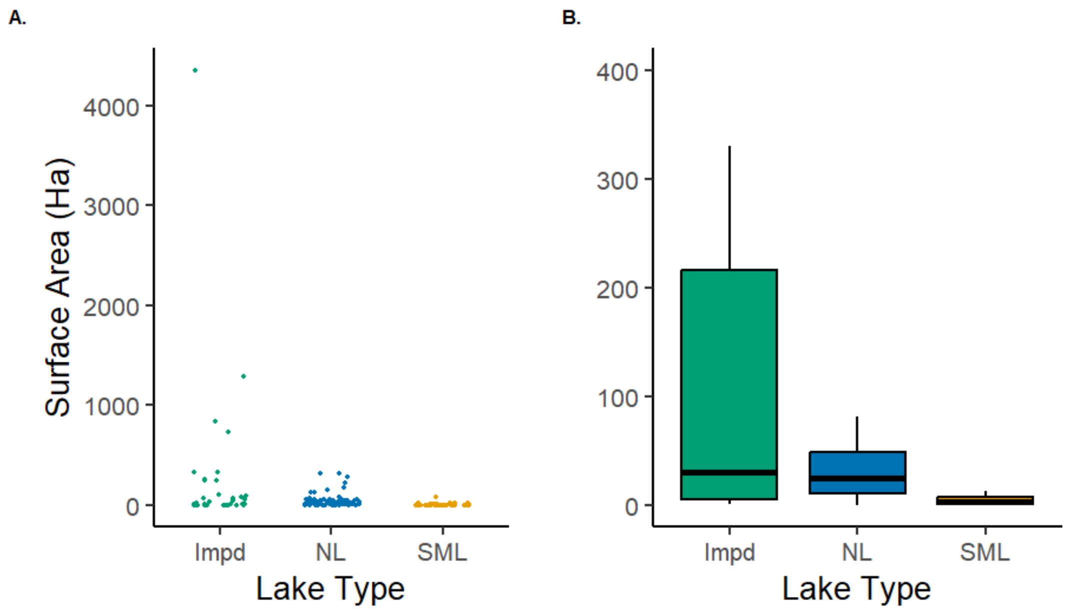

Figure 25 Surface area distribution by lake type for 160 lakes sampled in 2023 and 2024 by the (A) total surface area distribution by a dot plot and (B) surface area distribution by a box plot (Impd = impoundments; NL = natural lakes; SML = surface mine lakes).

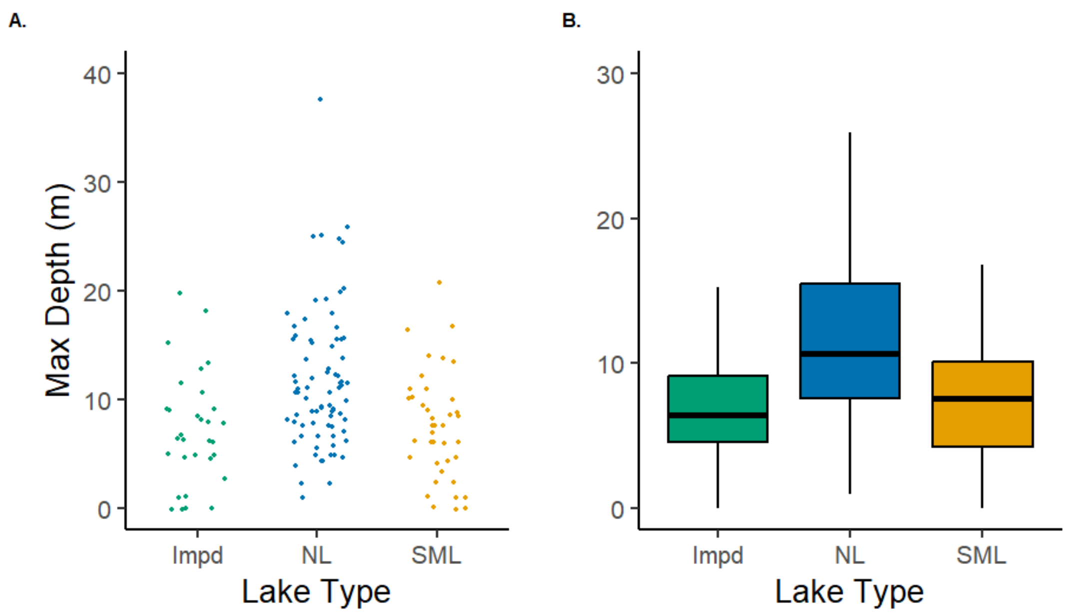

Figure 26 Maximum depth distribution by lake type for 160 lakes sampled in 2023 and 2024. Figure (A) illustrates the total distribution by a dot plot and (B) illustrates the same distribution with a box plot (Impd = impoundments; NL = natural lakes; SML = surface mine lakes).

Natural lakes had the highest median epilimnetic ANC concentration of 152 mg $CaCO_3$/L (Figure 27). Median ANC concentration for surface mine lakes was 104 mg $CaCO_3$/L, and surface mine lakes had the greatest ANC variation of the three lake types (39 to 297 mg $CaCO_3$/L). The median ANC concentration for impoundments was 96 mg $CaCO_3$/L.

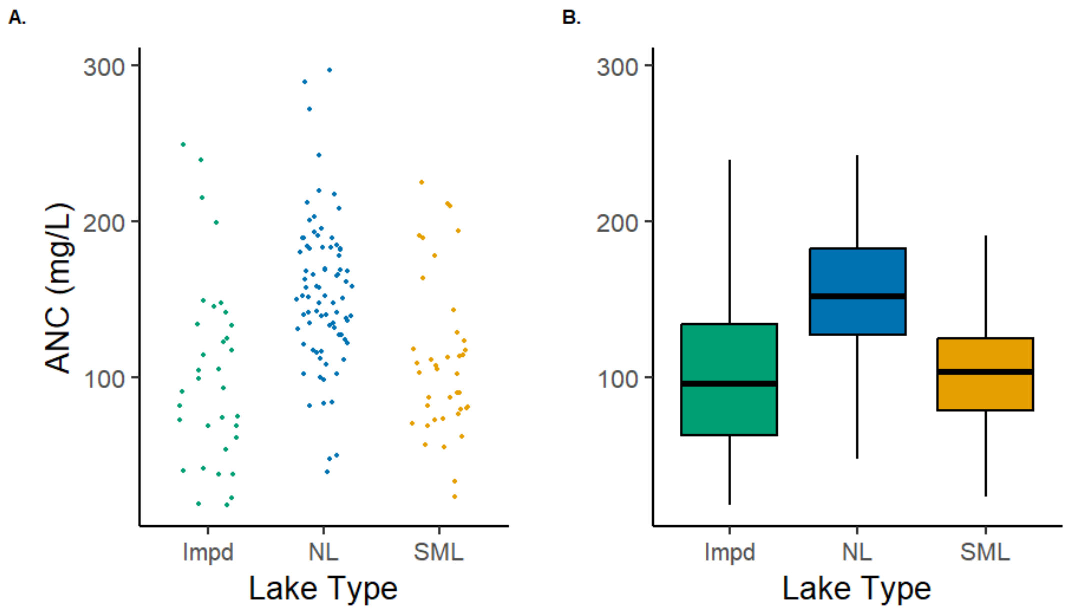

Figure 27 Acid neutralizing capacity (ANC) distribution by lake type for 160 lakes sampled in 2023 and 2024 by (A) total ANC distribution by a dot plot and (B) total distribution by a box plot (Impd = impoundments; NL = natural lakes; SML = surface mine lakes).

Median epilimnetic conductivity in surface mine lakes was almost two times the median of natural lakes, with conductivities of 641 and 408 µmhos/cm, respectively (Figure 28). Surface mine lakes also had the greatest variation in conductivity, with values ranging from 92 to 2708 µmhos/cm. Impoundments had the lowest conductivity of the lake types, with a median conductivity of 229 µhmos/cm.

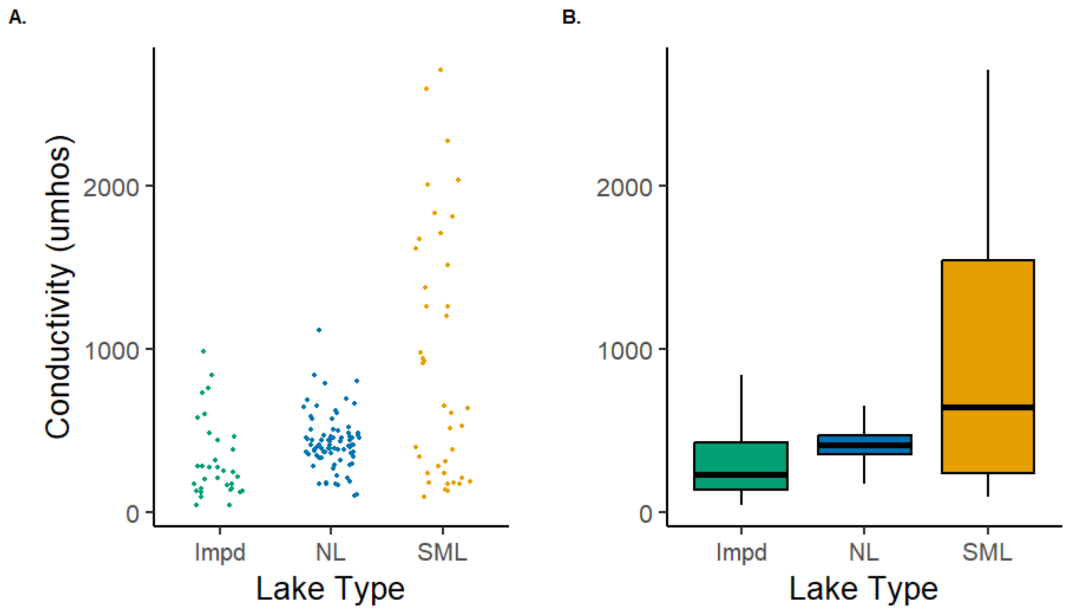

Figure 28 Conductivity distribution by lake type for 160 lakes sampled in 2023 and 2024. Figure (A) illustrates the total distribution by a dot plot and (B) illustrates the same distribution with a box plot (Impd = impoundments; NL = natural lakes; SML = surface mine lakes).

Epilimnetic pH values were consistent across lake types, with only a 0.13 deviation between median pH values (Figure 29). Impoundments had a median pH of 8.11, natural lakes had a median pH of 8.23, and surface mine lakes had a median pH of 7.96.

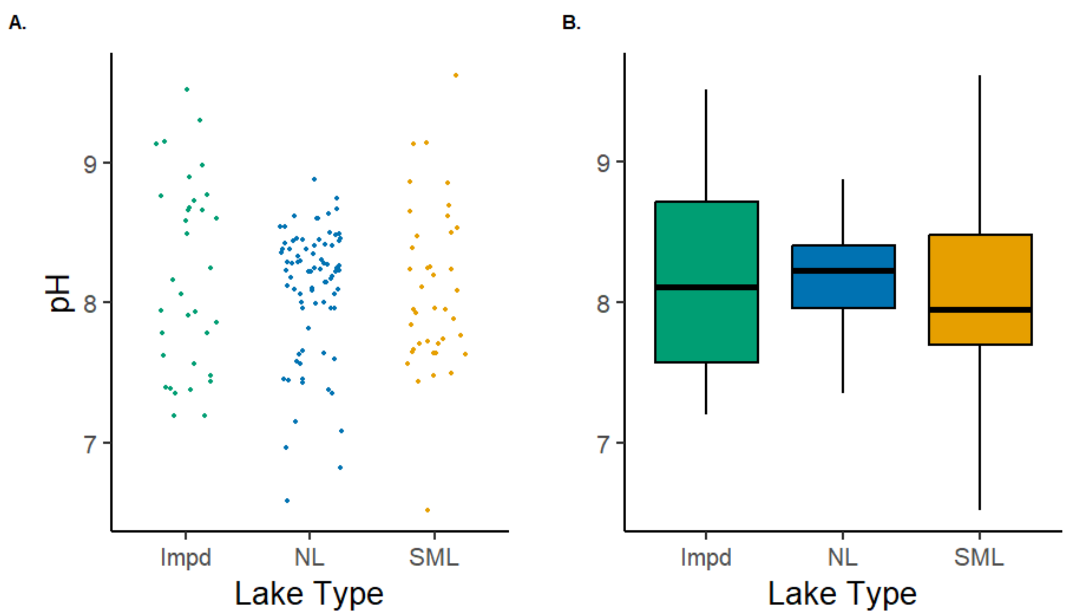

Figure 29 pH distribution by lake type for 160 lakes sampled in 2023 and 2024. Figure (A) illustrates the total distribution by a dot plot and (B) illustrates the same distribution with a box plot (Impd = impoundments; NL = natural lakes; SML = surface mine lakes).

Natural lakes and impoundments had similar median concentrations of NO_3-N, NH_3-N, and TP (Figure 30, Figure 31, Figure 32). Median nutrient concentrations in surface mine lakes are lower for all three parameters explored in surface samples.

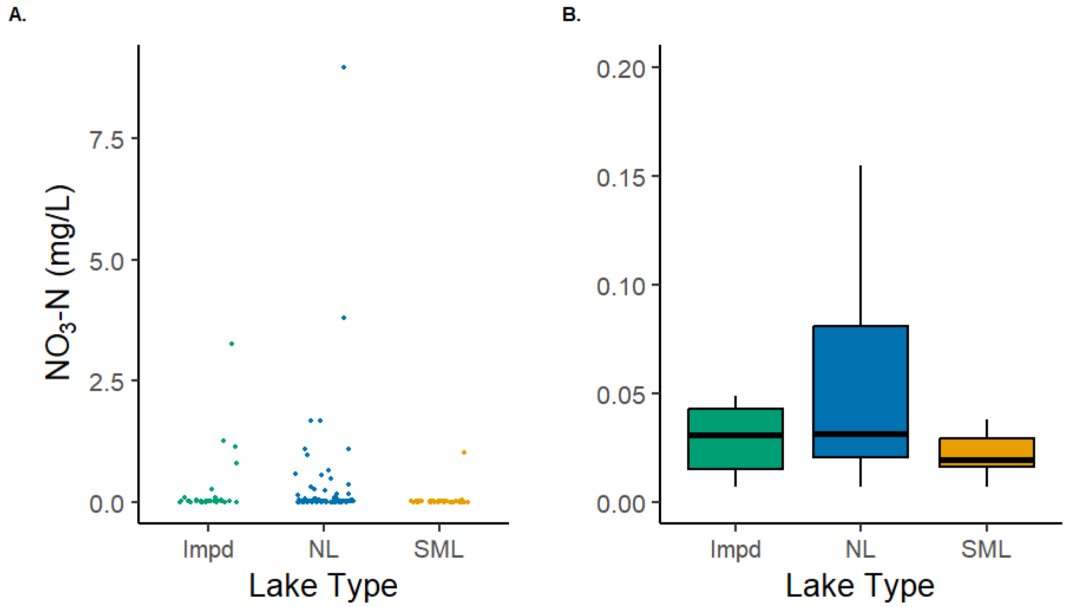

Figure 30 Nitrate-nitrogen (NO3-N) distribution by lake type for 160 lakes sampled in 2023 and 2024 by (A) total NO3-N distribution by a dot plot and (B) total distribution by a box plot (Impd = impoundments; NL = natural lakes; SML = surface mine lakes).

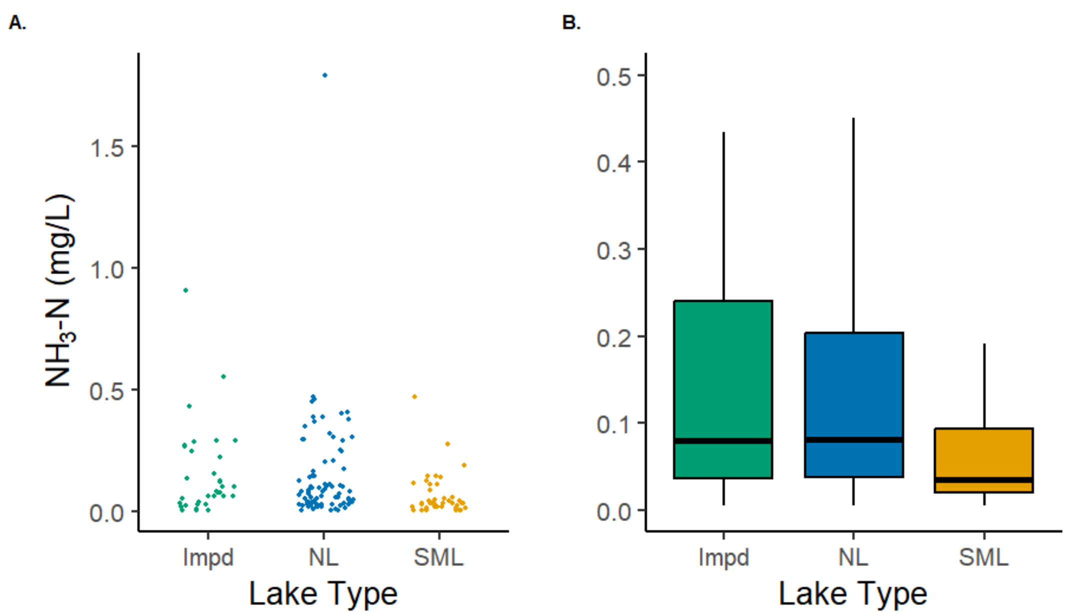

Figure 31 Ammonia-nitrogen (NH3-N) distribution by lake type for 160 lakes sampled in 2023 and 2024 by (A) total NH3-N distribution by dot plot and (B) total distribution by box plot (Impd = impoundments; NL = natural lakes; SML = surface mine lakes).

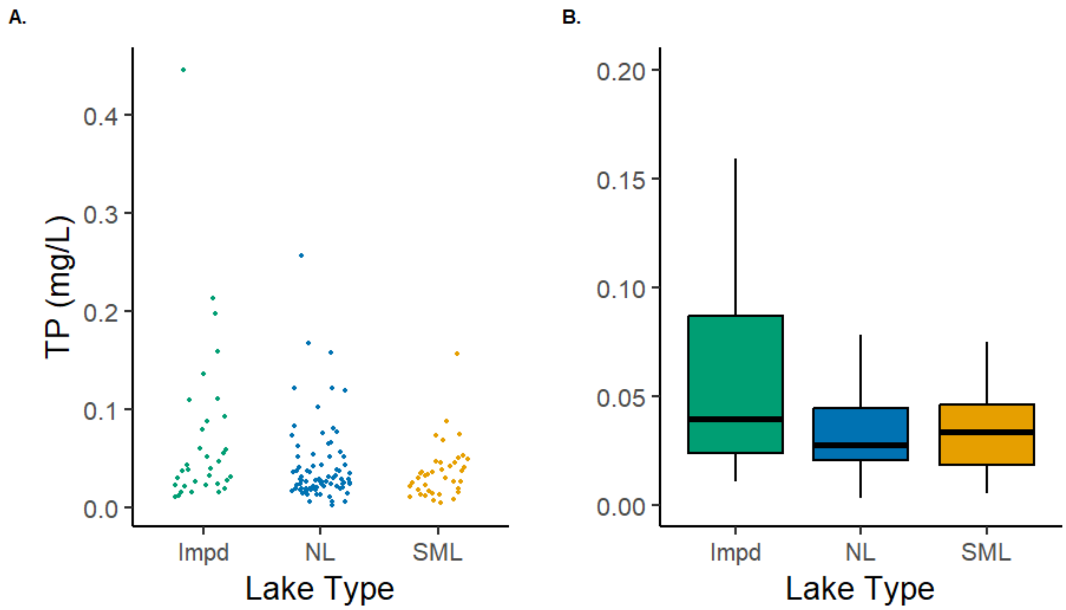

Figure 32 Total phosphorus (TP) distribution by lake type for 160 lakes sampled in 2023 and 2024 by the (A) total TP distribution via dot plot and the (B) TP distribution via box plot.

Chlorophyll-a concentrations were highest in impoundments, with a median chlorophyll-a concentration of 22.29 µg/L (Figure 33). Natural lakes had the second highest median chlorophyll-a concentration of 8.28 µg/L followed by surface mine lakes of 4.95 µg/L. The maximum chlorophyll-a concentration, 559.95 µg/L, across all lakes sampled was in a natural lake.

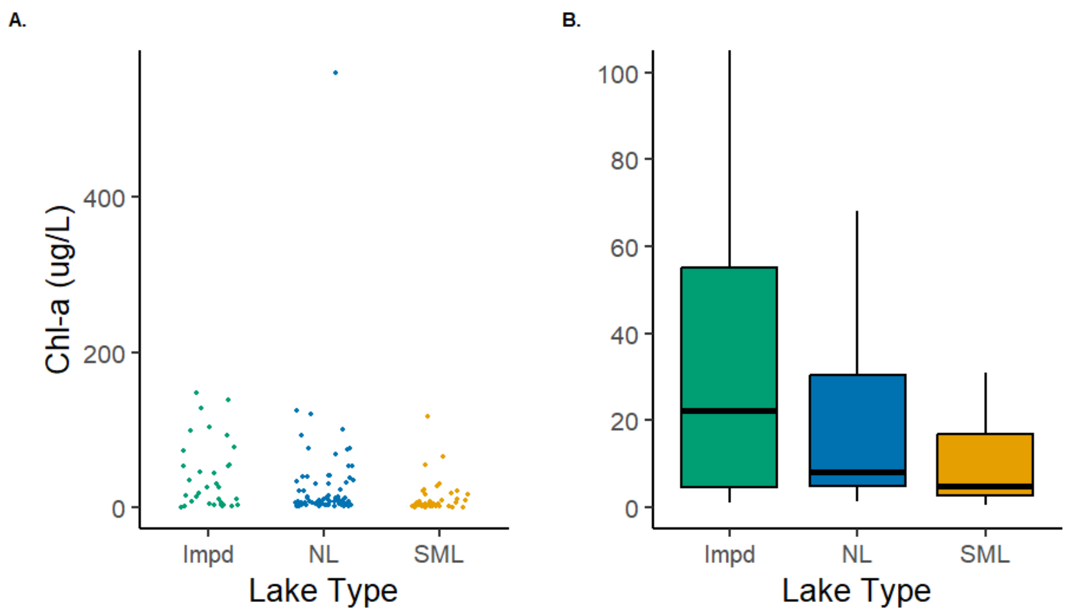

Figure 33 Chloropyll-a (chl-a) distribution by lake type for 160 lakes sampled in 2023 and 2024. Figure (A) illustrates the total distribution by a dot plot and (B) illustrates the same distribution with a box pot.

Secchi depths by lake type followed an inverse relationship to that of chlorophyll-a as expected (Figure 34). Median Secchi depth for surface mine lakes was 2.2 meters, 1.7 meters for natural lakes, and 1.1 meters for impoundments.

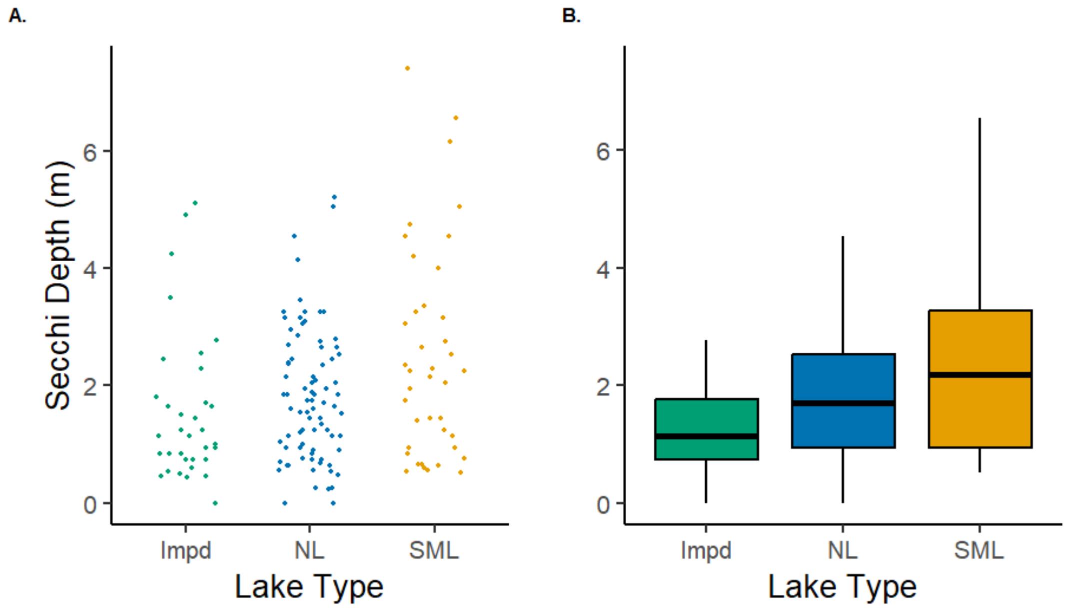

Figure 34 Secchi depth distribution by lake type for 160 lakes sampled in 2023 and 2024 by (A) total Secchi depth distribution via dot plot and (B) total distribution via box plot (Impd = impoundments; NL = natural lakes; SML = surface mine lakes).

Median TSI [chl-a] values for impoundments were greater than the bottom limit for the eutrophic interpretation, with a median of 61 (Figure 35). The median value for natural lakes was right at the eutrophic limit, with a value of 52. Median TSI [chl-a] for surface mine lakes was 47. Overall, 65 percent of impoundments were either eutrophic or hypereutrophic, compared to 56 percent of natural lakes and 40 percent of surface mine lakes.

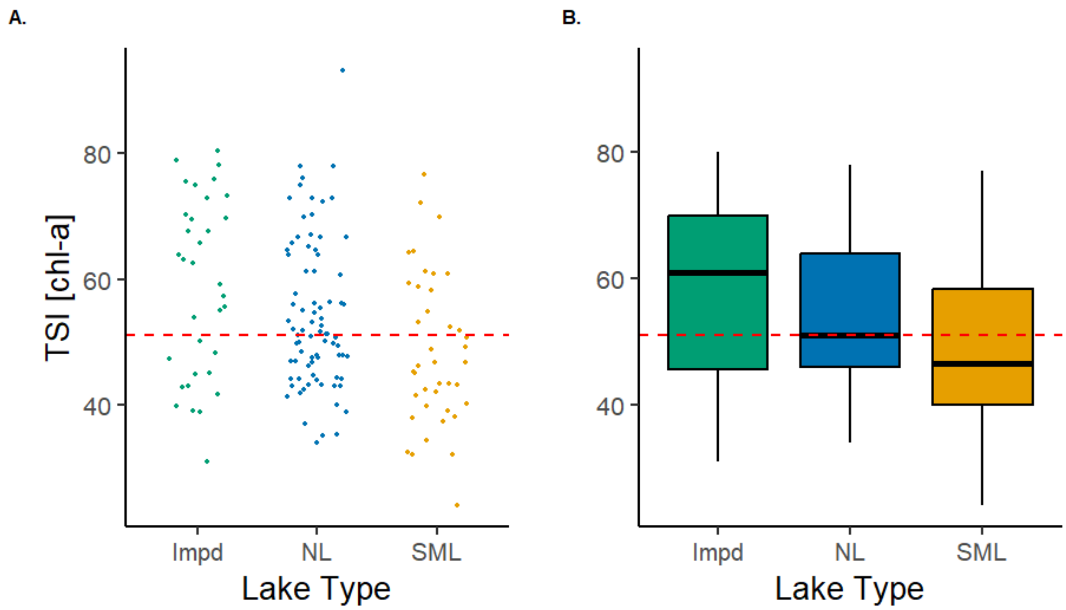

Figure 35 TSI [chl-a] distribution by lake type for 160 lakes sampled in 2023 and 2024. Figure (A) illustrates the total TSI [chl-a] distribution by a dot plot and (B) illustrates the same distribution with a box plot (Impd = impoundments; NL = natural lakes; SML = surface mine lakes). The dashed line indicates the TSI break between eutrophic and mesotrophic.

DISCUSSION

State of Indiana Lakes

Many lakes throughout the state of Indiana receive high nutrient loads and thus are productive aquatic systems. This was expected as agricultural activity is a dominant land use throughout the state, and the subsequent runoff of nutrients, specifically nitrogen and phosphorus, would contribute to increased productivity in lakes.

Nitrogen and phosphorus are two primary nutrients needed for plant growth. As a result, increased nutrient loading can contribute to increased algal growth. Algal communities occur in nearly all lakes and are an important part of the food chain. However, when nuisance blooms form, or cyanobacteria populations increase there is a potential for concern. Cyanobacteria can produce toxins that are harmful to human health and wildlife. Cyanobacteria accounted for more than 90 percent of algal cells measured in 47 percent of lakes sampled.

Trophic state is perhaps the most useful measure of the current state of Indiana Lakes, as well as a tool to compare Indiana to other states and regions across the United States. We found that over half (54 percent) of Indiana lakes were either eutrophic or hypereutrophic based on TSI [chl-a], indicating high levels of productivity. We did find some deviation in the relationship between the predicted relationship between TSI [chl-a] and TSI [TP]. According to Carlson (1977), chlorophyll-a concentrations can be predicted based on the TP concentration in the lake. However, we found that almost half of the actual values were less than the predicted values. Non-algal turbidity is likely driving this deviation. Indiana Lakes are generally more turbid because of sediment runoff compared to the lakes that Carlson used in his model. Increased non-algal turbidity would reduce light penetration, decreasing the depth of the euphotic zone, and decreasing algal photosynthesis. Leveraging the known relationship with Carlson TSI values we can gain additional insight into the function of Indiana lakes.

Spatial Patterns

Aggregating lakes by ecoregion is helpful to identify regional differences in lake water quality. Ecoregion 54 (Eastern Corn Belt Plains) and 55 (Central Corn Belt Plains) had higher median values for chlorophyll-a, TP, and TSI [chl-a] compared to Ecoregions 56, 71, and 72. Row crop agriculture is the primary land use with Ecoregions 54 and 55. The relationship between agricultural fertilizers and lake eutrophication is well established is likely the cause of increased nutrient concentrations and trophic state (Novotny 2003).

Ecoregions 71 and 72, located in southern Indiana, have less agricultural activity, more forested land, and are primarily impoundments and surface mine lakes. Even though reservoirs have larger watersheds and increased potential for higher nutrient loads, these ecoregions all had lower median productivity values. This indicates the importance of land use on lake water quality. Ecoregion 71 and 72 had higher median Secchi depth measurements compared to ecoregion 54 and 55.

While we see qualitative differences in our lakes aggregated by ecoregion, further analysis is needed to develop a quantitative comparison.

Lake Type Patterns

Limnological characteristics can vary greatly with lake type. Our data included three lake types: natural lakes, impoundments, and surface mine lakes. Impoundments generally had a larger surface area, were shallower, and more productive compared to natural lakes and surface mine lakes. This is expected as larger watersheds can contribute higher nutrient loads and shallower lakes have a large portion of the water column that is euphotic, contributing to increased productivity.

Surface mine lakes were unique compared to other lake types. Surface mine lakes had low median pH, mid median ANC concentration, and extremely high conductivity values compared to the other lake types. High conductivity in surface mine lakes is a byproduct of the mining process, where iron-sulfur compounds in mine waste can leach ions out of the soil and into the water column (Gyure et al. 1987). As conductivity is a measure of the ability of water to pass an electrical current, increased concentrations of dissolved ions cause higher conductivity in these lakes.

CONCLUSIONS

Summary conclusions from the 2023 and 2024 lake water quality assessment program include:

- Phosphorus concentrations in many Indiana lakes can be excessive and contribute to eutrophication.
- Internal loading of phosphorus from lake sediments is an important source of phosphorus in many lakes and is inherently difficult to control.
- High non-algal turbidity in many Indiana lakes may result in reduced algal communities otherwise predicted by available phosphorus concentrations.
- Cyanobacteria are common in Indiana lakes and should be monitored.
- Over half of Indiana lakes assessed were either eutrophic or hypereutropohic. However, 33 percent of lakes were mesotrophic.
- Impoundments were generally the most productive lakes assessed.
- Carlson's Trophic State Index is a useful measure of the overall trophic state of Indiana Lakes.
- Our randomized lake selection process — on average — generates data representative of Indiana lakes.

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APPENDICES

Appendix A – Information for Indiana lakes sampled in 2023 and 2024.

Lake Name	*County*	*Lake Type*	*Year*	*Surface Area (ha)*	*Max Depth (m)*
Marsh	Steuben	Natural Lake	2023	22.66	11.6
King	Fulton	Natural Lake	2023	7.69	10.7
Smalley	Noble	Natural Lake	2023	27.92	14.9
Mud (Chain of Lakes)	Noble	Natural Lake	2023	3.24	7.6
West Boggs	Martin	impoundment	2023	251.72	7.9
Cook	Marshall	Natural Lake	2023	33.99	15.5
Big Blue #13	Henry	impoundment	2023	70.01	13.4
Deam	Clark	impoundment	2023	78.92	8.5
Holem	Marshall	Natural Lake	2023	12.14	8.5
Crystal	Greene	Surface Mine Lake	2023	3.24	11
Price	Kosciusko	Natural Lake	2023	4.86	12.8
Sylvan	Noble	impoundment	2023	254.96	9.1
Lawrence	Marshall	Natural Lake	2023	27.92	19.2
Tippecanoe	Kosciusko	Natural Lake	2023	286.12	37.5
Crooked	Steuben	Natural Lake	2023	324.57	25.9
Center	Kosciusko	Natural Lake	2023	48.56	12.2
Bixler	Noble	Natural Lake	2023	47.35	11.6
Summit	Henry	impoundment	2023	329.83	12.8
Cedar (LaGrange)	LaGrange	Natural Lake	2023	48.56	9.4
Midland	Greene	Surface Mine Lake	2023	8.09	10.1
Barton	Steuben	Natural Lake	2023	38.04	9.1
Staynor/Gannon	Steuben	Natural Lake	2023	2.02	5.8
Spear	Kosciusko	Natural Lake	2023	7.28	9.4
Goose	Daviess	impoundment	2023	5.1	
Ferdinand City (New)	Dubois	impoundment	2023	4.05	4.6
Mississinewa Reservoir	Miami	impoundment	2023	1286.95	19.8
Big Turkey	LaGrange	Natural Lake	2023	182.12	19.8
Little Otter	Steuben	Natural Lake	2023	13.76	11.3
Oak	Clark	Surface Mine Lake	2023	0.81	4
Long (Hillenbrand)	Greene	Surface Mine Lake	2023	3.24	6.1
Cedar	Lake	Natural Lake	2023	316.07	4.3
Kuhn	Kosciusko	Natural Lake	2023	47.75	8.2
Mansfield Reservoir	Parke	impoundment	2023	833.68	18.3
Gilbert	Noble	Natural Lake	2023	11.33	11
Village (Indian)	Noble	Natural Lake	2023	4.86	6.7
Ferdinand City State Forest	Dubois	impoundment	2023	14.57	6.4

Lake Name	*County*	*Lake Type*	*Year*	*Surface Area (ha)*	*Max Depth (m)*
Geist Reservoir	Marion	impoundment	2023	728.46	6.7
Emma	LaGrange	Natural Lake	2023	17	9.8
Sparta	Noble	Natural Lake	2023	12.55	2.4
Monroe	Monroe	impoundment	2023	4350.53	11.6
Round	Whitley	Natural Lake	2023	53	15.5
Sand	Noble	Natural Lake	2023	19.02	15.5
Lake of the Woods	LaGrange	Natural Lake	2023	55.04	24.7
Messick	LaGrange	Natural Lake	2023	27.52	16.8
Shipshewana	LaGrange	Natural Lake	2023	81.75	4
Wampler	Greene	Surface Mine Lake	2023	28.33	7.6
Dogwood	Sullivan	Surface Mine Lake	2023	1.62	10.1
Pleasant	St. Joseph	Natural Lake	2023	11.74	11.9
Mateer	LaGrange	Natural Lake	2023	7.28	4.9
Gilmour	Sullivan	Surface Mine Lake	2023	1.62	4.3
Bowen	Noble	Natural Lake	2023	12.14	11
Fancher	Lake	Natural Lake	2023	4.05	12.2
Snow	Steuben	Natural Lake	2023	125.46	25
Hog	LaPorte	Natural Lake	2023	23.88	15.8
Twin Pitts (West)	Pike	Surface Mine Lake	2023	7.28	2.4
Fox	Steuben	Natural Lake	2023	56.66	17.4
Syracuse	Kosciusko	Natural Lake	2023	228.25	10.7
Graveyard	Sullivan	Surface Mine Lake	2023	19.43	14
Appleman	LaGrange	Natural Lake	2023	21.04	8.8
Wyandotte	Crawford	impoundment	2023	4.86	3.7
Narrow	Sullivan	Surface Mine Lake	2023	3.64	7.6
Eagle	Noble	Natural Lake	2023	32.78	13.7
Gage	Steuben	Natural Lake	2023	132.34	20.1
Upper Long	Noble	Natural Lake	2023	34.8	16.5
Golden	Steuben	Natural Lake	2023	48.16	8.5
Bower	Steuben	Natural Lake	2023	10.12	6.7
Chapel Pit	Greene	Surface Mine Lake	2023	1.21	6.1
Fish (Steuben)	Steuben	Natural Lake	2023	23.88	7.6
Round B (Ray)	Steuben	Natural Lake	2023	12.14	7.6
Sycamore	Greene	Surface Mine Lake	2023	2.83	8.2
Flat	Marshall	Natural Lake	2023	9.31	6.7
Yellowwood	Brown	impoundment	2023	53.83	9.1
Rider	Noble	Natural Lake	2023	2.02	4.6
Crosley	Jennings	impoundment	2023	5.67	6.1
Pigeon	Steuben	Natural Lake	2023	24.69	11.6
Alder	Greene	Surface Mine Lake	2023	1.21	3.4
Hackberry	Sullivan	Surface Mine Lake	2023	2.02	9.4

Lake Name	County	Lake Type	Year	Surface Area (ha)	Max Depth (m)
Elk Creek	Washington	impoundment	2023	19.43	10.7
Bear	Noble	Natural Lake	2023	55.04	18
Downing	Sullivan	Surface Mine Lake	2023	12.95	13.4
Cook	Marshall	Natural Lake	2024	33.99	15.5
Palestine	Kosciusko	Impoundment	2024	93.89	8.2
Plover Pit	Bartholomew	Surface Mine Lake	2024	1	1
Twin Pits, West	Pike	Surface Mine Lake	2024	7.28	2.4
Lemon	Monroe	Impoundment	2024	667.76	8.5
Myers	Marshall	Natural Lake	2024	38.85	18
Silver	Kosciusko	Natural Lake	2024	41.28	8.8
Turtle	Sullivan	Surface Mine Lake	2024	3.24	7.6
Rockville	Parke	Impoundment	2024	40.47	6.4
Daredevil Pit	Clay	Surface Mine Lake	2024	1	1
Center	Kosciusko	Natural Lake	2024	48.56	12.2
Robinson	Whitley	Natural Lake	2024	23.88	15.5
Little Turkey	LaGrange	Natural Lake	2024	54.63	10.1
Loon Pit	Warrick	Surface Mine Lake	2024	1	1
Patoka Reservoir	Dubois	Impoundment	2024	3593.74	15.8
Scales	Warrick	Surface Mine Lake	2024	26.71	6.1
Cottonwood	Greene	Surface Mine Lake	2024	0.7	7
White Oak #2	Knox	Impoundment	2024	2.83	4.9
Story (Lower)	Dekalb	Natural Lake	2024	31.16	9.1
Old	Gibson	Impoundment	2024	4.86	
Celina	Perry	Impoundment	2024	66.37	15.2
Mayfield	Sullivan	Surface Mine Lake	2024	6.07	8.8
Crane	Noble	Natural Lake	2024	11.33	7.9
Story (Upper)	Dekalb	Natural Lake	2024	0	8.8
Appleman	LaGrange	Natural Lake	2024	21.04	8.8
Hammond	Greene	Surface Mine Lake	2024	2.43	
Town	Fulton	Natural Lake	2024	8.9	4.9
Yellow Creek	Elkhart	Natural Lake	2024	6.48	6.1
Bass	Sullivan	Surface Mine Lake	2024	85.39	16.5
Eagle	Noble	Natural Lake	2024	32.78	13.7
Holland 2	Dubois	Impoundment	2024	8.09	4.9
Gambill	Sullivan	Surface Mine Lake	2024	4.86	13.7
Rosser Park	Lake	Surface Mine Lake	2024	16.19	
George (Hobart)	Lake	Impoundment	2024	109.27	2.7
Mollenkramer Reservoir	Ripley	Impoundment	2024	1	1
Loon (Steuben)	Steuben	Natural Lake	2024	55.85	5.5
Martin	LaGrange	Natural Lake	2024	10.52	16.8

Lake Name	County	Lake Type	Year	Surface Area (ha)	Max Depth (m)
Dale Reservoir	Spencer	Impoundment	2024	13.36	9.1
Star	Greene	Surface Mine Lake	2024	2.02	6.1
Little George	Clay	Surface Mine Lake	2024	1.05	16.8
Canada	Porter	Natural Lake	2024	4.05	11
Loon (Kosciusko)	Kosciusko	Natural Lake	2024	16.19	12.5
Buffalo Trace	Harrison	Impoundment	2024	11.74	4.6
Crystal	Greene	Surface Mine Lake	2024	3.24	11
Summit	Henry	Impoundment	2024	329.83	12.8
Willow	Sullivan	Surface Mine Lake	2024	1.62	8.5
Dogwood	Sullivan	Surface Mine Lake	2024	1.62	10.1
Cedar	Lake	Natural Lake	2024	316.07	4.3
Beaver Bottom	Johnson	Impoundment	2024	4.86	
Delaney Creek Park Lake	Washington	Impoundment	2024	1	1
Lawrence	Marshall	Natural Lake	2024	27.92	19.2
Mud	Noble	Natural Lake	2024	1.62	8.2
Cedar Lake	Whitley	Natural Lake	2024	1	1
South Twin	LaGrange	Natural Lake	2024	46.95	15.2
Goose	Daviess	Impoundment	2024	5.1	
White Pine	Sullivan	Surface Mine Lake	2024	0.81	4.6
Little Barbee	Kosciusko	Natural Lake	2024	27.52	7.9
Pretty	LaGrange	Natural Lake	2024	74.46	24.4
Boones Pond	Boone	Surface Mine Lake	2024	3.24	8.5
Hartz	Starke	Natural Lake	2024	11.33	9.4
Big Long	LaGrange	Natural Lake	2024	148.12	25
Mill Pond	Marshall	Impoundment	2024	52.2	4.9
Sparta	Noble	Natural Lake	2024	12.55	2.4
Long (Hillenbrand)	Greene	Surface Mine Lake	2024	3.24	6.1
Red Pine	Sullivan	Surface Mine Lake	2024	1.62	4.6
West Boggs	Martin	Impoundment	2024	251.72	7.9
Kiser	Kosciusko	Natural Lake	2024	3.64	6.1
Burns	Vigo	Impoundment	2024	6.07	
Fish (Lower)	LaPorte	Natural Lake	2024	54.23	4.9
Duck	Sullivan	Surface Mine Lake	2024	23.88	12.2
Gordy	Noble	Natural Lake	2024	12.55	10.7
Jones	Noble	Natural Lake	2024	46.54	7
Bobcat	Greene	Surface Mine Lake	2024	2	9.1
Bryants Creek	Monroe	Impoundment	2024	3.64	6.1
Indian Village	Noble	Natural Lake	2024	4.86	6.7
Wolf	Lake	Natural Lake	2024	155.81	4.9
Pigeon	Steuben	Natural Lake	2024	24.69	11.6

Lake Name	County	Lake Type	Year	Surface Area (ha)	Max Depth (m)
Mallard	Johnson	Impoundment	2024	7.28	
Airline	Greene	Surface Mine Lake	2024	10.12	20.7
Kekionga	Adams	Surface Mine Lake	2024	1.62	

Appendix B – Trophic state indices for all lakes sampled in 2023 and 2024.

Lake Name	***County***	***Year***	***TSI(SD)***	***TSI(Chl)***	***TSI(TP_Epi)***
Marsh	Steuben	2023	55	51	20
King	Fulton	2023	64	73	68
Smalley	Noble	2023	69	44	49
Mud (Chain of Lakes)	Noble	2023	57	72	71
West Boggs	Martin	2023	67	57	59
Cook	Marshall	2023	53	49	48
Big Blue #13	Henry	2023	53	55	52
Deam	Clark	2023	52	43	44
Holem	Marshall	2023	51	52	50
Crystal	Greene	2023	55	77	65
Price	Kosciusko	2023	51	44	56
Sylvan	Noble	2023	69	40	40
Lawrence	Marshall	2023	46	48	46
Tippecanoe	Kosciusko	2023	51	51	46
Crooked	Steuben	2023	43	56	52
Center	Kosciusko	2023	43	42	50
Bixler	Noble	2023	58	48	58
Summit	Henry	2023	37	39	45
Cedar (LaGrange)	LaGrange	2023	46	75	77
Midland	Greene	2023	50	47	43
Barton	Steuben	2023	45	44	40
Staynor/Gannon	Steuben	2023	52	35	47
Spear	Kosciusko	2023	51	43	30
Goose	Daviess	2023	52	76	60
Ferdinand City (New)	Dubois	2023	58	48	49
Mississinewa Reservoir	Miami	2023	61	64	57
Big Turkey	LaGrange	2023	58	55	48
Little Otter	Steuben	2023	50	51	49
Oak	Clark	2023	58	53	42
Long (Hillenbrand)	Greene	2023	52	64	60
Cedar	Lake	2023	80	61	57
Kuhn	Kosciusko	2023	36	37	61
Mansfield Reservoir	Parke	2023	72	73	54
Gilbert	Noble	2023	43	40	51
Village (Indian)	Noble	2023	62	47	50
Ferdinand City State Forest	Dubois	2023	62	66	69
Geist Reservoir	Marion	2023	61	68	72
Emma	LaGrange	2023	61	44	47
Sparta	Noble	2023	54	45	59
Monroe	Monroe	2023	62	63	62

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)
Round	Whitley	2023	57	56	56
Sand	Noble	2023	64	64	73
Lake of the Woods	LaGrange	2023	46	46	42
Messick	LaGrange	2023	66	53	54
Shipshewana	LaGrange	2023	64	55	51
Wampler	Greene	2023	49	72	69
Dogwood	Sullivan	2023	40	42	56
Pleasant	St. Joseph	2023	61	66	64
Mateer	LaGrange	2023	44	43	53
Gilmour	Sullivan	2023	50	55	52
Bowen	Noble	2023	47	61	52
Fancher	Lake	2023	48	67	67
Snow	Steuben	2023	45	48	52
Hog	LaPorte	2023	50	47	47
Twin Pitts (West)	Pike	2023	48	43	56
Fox	Steuben	2023	44	43	42
Syracuse	Kosciusko	2023	39	54	48
Graveyard	Sullivan	2023	69	61	51
Appleman	LaGrange	2023	52	56	48
Wyandotte	Crawford	2023	42	42	50
Narrow	Sullivan	2023	46	38	44
Eagle	Noble	2023	49	34	42
Gage	Steuben	2023	45	35	32
Upper Long	Noble	2023	51	70	65
Golden	Steuben	2023	57	65	53
Bower	Steuben	2023	53	53	44
Chapel Pit	Greene	2023	44	42	47
Fish (Steuben)	Steuben	2023	47	52	53
Round B (Ray)	Steuben	2023	43	41	53
Sycamore	Greene	2023	39	70	66
Flat	Marshall	2023	62	67	62
Yellowwood	Brown	2023	42	42	50
Rider	Noble	2023	50	50	50
Crosley	Jennings	2023	62	43	50
Pigeon	Steuben	2023	58	58	58
Alder	Greene	2023	64	59	53
Hackberry	Sullivan	2023	38	45	45
Elk Creek	Washington	2023	47	45	47
Bear	Noble	2023	54	55	52
Downing	Sullivan	2023	34	38	42
Cook	Marshall	2024	65	67	52
Palestine	Kosciusko	2024	64	75	81

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)
Plover Pit	Bartholomew	2024	55	61	60
Twin Pits, West	Pike	2024	66	51	39
Lemon	Monroe	2024	44	69	63
Myers	Marshall	2024	66	56	59
Silver	Kosciusko	2024	57	73	68
Turtle	Sullivan	2024	48	37	55
Rockville	Parke	2024		80	75
Daredevil Pit	Clay	2024	31	24	50
Center	Kosciusko	2024	42	42	55
Robinson	Whitley	2024	47	70	67
Little Turkey	LaGrange	2024	71	61	57
Loon Pit	Warrick	2024	61	59	58
Patoka Reservoir	Dubois	2024	60	54	55
Scales	Warrick	2024	57	61	49
Cottonwood	Greene	2024	43	46	57
White Oak #2	Knox	2024	47	70	70
Story (Lower)	Dekalb	2024	54	51	47
Old	Gibson	2024	64	56	61
Celina	Perry	2024	37	31	39
Mayfield	Sullivan	2024	37	32	28
Crane	Noble	2024	69	76	63
Story (Upper)	Dekalb	2024	48	47	51
Appleman	LaGrange	2024	47	48	51
Hammond	Greene	2024	38	40	57
Town	Fulton	2024	43	78	54
Yellow Creek	Elkhart	2024		93	84
Bass	Sullivan	2024	61	58	66
Eagle	Noble	2024		50	48
Holland 2	Dubois	2024	64	73	57
Gambill	Sullivan	2024	43	32	36
Rosser Park	Lake	2024	45	47	55
George (Hobart)	Lake	2024	72	54	80
Mollenkramer Reservoir	Ripley	2024	45	78	92
Loon (Steuben)	Steuben	2024	66	51	50
Martin	LaGrange	2024	66	49	58
Dale Reservoir	Spencer	2024	70	76	77
Star	Greene	2024	69	40	41
Little George	Clay	2024	66	34	53
Canada	Porter	2024	49	52	56
Loon (Kosciusko)	Kosciusko	2024	62	64	61
Buffalo Trace	Harrison	2024	53	45	52
Crystal	Greene	2024	48	43	55

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)
Summit	Henry	2024	55	39	55
Willow	Sullivan	2024	66	43	58
Dogwood	Sullivan	2024	33	39	77
Cedar	Lake	2024	80	78	78
Beaver Bottom	Johnson	2024	57	70	67
Delaney Creek Park Lake	Washington	2024	39	47	44
Lawrence	Marshall	2024	50	43	56
Mud	Noble	2024	49	73	73
Cedar Lake	Whitley	2024	38	39	31
South Twin	LaGrange	2024	55	44	43
Goose	Daviess	2024	54	68	63
White Pine	Sullivan	2024	55	45	51
Little Barbee	Kosciusko	2024	66	67	65
Pretty	LaGrange	2024	80	43	55
Boones Pond	Boone	2024	43	41	47
Hartz	Starke	2024	44	47	44
Big Long	LaGrange	2024	43	47	47
Mill Pond	Marshall	2024	58	70	57
Sparta	Noble	2024	60	48	52
Long (Hillenbrand)	Greene	2024	67	49	59
Red Pine	Sullivan	2024	47	49	59
West Boggs	Martin	2024	72	79	72
Kiser	Kosciusko	2024	59	50	53
Burns	Vigo	2024	57	59	54
Fish (Lower)	LaPorte	2024	52	53	66
Duck	Sullivan	2024	69	64	61
Gordy	Noble	2024	53	56	53
Jones	Noble	2024	56	65	73
Bobcat	Greene	2024	48	52	56
Bryants Creek	Monroe	2024	48	50	49
Indian Village	Noble	2024	68	65	61
Wolf	Lake	2024		63	64
Pigeon	Steuben	2024	37	50	46
Mallard	Johnson	2024	60	63	63
Airline	Greene	2024	38	32	33
Kekionga	Adams	2024	62	52	62