Indiana Lake Water Quality Assessment Report For 2012-2014

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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 results for 2012-2014.

Lake Water Quality Assessment

The goals of the lake water quality assessment component 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).

Public lakes are defined as those that have navigable inlets or outlets or those that exist on or adjacent to public land. Only public lakes that have boat trailer access from a public right-of-way are generally sampled in this program. Sampling occurs in July and August of each year to coincide with the period of thermal stratification (Figure 1) and the period of poorest annual water quality in lakes. Most Indiana lakes having maximum depths of 16 to 23 feet (5–7 m) or greater undergo thermal stratification during the summer. As the sun and air temperatures warm the surface water of a lake the warmed water becomes less dense. This “lighter” water floats on top of 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 mix all 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 significantly different during stratification.

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.

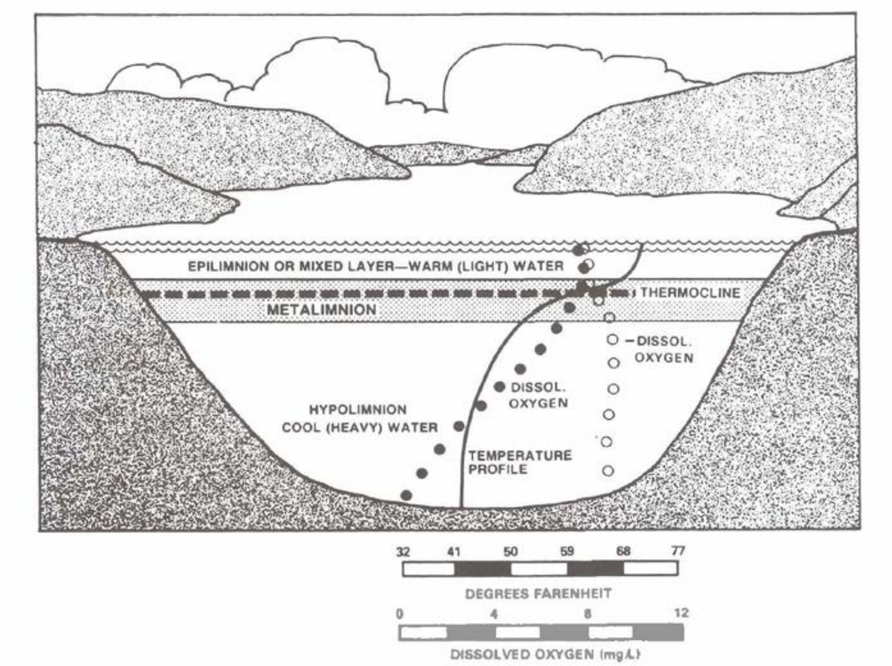

Figure 1. Summer thermal stratification prevents lake mixing because the cool waters of the hypolimnion are much denser than the warm waters of the epilimnion. Epilimnetic waters circulate with the wind but do not mix until the lake cools again in the fall. Adapted from: Olem and Flock, 1990.

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 USEPA in the National Lakes Assessment (NLA) of 2007 and 2012. The resulting list contained a total of 246 lakes and impoundments. We sampled lakes from this list over our 2-year sampling cycle (2012 – 2013) beginning with the first lake at the top and working downward until we had sampled 160 lakes over the two-year period, repeating the randomization for 2014. Using this sampling scheme, our 2012-2014 results should be statistically significant for the entire state and we could then better discuss lake water quality in Indiana. We will re-randomize our lake list for the 2015-2016 sampling period.

The 246 lakes in our randomized pool are a small fraction of the 1475 lakes, reservoirs, and ponds in our master lake list for Indiana but many of these other lakes are private, are smaller than 5 acres in size, and/or have no usable boat ramp. While the randomized sampling scheme allows us to gain a better understanding of Indiana lake quality over a two-year period, it is possible that the future sampling frequency for any given lake would be longer than the five-year period achieved historically, pre-2010 sampling protocol.

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. The scale is not linear but rather it is logarithmic. For example, a solution with a pH of 6 is ten times more acidic than a solution with a pH of 7. Pure water is said to be neutral, with a pH of 7. 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; 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.

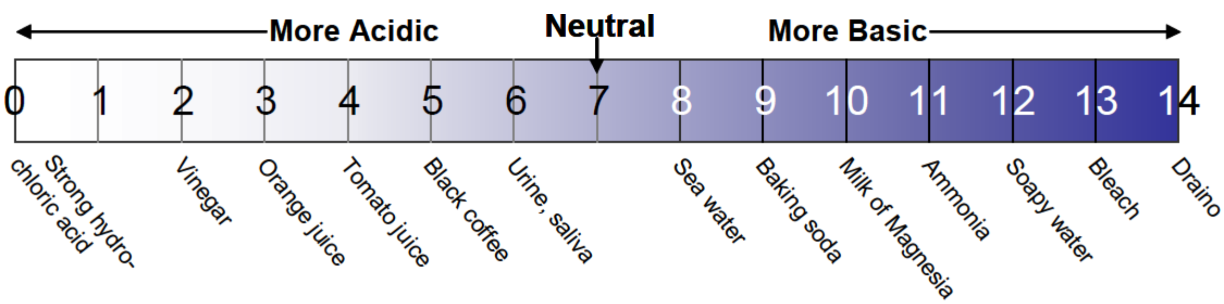

Figure 2. The pH scale compared with common solutions. Source: Addy et al., 2004.

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, and relative concentrations, and on the temperature of the liquid (APHA, 2005). 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. Because conductivity is the inverse of resistance, the unit of conductance is the mho (ohm spelled backwards), or in low-conductivity natural waters, the micromho.

Alkalinity

Alkalinity is the sum total of components in the water that tend to elevate the pH to the alkaline side of neutrality. It is measured by titration with standardized acid to a pH value of 4.5 and is expressed commonly as milligrams per liter as calcium carbonate (mg/L as $CaCO_3$). Alkalinity 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 other 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 30μg/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% 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. In the analytical procedures, total Kjeldahl nitrogen (TKN) was determined. Organic nitrogen is TKN minus ammonia.

Light Transmission

This measurement uses a light meter (photocell) to determine the rate at which light transmission is diminished in the upper portion of the lake's water column. Another important light transmission measurement is determination of the 1% light level. The 1% light level is the water depth to which one percent of the surface light penetrates. The 1% light level is considered the lower limit of algal growth in lakes and this area and above is referred to as the *euphotic zone*.

Dissolved Oxygen (D.O.)

D.O. is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. D.O. enters water by diffusion from the atmosphere and as a by-product of photosynthesis by algae and plants. The concentration of D.O. in epilimnetic waters continually equilibrates with the concentration of atmospheric oxygen to maintain 100% D.O. saturation. Excessive algae growth can over-saturate (greater than 100% saturation) the water with D.O when the rate of photosynthesis is greater than the rate of oxygen diffusion to the atmosphere. Hypolimnetic D.O. 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 D.O. to survive.

Secchi Disk Transparency

Secchi disk transparency refers to the depth to which the black and white Secchi disk can be seen in the lake water. Water clarity, as determined by a Secchi disk, is affected by two primary factors: algae and suspended particulate matter. Particulates (soil or dead leaves) may be introduced into the water by either runoff or sediments already on the bottom of the lake. Erosion from construction sites, agricultural lands, and riverbanks all lead to increased sediment runoff. Bottom sediments may be resuspended by bottom-feeding fish such as carp, or by motorboats or strong winds in shallow lakes.

Plankton

Plankton are important members of the aquatic food web. The plankton include phytoplankton or algae (microscopic plants) and zooplankton (tiny shrimp-like animals that eat algae). The phytoplankton are primary producers that convert light energy from the Sun to plant tissue through the process of photosynthesis. This forms the foundation of the aquatic food chain. Small microscopic shrimp-like crustaceans called zooplankton eat the phytoplankton. In turn, the zooplankton are extremely important food for young fish (Figure 3).

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). The cyanobacteria are of particular interest to limnologists and lake users because members of this group are those that often form nuisance blooms and their dominance in lakes may indicate poor water conditions. Some species of cyanobacteria are known to produce toxins.

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 the green algae (Chlorophyta) but is only one of several pigments in the blue-green algae (Cyanophyta), yellow-brown algae (Chrysophyta), and others. Despite this, chlorophyll-a is often used as a direct estimate of algal biomass although it might underestimate the production of those algae that contain multiple pigments.

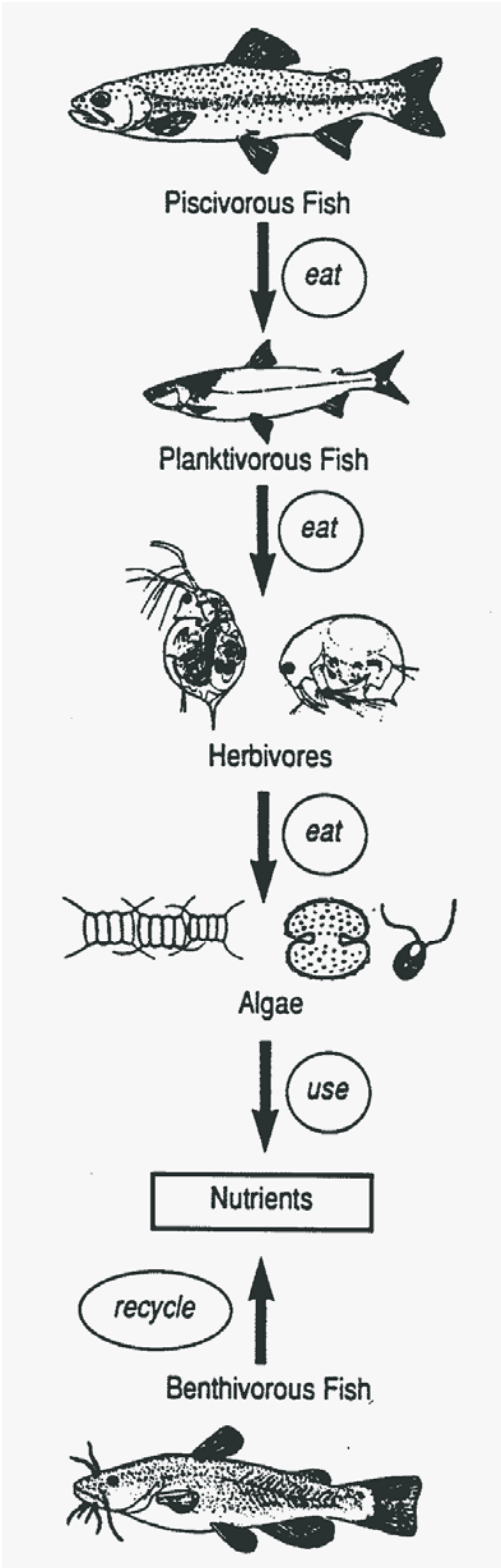

Figure 3. A simplified aquatic food chain.

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. In order 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 on 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. The majority of 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).

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 elongate with many branches

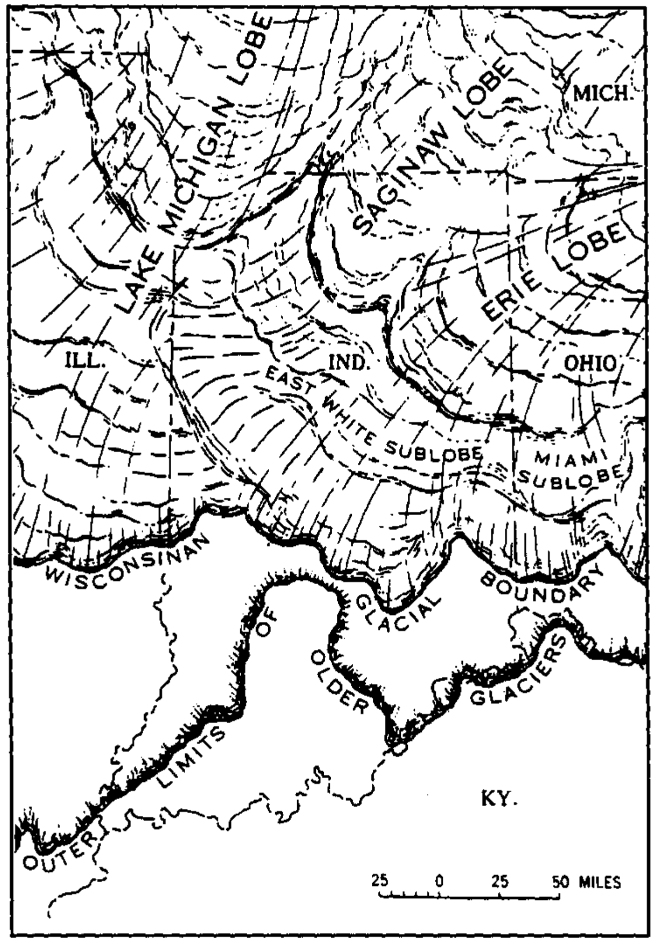

Figure 4. The Lake Michigan, Saginaw, and Erie lobes of the most recent glacial episode affected northern Indiana. Glacial lakes are thus limited to this part of the state.

representing the tributaries of the former stream or river. Strip pits are coal mine lakes (CML) 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.

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 plant remains 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. This ***cultural eutrophication*** can degrade a lake in as little as a few decades (Figure 5).

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 weeds aid in the determination of the trophic status, and other factors such as light and temperature impact the growth of algae and weeds.

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 neglect the actual data as these data may help in explaining other differences between lakes. As with any index, when the data are reduced to a single number for a TSI, some information is lost.

The Carlson Trophic State Index

The Carlson Trophic State Index, developed by Bob Carlson (1977) is the most widely used TSI in the United States (Figure 6). 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.

CARLSON'S TROPHIC STATE INDEX

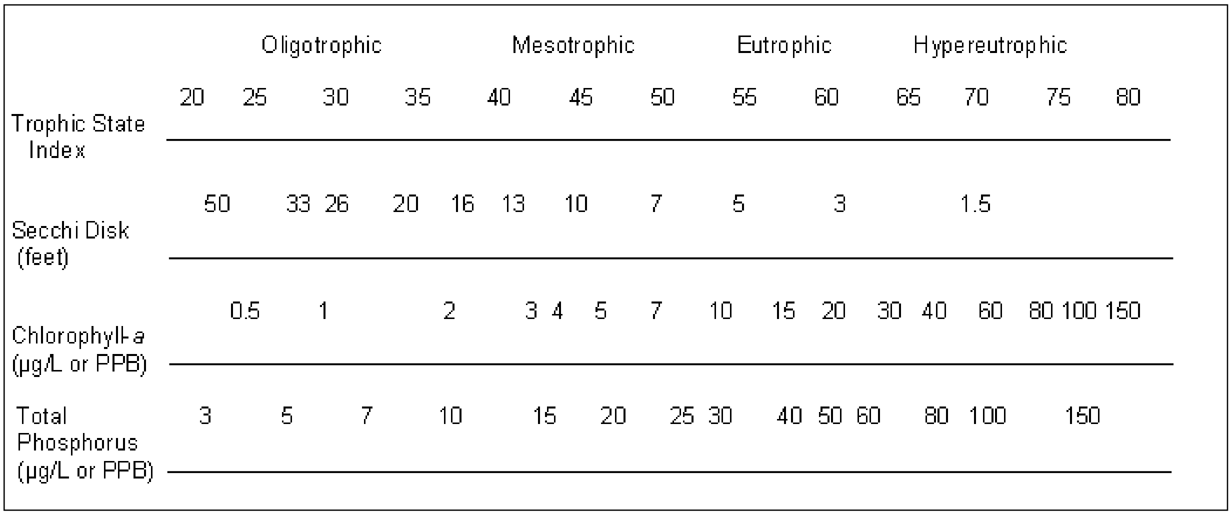

Figure 6. The Carlson Trophic State Index.

Ecoregion Descriptions

When we say that 'lakes are a reflection of their watershed' we refer to not only land use activities within the watershed that may influence lake characteristic, but also soil types, land slope, natural vegetation, climate, and other factors that define the ecological region or *ecoregion*. Omernik and Gallant (1988) defined ecoregions in the Midwest (Figure 7); the boundaries of these ecoregions were determined through the examination of land use, soils, and potential natural vegetation. These ecoregions have similar ecological properties throughout their range and these properties can influence lake water quality characteristics. The six ecoregions present in Indiana are described in Figure 7.

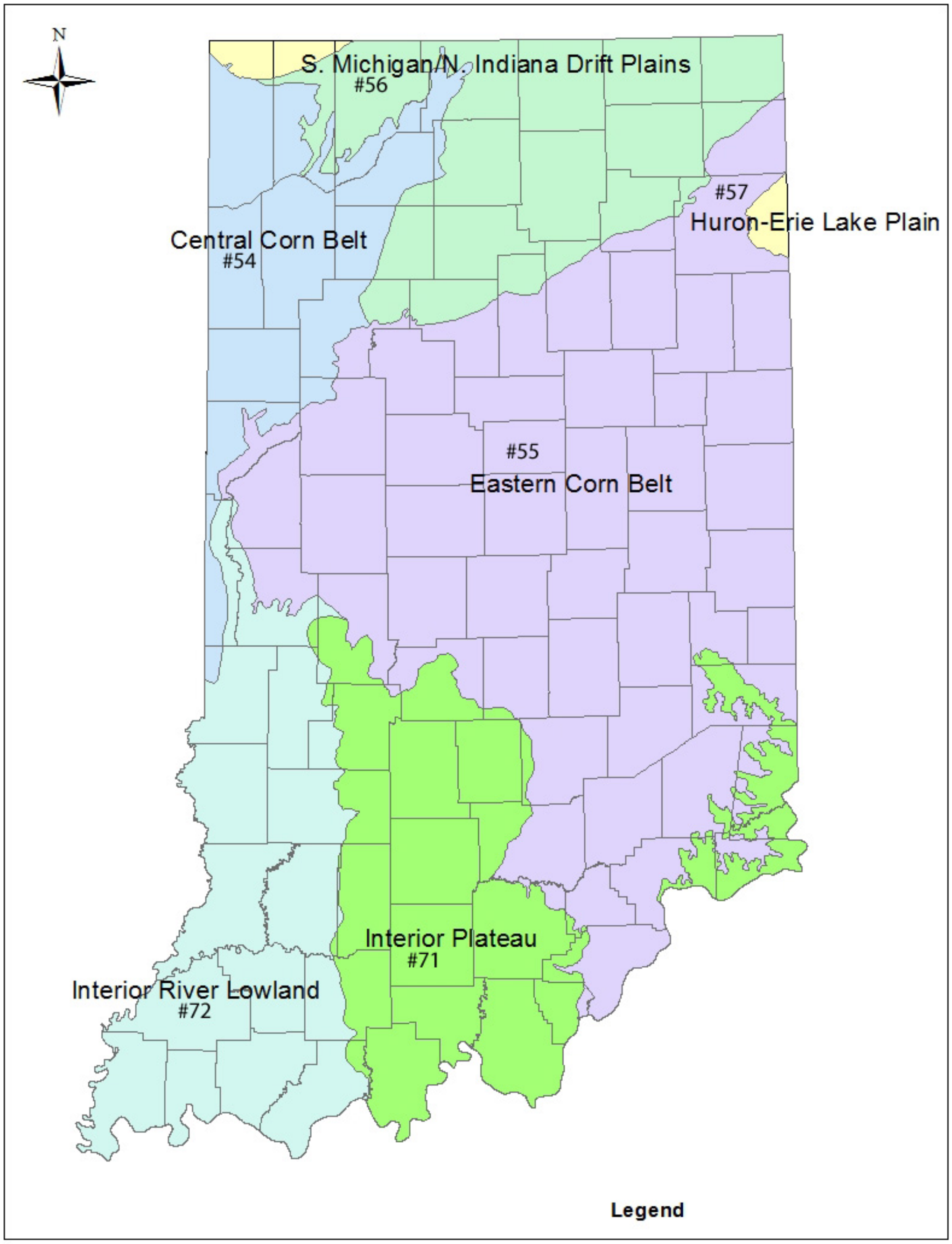

Figure 7. Ecoregions of Indiana.

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

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

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

Huron/Erie Lake plain (#57): This region 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% of this region is urbanized. There are no lakes in this region that could be assessed by the present study.

Interior Plateau (#71): This area occupies 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): This area 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.

METHODS

Field Procedures

Water samples are collected from the epilimnion and hypolimnion, generally 1 meter below the surface and from 1-2 meters above the bottom of the lake. Epilimnetic water samples were collected using a 2-meter long integrated sampler that samples an undisturbed column of water from the surface to a depth of 2-meters. The sampler is emptied into a clean, rinsed pitcher where it is thoroughly mixed before filling the sample bottles. Water samples were taken for soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate (NO_3^-), ammonia (NH_4^+), and total Kjeldahl nitrogen (TKN). SRP is filtered in the field using a 1.2 µm glass fiber filter and a hand pump. Prior to sampling, the TP, nitrate/ammonia, and TKN bottles are acidified with 0.125 ml of sulfuric acid (H_2SO_4).

Dissolved oxygen (D.O.) is measured using a Hach Hydrolab Temperature/Dissolved Oxygen/Conductivity Meter. Measurements are taken at 1-meter intervals through the water column to the lake bottom.

Secchi disk transparency measurements are determined by the depth at which the black and white disk is no longer visible in the water column. Light penetration is measured with a LiCor Spherical Quantum Sensor.

Phytoplankton were sampled using a 2-meter integrated sampler. The sampler is emptied into a clean, rinsed pitcher where it is thoroughly mixed before filling the sample bottles. The phytoplankton samples were preserved with Lugol's solution in situ. Zooplankton were collected with a tow net through the whole water column, utilizing a 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 to a 2-m depth. The apparatus is shut, retrieved, and poured into a pitcher. The sample is shaded and filtered with Whatman GF/F filter paper using a hand pump. The sample is filtered until the flow of water passing through the filter is minimal and the volume of sample filtered is then recorded. The filter paper is removed, placed in a bottle, and kept thoroughly chilled.

Lab Procedures

SRP is determined using the ascorbic acid method and measured colormetrically on a spectrophotometer (APHA, et al. 2005). TP samples are digested in hot acid to convert particulate phosphorus to dissolved phosphorus. After pH adjustment, the samples are analyzed as for SRP.

NO_3^- and NH_4^+ samples are filtered in the lab using a 0.45 micron membrane filter and a vacuum pump. This analysis is run on an Alpkem Flow Solution Model 3570 autoanalyzer (OI Analytical, 2000). TKN samples are first digested in hot acid before being analyzed on the autoanalyzer.

One milliliter of water for zooplankton analysis is transferred to a Sedgwick-Rafter Cell for identification and enumeration. The entire cell is scanned and all zooplankton are counted. Whole water samples of phytoplankton were concentrated using Utermoehl settling chambers. Either 25-ml or 50-ml of sample is concentrated to insure sufficient cell density. Settled concentrate is transferred into a 2-mL micro-centrifuge tube for storage. Counts are made using a nannoplankton chamber (PhycoTech, Inc.) and a phase contrast light microscope. Plankton identifications are made according to: Ward and Whipple (1959), Prescott (1982), Whitford and Schumacher (1984), Wehr and Sheath (2003), and St. Amand (2010).

Chlorophyll filters are placed in the freezer upon arriving to the lab. Once frozen, the filters are ground using 90% aqueous acetone to extract the chlorophyll and read on a spectrophotometer. Samples are corrected for pheophyton pigments.

All sampling techniques and laboratory analytical methods were performed in accordance with procedures in *Standard Methods for the Examination of Water and* Wastewater, 21st Edition (APHA, 2005).

RESULTS

Information about the lakes sampled in 2012-2014 is included in Appendix A. Raw data for all lakes assessed are available on the Indiana Clean Lakes Program website at: http://www.indiana.edu/~clp/.

The random selection process used to select lakes sampled during 2012-2014 created a data set about which we can draw conclusions that apply to all lakes in Indiana. This is the power of a randomized, statistically valid sampling protocol. While we can't possibly discuss all of the individual lakes assessed in this report, the reader can see the raw lake data on our website at: http://www.indiana.edu/~clp/.

Lakes Assessed

We assessed a total of 246 lakes during this three-year period; 83 in 2012, 81 in 2013, and 80 in 2014. A listing of the lakes assessed is included in Appendix A and maps showing the locations of lakes sampled during this period are shown in Figures 21 and 22. Although the selected lakes were randomly drawn, we did not sample the lakes in the order in which they were drawn. This would have resulted in extraordinary travel and expense. Instead, each week when possible, we sampled selected lakes that spanned several geographic areas. For example, note the lakes sampled during June 25-26, 2012 in Figure 8. This sampling pattern helped us to avoid sampling bias related to geography and to weather. For example, a summer storm in Noble County on a typical 2-day sampling trip could affect all the results for that entire week if we sampled all the lakes in Noble County at the same time.

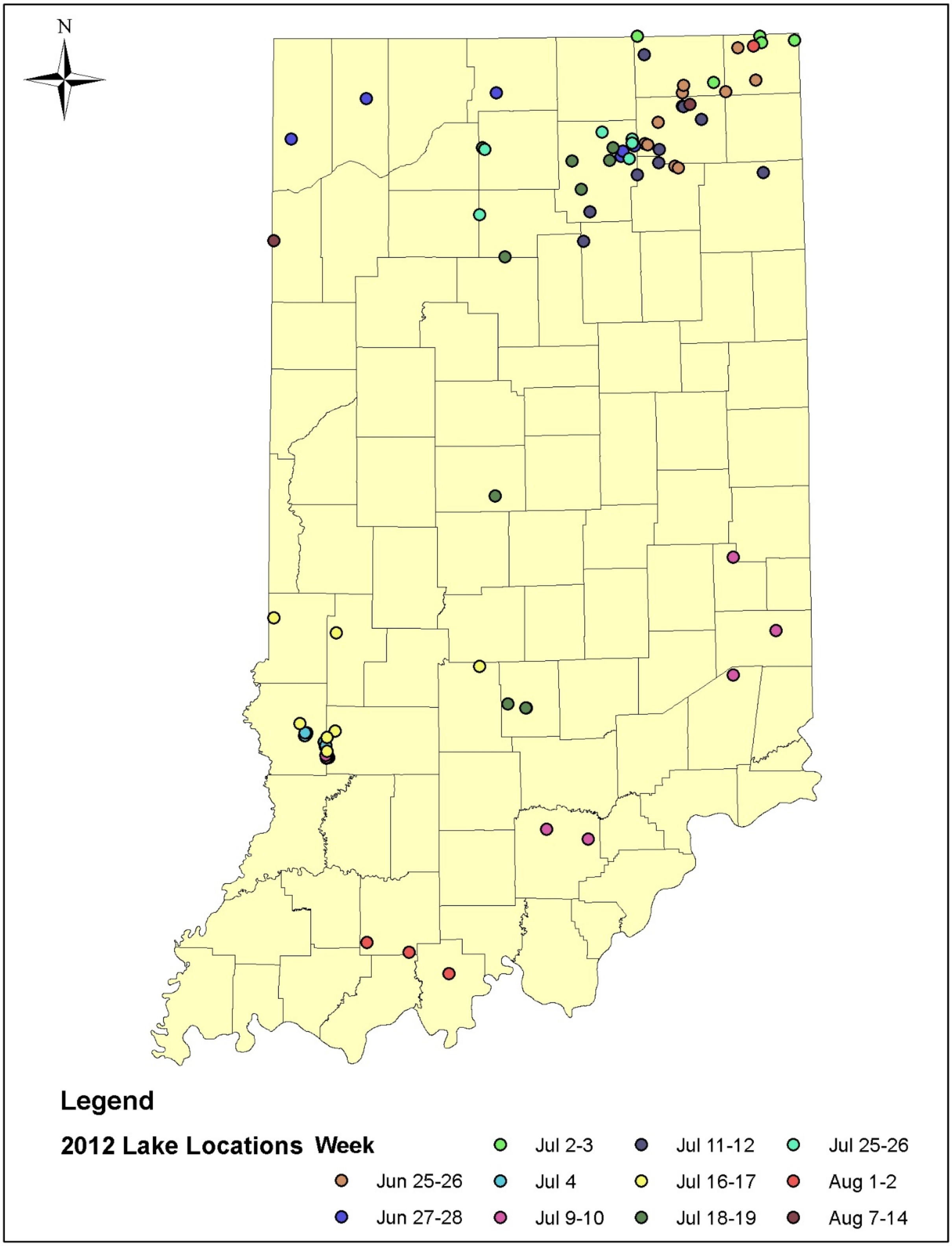

Figure 8. Lakes assessed during 2012.

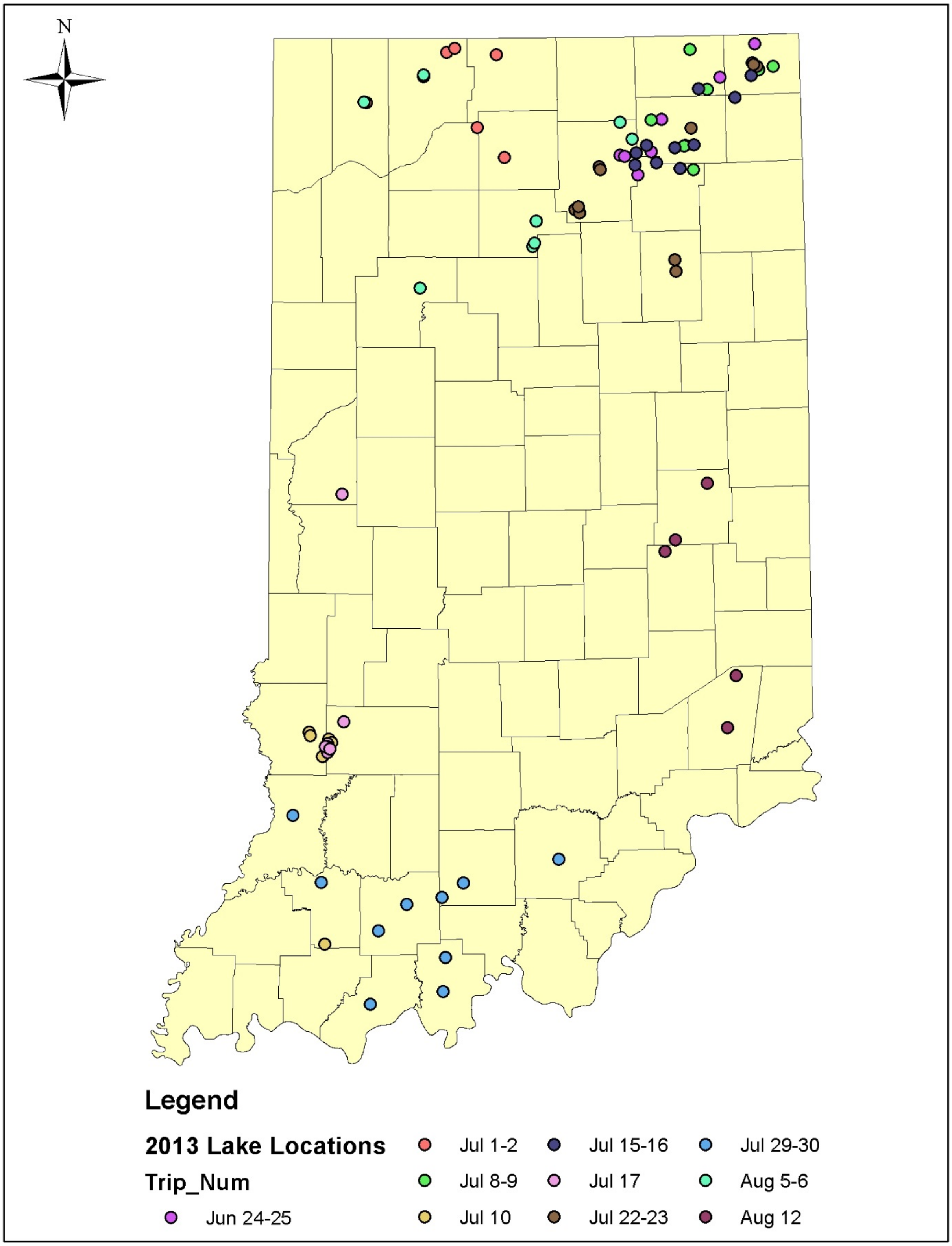

Figure 9. Lakes assessed during 2013.

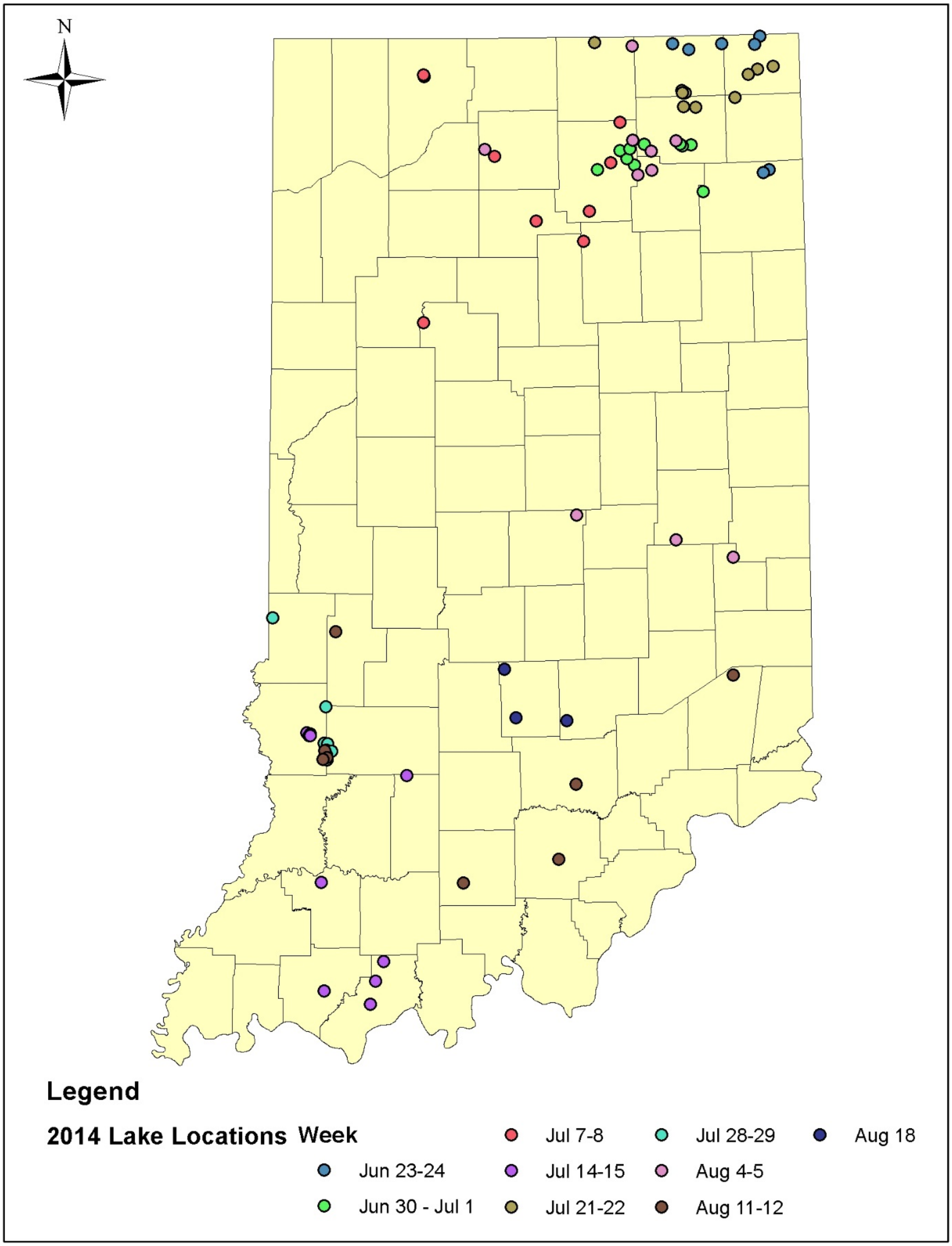

Figure 10. Lakes assessed during 2014.

Lakes ranged in size from several 5-acre (2-hectare) lakes, most of which were coal mine lakes (SML), to the largest lake in Indiana, 10,750-acre (4,350-ha) Lake Monroe. Besides Lake Monroe, only one other lake (Patoka) was more than 3,000 ha (Figure 11a). Most of the lakes sampled were less than 50 ha (124 acres) in size (Figure 11b). This is representative of the diversity of all lake sizes in Indiana as the majority of Indiana's lakes are small.

The lakes assessed ranged in maximum depth from shallow 5-foot deep Ontario Mill Pond in Lagrange County to 106-foot (32.3 meters) deep Clear Lake in Steuben County (Figure 12). Shallow lakes are often more productive than deep lakes because in shallow lakes, a higher percentage of the water volume is in the *euphotic zone* (surface waters where there is sufficient light for photosynthesis) than in deep lakes. Thus algal photosynthesis can occur in a larger percentage of the water column in shallow lakes than in deep lakes (Holdren et al., 2001). In addition, shallow lakes may not stratify since the entire water column is more easily mixed by wind and wave action than in deep lakes. Thus, nutrients from the sediments are more readily available to the entire water column in shallow lakes than in deep lakes. Nutrients from the sediments, combined with sunlight from the surface, fuel algal growth in shallow lakes. All these factors should result in higher chlorophyll-a concentrations in shallow lakes than in deep lakes.

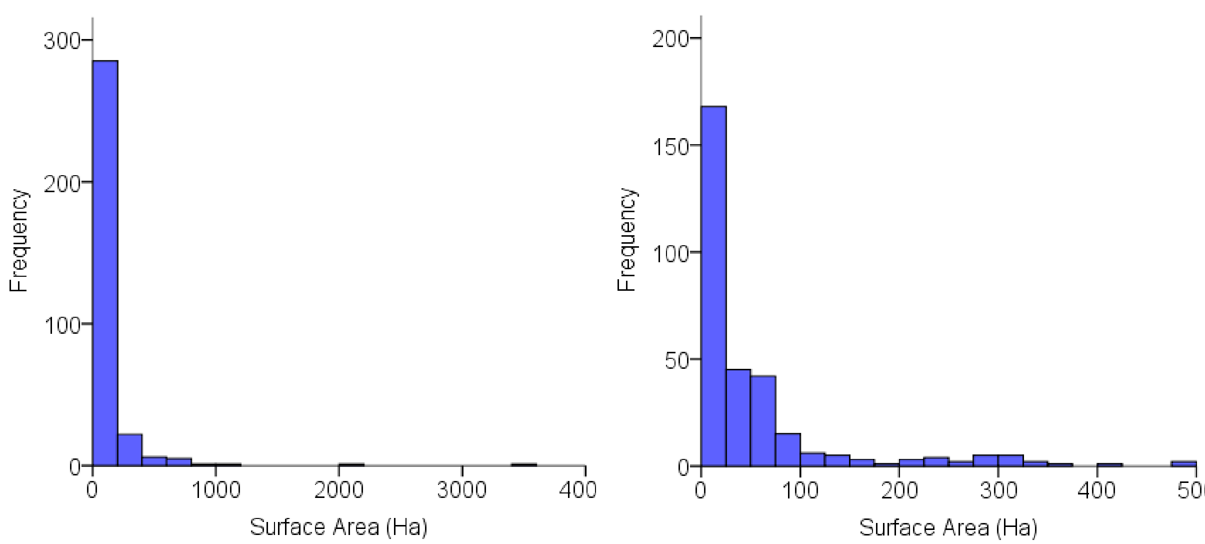

Figure 11. Frequency distributions of surface areas of the 324 lakes assessed during 2012-2014. The frequency on the Y-axis represents the number of lakes within each category on the X-axis. Figure 20b expands the 0-500 ha category to show more detail for the smaller lakes assessed.

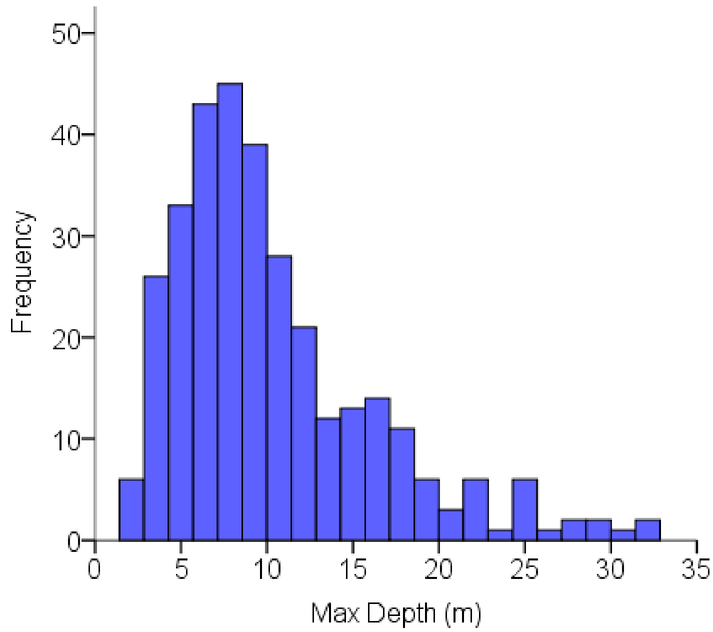

Figure 12. Frequency distribution of maximum lake depths for lakes assessed during 2012 – 2014.

Water Characteristics

pH. The pH frequency distributions were normally distributed (Figure 13). The median for the epilimnion sample was higher than that of the hypolimnion as expected. The process of photosynthesis consumes carbon dioxide, a weak acid. With removal of carbon dioxide, pH increases above neutrality. In the hypolimnion, where it is too dark for photosynthesis, the process of respiration dominates. A by-product of respiration is the release of carbon dioxide back into the water. This mild acid addition causes pH to decrease.

High pH values are indicative of high rates of photosynthesis. The highest epilimnetic pH recorded was 9.8 at Salinda Lake (Washington Co.). Ten other lakes had epilimnetic pH values greater than 9.0 (Table 1). All but 3 of these lakes with the highest pH are impoundments.

Reservoir 29 and Long Lake, an acidic, coal mine lake in Sullivan and Greene Co., respectively, had the lowest measured hypolimnetic pH of 6.2. Ogle Lake (Brown Co), an impoundment in Brown County State Park, and Blackman Lake (Lagrange Co.), a kettle lake, were next lowest at 6.3.

Table 1. Lakes with epilimnetic pH values above 9.0.

Lake	County	pH (epiliminion)	Lake type
Yellow Creek	Kosciusko	9	natural lake
Turtle	Sullivan	9	SML*
Brush Creek Reservoir	Jennings	9.2	impoundment
Duck	Sullivan	9.2	SML
Boones Pond	Boone	9.2	impoundment
Cagles Mill (Cataract)	Putnam	9.2	impoundment
Skunk	Greene	9.2	SML
Bass	Sullivan	9.3	SML
Bobcat	Greene	9.4	SML
Cedar	Lake	9.4	natural lake

*SML = Surface Mine Lake

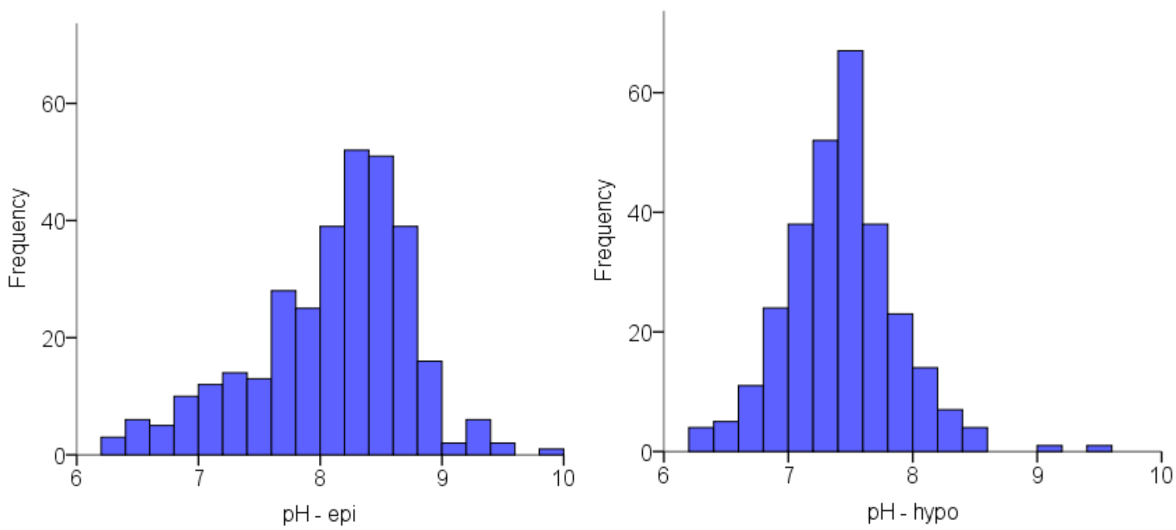

Figure 13. Frequency distribution of pH for both epilimnion (surface waters) and hypolimnion (bottom waters) for lakes assessed during 2012 – 2014.

Conductivity and Alkalinity. Figure 14 shows the frequency distributions for conductivity and alkalinity for all lakes assessed during 2012 – 2014. Thirty-two lakes had epilimnetic conductivities greater than 1,000 µmhos/cm; all but one of these lakes are coal mine lakes in southeastern Indiana. The one outlier was Clear Lake in LaPorte Co. The surface mining process liberates many ions that, when reaching water, cause elevated conductivities. Many of the ions released during surface mining are acids. Thus, many coal mine lakes have low alkalinities because the leached acids consume alkalinity. Lakes associated with bogs or other wetlands often contain an abundance of organic acids and such lakes may also have low alkalinity and low pH. The majority of the lakes with the lowers alkalinity wer located in unglaciated Southern Indiana.

Several lakes had very high hypolimnetic alkalinities (Figure 26). These were all coal mine lakes.

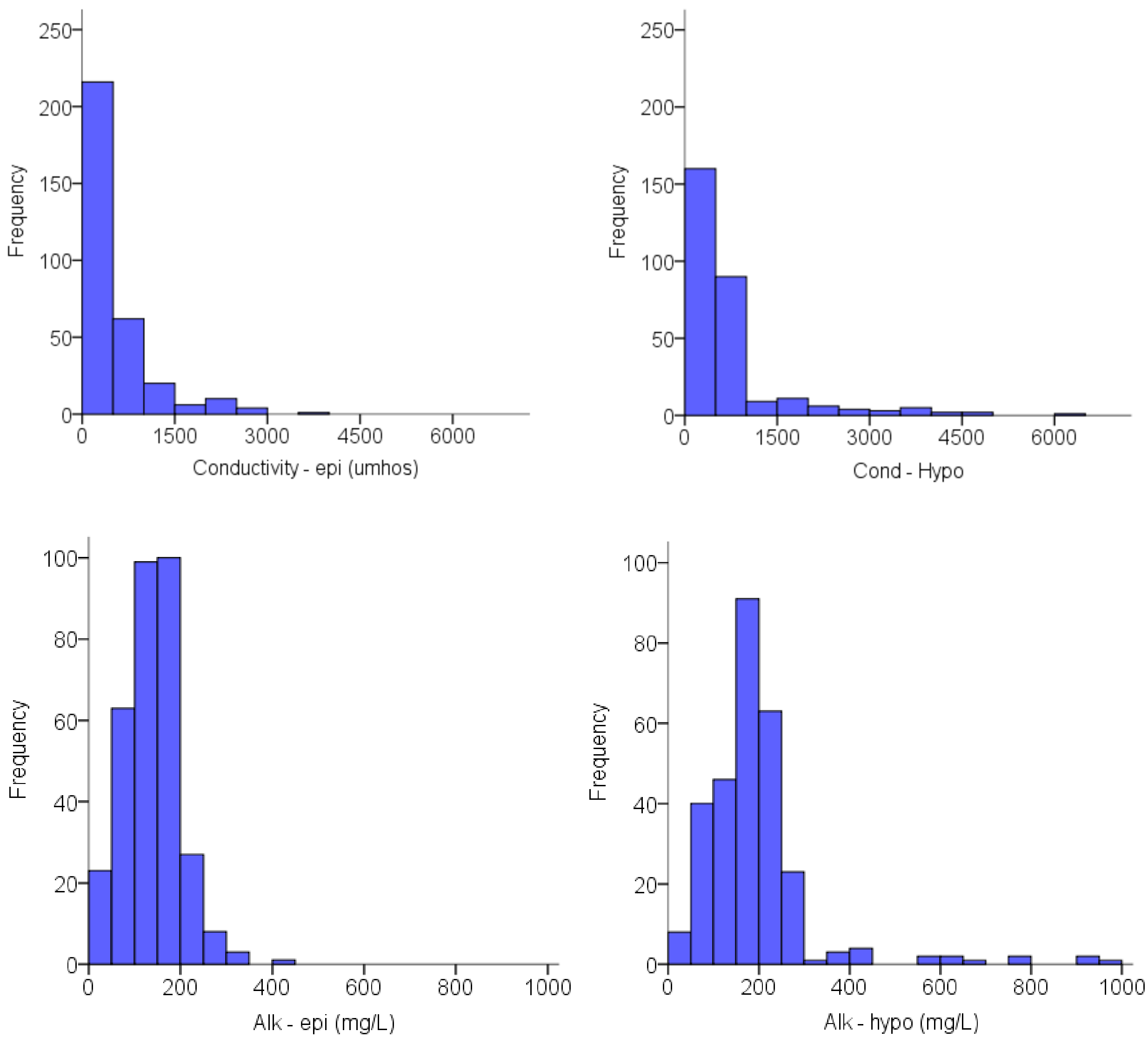

Figure 14. Frequency distributions for epilimnetic and hypolimnetic conductivity and alkalinity for lakes assessed during 2012 – 2014.

Secchi Disk Transparency. Figure 15 shows the frequency distribution of Secchi disk transparency among the lakes assessed during 2012 – 2014. Twenty lakes had Secchi disk transparency depths of 0.5 m (1.5 feet) or less and eight lakes had Secchi depths greater than 5.0 m (16.4 feet) (Table 2). Six of the lakes having the deepest Secchi depths were coal mine lakes. The median Secchi depth for all lakes assessed was 1.7 m.

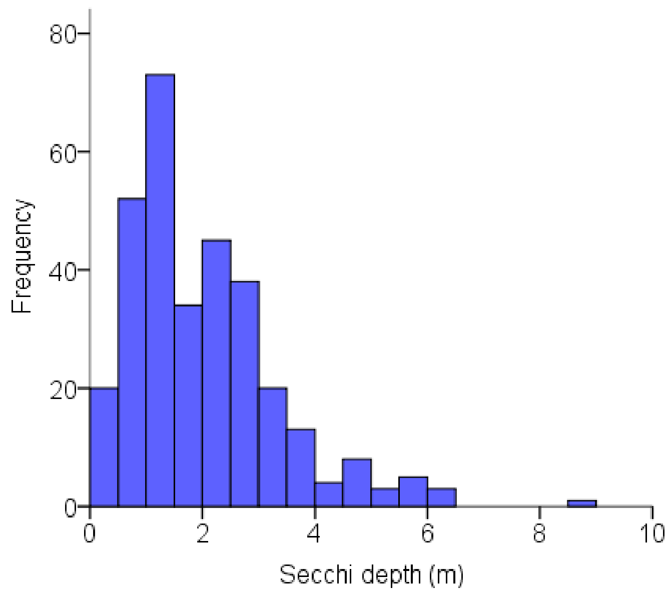

Figure 15. Frequency distribution for Secchi disk transparency for all lakes assessed during 2012 – 2014.

Soluble Reactive Phosphorus. SRP is usually low in the epilimnion of lakes since this is the phosphorus form available for use by algae and plants for growth. One lake (Cedarville Reservoir in Allen County) had an unusually high epilimnetic concentration of SRP at 0.094 mg/L. SRP concentrations are often much higher in the hypolimnion samples. This most likely is due to internal release of phosphorus from anoxic lake sediments, an important source of this important nutrient in many productive lakes. In addition, the hypolimnion of most lakes has insufficient light to allow for photosynthesis, which consumes SRP. Figure 16 shows the frequency distribution of hypolimnetic SRP in the 2012 – 2014 lakes. The median hypolimnetic SRP concentration was 0.041 mg/L. Lakes having the highest hypolimnetic SRP concentrations are shown in Table 3. These lakes have significant internal phosphorus loading.

Table 2. Minimum and Maximum Secchi Depths for Lakes Assessed During Summer 2012-2014.

Lake Name	County	Year	Secchi (m)
Salinda	Washington	2013	0.1
Versailles	Ripley	2013	0.15
Cedarville Reservoir	Allen	2014	0.2
Cedar	Lake	2012	0.25
Shipshewana	LaGrange	2012	0.25
Woods (Big Blue #3)	Rush	2013	0.3
Bischoff Reservoir	Ripley	2013	0.3
South Mud	Fulton	2013	0.35
Holland 2	Dubois	2012	0.4
Knightstown (Big Blue #7)	Henry	2013	0.4
Dale Reservoir	Spencer	2014	0.4
Salinda	Washington	2014	0.4
Eads	Sullivan	2012	0.45
Ferdinand City New	Dubois	2012	0.45
Reservoir 29	Sullivan	2014	5
Todd	Greene	2014	5.2
Pump	Sullivan	2013	5.6
Summit	Henry	2013	5.8
Big Cedar	Whitley	2012	5.95
Goose (Dugger)	Sullivan	2014	6.2
Daredevil	Clay	2012	6.3
Gambill	Sullivan	2014	8.7

Total Phosphorus. Total phosphorus (TP) is a better indicator of phosphorus in lakes because it includes soluble as well as particulate phosphorus. The frequency distributions for TP are shown in Figure 17. Then median epilimnetic TP concentration was 0.030 mg/L. This concentration is what many consider to be sufficient to cause eutrophic conditions. Thus, we could conclude that one-half of Indiana's lakes contain enough epilimnetic phosphorus to promote eutrophic conditions and, conversely, one-half do not. The highest of the epilimnetic total phosphorus concentrations were for Little Turkey Lake (Lagrange Co.) – 0.441 mg/L and for Chrisney Lake (Spencer Co.) – 0.379 mg/L. Only two other lakes in Ripley County exceeded 0.200 mg/L, Versailles Lake and Molenkramer Lake.

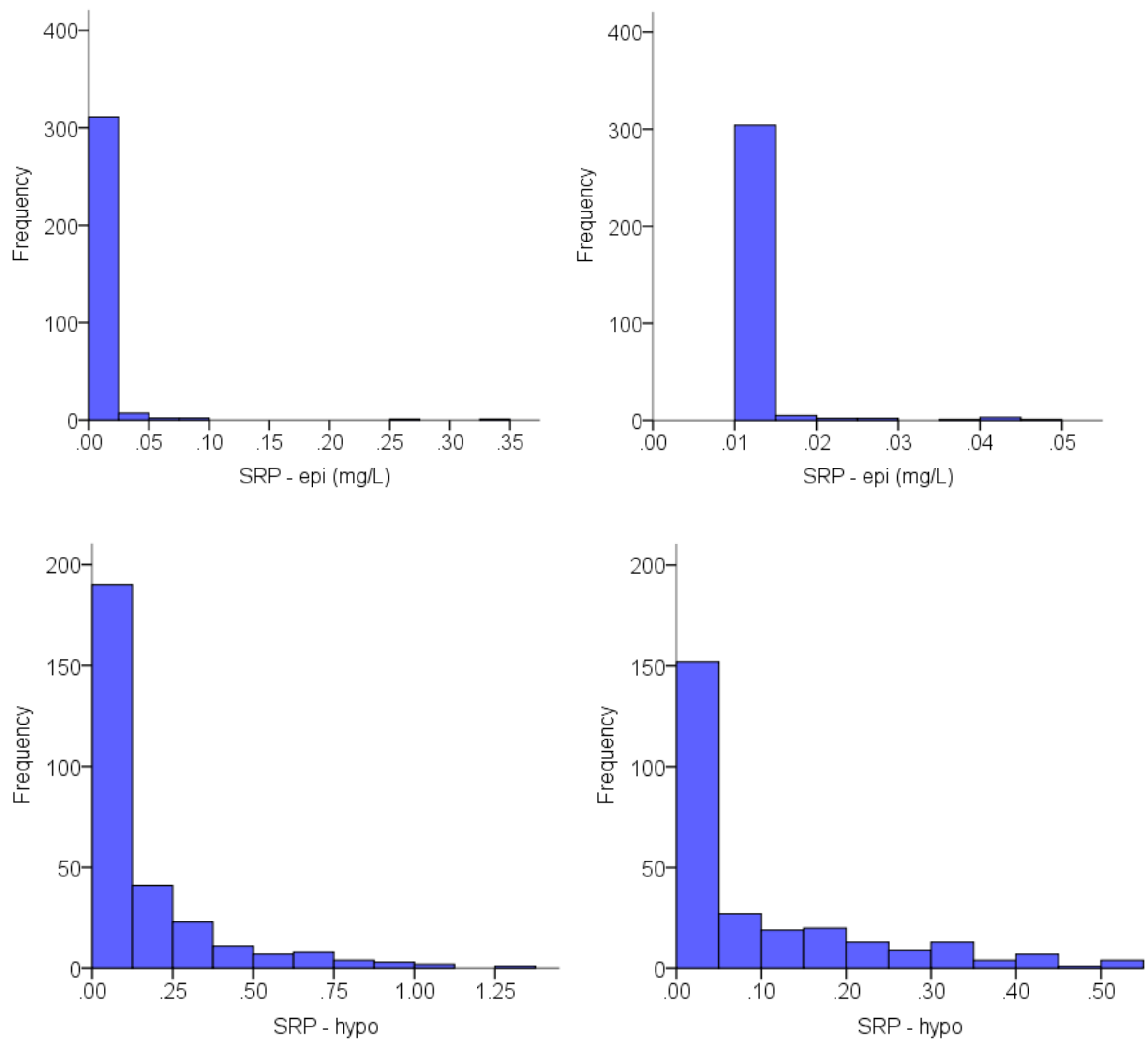

Figure 16. Frequency distributions for soluble reactive phosphorus for lakes assessed during 2012 – 2014. Finer detail is shown for the lower concentrations in the plots to the right.

Hypolimnetic total phosphorus concentrations are much higher than epilimnetic concentrations, again due to internal phosphorus loading from the sediments and additionally due to the accumulation of dead phytoplankton that settles into the hypolimnion, a process referred to as *plankton rain*. Eighteen lakes exceeded a TP concentration of 0.500 mg/L in their hypolimnion (Table 4). These lakes have serious phosphorus accumulation and/or release rates. At fall and spring turnover, this excessive phosphorus is mixed throughout the lake where it can grow more phytoplankton.

Table 3. Lakes with the Highest Hypolimnetic SRP Concentrations.

Lake Name	County	Year	Hypo SRP (mg/L)
Smalley	Noble	2013	0.500
Bischoff Reservoir	Ripley	2013	0.500
Old	Whitley	2013	0.536
Sacrider	Noble	2012	0.537
Hammond	Kosciusko	2013	0.571
Star	Greene	2013	0.610
Robinson	Whitley	2014	0.626
Smalley	Noble	2014	0.638
High	Noble	2012	0.683
Allen	Kosciusko	2012	0.709
Ferdinand City New	Dubois	2012	0.712
Dale Reservoir	Spencer	2014	0.730
Beaver Creek Reservoir	Dubois	2013	0.740
Loomis	Porter	2013	0.841
Hale	Sullivan	2013	0.845
Palestine	Kosciusko	2012	0.918
Worm Pit	Clay	2014	0.989
Frank	Greene	2014	0.991
T Lake	Sullivan	2014	1.104
Willow	Sullivan	2013	1.324

Nitrate-Nitrogen. Most lakes had relatively low nitrate-nitrogen concentrations (Figure 18). The median concentration for epilimnetic nitrate-nitrogen was 0.013 mg/L, which happens to be our laboratory detection limit. Thus, most of the lakes sampled had undectable epilimnetic nitrate-nitrogen concentrations. However, some lakes had significant concentrations. Outliers in the distribution included Pigeon Lake (Steuben Co.) with 6.6 mg/L and Crane Lake (Noble Co.) with 6.3 mg/L, both within the epilimnetic samples.

Hypolimnetic nitrate-nitrogen were mostly low as this form of nitrogen exists in well-oxygenated conditions. It is reduced to ammonia-nitrogen in the absence of oxygen.

Ammonia-Nitrogen. Ammonia-nitrogen is the reduced form of inorganic nitrogen. As such, it is found in more abundance in the hypolimnion rather than the epilimnion (Figure 18). Ammonia-nitrogen is a by-product of bacterial decomposition. In lakes with excessive organic matter at the sediments, ammonia production can be great. The process of bacterial decomposition consumes dissolved oxygen from the water. Therefore, in productive lakes with anoxic hypolimnia, ammonia is produced in great quantities and persists as ammonia due to the lack of dissolved oxygen that prevents its oxidation to nitrate-nitrogen.

Data collected during an international eutrophication program suggest that total nitrogen concentrations of 1.88 mg/L were representative of eutrophic conditions (Wetzel 2001). Forty-two of the lakes assessed during 2012-14 exceeded this concentration in the hypolimnetic sample. Since ammonia-nitrogen is but one componant of total nitrogen, it is likely that more lakes exceed this threshold for total nitrogen. Lakes with hypolimnetic ammonia-nitrogen greater than 3.0 mg/L are shown in Table 5. The Table 5 data indicate that these lakes suffer from excessive biological production of phytoplankton and/or aquatic macrophytes, which leads to high rates of bacterial decomposition and reduced dissolved oxygen in the hypolimnion.

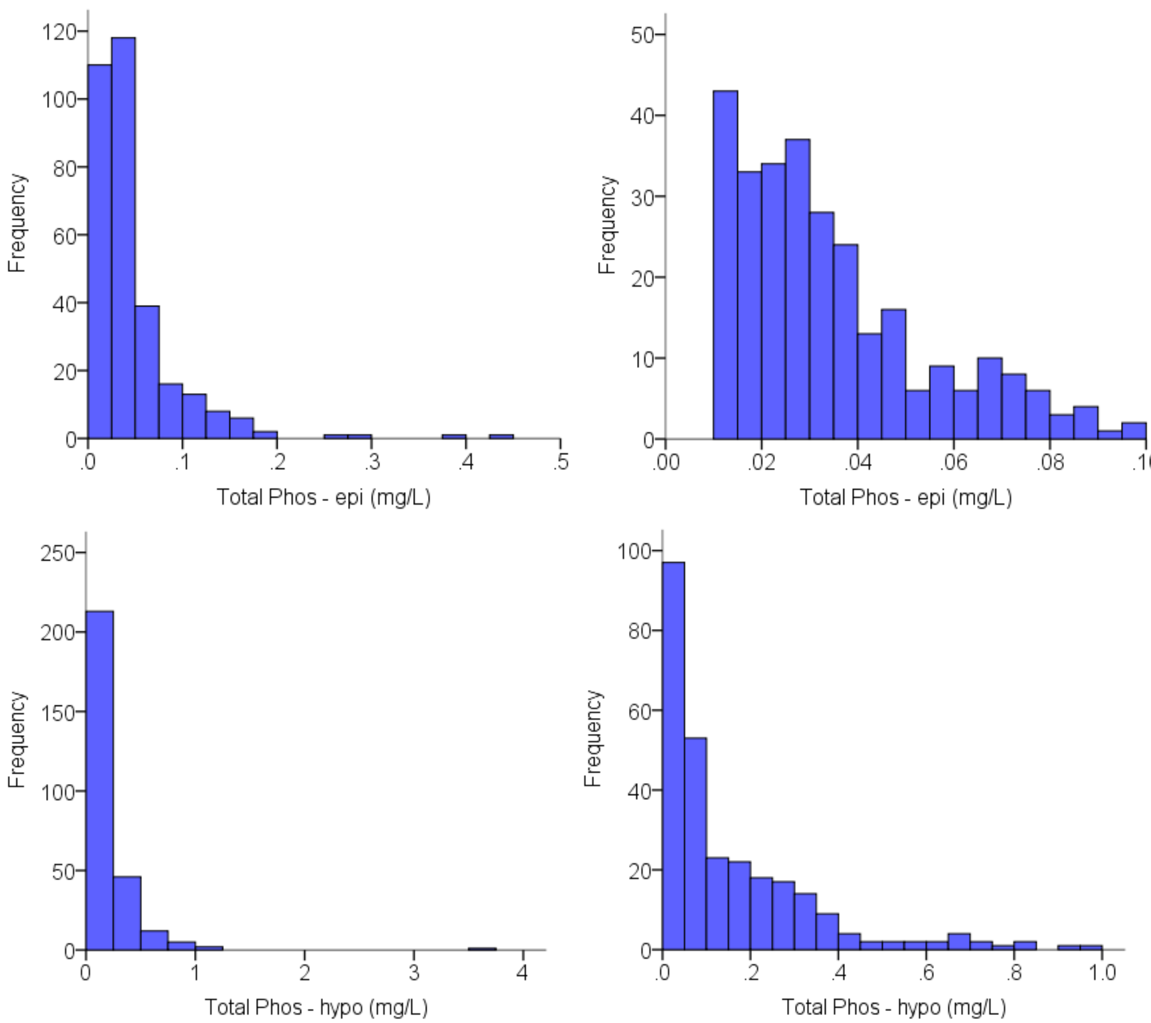

Figure 17. Frequency distributions for total phosphorus for lakes assessed during 2012 – 2014. Finer detail is shown for the lower concentrations in the plots to the right.

Table 4. Lakes with the Highest Hypolimnetic Total Phosphorus Concentrations.

Lake Name	County	Year	Hypo TP (mg/L)
Robinson	Whitley	2012	0.528
Old	Whitley	2013	0.570
Sacrider	Noble	2012	0.573
Star	Greene	2013	0.623
Bischoff Reservoir	Ripley	2013	0.640
Smalley	Noble	2013	0.655
Silver	Kosciusko	2012	0.660
Smalley	Noble	2014	0.661
Allen	Kosciusko	2012	0.698
Robinson	Whitley	2014	0.707
Cedarville Reservoir	Allen	2012	0.724
High	Noble	2012	0.756
Ferdinand City New	Dubois	2012	0.804
Dale Reservoir	Spencer	2014	0.812
Loomis	Porter	2013	0.914
Willow	Sullivan	2013	0.999
Palestine	Kosciusko	2012	1.125
Worm Pit	Clay	2014	3.670

Total Kjeldahl Nitrogen. Total Kjeldahl nitrogen (TKN) is one analytical procedure that uses Kjeldahl digestors. It doesn't however account all forms that contribute to what is called total nitrogen. TKN plus nitrate-nitrogen equals total nitrogen. Since total nitrogen concentrations of 1.88 mg/L are the threshold for eutrophic conditions, it is clear from Figure 18 that many Indiana lakes exceed this threshold. When we calculate mean total nitrogen from our data, a total of 36 of the lakes sampled would be considered eutrophic based on total nitrogen.

Phytoplankton. Nitrogen and phosphorus are the primary nutrients required for plant growth, both on the land and in the water. The excessive concentrations of phosphorus and nitrogen in Indiana's lakes produce an excessive amount of phytoplankton (algae). We use several related parameters to investigate the abundance and structure of a lake's plankton population.

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, irregardless 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).

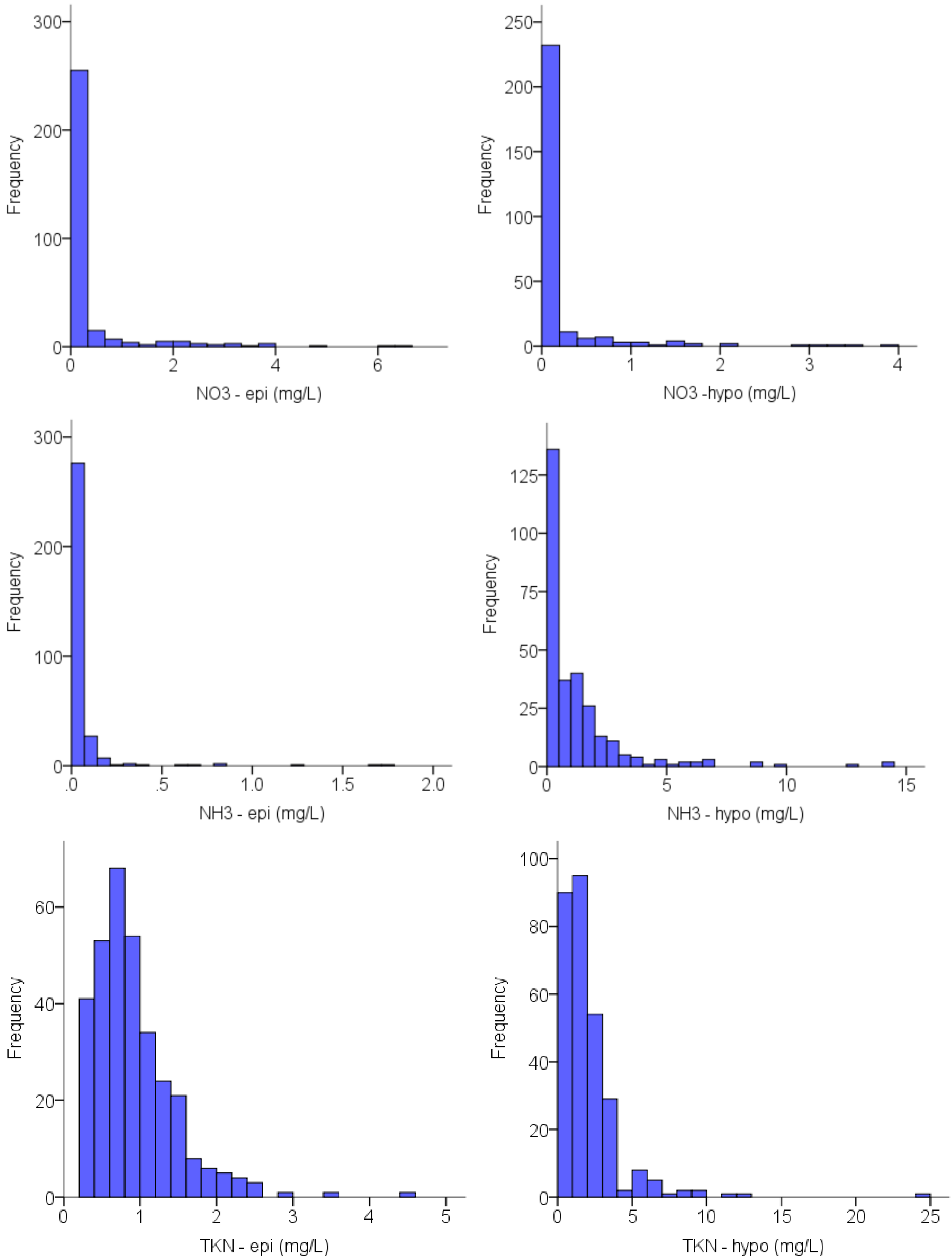

Figure 18. Frequency distributions for nitrate-nitrogen, ammonia-nitrogen and total Kjeldahl nitrogen for all lakes sampled during 2012 – 2014.

Table 5. Lakes with Highest Hypolimnetic Ammonia-Nitrogen Concentrations.

Lake Name	County	Year	Hypo NH_3^+ (mg/L)
Westler	Lagrange	2014	3.009
Pigeon	Steuben	2014	3.130
Loomis	Porter	2013	3.268
Salinda	Washington	2014	3.374
Ferdinand City New	Dubois	2012	3.668
Story (Lower)	Dekalb	2014	3.900
Gilbert	Marshall	2012	4.432
T Lake	Sullivan	2014	4.599
Deep	Sullivan	2013	4.781
High	Noble	2012	5.352
Bischoff Reservoir	Ripley	2013	5.646
Daredevil	Clay	2012	5.978
Worm Pit	Clay	2014	6.200
Dale Reservoir	Spencer	2014	6.341
Palestine	Kosciusko	2012	6.661
McClures	Kosciusko	2013	6.935
Price	Kosciusko	2012	8.770
Frank	Greene	2014	8.986
Willow	Sullivan	2013	12.973
Hale	Sullivan	2013	14.299

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. Chlorophyll-a – Chlorophyll is an important pigment in phytoplankton. It is the primary pigment in Chlorophyta (green algae) and one of several pigments in the Cyanobacteria (blue-green algae). The concentration of chlorophyll-a in a water sample is a direct measure of phytoplankton abundance.
4. 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.

Frequency distributions for plankton metrics are shown in Figure 19 and summary statistics are shown in Table 6. Just over half the lakes (57%) assessed had chlorophyll-a concentrations less than 10 µg/L, the lower boundary of the Carlson's eutrophic category (Figure 5). Thirty-six lakes (15%) exceeded 40 µg/L, a concentration indicative of hypereutrophic conditions (Table 7). Twenty-one of these lakes are impoundments.

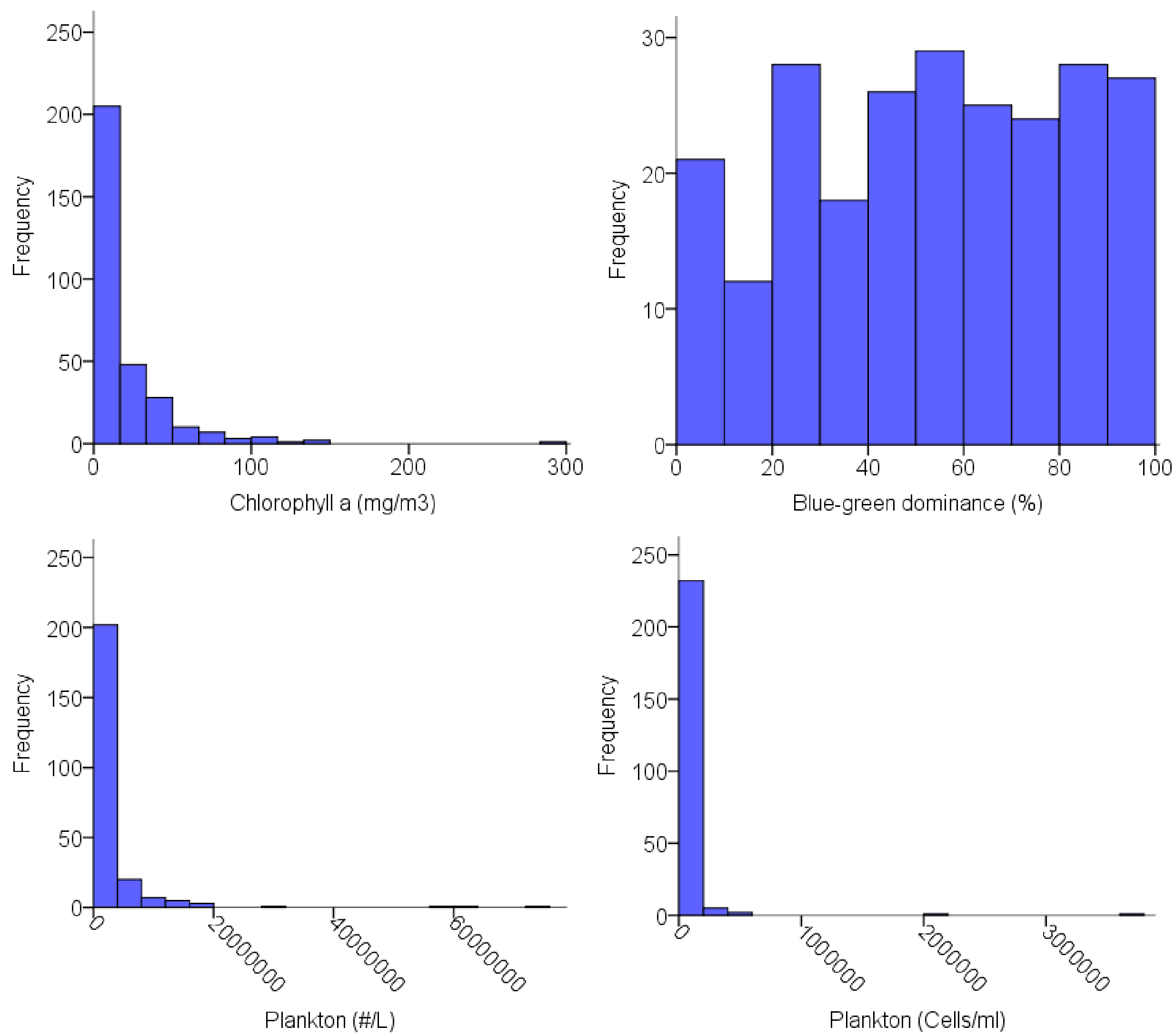

Figure 19. Frequency distributions of several plankton variables for all lakes assessed during 2012 – 2014.

Table 6. Summary of Plankton Analyses.

	Chlorophyll-a (µg/L)	Total Phytoplankton (cells/mL)	% Cyanobacteria Dominance
Median	7.9	1,147	54.8
Minimum	0.48	1	1.3
Maximum	292.1	3,712,007	99.7

Plankton cell densities ranged from a low of 1 cell/mL at Walnut Lake (Sullivan Co.) to a high of 3.7 million cells/mL at Cedar Lake (Lake Co.). One other lake had cell densities exceeding 1 million: Clear Lake (Steuben Co.) – 2.0 million cells/mL. Twenty-two lakes exceeded 100,000 cells/mL. Since 1 mL equals about 1/5 teaspoon, these algal cells are really dense.

Blue-green algae (cyanobacteria) dominate the phytoplankton in many (85%) of the lakes in Indiana (Figure 19). In fact, blue-greens composed more than 90% of the phytoplankton community in 107 lakes.

Trophic State. Table 8 shows the Carlson Trophic State Index for all lakes assessed during 2012 – 2014. Table 8 includes the individual TSIs for Secchi disk transparency, epilimnetic total phosphorus, and for chlorophyll-a along with the mean of the three TSIs. We used the mean TSI to assign trophic state. Of the eleven best mean Carlson TSIs (lowest scores), only two belonged to natural lakes: Lake George (Steuben Co.) and Green Lake (Steuben Co.). Six were coal mine lakes. Of the 34 worst mean Carlson TSIs (highest scores, hypereutrophic), half were natural lakes and the other half impoundments, including one surface mine lake.

Figure 20 illustrates the number of lakes assessed during 2012 – 2014 within each trophic category. More Indiana lakes were eutrophic than any other trophic state category. Over half the lakes, 165 lakes (68% of total), were either eutrophic or hypereutrophic. In our last Lake Water Quality Assessment Report (Jones et al, 2011), 55% of lakes assessed were eutrophic or hypereutrophic.

Table 7. Lakes with Highest Chlorophyll-a Concentrations.

LAKE	COUNTY	YEAR	Chl-a (µg/L)
Mud (Chain of Lakes)	Noble	2013	40.16
Trimble	Greene	2013	40.35
Lemon	Monroe	2012	40.51
Shaffer	White	2013	41.33
Manlove	Fayette	2014	41.45
Huntington Reservoir	Huntington	2013	41.94
McClures	Kosciusko	2013	42.41
Molenkramer Reservoir	Ripley	2012	42.44
Green Valley	Vigo	2014	43.04
Silver	Kosciusko	2012	43.79
Ferdinand City New	Dubois	2012	46.51
Pigeon	Steuben	2013	46.65
Green Valley	Vigo	2012	47.18
Everett	Allen	2014	47.24
Shipshewana	LaGrange	2012	48.70
Rivir (Chain of Lakes)	Noble	2013	49.76
Skinner	Noble	2013	51.74
Dock	Noble	2014	52.91
Golden	Steuben	2014	54.93
Ridinger	Kosciusko	2014	55.20
Salinda	Washington	2014	57.11
Manlove	Fayette	2012	60.11
Sylvan	Noble	2014	63.83
Holland 2	Dubois	2012	67.90
Bischoff Reservoir	Ripley	2013	68.89
South Mud	Fulton	2013	72.33
Palestine	Kosciusko	2012	72.37
Sullivan	Sullivan	2012	76.96
Knightstown (Big Blue #7)	Henry	2013	80.94
Freeman	Carroll	2014	83.48
Woods (Big Blue #3)	Rush	2013	113.66
Long	Noble	2013	115.73
Cedar	Lake	2012	124.03
Salinda	Washington	2013	139.80
Molenkramer	Ripley	2014	141.63
White Oak #1	Knox	2013	292.06

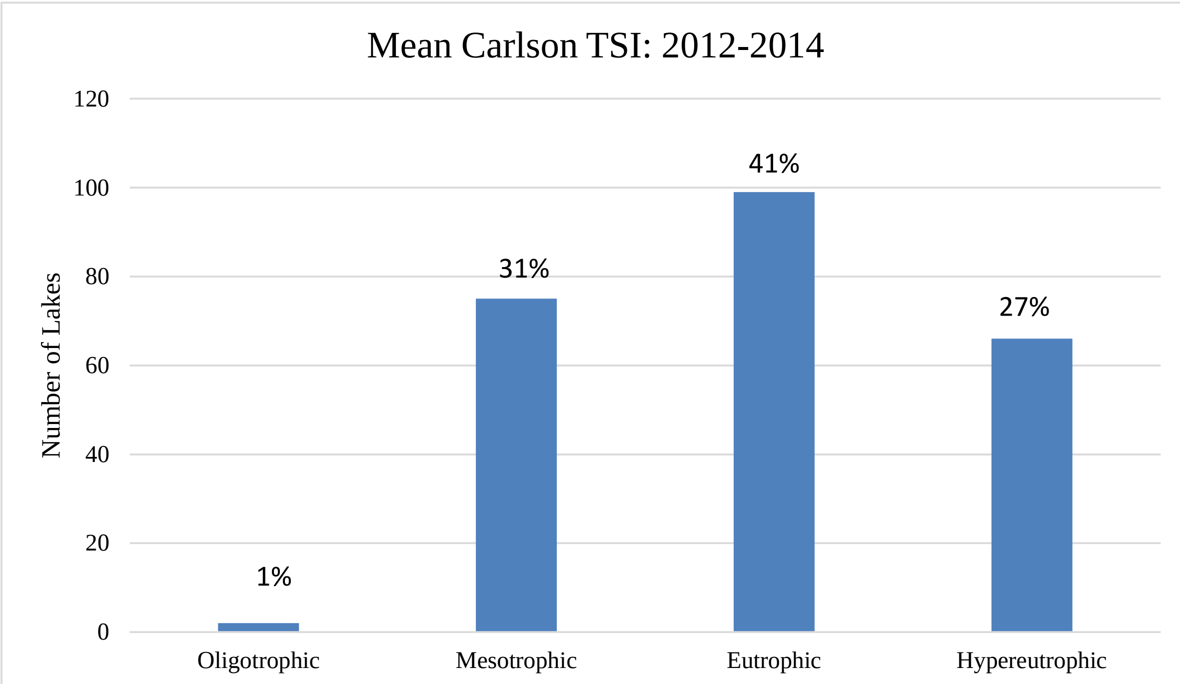

Figure 20. Mean Carlson TSI for lakes assessed during 2012-2014.

Table 8. Carlson TSI for Lakes Assessed During 2012-2014.

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)	TSI(Mean)
Adams	LaGrange	2013	49	49	46	53
Allen	Kosciusko	2012	46	49	49	61
Atwood	Lagrange	2014	47	41	49	48
Atwood	LaGrange	2012	45	39	48	48
Banning	Kosciusko	2014	55	49	54	53
Banning	Kosciusko	2013	55	52	64	56
Bartley	Noble	2014	54	63	62	67
Bass	Sullivan	2014	46	37	59	55
Bass (N. Chain)	St Joseph	2013	47	43	48	46
Bear Creek	Brown	2014	43	56	49	51
Beaver Creek Res.	Dubois	2014	62	63	71	68
Beaver Creek Res.	Dubois	2013	59	54	47	64
Beaver Dam	Kosciusko	2013	60	63	57	67
Big Barbee	Kosciusko	2014	60	66	60	69
Big Bower	Steuben	2013	55	62	59	61
Big Cedar	Whitley	2012	34	30	49	45
Big Chapman	Kosciusko	2012	46	44	37	45
Big Fry	Sullivan	2012	49	42	69	53

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)	TSI(Mean)
Bischoff Reservoir	Ripley	2013	77	72	71	79
Blackman	LaGrange	2013	56	54	42	57
Blue	Whitley	2013	56	52	46	62
Bobcat	Greene	2012	49	36	47	47
Boones Pond	Boone	2012	39	37	42	43
Booth	Steuben	2013	54	40	49	49
Brokesha	Lagrange	2014	36	33	63	46
Brookville Reservoir	Franklin	2012	49	45	44	46
Bruce	Fulton	2012	61	59	57	68
Bryants Creek	Monroe	2012	45	43	50	46
Buck	Steuben	2013	50	61	66	64
Canada	Porter	2012	49	43	46	52
Catfish	Sullivan	2013	59	63	59	60
Cedar	Lake	2012	80	78	78	79
Cedarville Reservoir	Allen	2012	70	57	79	73
Cedarville Reservoir	Allen	2014	83	60	79	74
Center	Kosciusko	2014	45	44	42	51
Center	Kosciusko	2012	46	44	45	52
Chrisney	Spencer	2013	60	52	51	56
Chrisney	Spencer	2014	53	51	90	63
Clair	Huntington	2013	59	55	49	60
Clear	Greene	2012	42	49	52	47
Clear	Steuben	2012	44	38	37	44
Clearwater	Marion	2014	48	43	51	47
Corky	Greene	2012	41	39	37	40
Cottonwood	Greene	2013	48	40	62	50
Crooked Creek	Brown	2014	49	59	44	55
Dale Reservoir	Spencer	2014	73	64	76	77
Dallas	Lagrange	2014	55	23	49	51
Daredevil	Clay	2012	33	33	37	34
Deep	Sullivan	2013	57	57	50	64
Diamond	Noble	2013	45	43	45	52
Dock	Noble	2014	60	70	67	68
Dogwood	Sullivan	2013	42	31	52	43
Duck	Sullivan	2012	39	39	41	42
Eads	Sullivan	2012	72	63	62	63
Eagle	Noble	2012	50	46	51	53
Elk Creek #9	Washington	2012	40	39	41	42
Engle	Noble	2013	47	46	37	43
Everett	Allen	2014	63	68	66	72
Ferdinand City New	Dubois	2012	72	68	77	78

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)	TSI(Mean)
Fish Lake (Scott)	LaGrange	2012	51	41	51	56
Flat	Marshall	2014	53	59	59	59
Flat	Marshall	2012	62	66	65	69
Fletcher	Fulton	2012	50	50	37	59
Flint	Porter	2013	56	65	57	64
Fox	Steuben	2014	45	41	55	48
Fox	Steuben	2013	44	34	37	46
Frank	Greene	2014	42	35	37	39
Freeman	Carroll	2014	60	74	63	67
Fry	Sullivan	2013	55	47	59	57
Fry (Upper)	Sullivan	2014	57	51	58	58
Geist Reservoir	Marion	2014	60	66	68	66
George	Steuben	2012	38	33	40	38
George	Steuben	2014	43	38	49	46
Gilbert	Marshall	2012	65	62	60	67
Golden	Steuben	2014	65	70	65	72
Goldeneye	Kosciusko	2012	48	46	59	51
Goose (Dugger)	Sullivan	2014	34	33	55	40
Goshen Dam Pond	Elkhart	2012	59	53	69	60
Green	Steuben	2012	41	33	44	39
Green Valley	Vigo	2012	67	68	71	68
Green Valley	Vigo	2014	67	67	55	64
Grouse Ridge	Bartholomew	2014	43	42	72	50
Hackberry	Sullivan	2014	54	53	47	56
Hale	Sullivan	2013	48	41	52	54
Hammond	Greene	2012	38	33	41	38
Hammond	Kosciusko	2013	44	44	63	55
Hemlock	Greene	2013	50	60	57	56
Hemlock	Greene	2014	56	57	37	53
High	Noble	2012	55	56	53	67
Hoffman	Kosciusko	2012	55	51	52	59
Hog	LaPorte	2013	49	48	49	53
Holland 2	Dubois	2012	73	72	69	71
Horseshoe	Greene	2013	50	49	52	50
Hunter	Elkhart	2014	44	34	49	42
Huntingburg City	Dubois	2013	59	52	44	53
Huntington Reservoir	Huntington	2013	69	67	74	72
Hurshtown impound.	Allen	2014	60	44	72	56
Indian	Perry	2013	56	52	49	53
Irish	Kosciusko	2012	55	50	53	55
J.C. Murphy	Newton	2012	60	60	66	62

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)	TSI(Mean)
Jackson	Greene	2014	50	51	55	52
James	Steuben	2012	47	38	44	45
James	Kosciusko	2012	59	50	44	61
John Hay	Washington	2012	46	47	44	51
Kickapoo	Sullivan	2014	55	60	48	65
Kiser	Kosciusko	2013	47	45	46	53
Knapp	Noble	2012	48	42	47	57
Knightstown (BigBlue7)	Henry	2013	73	74	70	72
Knightstown (BigBlue7)	Henry	2014	59		73	
Knob	Jackson	2014	47	58	55	54
Koontz	Starke	2013	55	55	67	58
Kreighbaum	Marshall	2014	50	51	55	57
Kuhn	Kosciusko	2012	47	44	51	49
Lake Lincoln	Spencer	2014	50	51	52	53
Lawrence	Marshall	2013	42	45	46	54
Lemon	Monroe	2012	69	67	61	67
Lime (Gage)	Steuben	2012	46	34	48	44
Little Bause	Noble	2013	40	66	46	50
Little Cedar	Whitley	2012	43	37	51	51
Little Chapman	Kosciusko	2014	60	53	55	58
Little Knapp	Noble	2012	49	52	57	57
Little Knapp	Noble	2014	54	59	59	59
Little Pike	Kosciusko	2013	70	63	65	66
Little Turkey	LaGrange	2013	53	51	92	64
Long	Noble	2013	57	77	64	70
Long (Dugger)	Sullivan	2013	37	42	59	46
Long (Pleasant)	Steuben	2012	62	62	52	64
Long (Hillenbrand)	Greene	2014	41	45	56	46
Loomis	Porter	2013	57	62	63	71
Loon	Whitley	2012	57	53	47	64
Loon	Steuben	2013	60	54	54	57
Lukens	Wabash	2012	52	46	52	57
Lukens	Wabash	2014	53	55	52	61
Manitou	Fulton	2013	70	64	60	66
Manitou	Fulton	2014	60	60	56	64
Manlove	Fayette	2012	62	71	77	70
Manlove	Fayette	2014	61	67	74	67
McClish	Steuben	2012	43	34	54	45
McClures	Kosciusko	2013	60	67	66	69
Miller (Chain-O)	Noble	2014	56	65	67	65
Molenkramer	Ripley	2014	57	79	86	74

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)	TSI(Mean)
Molenkramer Reservoir	Ripley	2012	67	67	71	68
Monroe Reservoir	Monroe	2012	42	40		
Moss	Noble	2014	49	51	48	54
Mud (Chain of Lakes)	Noble	2013	61	67	71	67
Mulberry	Greene	2012	52	54	51	52
Muncie	Noble	2013	57	66	58	65
North Little	Kosciusko	2014	55	66	60	65
North Twin	LaGrange	2014	49	36	49	45
Nyona	Fulton	2013	64	64	63	71
Ogle	Brown	2012	45	44	42	45
Old	Whitley	2013	49	63	56	66
Oliver	LaGrange	2012	52	42	49	47
Ontario Mill Pond	LaGrange	2013	54	40	54	49
Ontario Mill Pond	LaGrange	2014	57	51	65	58
Palestine	Kosciusko	2012	69	73	75	80
Patoka Reservoir	Dubois	2013	46	30		34
Pigeon	Steuben	2014	52	52	56	60
Pigeon	Steuben	2013	56	68	59	61
Pike	Kosciusko	2013	65	63	57	68
Pine	LaPorte	2014	44	43	56	49
Pine (North & South)	LaPorte	2013	46	49	53	54
Pretty	LaGrange	2012	49	38	37	43
Price	Kosciusko	2012	46	50	54	52
Prides Creek	Pike	2014	47	36	55	46
Prides Creek	Pike	2013	44	26	41	37
Pump	Sullivan	2014	50	33	55	47
Pump	Sullivan	2013	35	30	20	38
Redbud	Sullivan	2014	44	41	37	48
Reservoir 26	Sullivan	2012	61	58	62	60
Reservoir 26	Sullivan	2014	67	65	74	71
Reservoir 29	Sullivan	2014	37		37	
Ridinger	Kosciusko	2014	65	70	74	69
Ridinger	Kosciusko	2013	62	59	58	65
Rivir (Chain of Lakes)	Noble	2013	67	69	48	72
Robinson	Whitley	2014	65	65	65	73
Robinson	Whitley	2012	57	53	49	65
Robinson	Whitley	2013	60	51	64	60
Rothenberger	Kosciusko	2014	47	57	53	58
Round	Whitley	2013	47	47	48	58
Round B (Ray)	Steuben	2012	43	41	44	43
Sacrider	Noble	2012	45	42	49	58

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)	TSI(Mean)
Saddle	Perry	2013	51	38	30	40
Salinda	Washington	2013	93	79	68	80
Salinda	Washington	2014	73	70	70	72
Saugany	LaPorte	2013	40	39	52	44
Scales	Warrick	2014	55	57	62	61
Sechrist	Kosciusko	2013	45	49	53	55
Shaffer	White	2013	63	67	73	68
Shipshewana	LaGrange	2012	80	69	75	76
Silver	Kosciusko	2012	65	68	61	74
Skinner	Noble	2013	70	69	54	74
Skunk	Greene	2012	52	53	53	53
Smalley	Noble	2014	64	59	62	71
Smalley	Noble	2013	57	57	59	68
Snow	Steuben	2014	53	50	51	51
Snow	Steuben	2013	56	49	49	59
South	Sullivan	2014	63	58	58	61
South Mud	Fulton	2013	75	73	65	77
Spencer	Sullivan	2012	48	44	20	40
Spring Valley (Tucker	Orange	2014	46	41	51	49
Springs Valley (Tucker)	Orange	2013	40	42	37	39
Star	Greene	2013	38	35	61	54
Steinbarger	Noble	2012	57	50	45	60
Stone	LaPorte	2014	42		47	
Stone	LaPorte	2013	44	47	52	49
Story (Lower)	Dekalb	2013	57	64		
Story (Lower)	Dekalb	2014	47	50	41	49
Stump Jumper	Clay	2012		41	37	
Sullivan	Sullivan	2012	67	73	69	72
Summit	Henry	2013	35	38	32	42
Sycamore	Greene	2012	47	41	37	42
Sylvan	Noble	2014	70	71	65	72
Sylvan	Noble	2012	55	63	59	58
Syracuse	Kosciusko	2013	47	47	52	50
Syracuse	Kosciusko	2014		47	49	
T Lake	Sullivan	2014	43	45	37	52
Tamarack (Rome City)	Noble	2012	49	52	52	57
Tamarack (Rome City)	Noble	2014	57	59	64	65
Tippecanoe	Kosciusko	2012	52	49	53	52
Tipsaw	Perry	2012	49	49	47	52
Todd	Greene	2012	38	35	37	37
Todd	Greene	2014	36	33	51	40

Lake Name	County	Year	TSI(SD)	TSI(Chl)	TSI(TP_Epi)	TSI(Mean)
Tree	Sullivan	2014	51	44	42	50
Trimble	Greene	2013	54	67	49	57
Troy Cedar	Whitley	2014	67	59	56	68
Tulip	Greene	2013	42	42	55	47
Turtle	Sullivan	2012	45	39	46	45
Turtle	Sullivan	2014	45	45	55	49
Versailles	Ripley	2013	87	67	85	79
Wabee	Kosciusko	2012	38	35	46	43
Wall	LaGrange	2014	41	39	52	45
Walnut	Sullivan	2014	55	42	37	49
Webster	Kosciusko	2014	59	47	53	60
West	Greene	2012	52	36	41	42
Westler	Lagrange	2014	62	56	56	66
White Oak #1	Knox	2013	65	86	66	70
Willow	Sullivan	2013	48	46	55	63
Woods (Big Blue #3)	Rush	2013	77	77	76	76
Worm Pit	Clay	2014	38	35	41	62
Worster (Potato Creek)	St Joseph	2012	70	62	62	65
Yellow Creek	Kosciusko	2013	62			
Yellowwood	Brown	2012	45	44	52	50

Trophic Category Key

Oligotrophic: 0-35 TSI
Mesotrophic: 36-50
Eutrophic: 51-64
Hypereutrophic: >65

DISCUSSION

Spatial Patterns

Do lakes in one region of Indiana have different water quality than those in other regions? In other words, are there geographical spatial patterns in water quality? Figure 21 shows the Carlson averaged trophic state index for all lakes assessed during 2012 – 2014. The average of the three TSIs used in the Carlson Index (Secchi disk, epilimnetic total phosphorus, and chlorophyll-a) were used to establish trophic state. It is difficult to identify any trophic patterns with 246 marks for the lakes spread over the state. To help identify patterns, we will aggregate the data by ecoregion.

Figure 22 shows the median Carlson TSI for lakes within each of the five Indiana ecoregions that have lakes in Indiana. Ecoregions 54 (Eastern Corn Belt Plains) and 55 (Central Corn Belt Plains) both have median Carlson TSI scores of approximately 65, the highest of the five Ecoregions. A TSI score of 65 is within the eutrophic category (51-64) (Table 8). Row crop agriculture is the primary land use within these two ecoregions and this shouldn't be a surprise since the link between agricultural fertilizers and lake eutrophication is well-established (Novotny, 2003). Ecoregion 56 in northeastern Indiana contains most of our glacial lakes. The median TSI for lakes within this ecoregion is 58, which is in the middle of the eutrophic scale. The two southern Indiana Ecoregions (71 and 72) have the lowest median TSIs. These ecoregions are characterized by less agriculture, more forested land, more topography and less lakeshore development; the primary lake types are impoundments. By their design impoundments have large watersheds and receive greater runoff, sediment and nutrient delivery from their watersheds, on average, than do glacial lakes of comparable surface area. That impoundments located in the more forested Ecoregions 71 and 72 are less eutrophic speaks volumes of the influence of land use on lake trophic state.

Similarly, lakes within the two Corn Belt Plains and the Southern Michigan/Northern Indiana Drift Plains ecoregions have the highest median average total phosphorus concentrations, in the hypereutrophic range (Figure 23 and Figure 6). The average TP from each lake was used in this chart. In cases where a lake was too shallow to have a hypolimnion, the epilimnetic concentration only was used. In the southern ecoregions (71 and 72) the median TP concentrations are in the middle range of the eutrophic classification.

Havens and Nürnberg (2004) suggest that with increasing total phosphorus concentrations, chlorophyll-a concentrations increase. The excess phosphorus apparent in Figure 23 grows abundant phytoplankton, as shown by chlorophyll-a medians in Figure 24. The ecoregion with the highest median total phosphorus concentrations had the highest median chlorophyll-a concentrations, as predicted by Havens and Nürnberg.

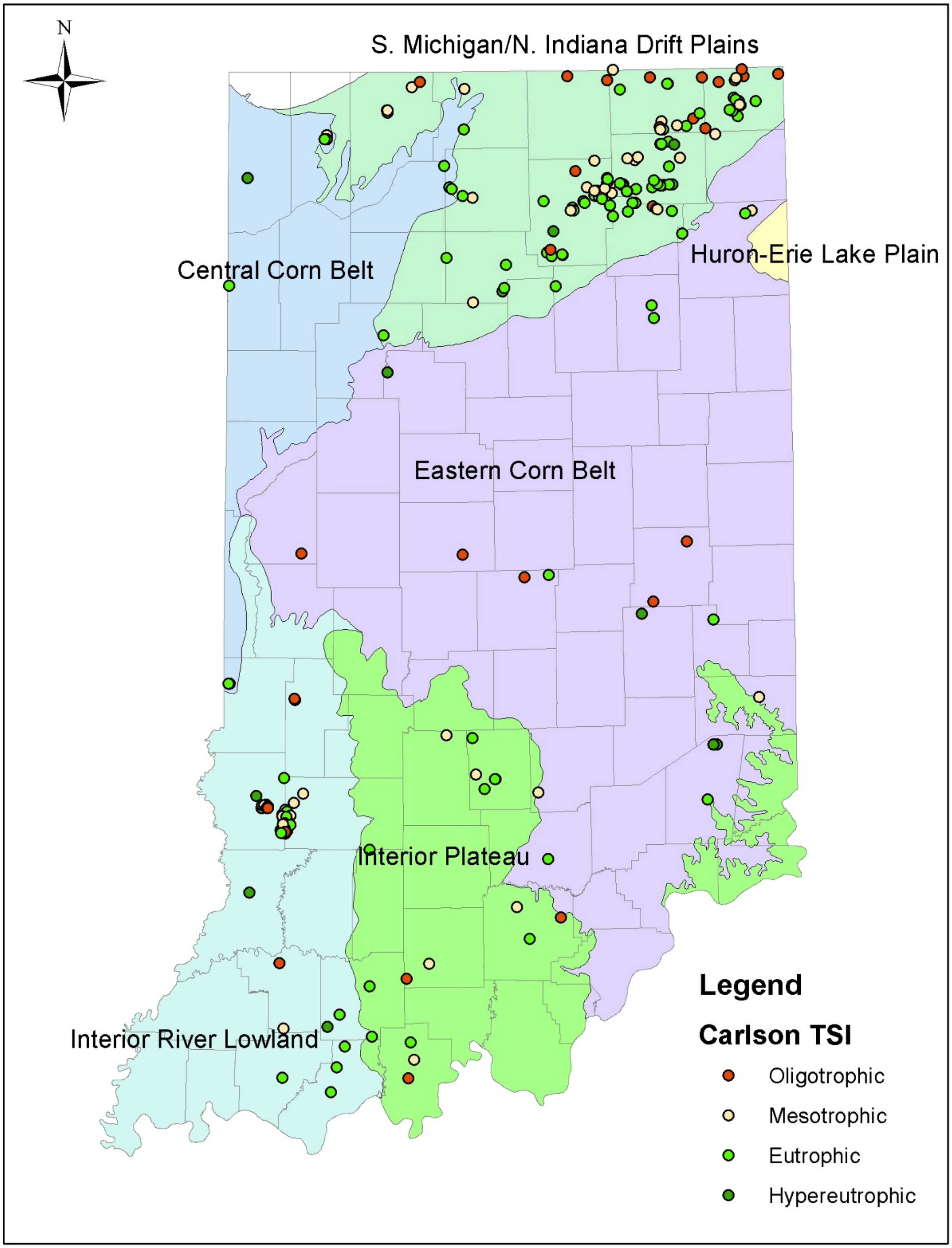

Figure 21. Carlson mean TSI trophic state for lakes assessed during 2012-2014 overlain on Indiana Ecoregions.

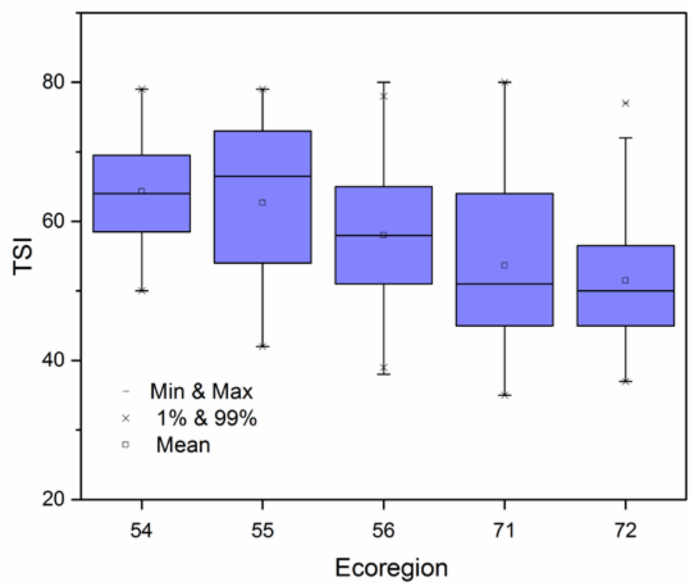

Figure 22. Mean Carlson TSI of all lakes assessed during 2012-2014 aggregated by Ecoregion.

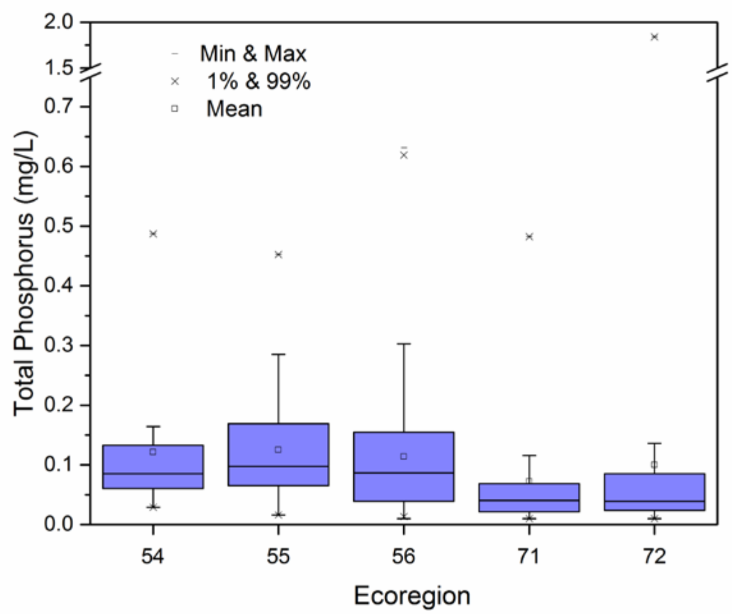

Figure 23. Mean total phosphorus of all lakes assessed during 2012 – 2014 aggregated by Ecoregion.

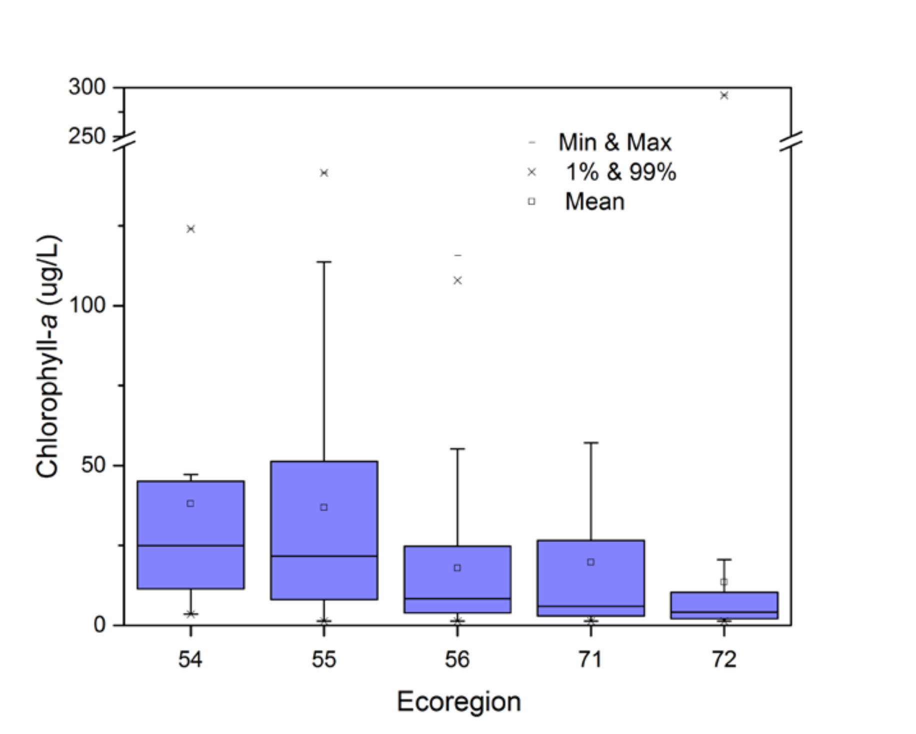

Figure 24. Chlorophyll-a of all lakes assessed during 2012 – 2014 aggregated by Ecoregion.

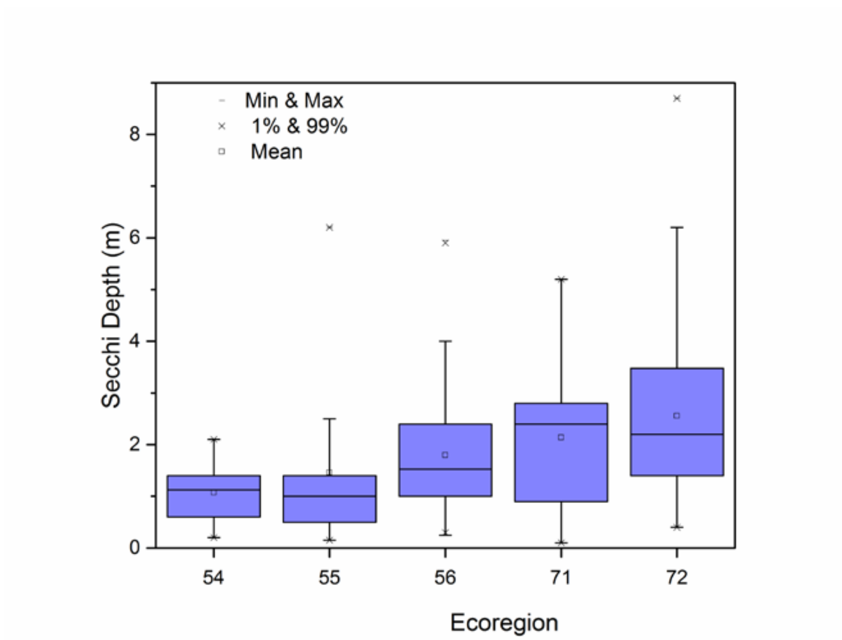

Figure 25. Secchi disk transparency of all lakes assessed during 2012 – 2014 aggregated by Ecoregion.

Abundant phytoplankton contributes to reduced clarity in the lakes (Figure 25). In both plots, lakes within the Corn Belt Plains had higher chlorophyll-a and lower transparency than lakes within the other ecoregions, both within the eutrophic range.

While we see real differences among the five ecoregions for all of the water quality parameters examined, it is clear that for the most part, Indiana lakes have excessive phosphorus concentrations that contribute to the growth of abundant phytoplankton. Given this, it might come as a surprise that Indiana lakes actually produce less phytoplankton than what is predicted by the phosphorus available to help grow the phytoplankton in about half the lakes sampled (Figure 26).

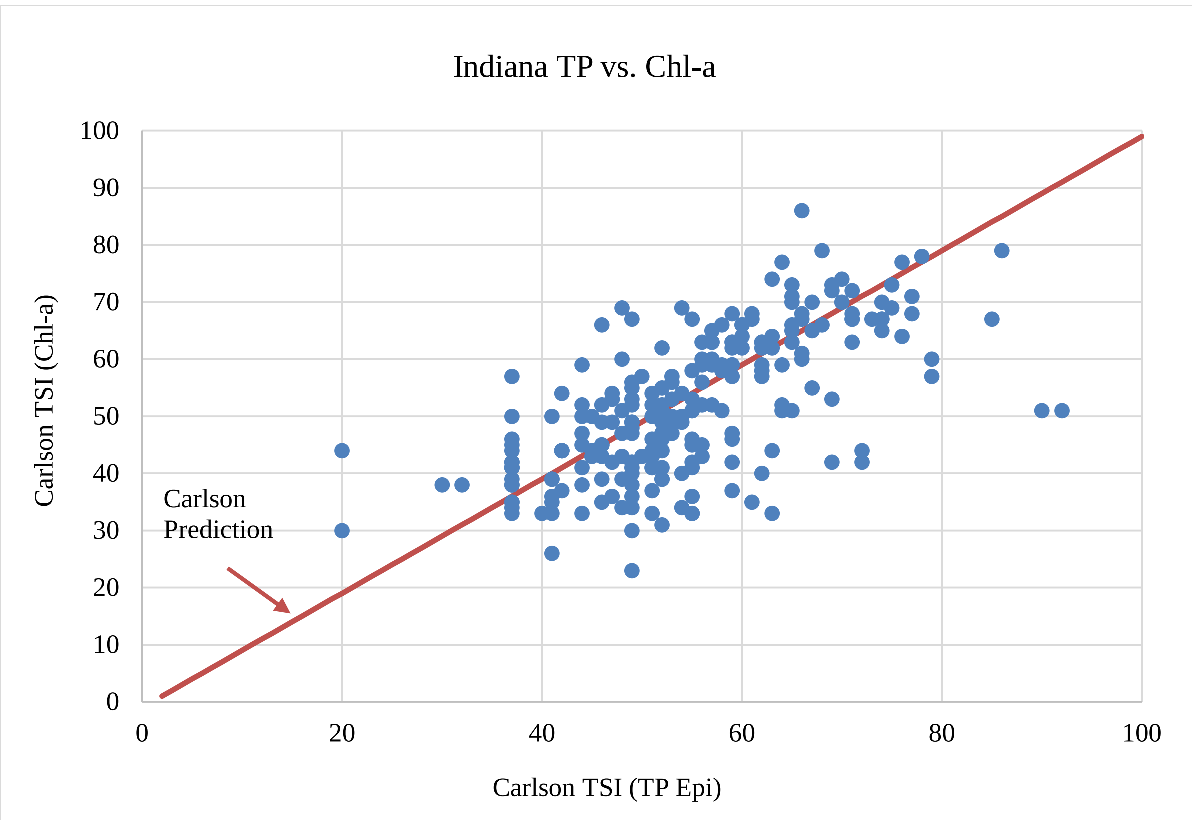

Figure 26. Carlson TP TSI scores plotted against Carlson Chl-a TSI scores for all 246 lakes assessed during 2012-2014. The red line is the predicted relationship between the two parameters.

Carlson's three TSIs are statistically related whereby one can predict the chlorophyll produced in a given lake based on the total phosphorus concentration in that same lake (Carlson, 1977). For example, a lake with a TP TSI of 60 should also have a Chl-a TSI of 60. When we compare the TP TSI in Figure 26 with Carlson's predicted line, it is clear that Indiana lakes produce less chlorophyll-a (the red line) for the amount of phosphorus present. Nearly half of the chlorophyll-a values fall below the predicted values.

The most likely reason for this is non-algal turbidity. Indiana lakes have more turbidity caused by sediment resuspension and sediment runoff than did the lakes in the Upper Midwest that Carlson used to develop his model. Turbidity in Carlson's lakes was caused mostly by phytoplankton. This increased non-algal turbidity limits the depth of light penetration in the lake, thereby decreasing the depth of the euphotic zone, which in turn, decreases algal photosynthesis. So, by considering Carlson's TSI, we gain insight to how Indiana lakes behave.

Lake Type Patterns

As discussed previously, Indiana has a number of different lake types but these can be grouped into three categories: natural lakes, impoundments and coal mine lakes. When an independent consulting company examined Indiana lake data collected from all sources as background to creating statewide nutrient criteria, as mandated by USEPA, they concluded that there weren't significant differences between geographic regions of Indiana (Tetra Tech, 2008). The analysis instead concluded that there were significant differences between the three major lake types in Indiana. With this in mind, we analyzed our 2012 – 2014 data by lake type.

As Figure 27 shows, coal mine lakes are the smallest in surface area and there is little variation in surface area among the coal mine lakes. This is shown by the low height of the box for coal mine lakes. In Indiana, impoundments have the largest surface area (as a group) and there is large variation between the small and large impoundments (high box). Lake Monroe, the largest lake in Indiana is indicated by the "x" at the top extreme of the distribution.

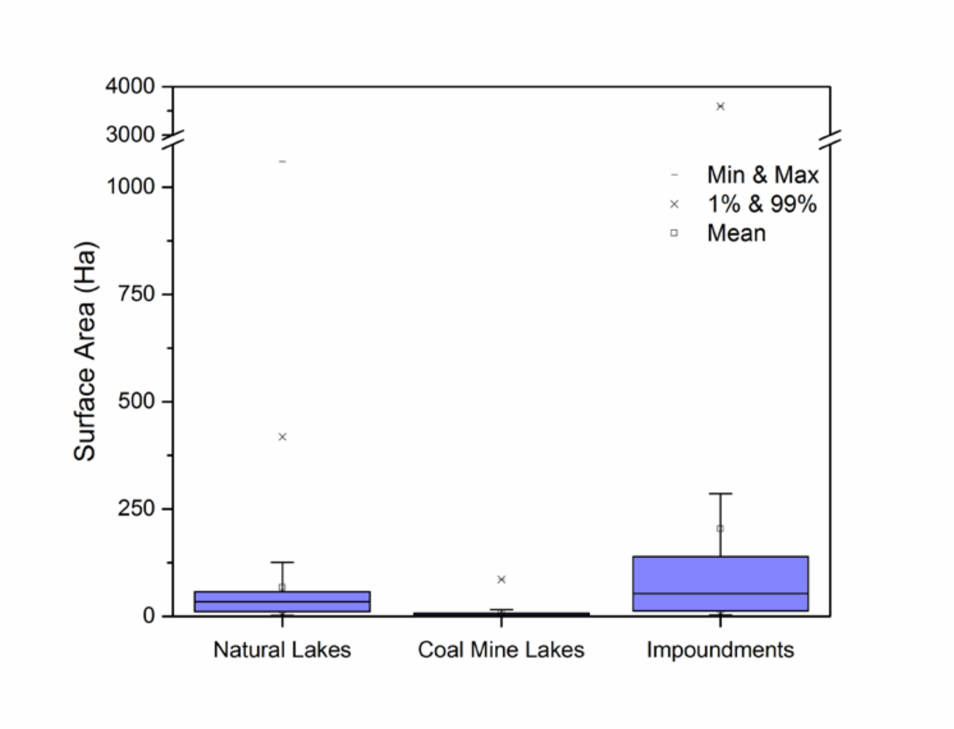

Figure 27. Box plot of surface areas for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square. A shallow box indicates less variation in the data while a tall box indicates more variation.

Natural lakes are generally deeper than the impoundments and coal mine lakes in Indiana (Figure 28). Impoundments as a group are the shallowest lake types. In many parts of the U.S., particularly the South, impoundments are substantially deeper than natural lakes. However the South has few natural lakes and the impoundments are deep and large by design to meet the necessary water needs in that region.

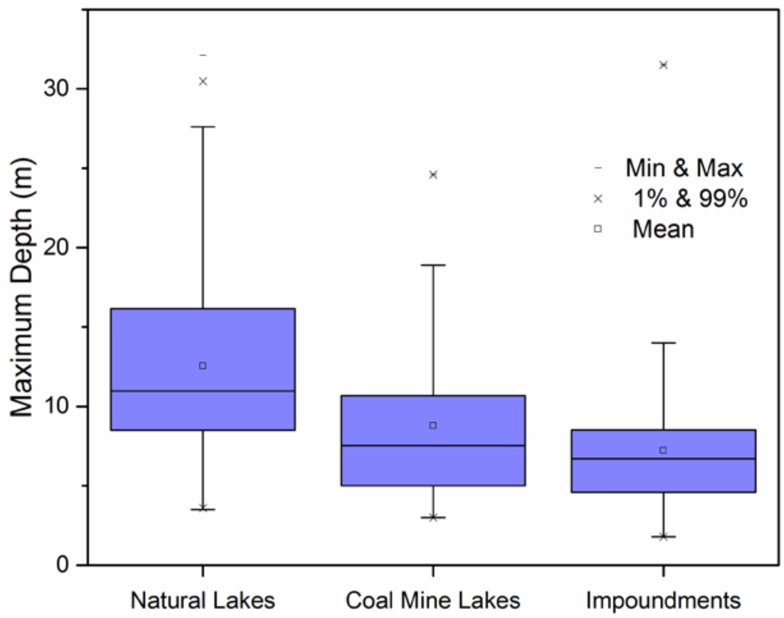

Figure 28. Box plot of maximum depth for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.

Figure 29 shows how alkalinity varies among the Indiana lake types. As mentioned previously, alkalinity or pH buffering capacity is derived primarily from a lake's physical setting, including bedrock geology. Lakes situated in areas with limestone bedrock (southwestern Indiana) and glacial till (northern Indiana) tend to have higher alkalinities because more alkalinity-producing rocks are present. The patterns shown in Figure 29 reflect this as well as the geographical setting. Natural lakes occur primarily in glaciated Northern Indiana where till deposits are thick. Impoundments occur in the non-glaciated regions of Indiana – in the

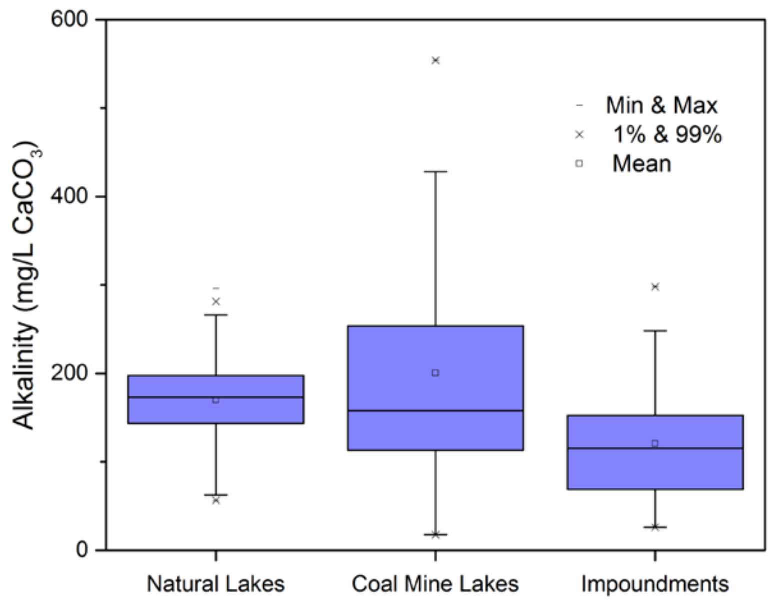

Figure 29. Box plot of alkalinity for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.

central and southern areas. The exception is the coal mine lakes. Despite being located in Southwestern Indiana, they derive their higher alkalinities from limestone, which is the rock layer immediately below the Pennsylvanian coal deposits. Once the coal is removed, limestone forms the bottom of many of the coal mine lake basins.

Ions that generate alkalinity are just some of the dissolved ions in lakes. There are many other dissolved ions present that don't contribute to alkalinity. Figure 30 shows the distribution of conductivity among the three lake type groups. Since conductivity is the ability of water to pass an electrical current, and since this ability is a function of the concentration of dissolved ions in the water, conductivity is a useful approximation of total dissolved ions. As Figure 30 illustrates, the conductivities of natural lakes and impoundments are similar, but the coal mine lakes have significantly higher conductivities. This difference is statistically significant at the 0.01 level ($\rho < 0.001$). This means that the probability that the conductivity means of these two populations (natural lakes and coal mine lakes) is due to chance is less than 0.1%. In other words, the difference is real. Conductivities are high in coal mine lakes because coal mine lakes are susceptible to the effects of acid mine drainage, which occurs when iron-sulfur compounds in

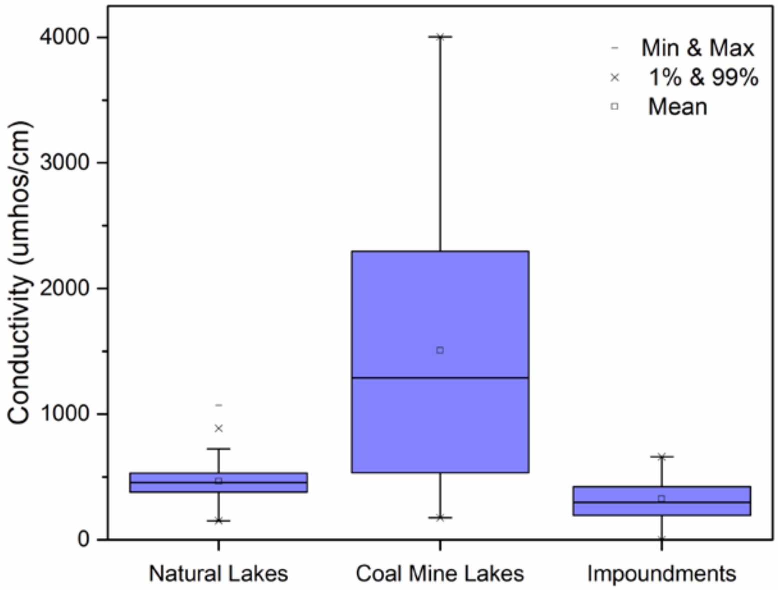

Figure 30. Box plot of conductivity for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.

mine waste are exposed to air and moisture and are oxidized by chemical and microbial reactions to sulfuric acid (Gyure et al., 1987). Acidic leachates then flow through soil and mine spoils, and eventually into coal mine lakes, picking up dissolved materials on their way.

Figure 31 shows the distribution of pH among natural lakes, impoundments and coal mine lakes. The mean for coal mine lakes is lower than that of both natural lakes and impoundments. Acids mobilized during coal surface mining can lower pH values in these lakes despite the presence of limestone bedrock beneath many of them.

It is interesting to note that the impoundments have extreme low outliers, the lowest pH values of all the lakes along with the coal mine lake outlier. This occurs at Ontario Mill Pond (Lagrange Co.). Ontario Mill Pond lies within a series of shallow impoundments with many wetland areas.

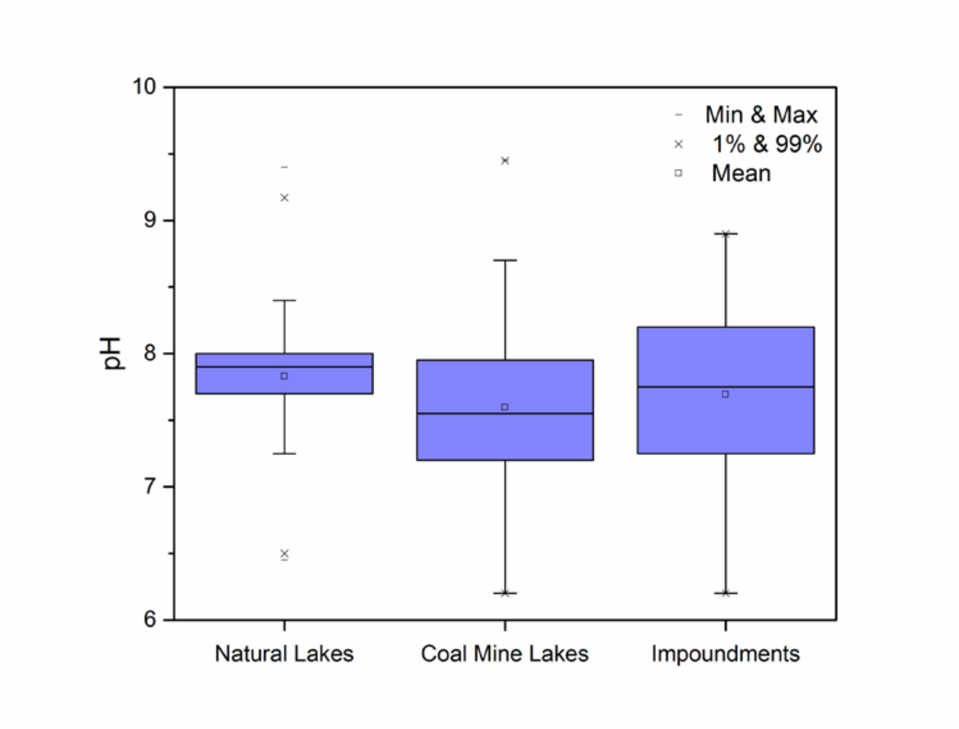

Figure 31. Box plot of pH for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.

Low water pH caused by acid mine drainage can have negative implications for productivity. Specifically, low pH can increase the solubility (and thus aqueous concentration) of copper, aluminum, and other metals such as lead and arsenic in lakes. High concentrations of copper have been shown to inhibit algal growth (Lehman et al., 2004) and high concentrations of aluminum can decimate fish populations by precipitating on fish gills, thus impairing gaseous exchange. Reservoir 29, one of the coal mine lakes in the Greene-Sullivan State Forest has historically been affected by acid mine drainage, and had an epilimnetic pH of 2.7 in 1987 (Gyure et al., 1987). Management efforts such as liming helped increase Reservoir 29's epilimnetic and hypolimnetic pH to 6.6 and 6.2, respectively, by July, 2014 when we sampled it. However, Reservoir 29's pH remains below the average for all the coal mine lakes that were sampled during 2012 - 2014.

Secchi disk transparency is one of the oldest and easiest lake quality indicators in use today. Materials suspended in the water interfere with the depth to which an observer can see the disk as it descends. These suspended materials include phytoplankton produced within the lake and sediments that may have either been washed into the lake from the watershed or resuspended by boats or wind from the lake bottom.

The coal mine lakes have small watersheds so there is less runoff compared to impoundments or natural lakes. In addition, they are often nutrient-poor following surface mining. The rock and soil disturbed by surface coal mining are naturally low in nitrogen and phosphorus. For this reason, Secchi disk transparency among the coal mine lakes is the lowest of the three lake types. Impoundments, with their large watersheds, often have "muddy" water following rainstorms. This is a sign of watershed erosion and the eroded sediments decrease Secchi disk transparency. Natural lakes have smaller watersheds than impoundments but farming and residential development within these watersheds contribute plenty of nutrients that grow phytoplankton. And it is the phytoplankton growth that most often contributes to poor Secchi disk transparency in natural lakes.

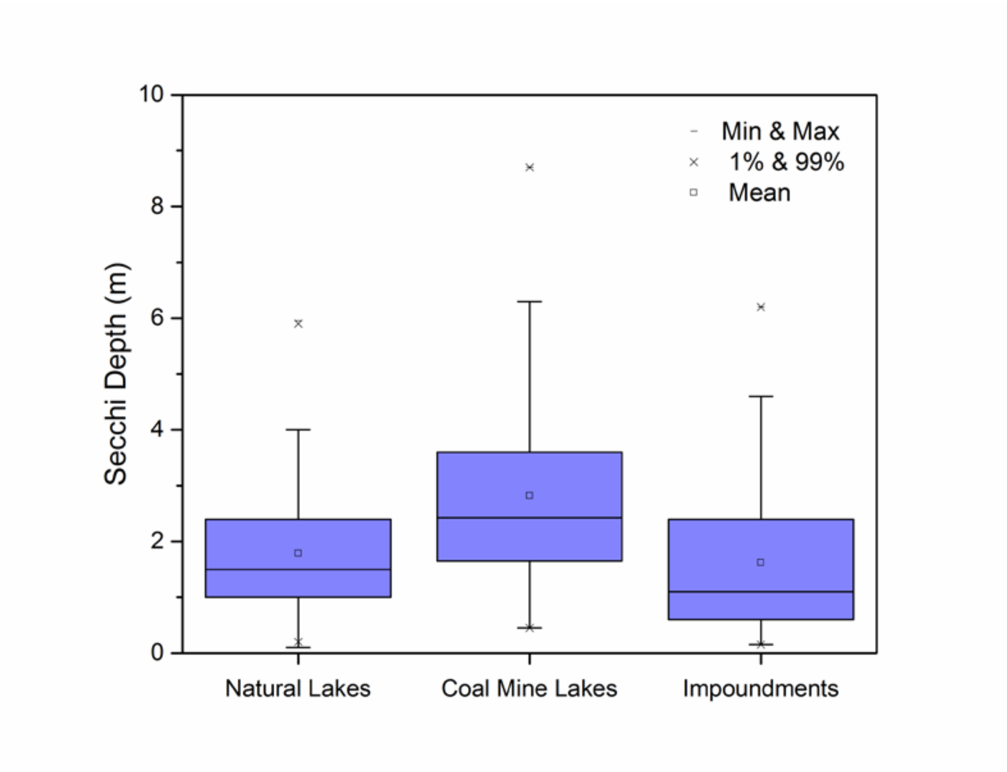

Figure 32. Box plot of Secchi disk transparency for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.

That natural lakes have higher total phosphorus concentrations is illustrated in Figure 33. The mean total phosphorus concentration for the natural lakes is only slightly higher than that for impoundments but the range of concentrations for the natural lakes is slightly greater. Coal mine lakes have a statistically significant ($\rho < 0.01$) lower mean total phosphorus concentration than the other two lake types for reasons mentioned previously, but is also the lake group with the highest concentration in Worm Pit (Clay Co) as shown by the x symbol in Figure 33.

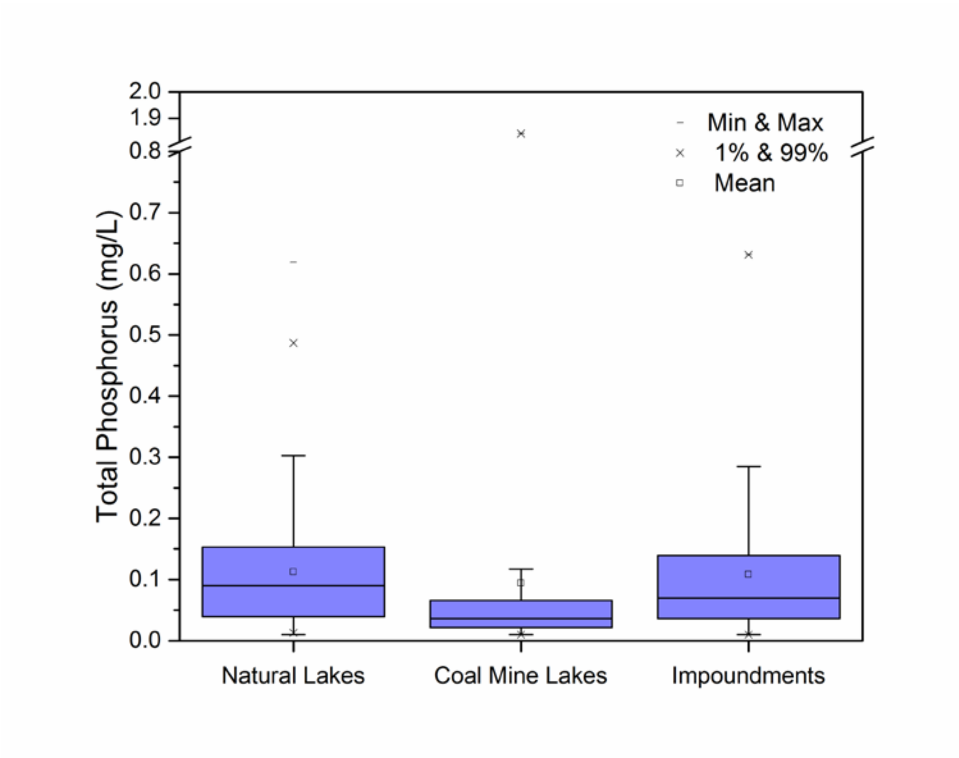

Figure 33. Box plot of mean total phosphorus for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.

The range of nitrate-nitrogen concentrations for the coal mine lakes was exceedingly small, evidence of highly uniform conditions among these lakes. High concentration outliers in the nitrate-nitrogen distributions include Pigeon Lake (Steuben Co.) for the natural lakes and Huntington Reservoir (Huntington Co.) for the impoundments.

The highest mean ammonia-nitrogen concentration occurred at Hale Lake (Sullivan Co.) a coal mine lake. Another coal mine lake (Willow Lake in Sullivan Co.) had the next highest ammonia-nitrogen concentration. This anomaly skewed the mean upward for the coal mine lakes, which typically had low ammonia-nitrogen concentrations. Price Lake (Kosciusko Co.) was the high ammonia-nitrogen concentration outlier for the natural lakes.

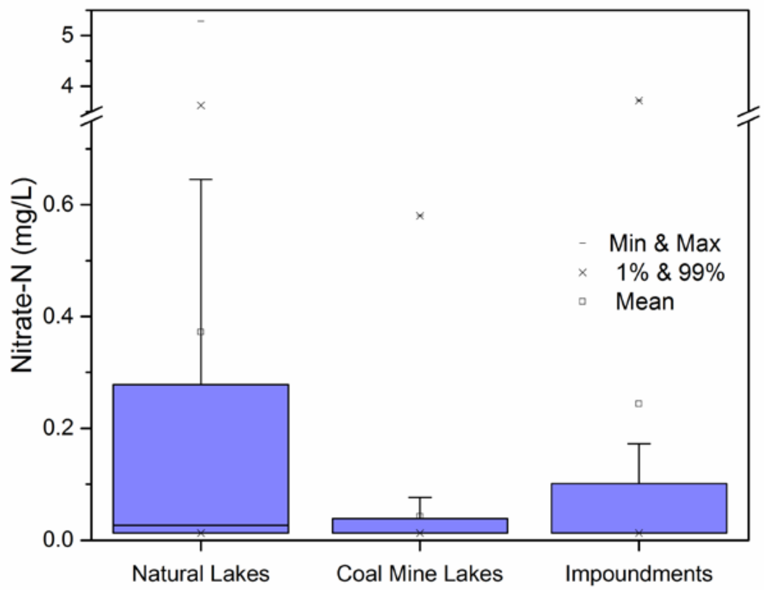

Figure 34. Box plot of mean nitrate-nitrogen for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.

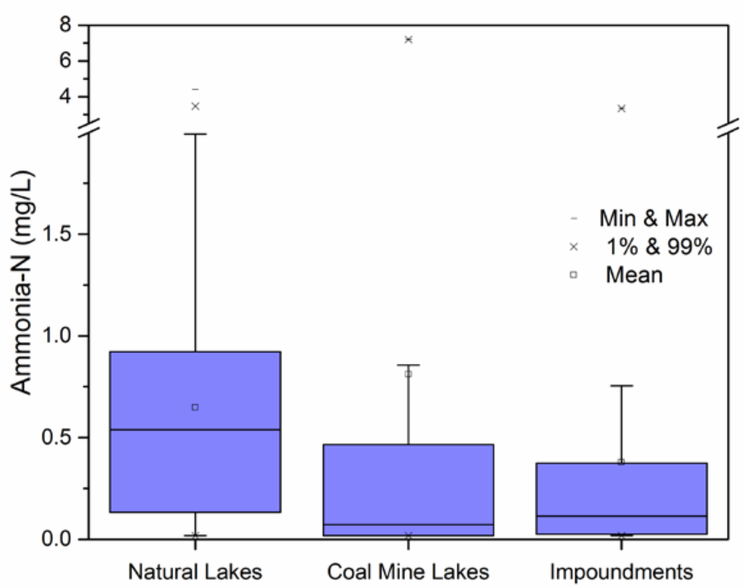

Figure 35. Box plot of mean ammonia-nitrogen for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.

The more readily-available nutrients in natural lakes and impoundments grow more phytoplankton in these lake types compared with coal mine lakes. The mean chlorophyll-a concentration for the coal mine lakes was significantly lower than the means for natural lakes and impoundments. There was also less variation in the range of chlorophyll-a concentrations for the coal mine lakes, which are typically less biologically productive. Extremely high outlier concentrations for impoundments were at White Oak #1, a reservoir in Knox Co.

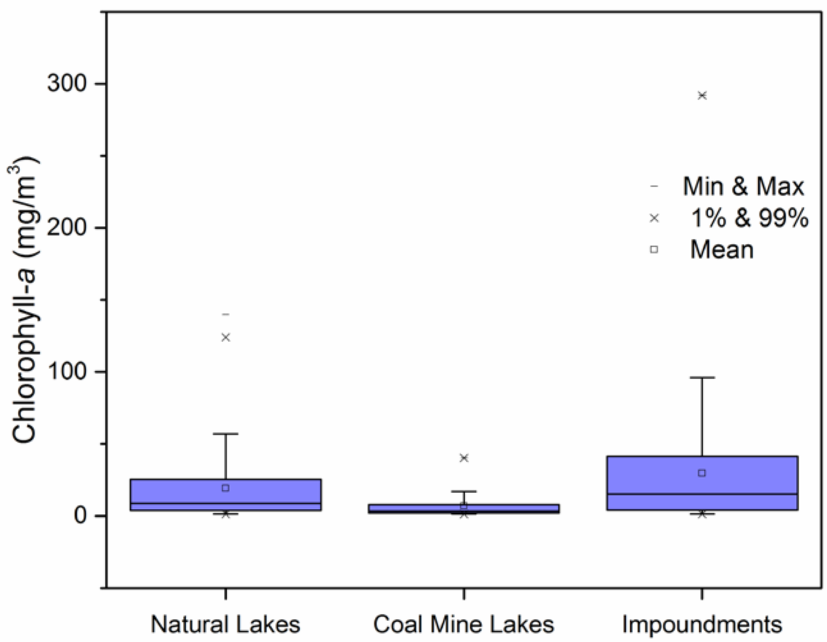

Figure 36. Box plot of chlorophyll-a for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.

Overall water quality among the populations of natural lakes, impoundments and coal mine lakes can be summarized by the mean Carlson's Trophic State Index (TSI) (Figure 37). These results are consistent with expectations based on the previous analysis of the other water quality parameters. Coal mine lakes have the lowest median and mean Carlson TSI; natural lakes have the next lowest, and impoundments have the highest TSIs. The mean TSI for each lake type is statistically different than the other lake types. The mean Carlson TSI is a good metric for evaluating Indiana lakes.

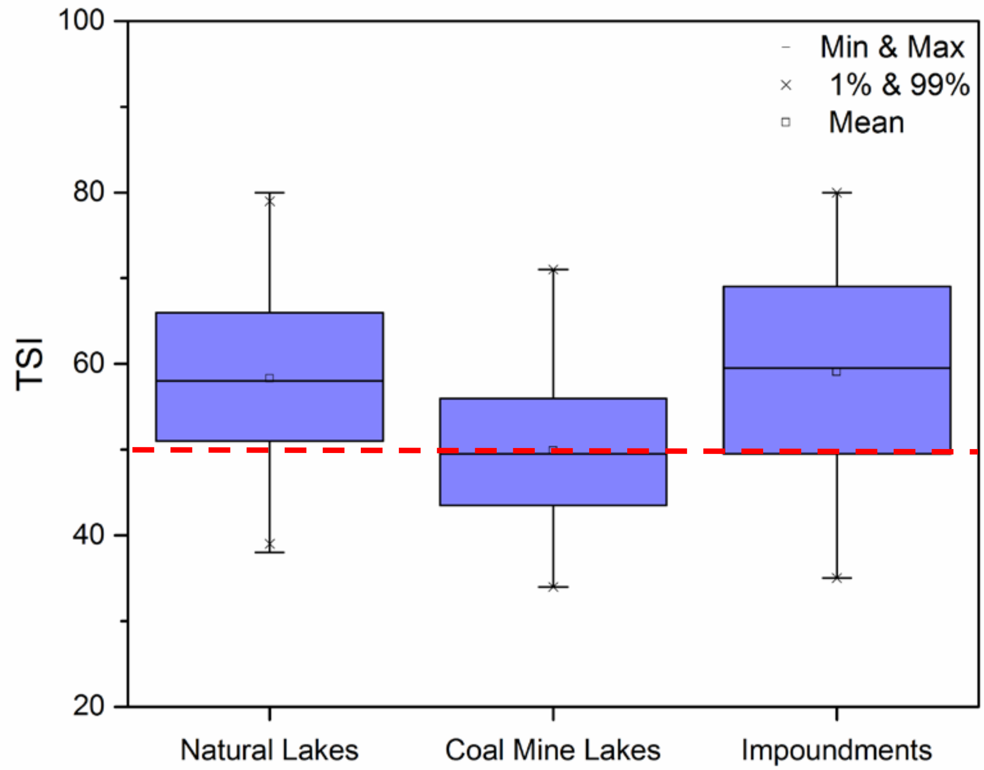

Figure 37. Box plot of mean Carlson's TSI for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square. The dashed red line is the lower limit of the eutrophic classification.

CONCLUSION

Summary conclusions from the 2012 – 2014 lake water quality assessment program include:

- Phosphorus concentrations in many Indiana lakes are excessive.
- Internal phosphorus loading from lake sediments is an important source of phosphorus to many lakes and this is very difficult to control.
- High non-algal turbidity decreases light penetration into many lakes and this, in turn, results in less algae produced than would be otherwise predicted based on the available phosphorus.
- Cyanobacteria (blue-green algae) are common in Indiana lakes and were the dominant algal group in 85% of lakes assessed.
- Most Indiana lakes are eutrophic and the number of eutrophic lakes is increasing; 68% of all lakes assessed during 2012 – 2014 vs. 46% of all lakes assessed during 2010 – 2011.
- Impoundments are most eutrophic, natural lakes are next, and coal mine lakes are least eutrophic.
- Carlson's Trophic State Index is a useful measure of overall trophic state in Indiana lakes.
- The randomized lake selection process used in 2012 – 2014 generates data representative of all Indiana lakes

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APPENDIX A:

INFORMATION ABOUT LAKES SAMPLED DURING 2012 AND 2014

Sources: Clark (1980); IDNR (1993); CLP (2014)

Key

Natural Lake = Glacial origin

Impoundment = Reservoir

SML = Coal mine Lake

Borrow Pit = excavation hole created by construction

Lake Name	County	Year	Area (acres)	Max Depth (ft)	Lake Type
Cedarville Reservoir	Allen	2012	244.9	16.6	impoundment
Cedarville Reservoir	Allen	2014	244.9	14.4	impoundment
Everett	Allen	2014	43.0	39.0	impoundment
Hurshtown impoundment	Allen	2014	264.9	24.0	impoundment
Grouse Ridge	Bartholomew	2014	20.0	28.2	impoundment
Boones Pond	Boone	2012	8.0	23.4	impoundment
Bear Creek	Brown	2014	7.0	19.5	impoundment
Crooked Creek	Brown	2014	13.0	22.4	impoundment
Ogle	Brown	2012	20.0	19.2	impoundment
Yellowwood	Brown	2012	133.0	26.2	impoundment
Freeman	Carroll	2014	1546.4	34.1	impoundment
Daredevil	Clay	2012	33.0	56.3	SML
Stump Jumper	Clay	2012	5.9	6.0	SML
Worm Pit	Clay	2014		56.6	SML
Story (Lower)	Dekalb	2013	77.0	29.1	natural lake
Story (Lower)	Dekalb	2014	77.0	29.2	natural lake
Beaver Creek Res.	Dubois	2014	172.9	24.4	impoundment
Beaver Creek Reservoir	Dubois	2013	172.9	24.3	impoundment
Ferdinand City New	Dubois	2012	10.0	11.8	impoundment
Holland 2	Dubois	2012	20.0	14.7	impoundment
Huntingburg City	Dubois	2013	180.9	19.5	impoundment
Patoka Reservoir	Dubois	2013	8876.5	39.0	impoundment
Goshen Dam Pond	Elkhart	2012	142.0	7.7	impoundment
Hunter	Elkhart	2014	99.0	26.3	natural lake
Manlove	Fayette	2012	15.0	8.3	impoundment
Manlove	Fayette	2014	15.0	9.8	impoundment
Brookville Reservoir	Franklin	2012	5257.9	100.8	impoundment
Bruce	Fulton	2012	244.9	27.2	natural lake
Fletcher	Fulton	2012	45.0	37.1	natural lake
Manitou	Fulton	2013	712.7	43.8	natural lake
Manitou	Fulton	2014	712.7	42.9	natural lake
Nyona	Fulton	2013	104.0	29.2	natural lake
South Mud	Fulton	2013	94.0	25.3	natural lake
Bobcat	Greene	2012	4.9	27.3	SML
Clear	Greene	2012	3.0	15.6	SML
Corky	Greene	2012	12.0	41.9	SML
Cottonwood	Greene	2013	1.7	16.0	SML
Frank	Greene	2014	8.0	53.6	SML
Hammond	Greene	2012	6.0	24.0	SML
Hemlock	Greene	2013	3.0	14.7	SML
Hemlock	Greene	2014	3.0	12.8	SML

Lake Name	County	Year	Area (acres)	Max Depth (ft)	Lake Type
Horseshoe	Greene	2013	27.0	22.4	SML
Jackson	Greene	2014	4.0	15.6	SML
Long Lake (Hillenbrand)	Greene	2014	8.0	23.4	SML
Mulberry	Greene	2012	3.0	15.7	SML
Skunk	Greene	2012	1.0	9.6	SML
Star	Greene	2013	5.0	22.4	SML
Sycamore	Greene	2012	7.0	23.4	SML
Todd	Greene	2012	8.0	35.2	SML
Todd	Greene	2014	8.0	31.2	SML
Trimble	Greene	2013	9.0	19.5	SML
Tulip	Greene	2013	2.5	21.4	SML
West	Greene	2012	96.8	78.7	SML
Knightstown (Big Blue #7)	Henry	2013	40.0	14.7	impoundment
Knightstown (Big Blue #7)	Henry	2014	40.0	15.6	impoundment
Summit	Henry	2013	814.7	44.8	impoundment
Clair	Huntington	2013	43.0	35.2	impoundment
Huntington Reservoir	Huntington	2013	899.6	19.2	impoundment
Knob	Jackson	2014	10.0	13.8	impoundment
White Oak #1	Knox	2013	24.0	16.6	impoundment
Allen	Kosciusko	2012	25.0	48.6	SML
Banning	Kosciusko	2013	12.0	14.6	natural lake
Banning	Kosciusko	2014	12.0	14.4	natural lake
Beaver Dam	Kosciusko	2013	146.0	48.0	natural lake
Big Barbee	Kosciusko	2014	303.9	35.2	natural lake
Big Chapman	Kosciusko	2012	413.8	35.2	natural lake
Center	Kosciusko	2012	119.9	40.0	natural lake
Center	Kosciusko	2014	119.9	38.4	natural lake
Goldeneye	Kosciusko	2012	20.0	12.7	impoundment
Hammond	Kosciusko	2013	5.0	32.0	natural lake
Hoffman	Kosciusko	2012	186.9	29.1	natural lake
Irish	Kosciusko	2012	142.9	33.2	natural lake
James	Kosciusko	2012	266.9	59.5	natural lake
Kiser	Kosciusko	2013	9.0	20.8	natural lake
Kuhn	Kosciusko	2012	117.9	25.3	natural lake
Little Chapman	Kosciusko	2014	119.9	28.3	natural lake
Little Pike	Kosciusko	2013	25.0	11.2	natural lake
McClures	Kosciusko	2013	32.0	27.2	natural lake
North Little	Kosciusko	2014	12.0	25.3	natural lake
Palestine	Kosciusko	2012	231.9	25.3	impoundment
Pike	Kosciusko	2013	202.9	28.8	natural lake
Price	Kosciusko	2012	12.0	41.6	natural lake

Lake Name	County	Year	Area (acres)	Max Depth (ft)	Lake Type
Ridinger	Kosciusko	2013	135.9	38.1	natural lake
Ridinger	Kosciusko	2014	135.9	38.4	natural lake
Rothenberger	Kosciusko	2014	6.0	25.3	natural lake
Sechrist	Kosciusko	2013	99.0	56.6	natural lake
Silver	Kosciusko	2012	102.0	30.2	natural lake
Syracuse	Kosciusko	2013	563.8	33.3	natural lake
Syracuse	Kosciusko	2014	563.8	31.2	natural lake
Tippecanoe	Kosciusko	2012	706.7	91.8	natural lake
Wabee	Kosciusko	2012	117.0	46.4	natural lake
Webster	Kosciusko	2014	773.7	42.9	natural lake
Yellow Creek	Kosciusko	2013	150.9	67.2	natural lake
Adams	LaGrange	2013	292.9	88.6	natural lake
Atwood	LaGrange	2012	169.9	31.2	natural lake
Atwood	Lagrange	2014	169.9	29.2	natural lake
Blackman	LaGrange	2013	64.0	52.8	natural lake
Brokesha	Lagrange	2014	36.0	18.5	natural lake
Dallas	Lagrange	2014	282.9	97.5	natural lake
Fish Lake (Scott)	LaGrange	2012	138.9	52.7	natural lake
Little Turkey	LaGrange	2013	134.9	30.2	natural lake
North Twin	LaGrange	2014	134.9	135.0	natural lake
Oliver	LaGrange	2012	370.8	69.7	natural lake
Ontario Mill Pond	LaGrange	2013	38.0	7.8	impoundment
Ontario Mill Pond	LaGrange	2014	38.0	5.8	impoundment
Pretty	LaGrange	2012	183.9	80.0	natural lake
Shipshewana	LaGrange	2012	201.9	14.6	natural lake
Wall	LaGrange	2014	140.9	31.2	natural lake
Westler	Lagrange	2014	88.0	31.2	natural lake
Cedar	Lake	2012	780.7	11.7	natural lake
Hog	LaPorte	2013	59.0	48.0	natural lake
Pine	LaPorte	2014	563.8	51.7	natural lake
Pine (North & South)	LaPorte	2013	563.8	50.9	natural lake
Saugany	LaPorte	2013	74.0	60.5	natural lake
Stone	LaPorte	2013	125.0	36.2	natural lake
Stone	LaPorte	2014	125.0	35.2	natural lake
Geist Reservoir	Marion	2013	1799.3	22.6	impoundment
Geist Reservoir	Marion	2014	1799.3	22.6	impoundment
Flat	Marshall	2012	23.0	20.5	natural lake
Flat	Marshall	2014	23.0	19.5	natural lake
Gilbert	Marshall	2012	35.0	27.3	natural lake
Kreighbaum	Marshall	2014	20.0	32.0	natural lake
Lawrence	Marshall	2013	69.0	61.4	natural lake

Lake Name	County	Year	Area (acres)	Max Depth (ft)	Lake Type
Bryants Creek	Monroe	2012	9.0	12.8	impoundment
Lemon	Monroe	2012	1649.4	21.4	impoundment
J.C. Murphy	Newton	2012	1199.5	6.4	impoundment
Bartley	Noble	2014	34.0	29.2	natural lake
Diamond	Noble	2013	105.0	78.0	natural lake
Dock	Noble	2014	16.0	22.4	natural lake
Eagle	Noble	2012	81.0	43.8	natural lake
Engle	Noble	2013	48.0	25.3	natural lake
High	Noble	2012	123.0	24.4	natural lake
Knapp	Noble	2012	88.0	54.4	natural lake
Little Bause	Noble	2013	7.0	16.6	natural lake
Little Knapp	Noble	2012	5.0	12.7	natural lake
Little Knapp	Noble	2014	5.0	14.7	natural lake
Long	Noble	2013	40.0	30.4	natural lake
Miller (Chain-O)	Noble	2014	11.0	26.2	natural lake
Moss	Noble	2014	9.0	16.6	natural lake
Mud (Chain of Lakes)	Noble	2013	8.0	24.4	natural lake
Muncie	Noble	2013	47.0	20.5	natural lake
Rivir (Chain of Lakes)	Noble	2013	24.0	30.2	natural lake
Sacrider	Noble	2012	33.0	54.6	natural lake
Skinner	Noble	2013	125.0	30.4	natural lake
Smalley	Noble	2013	69.0	40.0	natural lake
Smalley	Noble	2014	69.0	43.9	natural lake
Steinbarger	Noble	2012	73.0	35.1	natural lake
Sylvan	Noble	2012	629.8	20.5	impoundment
Sylvan	Noble	2014	629.8	28.3	impoundment
Tamarack (Rome City)	Noble	2012	50.0	33.2	natural lake
Tamarack (Rome City)	Noble	2014	50.0	34.1	natural lake
Spring Valley (Tucker)	Orange	2014	140.9	31.2	impoundment
Springs Valley (Tucker)	Orange	2013	140.9	30.4	impoundment
Indian	Perry	2013	148.9	24.3	impoundment
Saddle	Perry	2013	41.0	20.5	impoundment
Tipsaw	Perry	2012	1417.8	23.4	impoundment
Prides Creek	Pike	2013	90.0	26.2	impoundment
Prides Creek	Pike	2014	90.0	27.3	impoundment
Canada	Porter	2012	10.0	19.5	natural lake
Flint	Porter	2013	89.0	44.8	natural lake
Loomis	Porter	2013	62.0	53.8	natural lake
Bischoff Reservoir	Ripley	2013	199.9	21.4	impoundment
Molenkramer	Ripley	2014	93.0	7.7	impoundment
Molenkramer Reservoir	Ripley	2012	93.0	34.7	impoundment

Lake Name	County	Year	Area (acres)	Max Depth (ft)	Lake Type
Versailles	Ripley	2013	229.9	14.7	impoundment
Woods (Big Blue #3)	Rush	2013	44.0	12.8	impoundment
Chrisney	Spencer	2013	26.0	12.8	impoundment
Chrisney	Spencer	2014	26.0	12.6	impoundment
Dale Reservoir	Spencer	2014	33.0	26.3	impoundment
Lake Lincoln	Spencer	2014	58.0	20.5	impoundment
Bass (N. Chain)	St Joseph	2013	88.0	29.1	natural lake
Worster (Potato Creek)	St Joseph	2012	326.9	17.6	impoundment
Koontz	Starke	2013	345.9	29.1	natural lake
Big Bower	Steuben	2013	25.0	21.4	natural lake
Booth	Steuben	2013	10.0	40.0	natural lake
Buck	Steuben	2013	20.0	34.4	natural lake
Clear	Steuben	2012	799.7	102.7	natural lake
Fox	Steuben	2013	140.0	56.6	natural lake
Fox	Steuben	2014	140.0	56.6	natural lake
George	Steuben	2012	508.8	69.2	natural lake
George	Steuben	2014	508.8	72.3	natural lake
Golden	Steuben	2014	119.0	27.3	natural lake
Green	Steuben	2012	24.0	31.7	natural lake
James	Steuben	2012	1033.6	81.9	natural lake
Lime (Gage)	Steuben	2012	30.0	23.4	natural lake
Long (Pleasant)	Steuben	2012	92.0	27.3	natural lake
Loon	Steuben	2013	137.9	15.6	natural lake
McClish	Steuben	2012	35.0	53.6	natural lake
Pigeon	Steuben	2013	61.0	34.1	natural lake
Pigeon	Steuben	2014	61.0	35.1	natural lake
Round B (Ray)	Steuben	2012	30.0	22.4	natural lake
Snow	Steuben	2013	309.9	80.0	natural lake
Snow	Steuben	2014	309.9	74.2	natural lake
Bass	Sullivan	2014	210.9	46.8	SML
Big Fry	Sullivan	2012	4.5	9.8	SML
Catfish	Sullivan	2013	3.0	13.7	SML
Deep	Sullivan	2013	29.0	60.5	SML
Dogwood	Sullivan	2013	4.0	34.1	SML
Duck	Sullivan	2012	59.0	34.1	SML
Eads	Sullivan	2012	8.0	10.7	SML
Fry	Sullivan	2013	4.0	15.7	SML
Fry (Upper)	Sullivan	2014	4.0	10.7	SML
Goose (Dugger)	Sullivan	2014	72.0	52.7	SML
Hackberry	Sullivan	2014	5.0	30.2	SML
Hale	Sullivan	2013	15.0	26.3	SML

Lake Name	County	Year	Area (acres)	Max Depth (ft)	Lake Type
Kickapoo	Sullivan	2014	30.0	38.4	impoundment
Long (Dugger)	Sullivan	2013	38.0	67.2	SML
Pump	Sullivan	2013	22.0	48.8	SML
Pump	Sullivan	2014	22.0	49.7	SML
Redbud	Sullivan	2014	4.0	31.2	SML
Reservoir 26	Sullivan	2012	47.0	9.8	SML
Reservoir 26	Sullivan	2014	47.0	10.7	SML
Reservoir 29	Sullivan	2014	140.0	25.3	SML
South	Sullivan	2014	12.0	17.6	SML
Spencer	Sullivan	2012	6.0	18.6	SML
Sullivan	Sullivan	2012	506.8	17.6	impoundment
T Lake	Sullivan	2014	5.0	24.4	SML
Tree	Sullivan	2014	6.0	19.5	SML
Turtle	Sullivan	2012	8.0	21.4	SML
Turtle	Sullivan	2014	8.0	21.4	SML
Walnut	Sullivan	2014	3.5	19.0	SML
Willow	Sullivan	2013	4.0	28.8	SML
Green Valley	Vigo	2012	50.0	13.8	impoundment
Green Valley	Vigo	2014	50.0	17.6	impoundment
Lukens	Wabash	2012	46.0	39.0	natural lake
Lukens	Wabash	2014	46.0	40.0	natural lake
Scales	Warrick	2014	66.0	16.0	SML
Elk Creek #9	Washington	2012	48.0	21.5	impoundment
John Hay	Washington	2012	209.9	24.4	impoundment
Salinda	Washington	2013	125.9	19.2	natural lake
Salinda	Washington	2014	125.9	22.4	natural lake
Shaffer	White	2013	1290.5	19.5	impoundment
Big Cedar	Whitley	2012	144.0	72.2	natural lake
Blue	Whitley	2013	238.9	46.8	natural lake
Little Cedar	Whitley	2012	10.0	51.2	natural lake
Loon	Whitley	2012	15.0	88.3	natural lake
Old	Whitley	2013	32.0	39.0	natural lake
Robinson	Whitley	2012	59.0	47.7	natural lake
Robinson	Whitley	2013	59.0	48.8	natural lake
Robinson	Whitley	2014	59.0	49.2	natural lake
Round	Whitley	2013	130.9	58.6	natural lake
Troy Cedar	Whitley	2014	15.0	81.0	natural lake