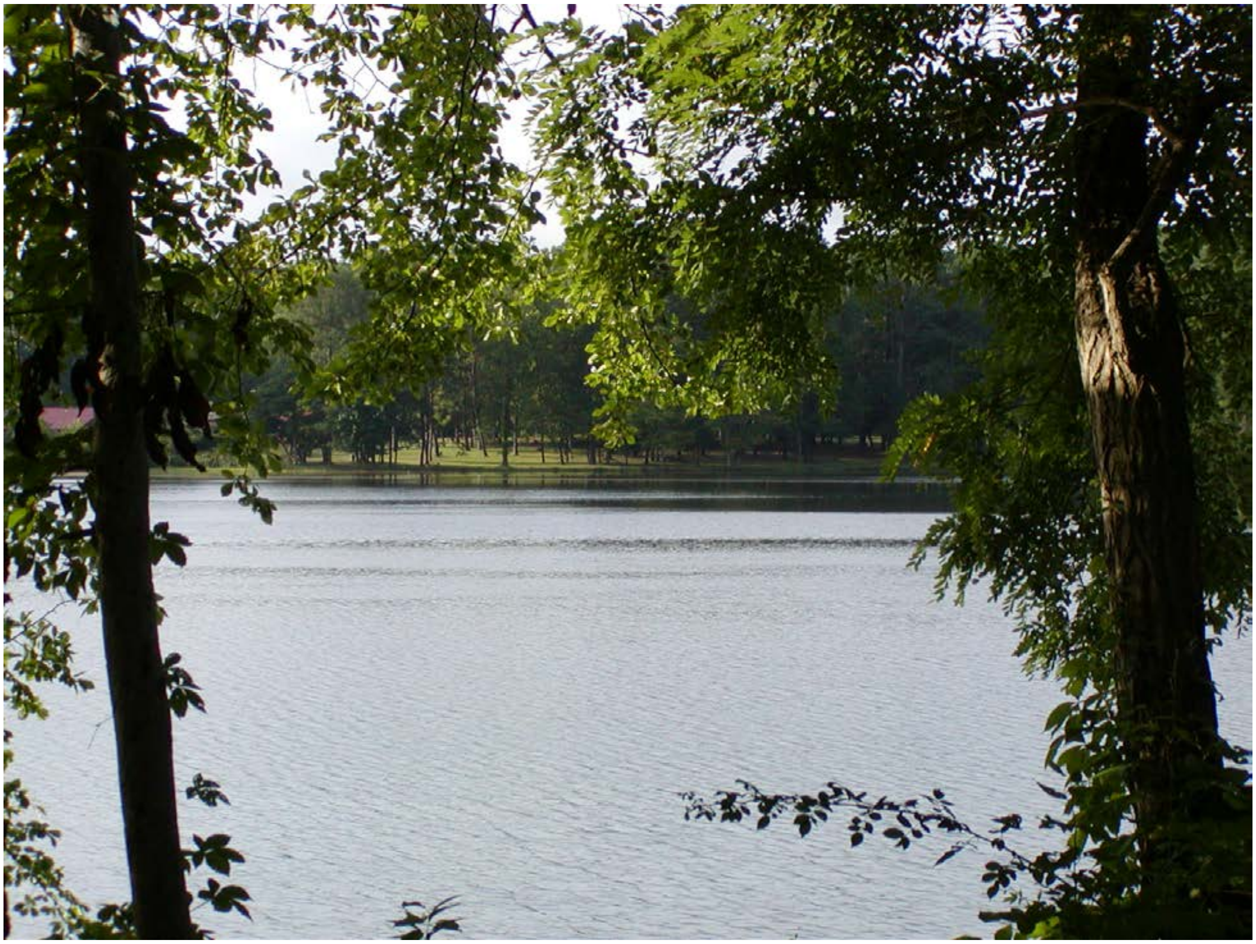
# Indiana Lake Water Quality Assessment Report For 2009 - 2011



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**Acknowledgments**

The report represents three years of traversing the State of Indiana, reading maps, searching for lake access, extracting stuck trailers, seemingly endless washing of laboratory glassware, and most importantly, having the opportunity to visit and sample the beautiful and varied lakes of Indiana.  This work required the dedicated efforts of many people.  Therefore, it is with gratitude that we recognize the superb efforts of the following SPEA graduate students who conducted the lake sampling and laboratory analyses of the water samples: Melanie Arnold, Laura Barnhart, Tammy Behrman, Julia Bond, David Christopher, Abigail Grieve, Holly Halifax, Ryan Largura, Chase McCormick, Carissa Moncavage, Thomas Parr, Sarah Powers, Moira Rojas and Dana Wilkinson.

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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 2009-2011.

## 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 one meter below 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.

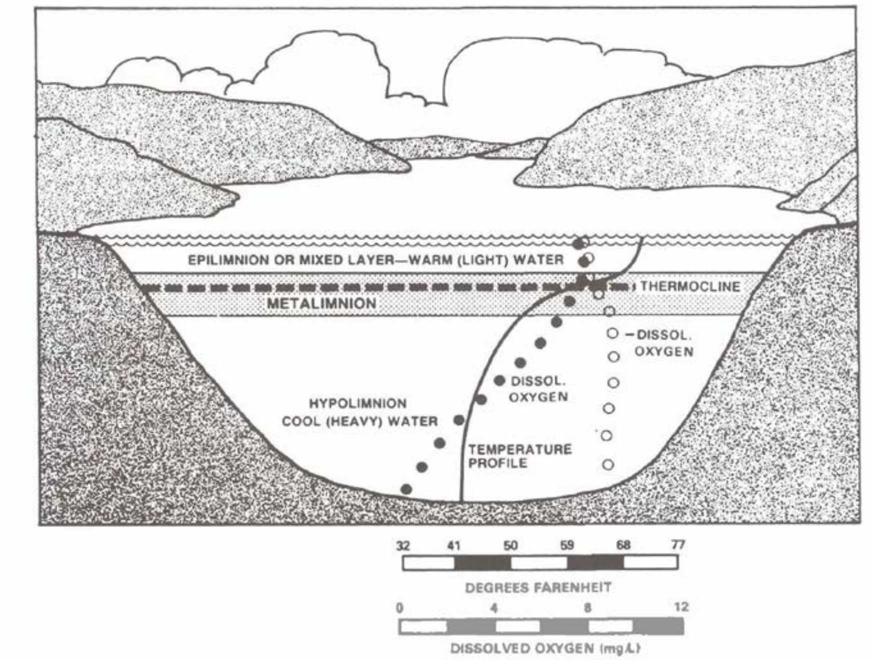



**Figure 1. Summer thermal stratification prevents lake mixing because the cool waters of the hypolimnion are much denser than the warm waters of the epilimnion. Epilimnetic waters circulate with the wind but do not mix until the lake cools again in the fall. Adapted from: Olem and Flock, 1990.**

*Changes in 2010*

Our annual goal is to assess approximately 80 lakes each summer. For most of the first twenty-two years of the Indiana Clean Lakes Program, including 2009, lake sampling proceeded geographically and systematically, county-by-county, through the state to minimize travel costs. With this sampling scheme, we could sample all the candidate lakes in Indiana in about five years. Unfortunately, in any given two-year period in which data were reported to the U.S. Environmental Protection Agency (USEPA) in the biennial 305(b) Water Quality Report, called the Indiana Integrated Water Monitoring and Assessment Report, results were regionally restricted and could not be applied to Indiana statewide.

For this reason, beginning with the 2010 sampling season, we randomized 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. The resulting list contained a total of 401 lakes and impoundments. We sampled lakes from this list over our 2-year sampling cycle (2010 – 2011) beginning with the first lake at the top and working downward until we had sampled 160 lakes over the two-year period. Using this sampling scheme, our 2010 – 2011 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 2012 - 2013 sampling period.

The 401 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 new, 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.

Other changes implemented in 2010 to better coincide with the sampling protocols implemented by the USEPA for the NLA in 2007 were: 1) use a 2-meter integrated sampling tube to collect the epilimnetic water sample rather than a discrete sample from a one-meter depth using a Kemmerer Sampler, 2) use the 2-meter integrated sampler to collect a whole-water sample for phytoplankton analysis as opposed to using a tow net from the 1% light level to the surface, and 3) quantify the phytoplankton in units of cells per mL versus Natural Units per liter.

Using an integrated sampler collects a composite water sample representative of the 0 to 2-meter water column. This is thought by limnologists to be more representative of a lake's epilimnion than collecting a discrete sample at the one-meter depth.

The changes in the plankton collection and enumeration protocols were necessitated because today, very few limnologists express plankton data as Natural Units per liter (NU/L). NU/L is an outdated reporting unit that fails to differentiate between single-cell phytoplankton and colonial types that may have 100 or more cells per natural unit. In both of these cases, the count would be 1 NU/L but the multi-celled colonial form would clearly have a different effect on the ecology of the lake than the single cell would. In addition, scientific literature related to detecting and identifying cyanobacteria toxins in lakes reports cyanobacteria as cells per milliliter (cells/mL). The World Health Organization and other agencies have published criteria designed to protect public health that use cells/mL as the measuring unit. For these reasons, we updated our plankton protocols.

## 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.

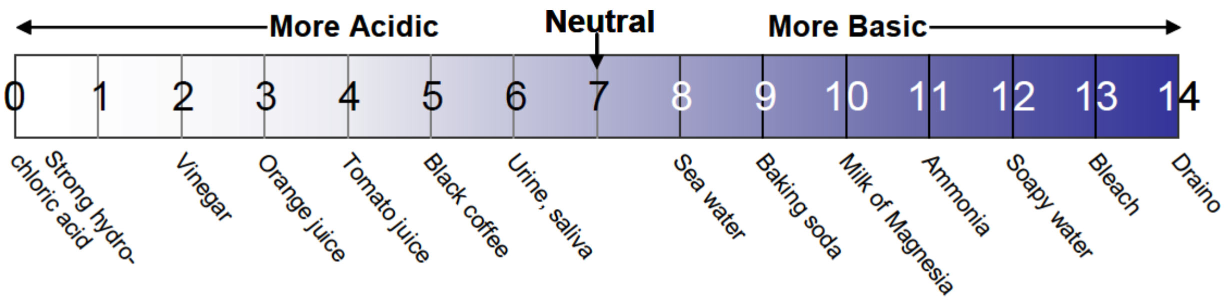



Figure 2. The pH scale compared with common solutions. Source: Addy et al., 2004.

*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 <u>rate</u> 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.

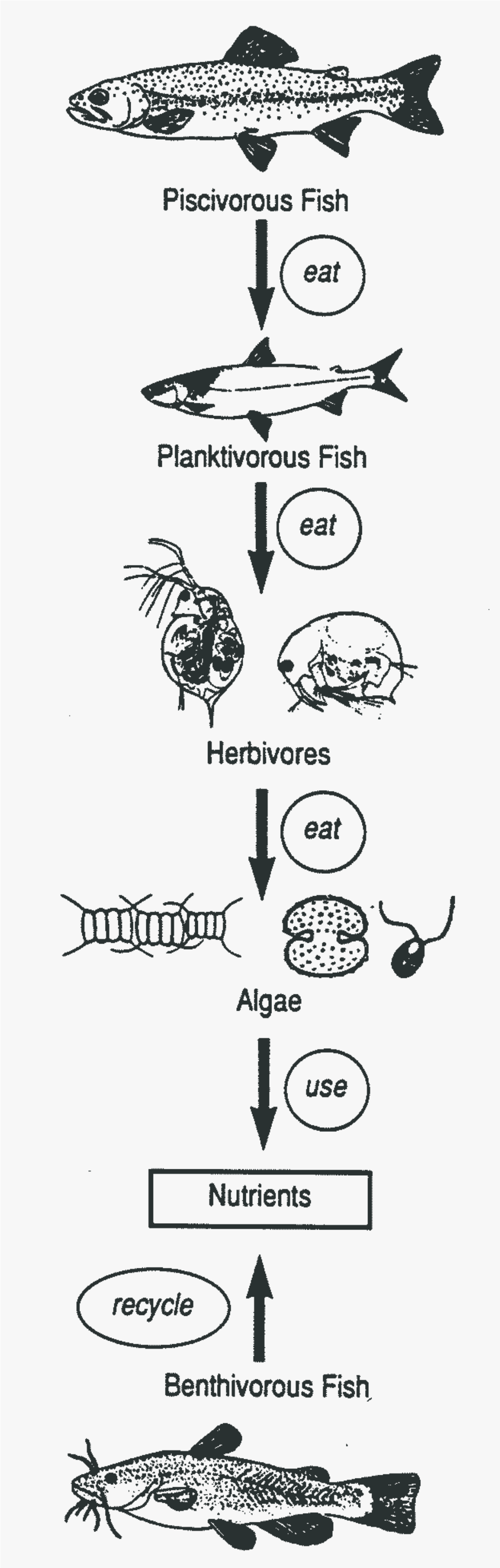



**Figure 3. A simplified aquatic food chain.**

## 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

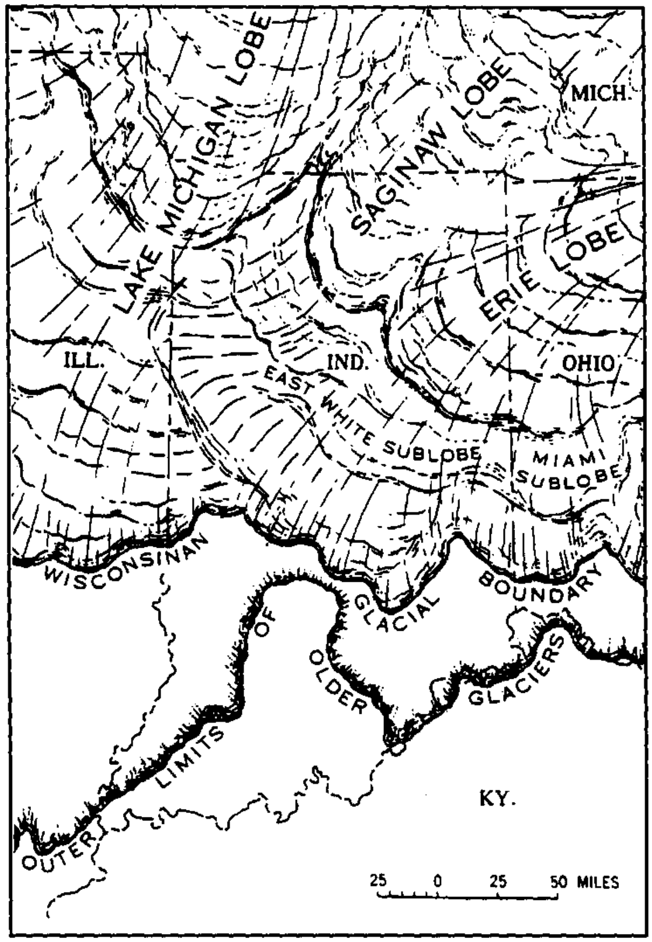



**Figure 4. The Lake Michigan, Saginaw, and Erie lobes of the most recent glacial episode affected northern Indiana. Glacial lakes are thus limited to this part of the state.**

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

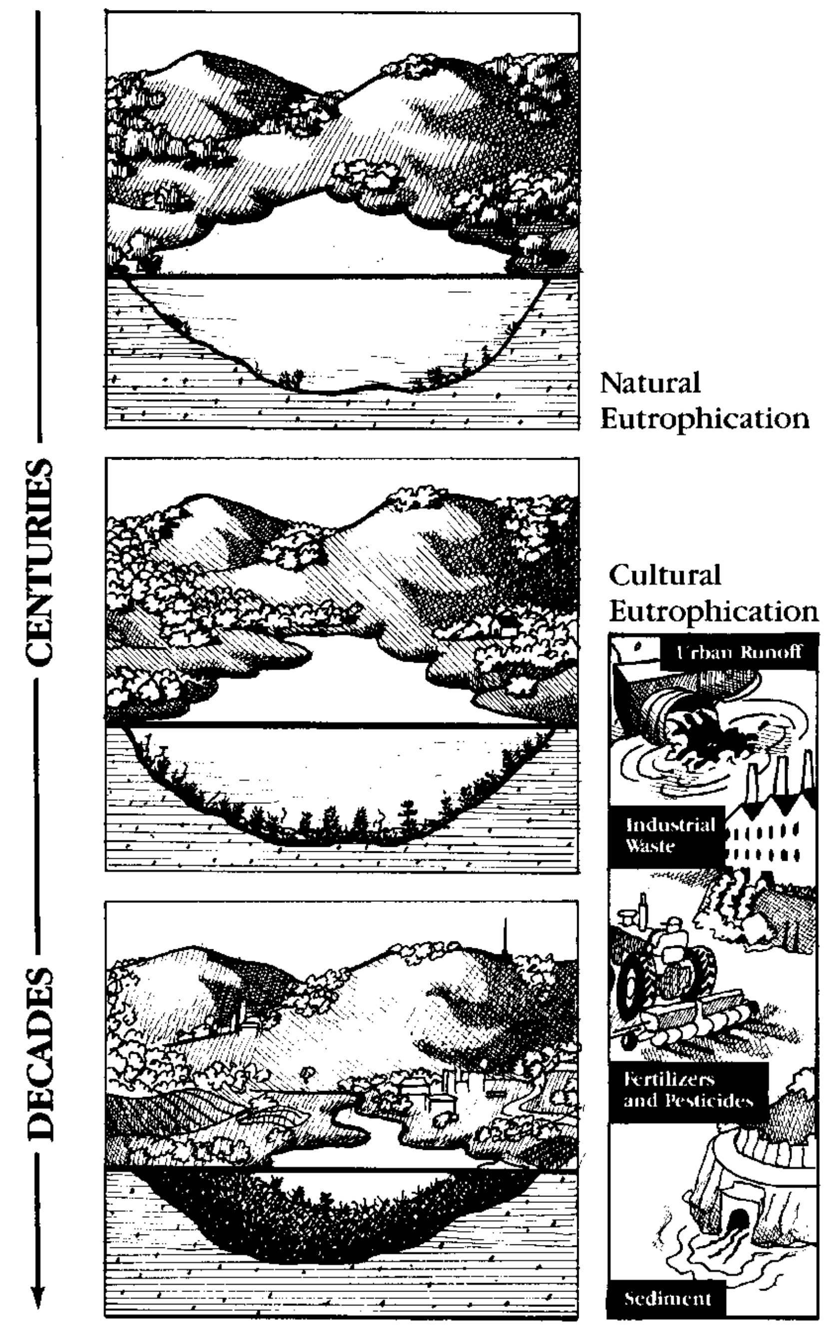
Due to the complex nature and variability of water quality data, a trophic state index (TSI) is used to aid in the evaluation of water quality data. A TSI assigns a numerical value to different levels of standard water quality measurements. The sum of these points for all parameters in the TSI represents 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 Indiana Trophic State Index*

The original purpose of the Indiana State Tropic Index (ITSI) was to identify lakes with problems and to determine the reasons for complaints from lake users. The ITSI was not used to rank Indiana lakes until the mid-1970’s.

The ITSI consists of 10 metrics (Table 1), all of which must be evaluated in order to achieve an accurate score. The metrics include biological, chemical, and physical parameters. Water samples for nitrogen and phosphorus are collected and analyzed from both the epilimnion and the hypolimnion and the mean of the values is assigned a certain number of eutrophy points based on the mean concentration.

**LAKE EUTROPHICATION**




The natural process by which lakes form, evolve and disappear takes thousands of years. Human activites, however, can change these lakes — for better or worse — in less than a single generation.

**Figure 5. Lake eutrophication. Adapted from Freshwater Foundation (1985).**

**Table 1. The Indiana Trophic State Index**

| Parameter and Range | | | Eutrophy Points |
|---|---|---|---|
| I. | Total Phosphorus (µg/L) | | |
| | A. | At least 30 | 1 |
| | B. | 40 to 50 | 2 |
| | C. | 60 to 190 | 3 |
| | D. | 200 to 990 | 4 |
| | E. | 1000 or more | 5 |
| II. | Soluble Phosphorus (µg/L) | | |
| | A. | At least 30 | 1 |
| | B. | 40 to 50 | 2 |
| | C. | 60 to 190 | 3 |
| | D. | 200 to 990 | 4 |
| | E. | 1000 or more | 5 |
| III. | Organic Nitrogen (mg/L) | | |
| | A. | At least 0.5 | 1 |
| | B. | 0.6 to 0.8 | 2 |
| | C. | 0.9 to 1.9 | 3 |
| | D. | 2.0 or more | 4 |
| IV. | Nitrate (mg/L) | | |
| | A. | At least 0.3 | 1 |
| | B. | 0.4 to 0.8 | 2 |
| | C. | 0.9 to 1.9 | 3 |
| | D. | 2.0 or more | 4 |
| V. | Ammonia (mg/L) | | |
| | A. | At least 0.3 | 1 |
| | B. | 0.4 to 0.5 | 2 |
| | C. | 0.6 to 0.9 | 3 |
| | D. | 1.0 or more | 4 |
| VI. | Dissolved Oxygen: Percent Saturation at 5 feet from surface | | |
| | A. | 114% or less | 0 |
| | B. | 115% 50 119% | 1 |
| | C. | 120% to 129% | 2 |
| | D. | 130% to 149% | 3 |
| | E. | 150% or more | 4 |

**Indiana Trophic State Index (continued)**

| | | |
|---|---|---|
| VII. | Dissolved Oxygen:<br>Percent of measured water column with at<br>least 0.1 ppm dissolved oxygen | |
| | A. 28% or less | 4 |
| | B. 29% to 49% | 3 |
| | C. 50% to 65% | 2 |
| | D. 66% to 75% | 1 |
| | E. 76% 100% | 0 |
| VIII. | Light Penetration (Secchi Disk) | |
| | A. Five feet or under | 6 |
| IX. | Light Transmission (Photocell)<br>Percent of light transmission at a depth of 3 feet | |
| | A. 0 to 30% | 4 |
| | B. 31% to 50% | 3 |
| | C. 51% to 70% | 2 |
| | D. 71% and up | 0 |
| X. | Total Plankton per liter of water sampled from a single vertical tow between the 1% light level and the surface: | |
| | A. less than 3,000 natural units/L | 0 |
| | B. 3,000 - 6,000 natural units/L | 1 |
| | C. 6,001 - 16,000 natural units/L | 2 |
| | D. 16,001 - 26,000 natural units/L | 3 |
| | E. 26,001 - 36,000 natural units/L | 4 |
| | F. 36,001 - 60,000 natural units/L | 5 |
| | G. 60,001 - 95,000 natural units/L | 10 |
| | H. 95,001 - 150,000 natural units/L | 15 |
| | I. 150,001 - 5000,000 natural units/L | 20 |
| | J. greater than 500,000 natural units/L | 25 |
| | K. Blue-Green Dominance: additional points | 10 |

In the Indiana Trophic State Index, the total eutrophy points range from 0 to 75. **Oligotrophic** conditions are represented with a score of 0 to 15. **Mesotrophic** conditions score 16 to 30 points. **Eutrophic** conditions score 31 to 45. **Hypereutrophic** lakes have ITSI scores greater than 46.

The higher the number of eutrophy points assigned to a parameter, the more likely that parameter is to support increased productivity in the lake. In general, eutrophy points range from 1 to 4. However, the scale is weighted based on the amount of plankton in the sample and the dominance of blue-green algae in the sample. Extra weight is given to the presence of algae due to public perception of poor water quality.  Eutrophy points for all metrics are then summed to produce the final ITSI score for the lake.

*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**

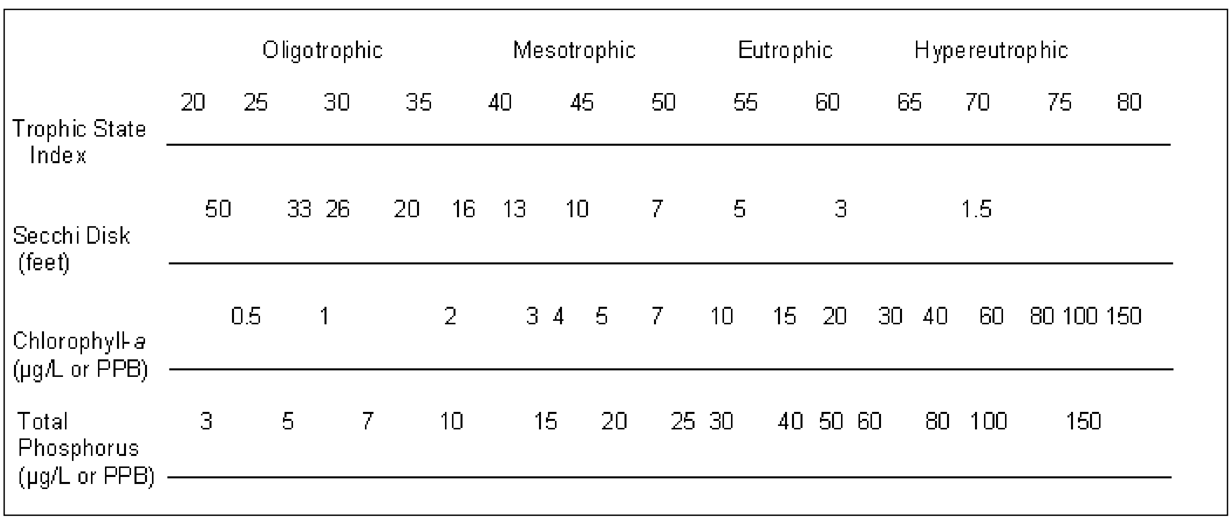



**Figure 6. The Carlson Trophic State Index.**

**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.

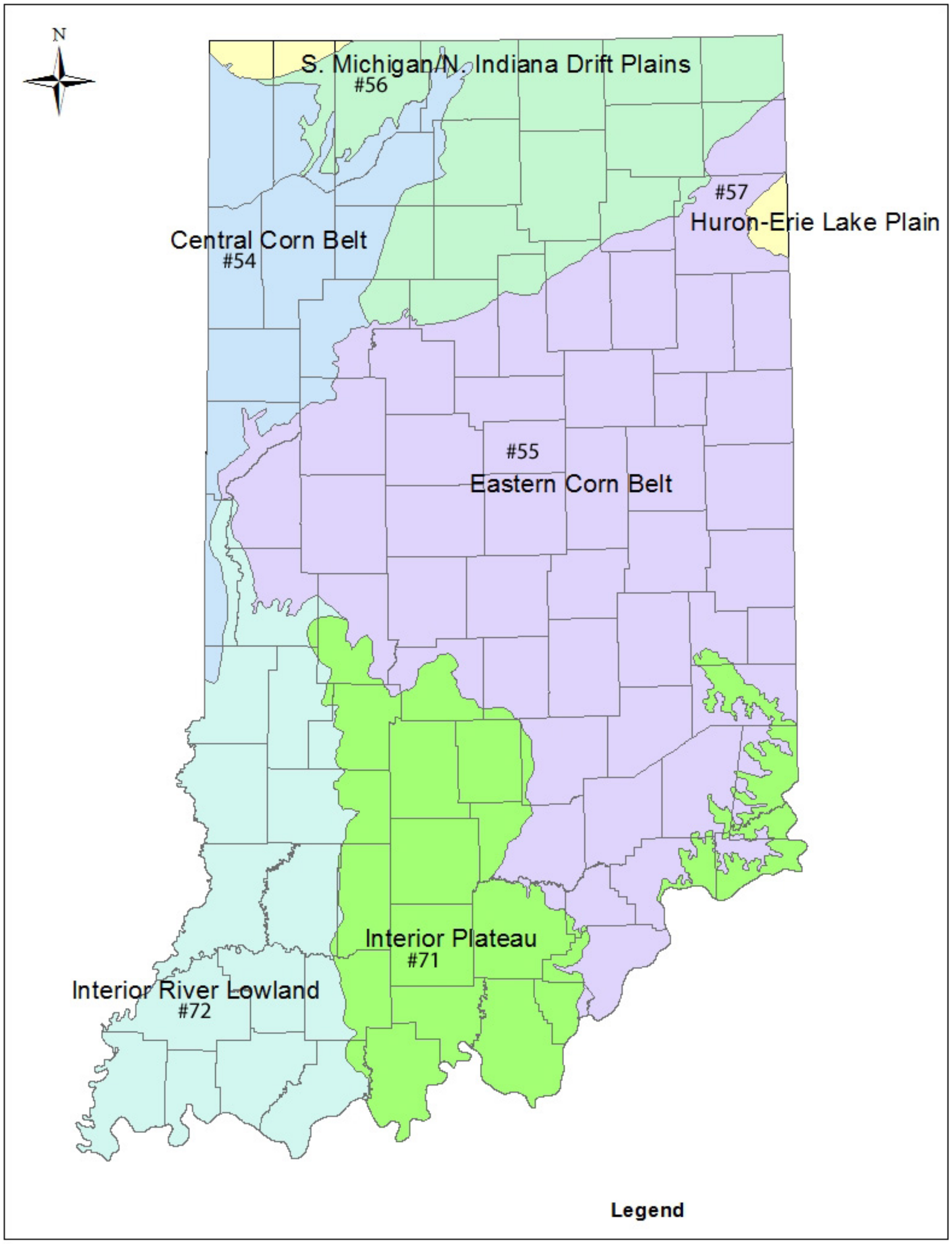



**Figure 7. Ecoregions of Indiana.**

**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. Beginning in 2010, 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 YSI Model 85 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.

Prior to 2010, plankton samples were collected with a tow net that was lowered to the 1% light level as determined by the light meter. The water is filtered through a fine-mesh net (63-microns) that concentrates the plankton. The plankton are washed into an opaque bottle with ultra-pure water and Lugol's solution is added to preserve the sample at the rate of 0.4 mL Lugol's per 100 mL of sample. Beginning in 2010, phytoplankton were sampled using a 2-meter integrated sampler. Zooplankton were collected with a tow net as previously, utilizing a 80-micron mesh on the net and bucket.

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. Prior to 2010, phytoplankton samples were also counted using a Sedgwick-Rafter Cell. Fifteen random fields were selected and the genera were identified at 100x magnification. Algae were reported as *natural units*, which records one colonial filament of multiple cells as one natural unit and one cell of a singular alga also as one natural unit. The number of organism per liter is then calculated. Beginning in 2010, 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

Analysis of the results for this contract period (2009-2010) was made difficult by changes in lake selection, sampling and analysis protocols. For these reasons, we will analyze the 2009 results separately because historic methods were used for lakes selected and sampled in 2009. Then we will analyze the effects of implementing the new protocols in 2010. Finally, we will analyze the 2010 and 2011 data set. Information about the lakes sampled in 2009 and in 2010-2011 is included in Appendix A. Raw data for all lakes assessed between 2009 and 2011 are available on the Indiana Clean Lakes Program website at: http://www.indiana.edu/~clp/.

### 2009 Lake Data

In 2009, we assessed 68 lakes (Figure 8). The 2009 lakes sampled were those that hadn't been sampled in the previous five years or longer. They were located primarily in NE Indiana and the southern part of the state. Fifty-four lakes were sampled in July and early August under our previous contract and, after a gap of several weeks, we resumed sampling fourteen more lakes in late August under our current contract. This report includes results for all 68 lakes sampled in 2009.

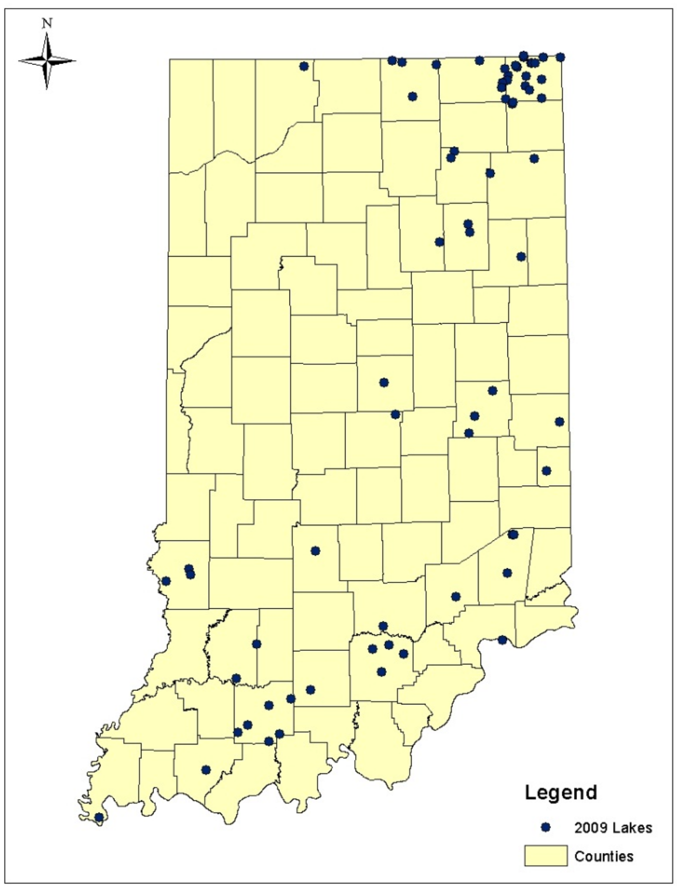



**Figure 8. Location of the lakes sampled in 2009.**

Summary results for 2009 for selected water quality variables are shown in Table 2. The lake at the median of the distribution for each variable had a relatively high mean total phosphorus concentration (0.066 mg/L), a Secchi disk transparency of 1.4 meters, a chlorophyll-a concentration of 8.5 µg/L, had an algae community dominated by blue-green algae, and had a ITSI classification on the border between mesotrophic and eutrophic. One-half the lakes assessed in 2009 had values below these medians and one-half had values above these medians. A phosphorus concentration of 0.030 mg/L or greater can lead to eutrophic conditions, so more than one-half of the lakes sampled had what we would consider to be excessive phosphorus concentrations. The excessive phosphorus likely lead to the dominance by blue-green algae. While the median Secchi disk transparency is in the eutrophic range, the chlorophyll-a concentration is within the mesotrophic range. In past years, our data have suggested that higher non-algal turbidity in many Indiana lakes limits light enough to reduce chlorophyll-a concentrations below their maxima and that seems to be the case with the 2009 lakes.

**Table 2. Mean Values of Select Variables for All 2009 Lakes Sampled.**

| Statistic | Total Phos. (mg/L) | Secchi Disk (m) | Chlorophyll-a (µg/L) | Blue-Green Dominance (%) | Indiana TSI |
|---|---|---|---|---|---|
| Median | 0.066 | 1.4 | 8.5 | 67.3 | 30 |
| Minimum | 0.010 | 0.2 | 1.33 | 0.1 | 5 |
| Maximum | 0.578 | 6.3 | 116.0 | 99.9 | 64 |

About one-half of the lakes assessed in 2009 were classified as eutrophic or hypereutrophic by the Indiana TSI while about one-half were classified as oligotrophic or mesotrophic (Figure 9). Thirty of the lakes were classified as mesotrophic and only five were in the oligotrophic classification.

The lakes assessed in 2009 were previously assessed between 1996 and 2003. When we compared the Indiana TSI scores for the 2009 lakes with their most recent previous ITSI score, we found that six lakes had lower ITSI scores in 2009, which means they improved in trophic state (Figure 10). Thirty-nine lakes had ITSI score changes of +/- 9 points, which we consider as no significant change. Twenty-three lakes had higher ITSI scores in 2009, which means their trophic state worsened between the assessments. Overall, the trophic state worsened for more lakes than those that improved during this period. Increases in mean trophic state occurred in lake populations sampled from all of Indiana’s ecoregions in 2009 (Figure 11). Lakes within Ecoregion 54 (Central Corn Belt) had the largest increase in mean Indiana TSI. Remember that these analyses apply only to the lakes sampled in 2009 and are not necessarily representative of all lakes in Indiana.

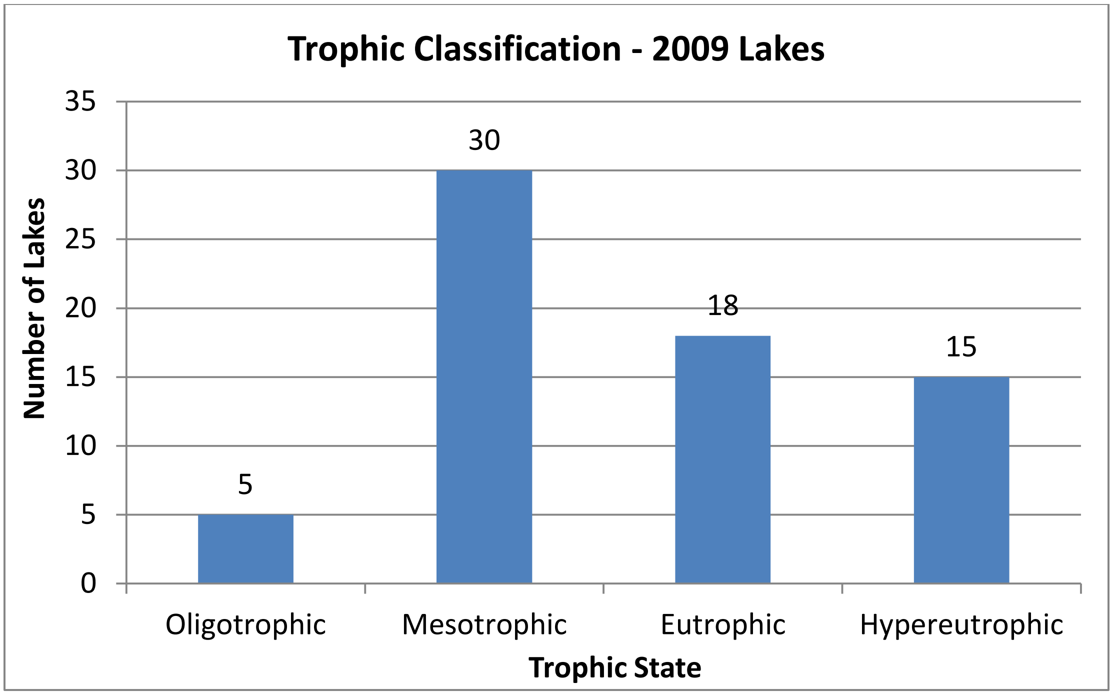



**Figure 9. Trophic classification of lakes assessed during 2009.**

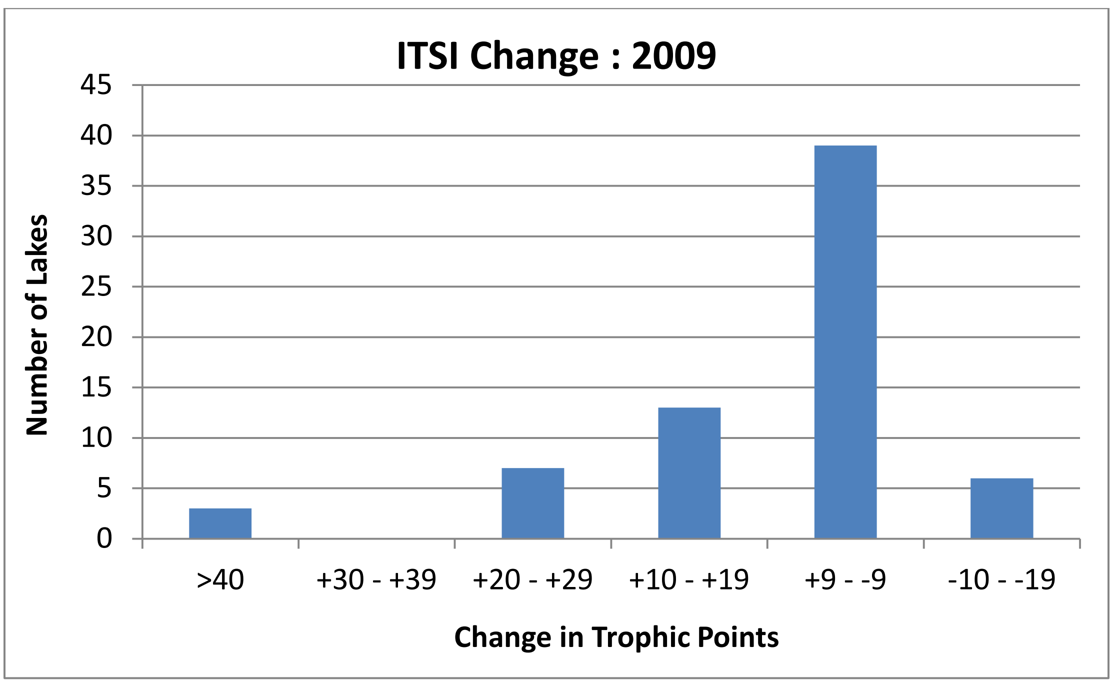



**Figure 10. Frequency of Indiana TSI trophic point change for lakes sampled in 2009. ITSI score from most recent sampling was compared with 2009 results.**

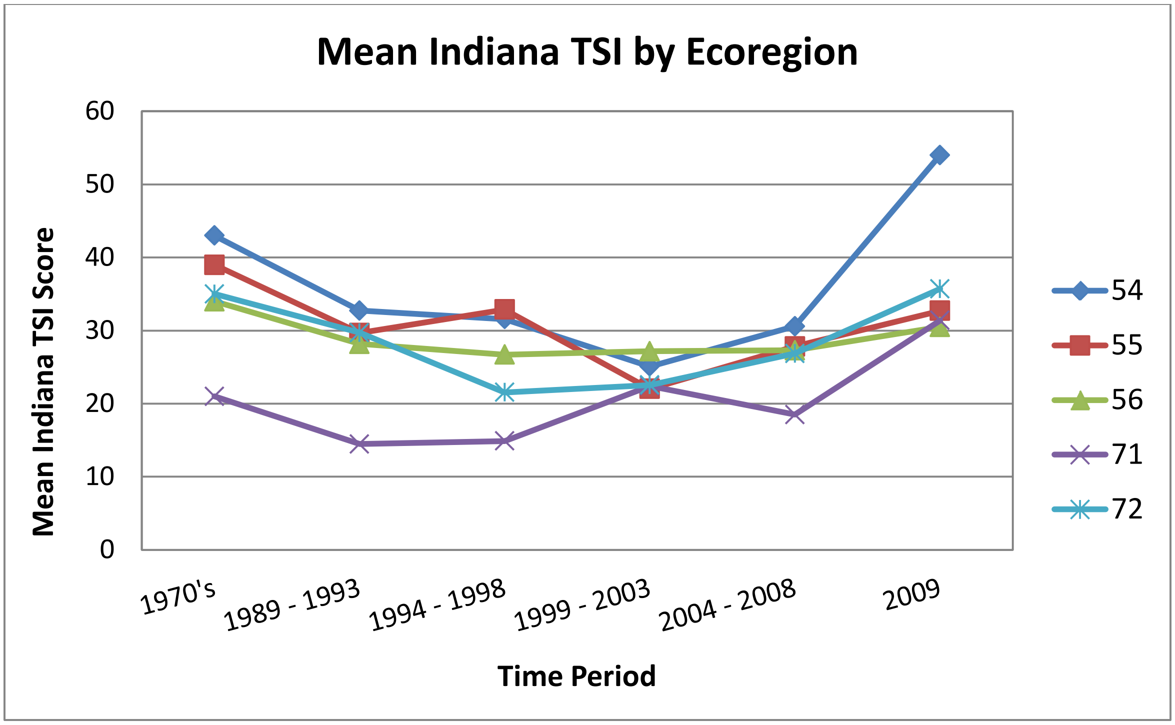



**Figure 11. Long-term trophic state by Ecoregion. Note: the 2009 population of lakes is just 1/5 that of the other time periods.**

**Comparison of Old vs. New Protocols**

To evaluate any potential changes caused by switching to an integrated 2-meter sample to characterize a lake's epilimnion versus collecting a discrete sample from the 1-meter depth, we collected samples with both methods for the first two weeks of sampling in 2010. Seventeen lakes were sampled during this period. Although this was a relatively small sample size, we had to balance the added costs of this extra sampling against the statistical robustness of the results.

*Water Chemistry*

Results for the water chemistry data comparing the two sampling methods are shown in Table 3 and Figures 12 – 17. We used paired statistical tests to compare the means of the two sample populations: 1) water samples collected with the 2-meter integrated sampler, and 2) water samples collected from the 1-meter depth. The sample sizes were bit small to determine if the values were normally distributed so we used both the t-test, which is designed for normally distributed data, and the Wilcoxon signed-ranks test, which is designed for data that are not normally distributed (non-parametric). The sign test, a less robust nonparametric test, was also used. All results were not significant at the 95% confidence level ($\alpha = 0.05$). This means that there were no statistically significant differences between the two sampling methods.

**Table 3. Results of statistical tests comparing the two sampling methods for water chemistry samples. SRP was not included because all results were below our detection limit.**

| | TP | pH | alk | $NO_3$ | $NH_4$ | TKN |
|---|---|---|---|---|---|---|
| n | 17 | 17 | 17 | 8 | 13 | 16 |
| Wilcoxon Signed | -22.5 **0.12** | 20.5 **0.20** | -6.5 **0.70** | 5 **0.55** | -7.5 **0.63** | -31 **0.08** |
| sign test | -1.5 **0.58** | 2 **0.42** | -1 **0.79** | 1 **0.73** | -0.5 **1** | -2.5 **0.30** |
| paired t test | -1.62 **0.12** | 1.5 **0.15** | -0.27 **0.79** | 0.02 **0.99** | -0.88 **0.4** | -1.96 **0.07** |

$\alpha = 0.05$
95% confidence level
values below the detection limit were removed
Test statistic value is followed by the p-value in bold

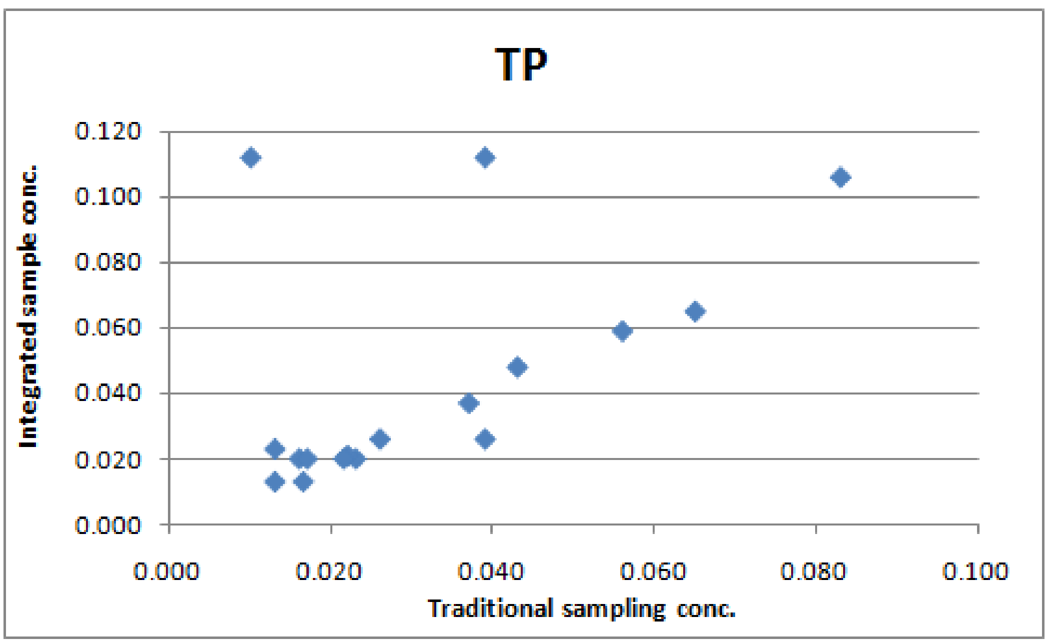



**Figure 12. Comparison of total phosphorus results (as mg/L) for integrated samples and 1-meter depth samples (traditional). n = 17**

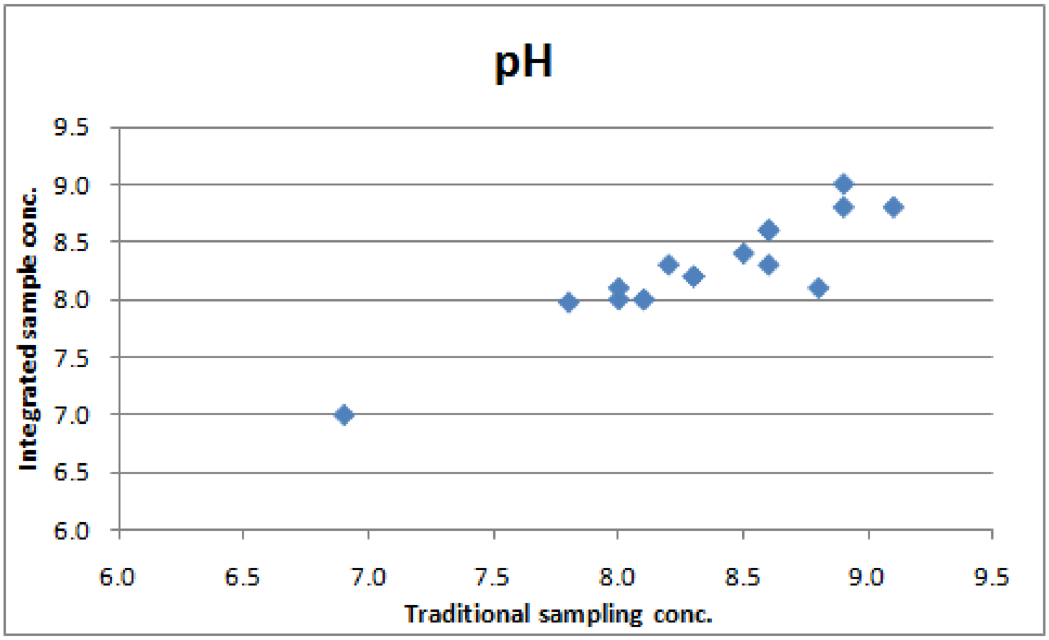



**Figure 13. Comparison of pH results for integrated samples and 1-meter depth samples (traditional). n = 17**

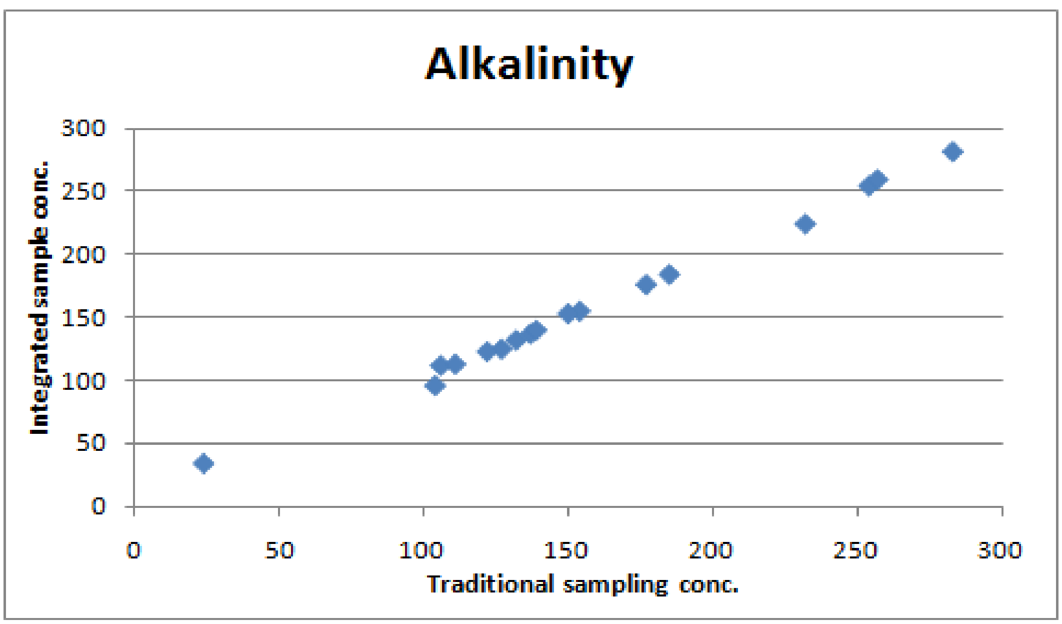



**Figure 14. Comparison of alkalinity results (as mg $CaCO_3$/L) for integrated samples and 1-meter depth samples (traditional). n = 17**

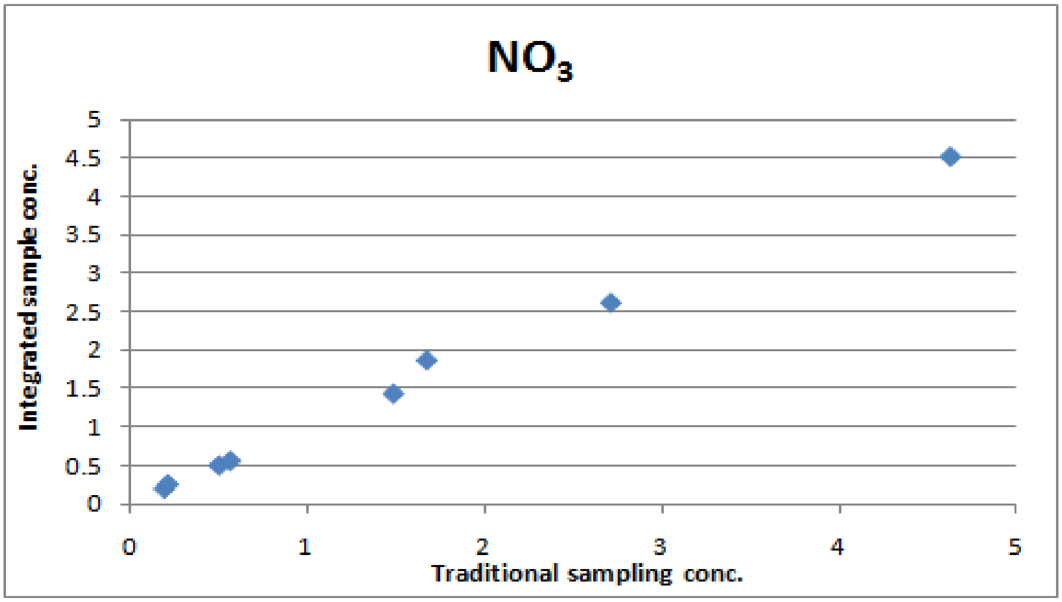



**Figure 15. Comparison of nitrate-nitrogen results (as mg/L) for integrated samples and 1-meter depth samples (traditional). n = 8; results below the detection limit were not used.**

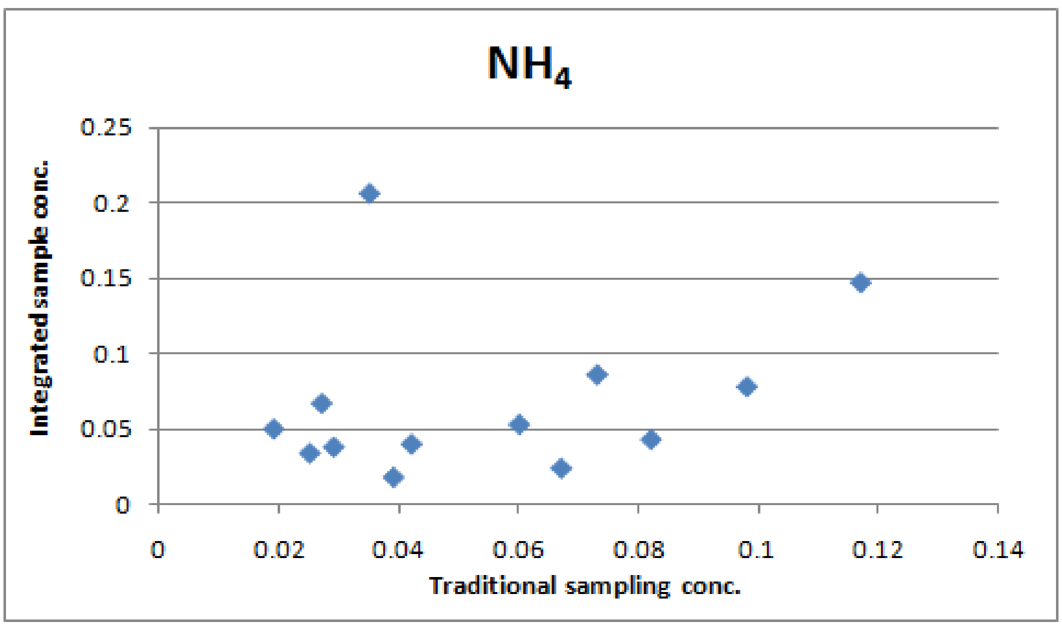



**Figure 16. Comparison of ammonia-nitrogen results (as mg/L) for integrated samples and 1-meter depth samples (traditional). n = 13; results below the detection limit were not used.**

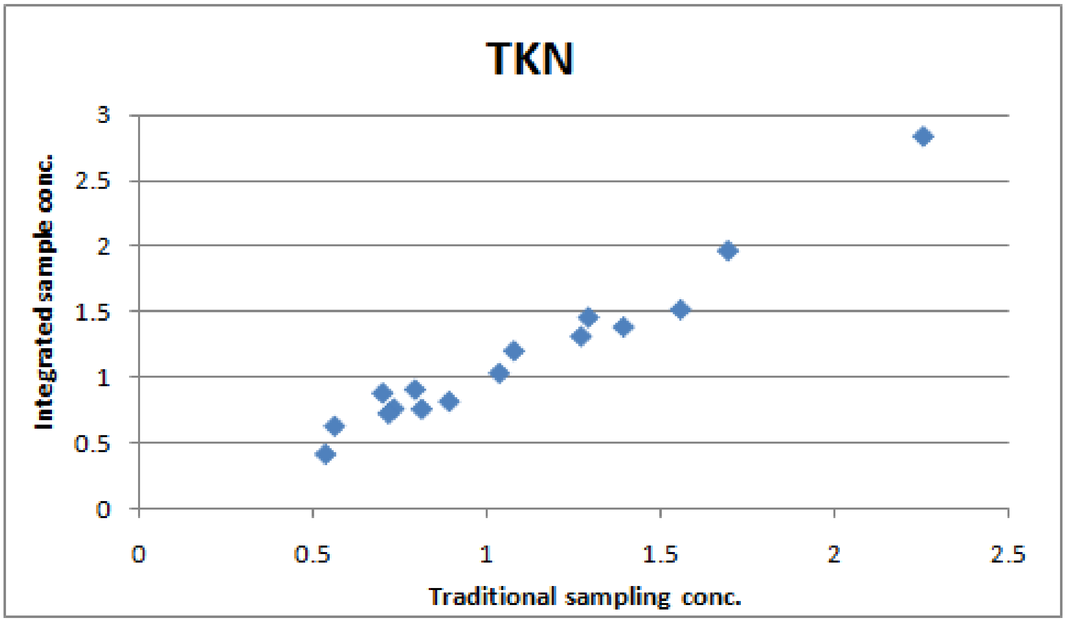



**Figure 17. Comparison of total Kjeldahl nitrogen results (as mg/L) for integrated samples and 1-meter depth samples (traditional). n = 16; results below the detection limit were not used.**

*Phytoplankton*

In 2010, we made two changes in our phytoplankton protocol:

1. Collect water samples using the 2-meter integrated sampler rather than towing a plankton net with a 63-micron mesh from the 1% light level to the surface. This allowed us to collect all phytoplankton from the water not just those plankton larger than 63-microns.
2. Report the results in units of cell/mL rather than NU/L. This better represents the number of phytoplankton present and are the standard units currently used in this field of study.

Table 4 shows the results from applying both sampling and quantification methods on 17 randomly-selected lakes and reservoirs sampled in 2010. It is clear that the integrated samples contained significantly more phytoplankton than the tow net samples, by an average factor of 923 when results were expressed as Natural Units and an average factor of 1267 for cells. Nannoplankton smaller than 63 microns in size can make a significant portion of a lake’s phytoplankton population but these are not collected when using a tow net. For this reason, phycologists do not recommend using a tow net to collect phytoplankton.

**Table 4. Total plankton counts from two sampling methods and two measuring units.**

| LAKE | TYPE | NU/L | CELLS/mL |
|---|---|---|---|
| Brush Creek Reservoir | Integrated | 45,100,689 | 423,850 |
| Cicott | Integrated | 1,483,342 | 11,750 |
| Clear | Integrated | 496,325 | 2,589 |
| Eagle Creek Reservoir | Integrated | 18,338,736 | 201,822 |
| Fish | Integrated | 7,013,871 | 151,369 |
| Henry | Integrated | 3,623,144 | 214,767 |
| Hogback | Integrated | 1,381,637 | 13,070 |
| Indiana | Integrated | 1,133,301 | 7,976 |
| King | Integrated | 24,054,726 | 571,936 |
| Knightstown (Big Blue #7) | Integrated | 8,820,005 | 224,830 |
| Lake of the Woods | Integrated | 7,046,985 | 150,107 |
| Long (Pleasant) | Integrated | 614,023 | 2,635 |
| Loon | Integrated | 4,518,367 | 30,417 |
| Prairie Creek Reservoir | Integrated | 2,822,602 | 34,977 |
| South Mud | Integrated | 11,024,674 | 45,118 |
| Thomas | Integrated | 1,866,656 | 18,171 |
| Wawasee | Integrated | 3,526,132 | 83,335 |
| Brush Creek Reservoir | Tow | 14,257 | 130 |
| Cicott | Tow | 13,320 | 615 |
| Clear | Tow | 6,314 | 118 |
| Eagle Creek Reservoir | Tow | 4,705 | 66 |
| Fish | Tow | 408,081 | 10,941 |
| Henry | Tow | 701,615 | 5,750 |
| Hogback | Tow | 514,675 | 5,067 |
| Indiana | Tow | 2,746 | 158 |
| King | Tow | 7,459 | 997 |
| Knightstown (Big Blue #7) | Tow | 1,111 | 29 |
| Lake of the Woods | Tow | 169,694 | 5,735 |
| Long (Pleasant) | Tow | 323,433 | 4,009 |
| Loon | Tow | 7,771 | 133 |
| Prairie Creek Reservoir | Tow | 10,780 | 109 |
| South Mud | Tow | 16,687 | 919 |
| Thomas | Tow | 2,314 | 115 |
| Wawasee | Tow | 10,567 | 709 |

The phytoplankton peer-reviewed literature expresses phytoplankton units as cells rather than Natural Units. The use of cells rather than Natural Units is particularly important when considering cyanobacteria and their potential for producing toxins because cyanotoxins are produced by cells not by Natural Units. Thus, the more cyanobacteria cells that are present in a lake create a greater potential for toxin production. The World Health Organization public health guidance levels for cyanotoxin exposure are based on the density of cyanobacteria cells present in the water (Chorus et al. 2000).

Our change in phytoplankton protocols are justified by prevailing science and protocols used in the field of phycology. In addition to affecting the magnitude and units of phytoplankton reported for Indiana lakes, the switch to new protocols will also require changes in the Indiana Trophic State Index (ITSI). The ITSI has been used to characterize Indiana lakes for nearly 40 years (IDEM, 1986). The plankton metric of the ITSI requires a tow net sample with units expressed as NU/L (Table 1). Is there a way to convert phytoplankton integrated samples expressed as cells/mL to tow net counts expressed as NU/L so that the ITSI may be used into the future?

Using the results from the 17 lakes, we found a reasonable linear relationship between NU/L and cells/mL in both our tow net samples and the samples collected with the integrated sampler (Figures 18 and 19). The good relationship suggests that we can estimate NU/L from samples reported in units of cells/mL.

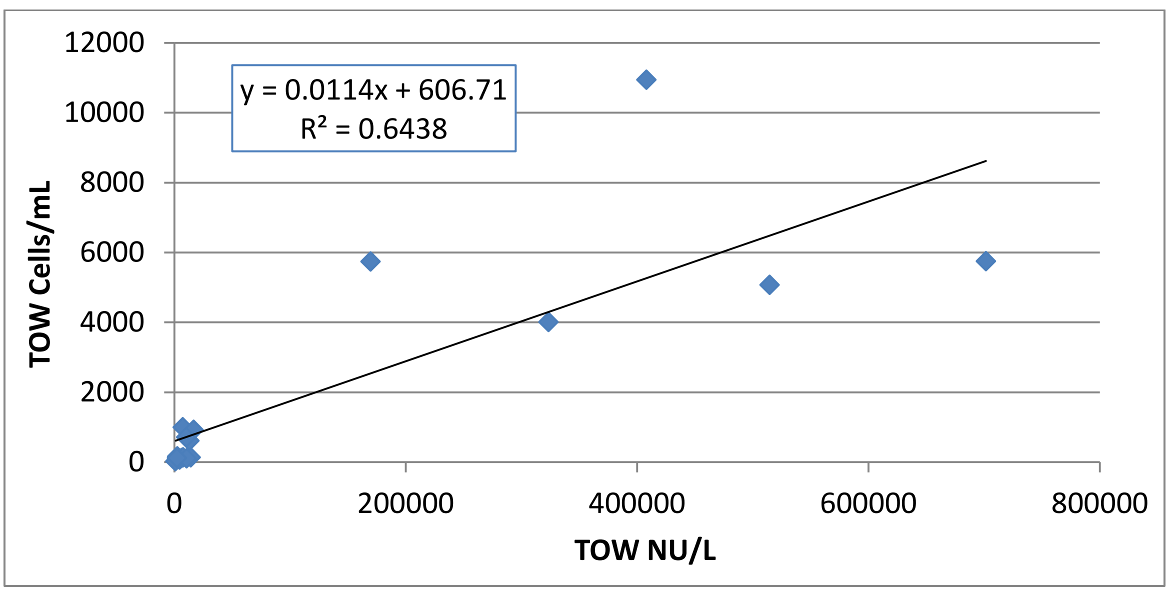



**Figure 18. Relationship between tow net samples expressed as units of cells/mL vs. NU/L. The equation of the best fit line is shown along with the correlation coefficient.**

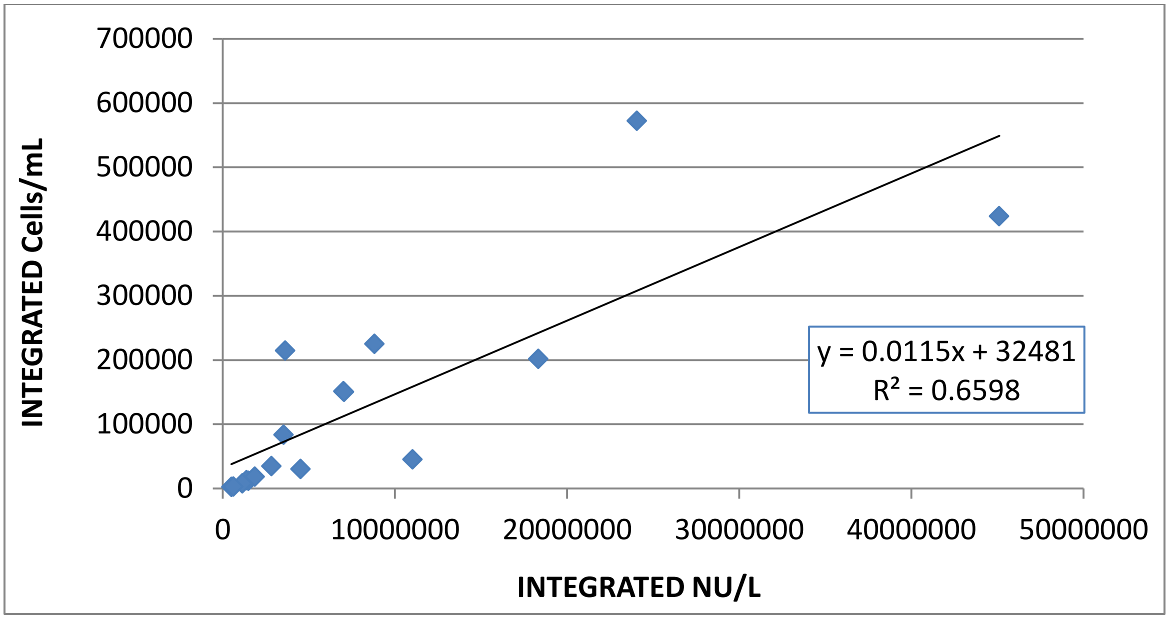



**Figure 19. Relationship between integrated samples expressed as units of cells/mL vs. NU/L. The equation of the best fit line is shown along with the correlation coefficient.**

Unfortunately, there is no clear statistical relationship between NU/L collected using a tow net and cells/mL using an integrated sampler (Figure 20). This represents the change made with switching to the new phytoplankton protocols. Without a statistical relationship to convert integrated cells/mL to tow net NU/L, the plankton trophic points in the Indiana TSI will be significantly different. Two options are available:

1. Abandon the use if the Indiana TSI in favor of other evaluative techniques, for example, the Carlson TSI.
2. Accept that the ITSI with the new plankton protocols will generate substantially different scores and go forward with it.

We recommend that in future years, the use of the Indiana TSI be discontinued and that the Carlson mean TSI be used to evaluate lake trophic state.

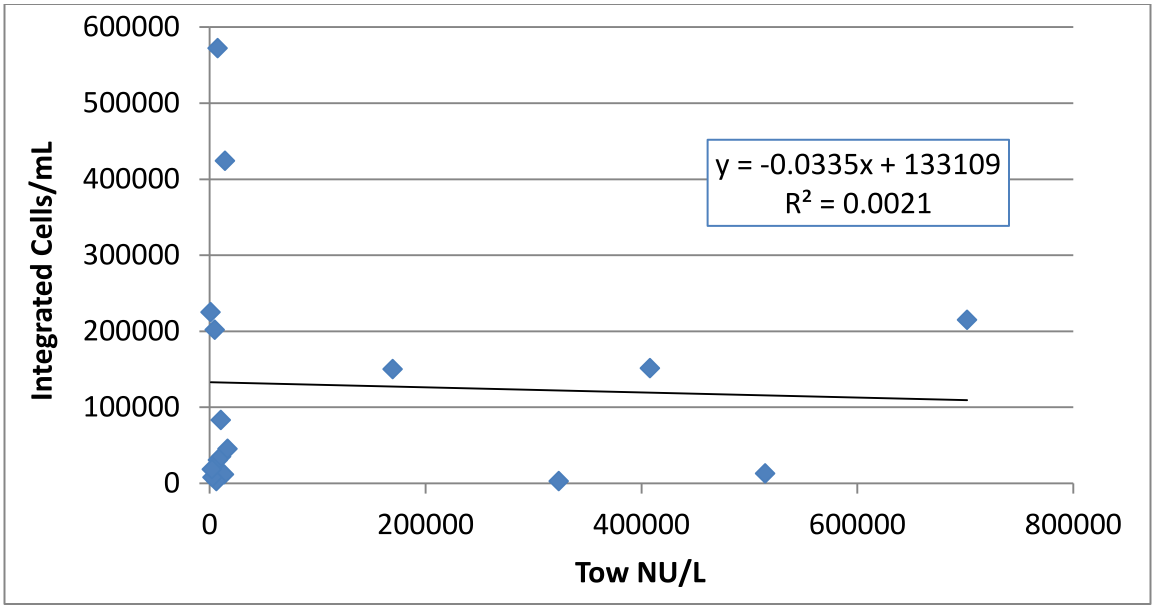



**Figure 20. Relationship between integrated samples expressed as units of cells/mL vs. tow net samples expressed as NU/L. The equation of the best fit line is shown along with the correlation coefficient. The lack of any correlation is apparent.**

**2010 and 2011 Results**

The random selection process used to select lakes sampled during 2010 and 2011 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 160 lakes during this two-year period; 79 in 2010 and 81 in 2011. 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 July 6-8, 2010 in Figure 21. 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.

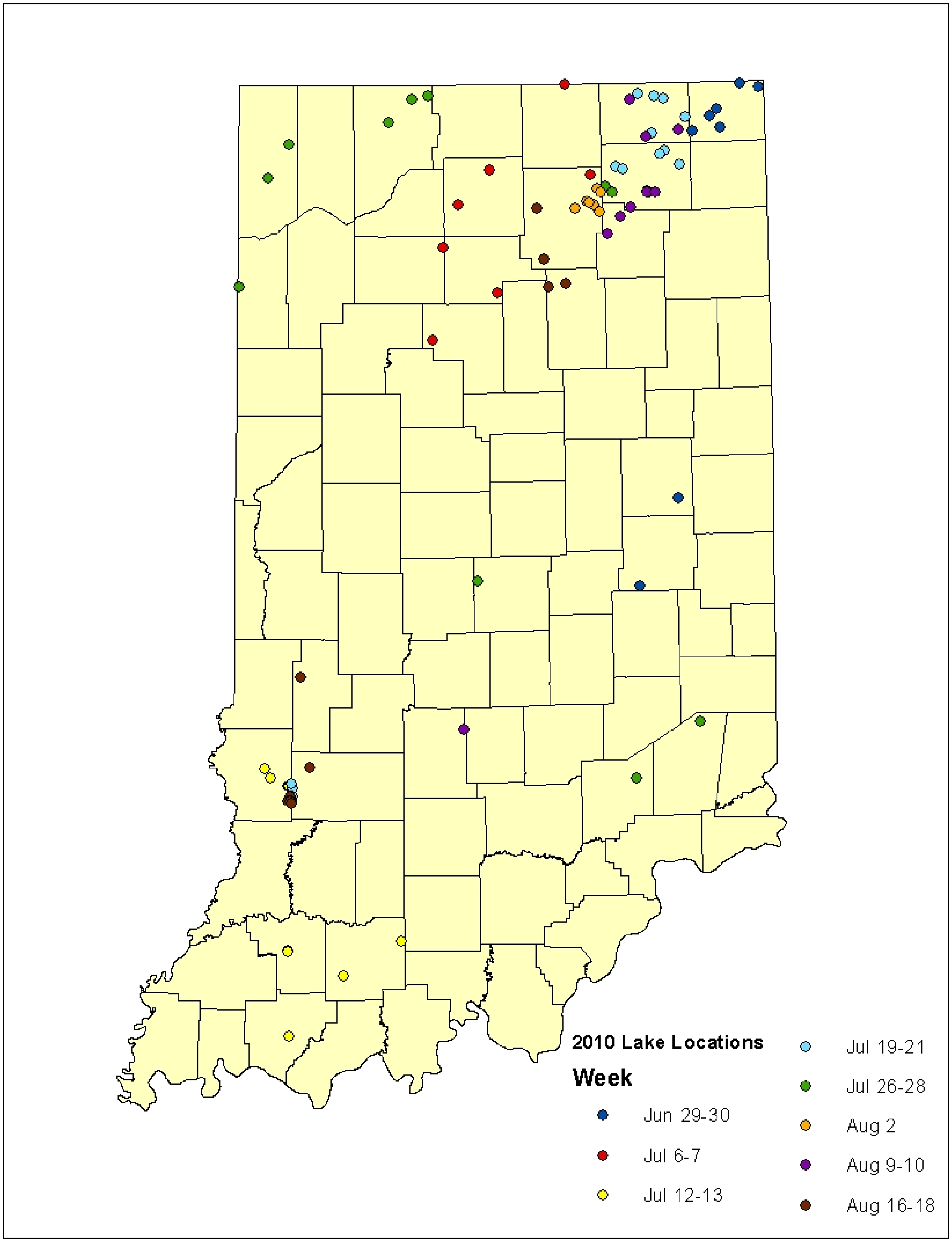



**Figure 21. Lakes assessed during 2010.**

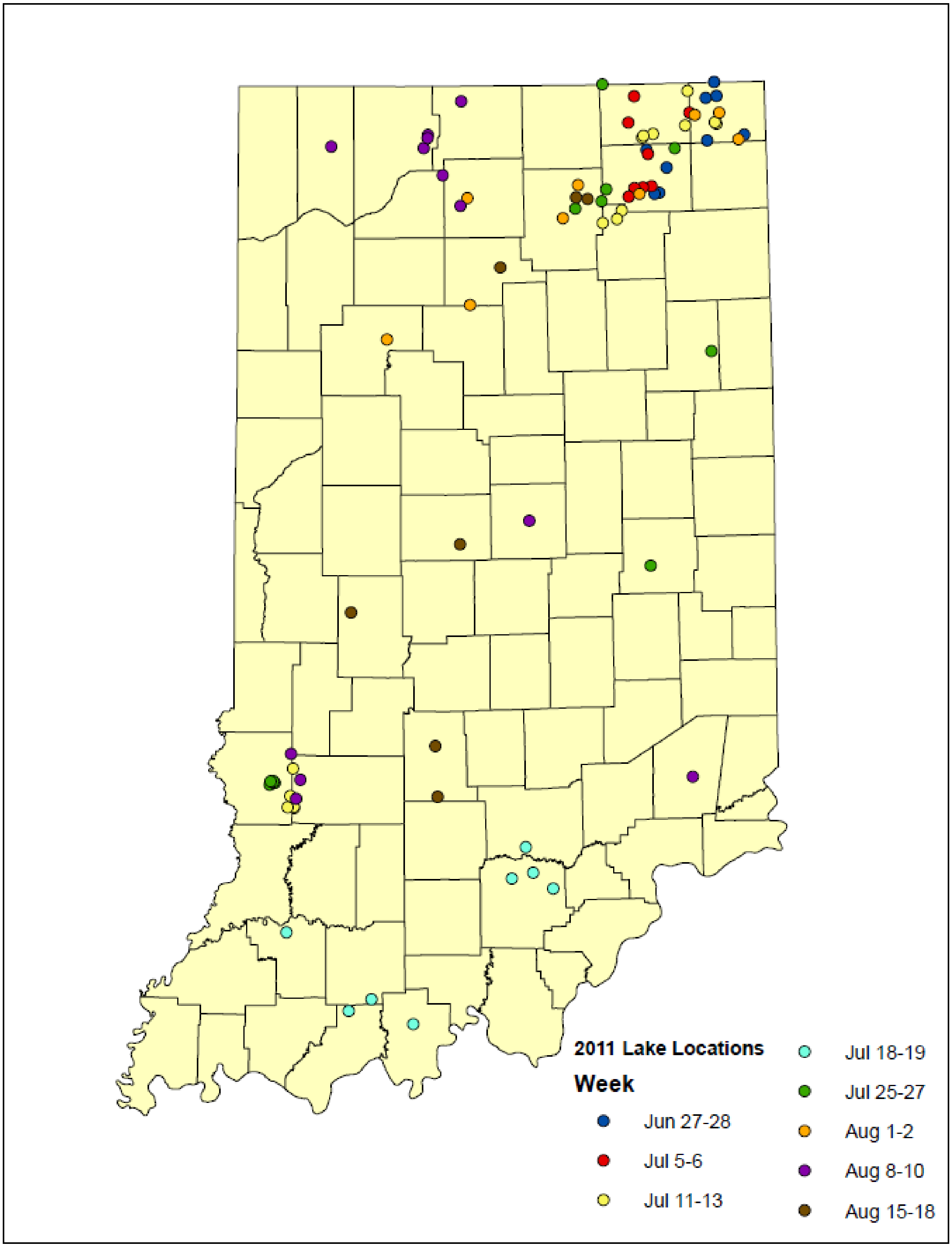



**Figure 22. Lakes assessed during 2011.**

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 23a). Most of the lakes sampled were less than 50 ha (124 acres) in size (Figure 23b).  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 Nasby Mill Pond in Lagrange County and Tamarack Lake in the Kingsbury Fish & Wildlife Area in LaPorte County to 106-foot (32.3 meters) deep Clear Lake in Steuben County (Figure 24).  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.

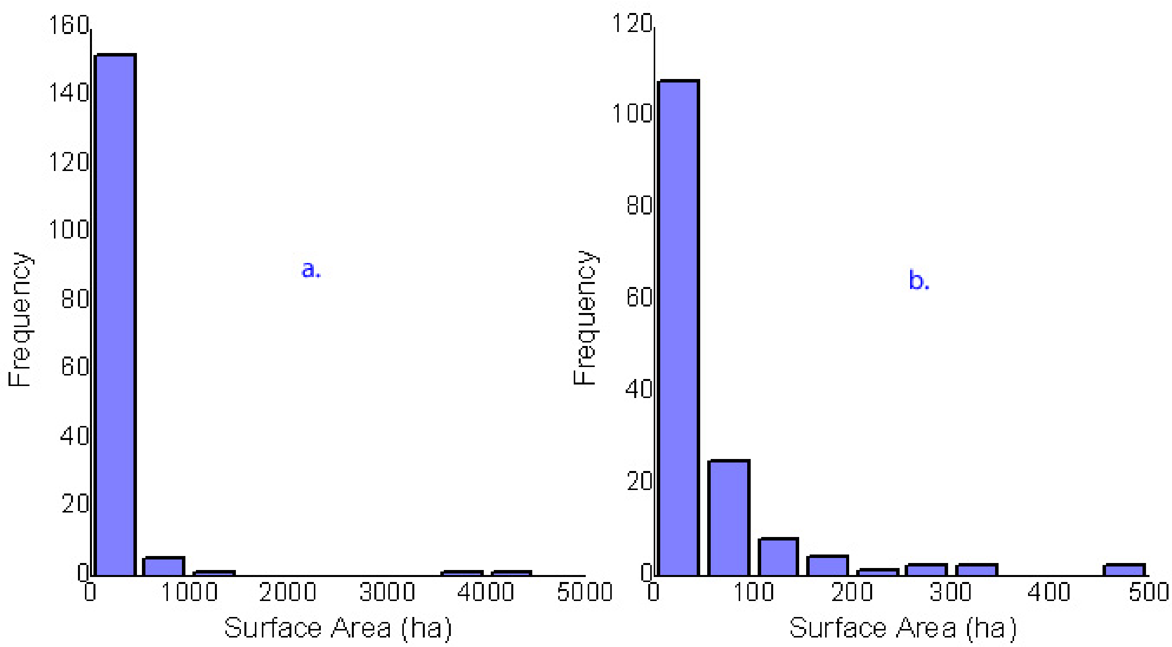



**Figure 23.  Frequency distributions of surface areas of the 179 lakes assessed during 2010-11.  The frequency on the Y-axis represents the number of lakes within each category on the X-axis.  Figure 20b expands the 0-500 ha category to show more detail for the smaller lakes assessed.**

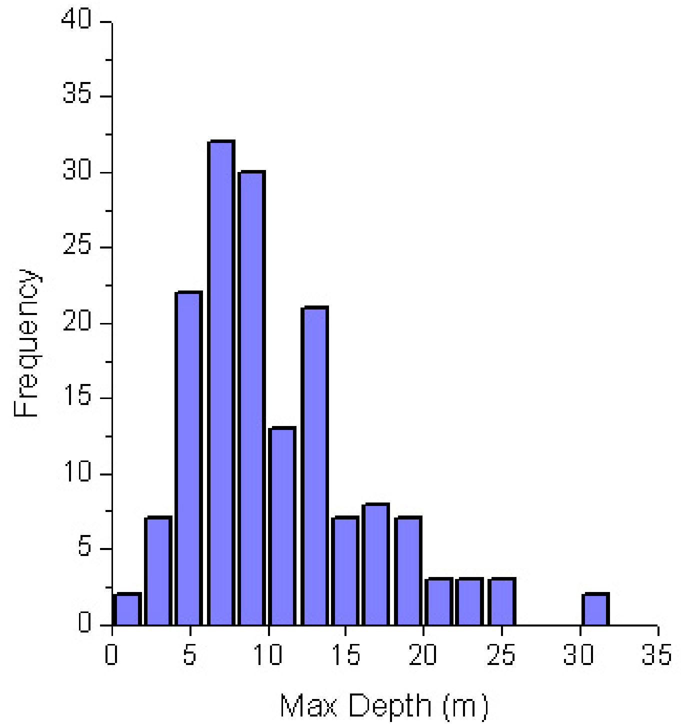



**Figure 24. Frequency distribution of maximum lake depths for lakes assessed during 2010 – 2011.**

*Water Characteristics*

**pH.** The pH frequency distributions were normally distributed (Figure 25). 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 9.5 at Lake Lemon (Monroe Co.). Four other lakes had epilimnetic pH values greater than 9.0. They were: Bass (Sullivan Co.), Dale (Spencer Co.), Huntingburg City (Dubois), and Morse (Hamilton). All five lakes with the highest pH are southern Indiana impoundments.

Reservoir 29, an acidic, coal mine lake in Sullivan Co., had the lowest measured hypolimnetic pH of 6.3. Canada Lake (Porter) and Spurgeon Hollow Reservoir (Washington Co.) were next lowest at 6.4.

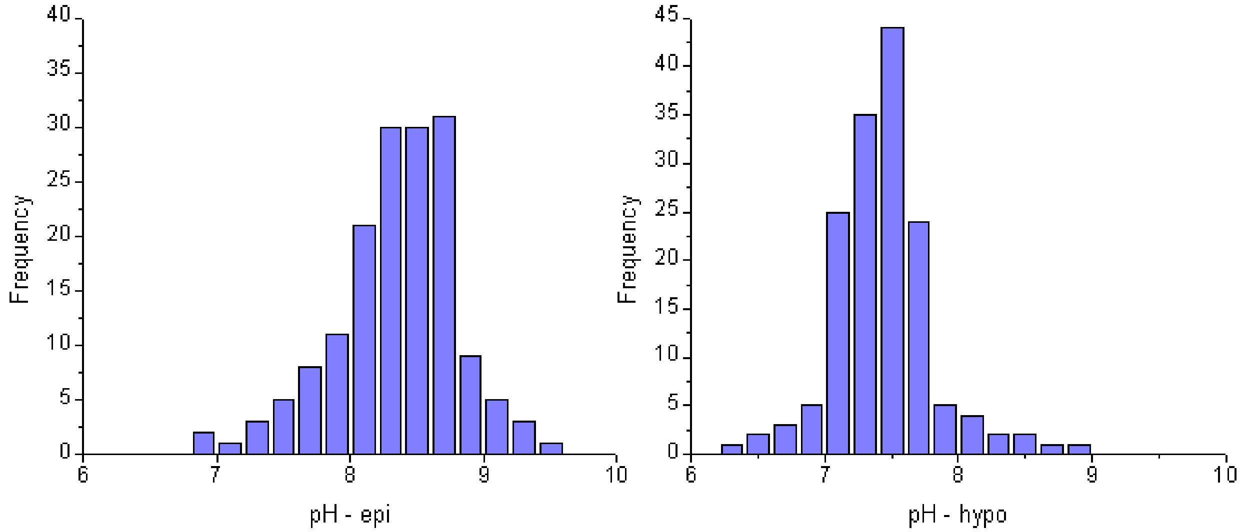



**Figure 25. Frequency distribution of pH for both epilimnion (surface waters) and hypolimnion (bottom waters) for lakes assessed during 2010 – 2011.**

**Conductivity and Alkalinity.** Figure 26 shows the frequency distributions for conductivity and alkalinity for all lakes assessed during 2010 – 2011. Eighteen lakes had epilimnetic conductivities greater than 1,000 µmhos/cm; all of these lakes are coal mine lakes in southeastern Indiana. 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. With the exception of Thomas Lake in Marshall Co., of the nine lakes with the lowest alkalinity, all were located in unglaciated Southern Indiana.

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

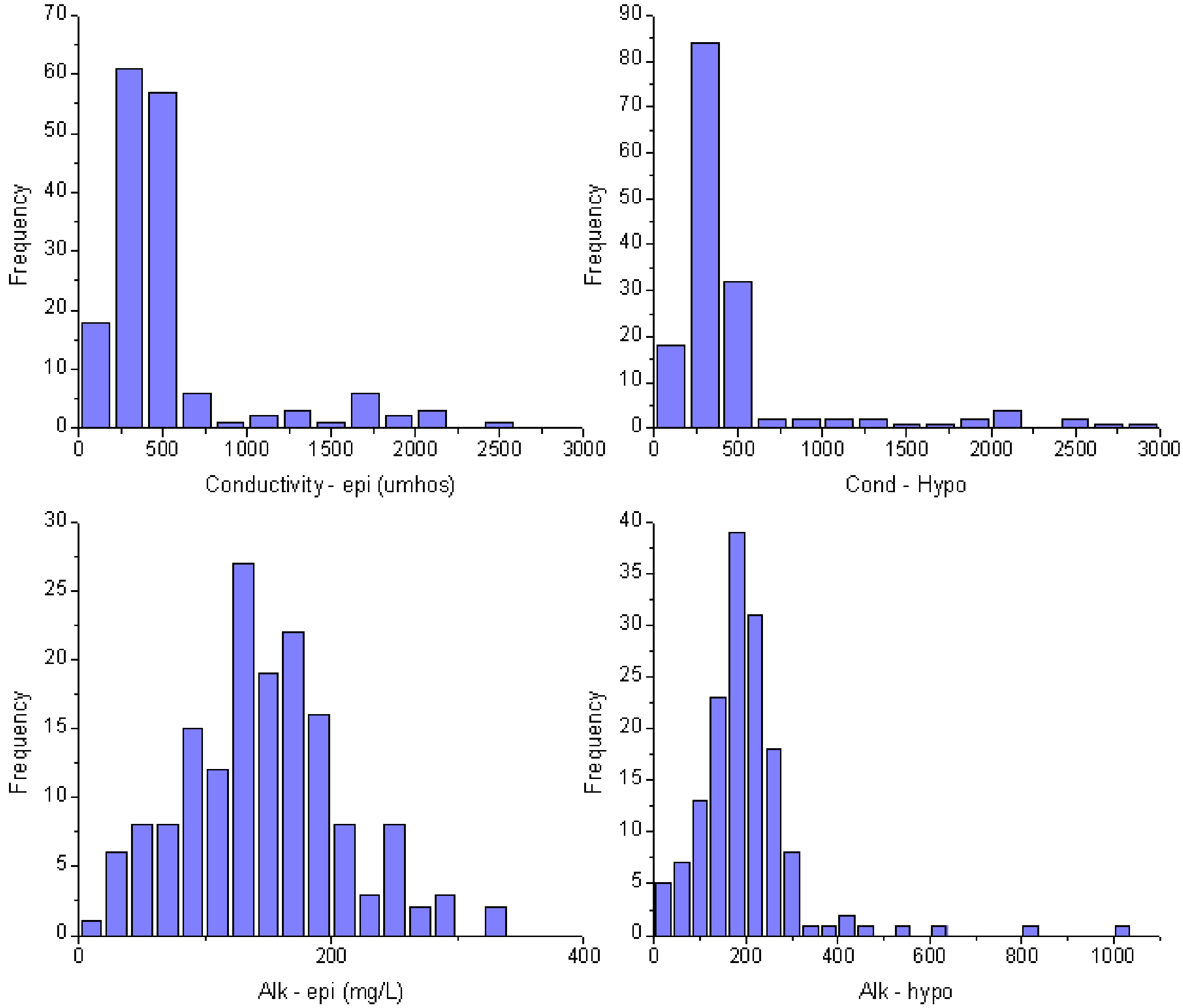



**Figure 26. Frequency distributions for epilimnetic and hypolimnetic conductivity and alkalinity for lakes assessed during 2010 – 2011.**

**Secchi Disk Transparency.** Figure 27 shows the frequency distribution of Secchi disk transparency among the lakes assessed during 2010 – 2011. Seven lakes had Secchi disk transparency depths of less than 0.5 m (1.5 feet) and eight lakes had Secchi depths greater than 5.0 m (16.4 feet) (Table 5). Four of the lakes with the shallowest Secchi depth were impoundments. Five of the lakes having the deepest Secchi depths were coal mine lakes. The median Secchi depth for all lakes assessed was 1.6 m.

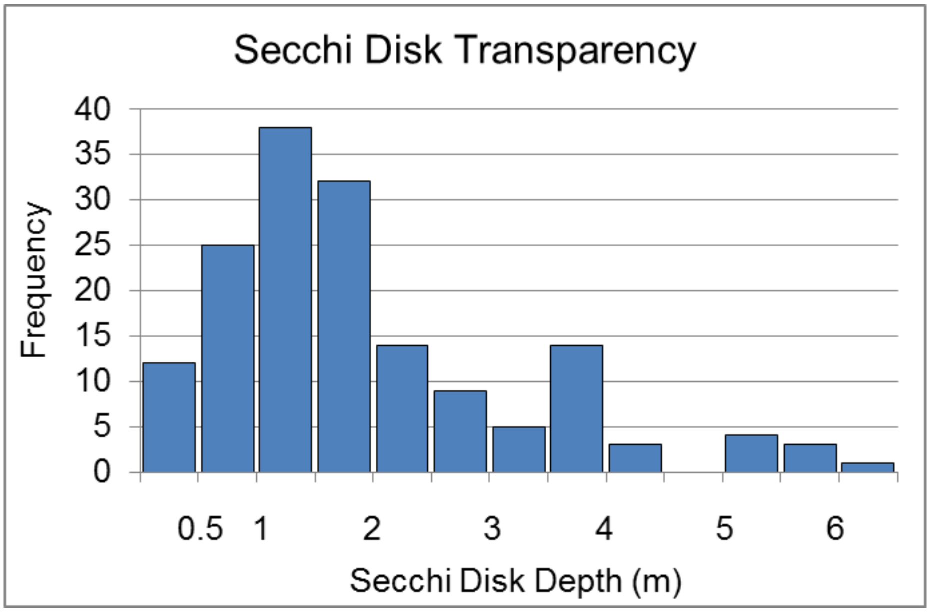



**Figure 27. Frequency distribution for Secchi disk transparency for all lakes assessed during 2010 – 2011.**

**Table 5. Minimum and Maximum Secchi Depths for Lakes Assessed During Summer 2010 – 2011.**

| LAKE | COUNTY | SECCHI DEPTH (M) |
|---|---|---|
| Versailles | Ripley | 0.2 |
| Lemon | Monroe | 0.3 |
| George (Hobart) | Lake | 0.4 |
| J.C. Murphy | Newton | 0.4 |
| McClures | Kosciusko | 0.4 |
| Knightstown (Big Blue #7) | Henry | 0.4 |
| Tamarack | LaPorte | 0.45 |
| Long (Dugger) | Sullivan | 5.1 |
| Scheister | Clay | 5.4 |
| Hammond | Greene | 5.4 |
| Stump Jumper | Clay | 5.5 |
| Clear | Steuben | 5.6 |
| Hudson | LaPorte | 5.6 |
| Boones Pond | Boone | 5.8 |
| Airline Pit | Greene | 6.2 |

**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 (Lake George near Hobart in Lake County) had an unusually high epilimnetic concentration of SRP at 0.095 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 28 shows the frequency distribution of hypolimnetic SRP in the 2010 – 2011 lakes. The median hypolimnetic SRP concentration was 0.033 mg/L. Lakes having the highest hypolimnetic SRP concentrations are shown in Table 6. These lakes have significant internal phosphorus loading.

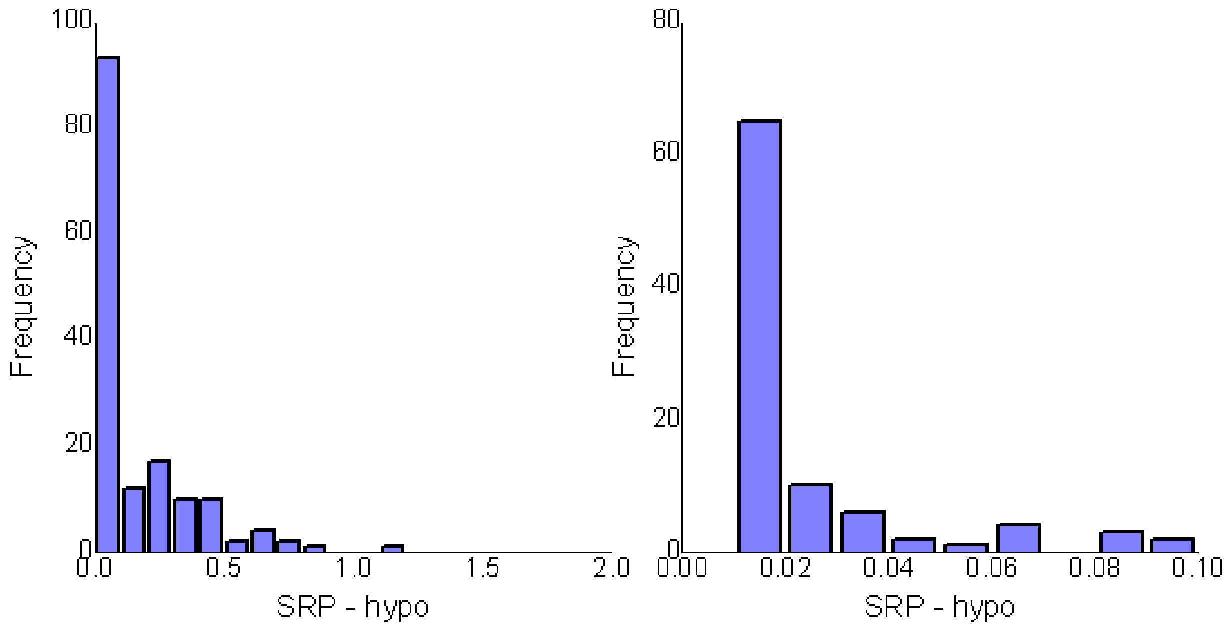



**Figure 28. Frequency distribution of soluble reactive phosphorus in sampled lakes.**

**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 29. Then median epilimnetic TP concentration was 0.027 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 Kiser Lake (Kosciusko Co.) – 0.501 mg/L and for Steinbarger Lake (Noble Co.) – 0.314 mg/L. No other lakes exceeded 0.200 mg/L.

**Table 6. Lakes with the Highest Hypolimnetic SRP Concentrations.**

| LAKE | COUNTY | Hypo SRP (mg/L) |
|---|---|---|
| Crystal | Greene | 0.642 |
| Mud (Chain of Lakes) | Noble | 0.645 |
| Old | Whitley | 0.647 |
| Hogback | Steuben | 0.660 |
| King | Fulton | 0.707 |
| Hackenburg | LaGrange | 0.780 |
| Norman | Noble | 0.869 |
| Shakamak | Sullivan | 1.166 |

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*. Sixteen lakes exceeded a TP concentration of 0.500 mg/L in their hypolimnion (Table 7). 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.

**Nitrate-Nitrogen.** Most lakes had relatively low nitrate-nitrogen concentrations (Figure 30). 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 Little Turkey Lake (Steuben Co.) with 8.51 mg/L and Knightstown Reservoir (Henry Co.) with 4.52 mg/L, both within the epilimnetic samples. Rider (Noble Co.) and Henry (Steuben Co.) both had epilimnetic nitrate-nitrogen concentrations over 2.0 mg/L.

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 30). 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-

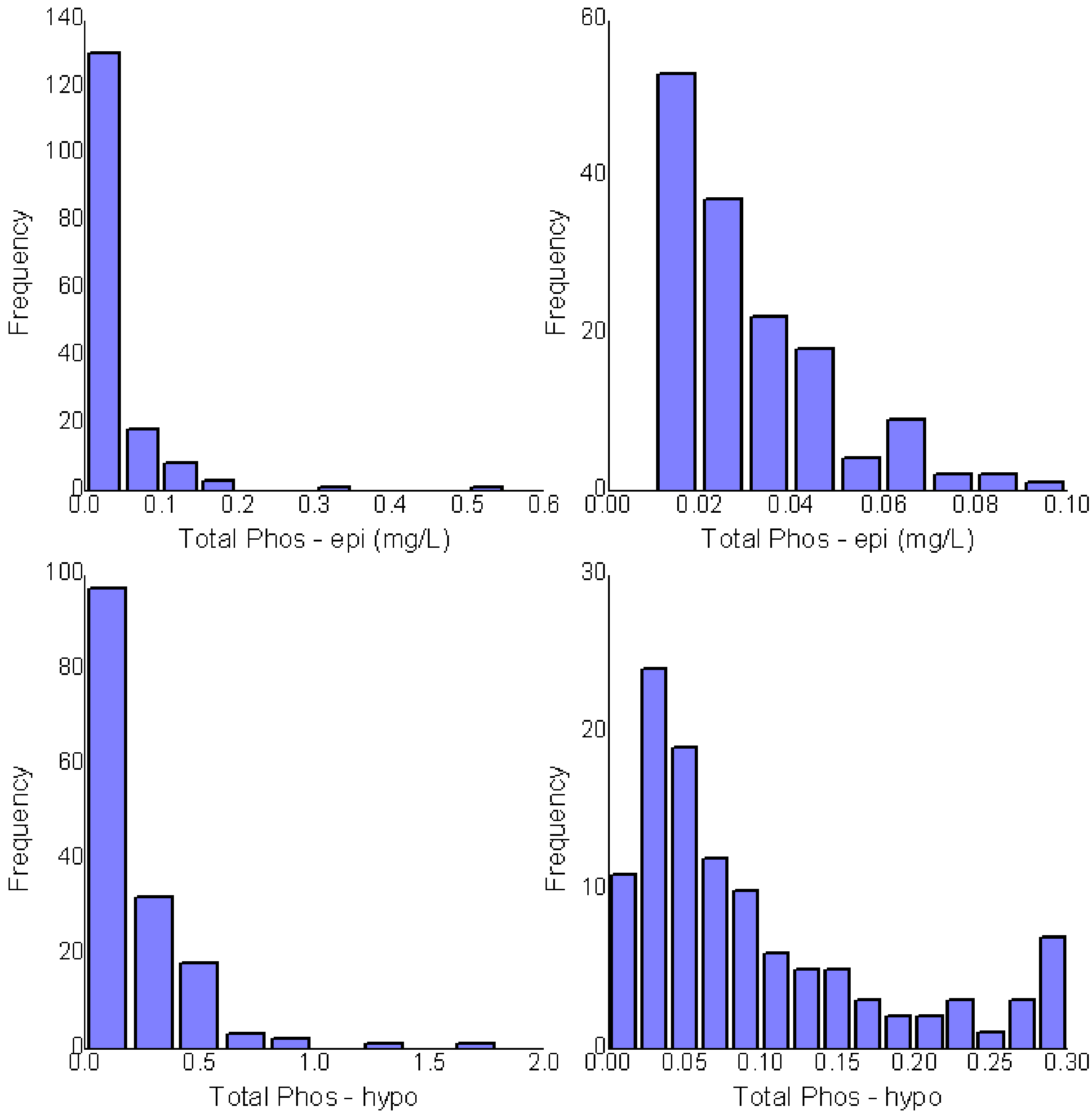



**Figure 29. Frequency distributions for total phosphorus for lakes assessed during 2010 – 2011. Finer detail is shown for the lower concentrations in the plots to the right.**

five of the lakes assessed during 2010-11 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 8. The Table 8 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.

**Table 7. Lakes with the Highest Hypolimnetic Total Phosphorus Concentrations.**

| LAKE | COUNTY | Hypo TP (mg/L) |
|---|---|---|
| Bixler | Noble | 0.502 |
| Ridinger | Kosciusko | 0.511 |
| Miller (Chain of Lakes) | Noble | 0.513 |
| Hogback | Steuben | 0.532 |
| James | Kosciusko | 0.536 |
| Barrel and a Half | Kosciusko | 0.546 |
| Jones | Noble | 0.550 |
| Eagle Creek Reservoir | Marion | 0.553 |
| Narrow | Sullivan | 0.593 |
| Dixon | Marshall | 0.651 |
| Old | Whitley | 0.737 |
| Mud (Chain of Lakes) | Noble | 0.776 |
| Williams | Noble | 0.854 |
| Norman | Noble | 0.991 |
| Shakamak | Sullivan | 1.318 |
| Hog | Steuben | 1.618 |

**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 30 that many Indiana lakes exceed this threshold. When we calculate mean total nitrogen from our data, a total of seventy-six (nearly one-half) 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).

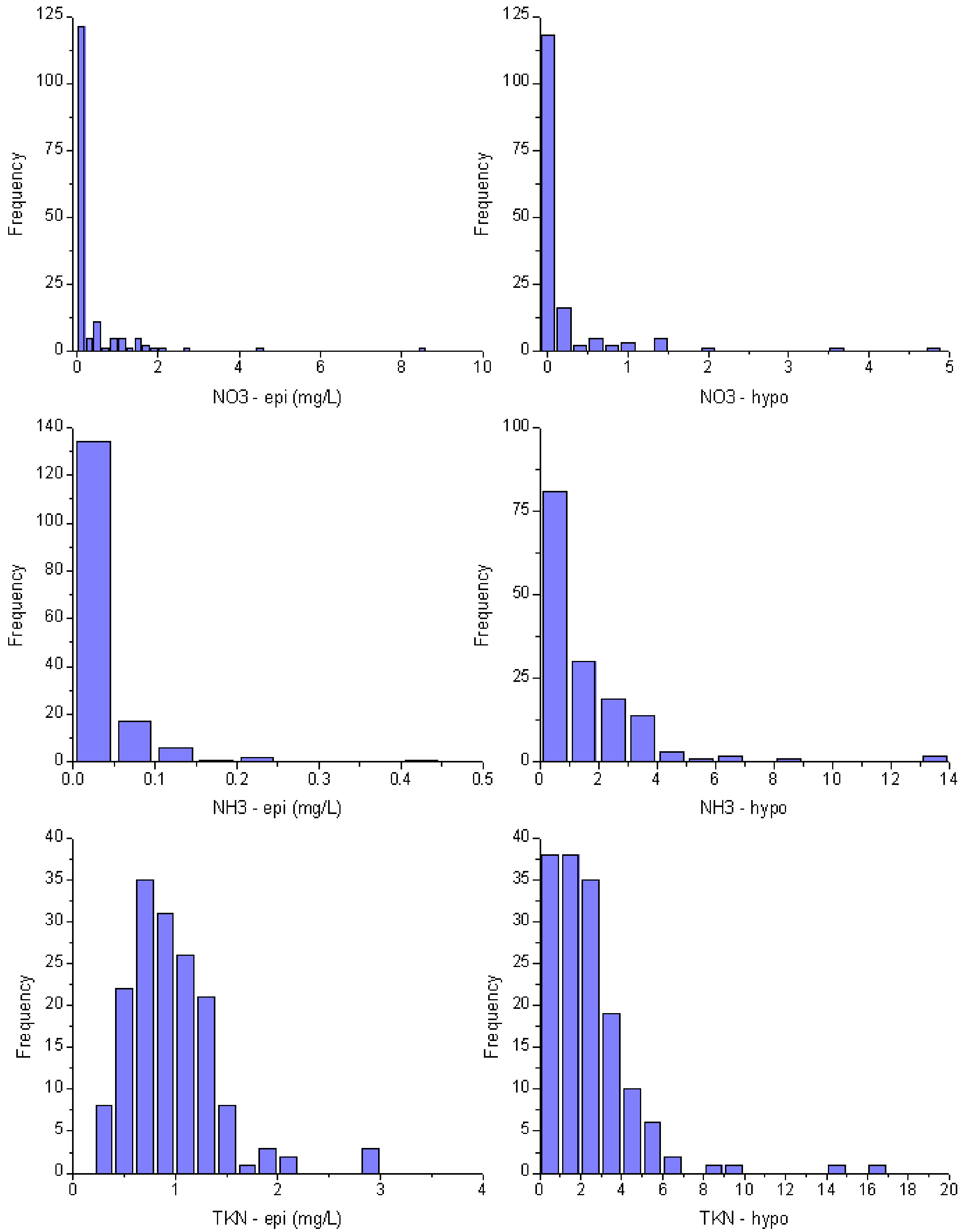



**Figure 30. Frequency distributions for nitrate-nitrogen, ammonia-nitrogen and total Kjeldahl nitrogen for all lakes sampled during 2010 – 2011.**

**Table 8. Lakes with Highest Hypolimnetic Ammonia-Nitrogen Concentrations.**

| LAKE | COUNTY | Hypo $NH_4$ (mg/L) |
|---|---|---|
| Big Blue #13 (Westwood) | Henry | 3.244 |
| Robinson | Whitley | 3.261 |
| Sycamore | Greene | 3.414 |
| Ridinger | Kosciusko | 3.427 |
| Little Chapman | Kosciusko | 3.469 |
| Brush Creek Reservoir | Jennings | 3.533 |
| Thomas | Marshall | 3.555 |
| South Mud | Fulton | 3.650 |
| Long | Wabash | 3.717 |
| Bartley | Noble | 3.745 |
| Williams | Noble | 3.770 |
| Shakamak | Sullivan | 3.840 |
| Glen Flint | Putnam | 3.917 |
| Dixon | Marshall | 3.941 |
| Norman | Noble | 4.001 |
| Messick | LaGrange | 4.523 |
| Manitou | Fulton | 4.868 |
| Bischoff Reservoir | Ripley | 5.429 |
| Crystal | Greene | 6.056 |
| Downing | Sullivan | 6.994 |
| Narrow | Sullivan | 8.287 |
| McClures | Kosciusko | 13.089 |
| Trout | Sullivan | 13.637 |
| Airline | Greene | 32.677 |

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 – One metric in the Indiana TSI 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 31 and summary statistics are shown in Table 9. Most lakes (102 out of 160; 64%) assessed had chlorophyll-a concentrations less than 10 µg/L, the lower boundary of the Carlson's eutrophic category (Figure 5). Eight lakes exceeded 40 µg/L, a concentration indicative of hypereutrophic conditions (Table 10). Six of these lakes are impoundments.

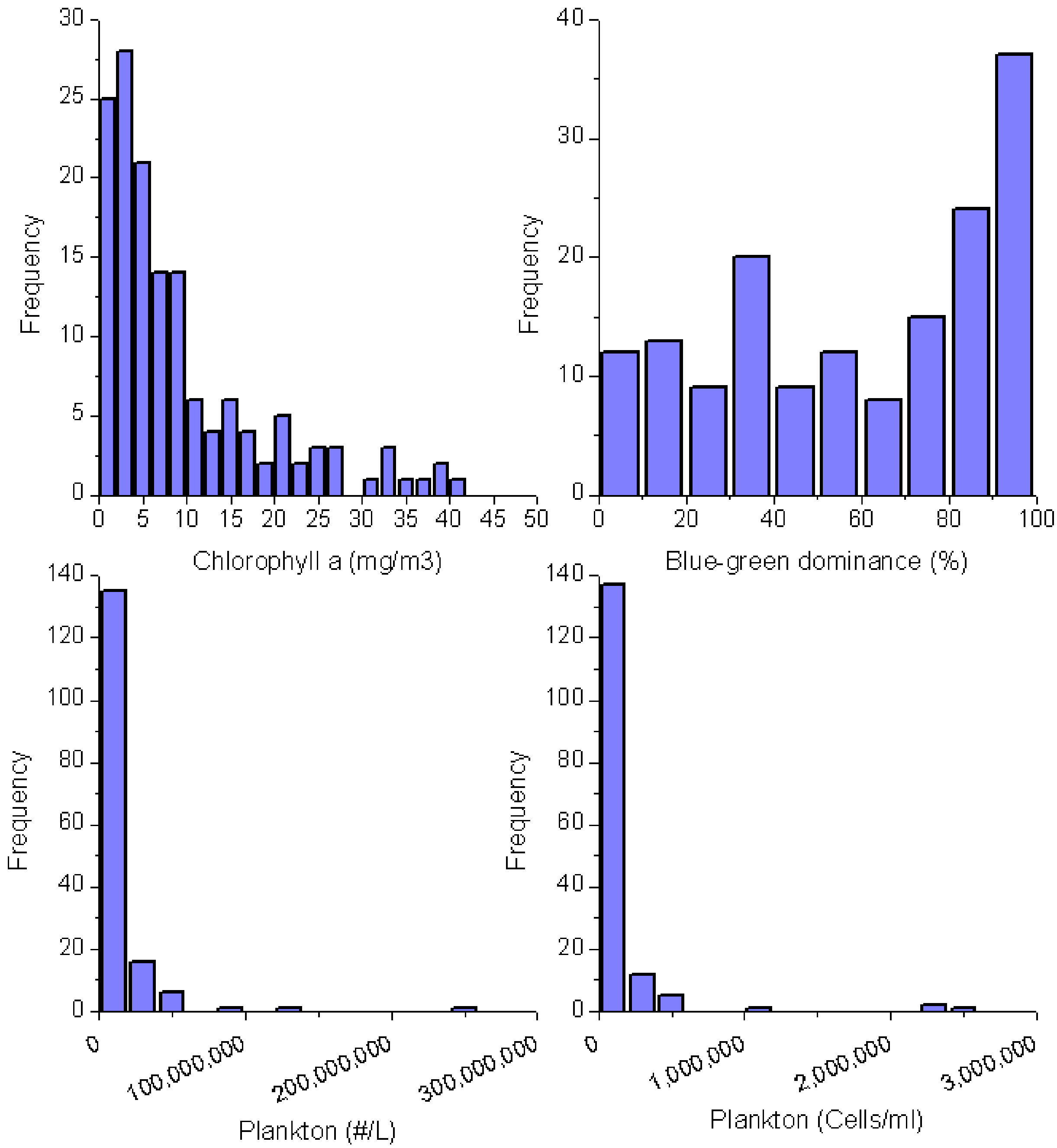



**Figure 31. Frequency distributions of several plankton variables for all lakes assessed during 2010 – 2011.**

**Table 9. Summary of Plankton Analyses.**

| | Chlorophyll-a (µg/L) | Total Phytoplankton (cells/mL) | % Cyanobacteria Dominance |
|---|---|---|---|
| **Median** | 6.16 | 36,060 | 63.9 |
| **Minimum** | 0.34 | 750 | 1.0 |
| **Maximum** | 156.75 | 2,456,584 | 99.4 |

**Table 10. Lakes with Highest Chlorophyll-a Concentrations.**

| LAKE | COUNTY | CHL-a (µg/L) |
|---|---|---|
| Troy Cedar | Whitley | 41.52 |
| Lemon | Monroe | 51.40 |
| Dixon | Marshall | 52.50 |
| Dale Reservoir | Spencer | 52.75 |
| Morse Reservoir | Hamilton | 55.92 |
| J.C. Murphy | Newton | 67.28 |
| Shaffer | White | 67.52 |
| Versailles | Ripley | 97.80 |
| Tamarack | LaPorte | 156.75 |

Plankton cell densities ranged from a low of 72 cells/mL at Simonton Lake (Elkhart Co.) to a high of 2.4 million cells/mL at Fancher Lake (Lake Co.). Three other lakes had cell densities exceeding 1 million: Morse Reservoir (Hamilton Co.) – 1.1 million cells/mL; Knightstown Reservoir (Henry Co.) – 2.2 million cells/mL; and McClures Lake (Kosciusko Co.) – 2.3 million 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 (61%) of the lakes in Indiana (Figure 31). In fact, blue-greens composed more than 90% of the phytoplankton community in 37 lakes.

**Trophic State.** Table 11 shows the Carlson Trophic State Index for all lakes assessed during 2010 – 2011. Table 11 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 ten best mean Carlson TSIs (lowest scores), only three belonged to natural lakes: Clear (Steuben Co.), Hudson (LaPorte Co.), and Mateer (Lagrange Co.). The rest were coal mine lakes. Of the ten worst mean Carlson TSIs (highest scores), only two belonged to natural lakes: Tamarack (LaPorte Co.) and King (Fulton Co.). The remaining eight were all impoundments, five of which were in Southern Indiana.

Figure 32 illustrates the number of lakes assessed during 2010 – 2011 within each trophic category. More Indiana lakes were eutrophic than any other trophic state category. Eighty-eight lakes (55% of total) were either eutrophic or hypereutrophic. In our last Lake Water Quality Assessment Report (Montgrain and Jones, 2009), 46% of lakes assessed were eutrophic or hypereutrophic. While a greater percentage of assessed lakes from 2010 – 2011 are eutrophic than previously, care must be taken in making comparisons as lakes assessed for the previous report were not selected randomly.

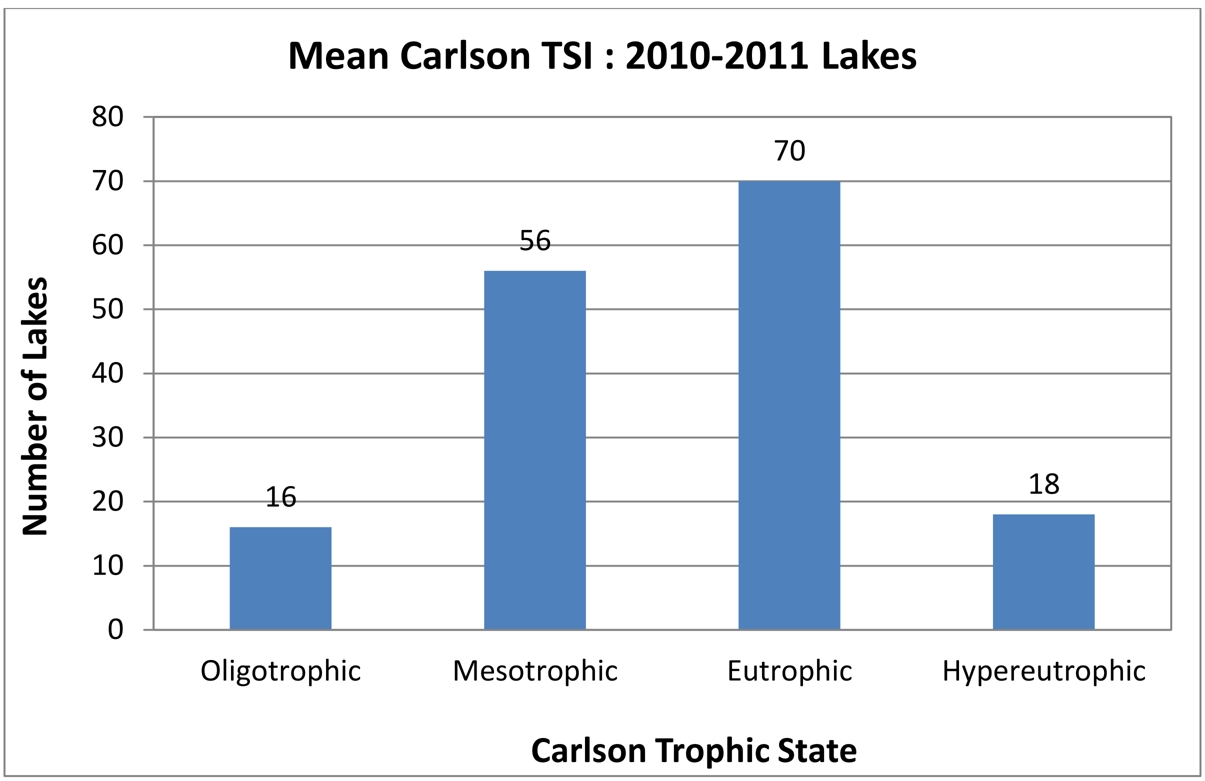



**Figure 32. Mean Carlson TSI for lakes assessed during 2010 – 2011.**

**Table 11. Carlson TSI for Lakes Assessed During 2010 – 2011.**

| LAKE NAME | COUNTY | TSI(SD) | TSI(Chl) | TSI(TP_Epi) | TSI(Mean) |
|---|---|---|---|---|---|
| Airline | Greene | 34 | 23 | 37 | 31 |
| Appleman | LaGrange | 53 | 46 | 53 | 51 |
| Ball | Steuben | 53 | 46 | 45 | 48 |
| Barrel and a Half | Kosciusko | 42 | 40 | 51 | 44 |
| Bartley | Noble | 56 | 52 | 55 | 54 |
| Bass | Sullivan | 43 | 41 | 44 | 43 |
| Bass (N. Chain) | St Joseph | 39 | 42 | 55 | 45 |
| Bear | Noble | 52 | 55 | 53 | 53 |
| Big | Noble | 60 | 56 | 55 | 57 |
| Big Blue #13 (Westwood) | Henry | 41 | 40 | 44 | 42 |
| Big Bower | Steuben | 40 | 57 | 59 | 52 |
| Big Chapman | Kosciusko | 49 | 41 | 37 | 42 |
| Big Fry | Sullivan | 45 | 45 | 48 | 46 |
| Bischoff Reservoir | Ripley | 70 | 62 | 68 | 67 |
| Bixler | Noble | 59 | 48 | 51 | 53 |
| Blue | Whitley | 57 | 57 | 40 | 51 |
| Bobcat | Greene | 55 | 52 | 51 | 53 |
| Boones Pond | Boone | 35 | 34 | 51 | 40 |
| Brush Creek Reservoir | Jennings | 70 | 61 | 64 | 65 |
| Buck | Steuben | 47 | 40 | 45 | 44 |
| Buck | LaGrange | 56 | 65 | 65 | 62 |
| Canada | Porter | 56 | 60 | 58 | 58 |
| Center | Kosciusko | 52 | 45 | 42 | 46 |
| Cicott | Cass | 41 | 28 | 47 | 39 |
| Clear | Steuben | 35 | 25 | 41 | 34 |
| Corky | Greene | 49 | 20 | 37 | 35 |
| Cree | Noble | 52 | 52 | 53 | 52 |
| Crystal | Greene | 53 | 51 | 50 | 51 |
| Dale Reservoir | Spencer | 70 | 69 | 73 | 71 |
| Dallas | LaGrange | 56 | 43 | 40 | 46 |
| Dewart | Kosciusko | 49 | 46 | 45 | 47 |
| Dixon | Marshall | 65 | 69 | 58 | 64 |
| Dock | Noble | 63 | 65 | 63 | 64 |
| Dogwood | Sullivan | 48 | 45 | 45 | 46 |
| Downing | Sullivan | 42 | 31 | 37 | 37 |
| Duely | Noble | 47 | 42 | 54 | 48 |
| Eagle | Noble | 59 | 51 | 60 | 57 |
| Eagle Creek Reservoir | Marion | 63 | 49 | 56 | 56 |
| Elk Creek #9 | Washington | 52 | 48 | 50 | 50 |
| Engle | Noble | 46 | 35 | 37 | 39 |
| Fancher | Lake | 47 | 37 | 45 | 43 |
| Ferdinand City Old | Dubois | 52 | 50 | 58 | 53 |
| Fish | Steuben | 65 | 58 | 72 | 65 |

| LAKE NAME | COUNTY | TSI(SD) | TSI(Chl) | TSI(TP_Epi) | TSI(Mean) |
|---|---|---|---|---|---|
| Fish (Lower) | LaPorte | 54 | 49 | 50 | 51 |
| Fish (Upper) | LaPorte | 56 | 51 | 52 | 53 |
| Fish Lake (Scott) | LaGrange | 59 | 51 | 55 | 55 |
| Fletcher | Fulton | 53 | 48 | 45 | 49 |
| Fox | Sullivan | 59 | 46 | 53 | 53 |
| Front | Sullivan | 49 | 60 | 45 | 51 |
| Gage | Steuben | 49 | 39 | 37 | 42 |
| George (Hobart) | Lake | 73 | 48 | 80 | 67 |
| Glen Flint | Putnam | 67 | 66 | 63 | 65 |
| Golden | Steuben | 57 | 61 | 57 | 58 |
| Goldeneye | Kosciusko | 45 | 38 | 48 | 44 |
| Goose | Whitley | 52 | 47 | 52 | 50 |
| Green | LaGrange | 52 | 46 | 47 | 48 |
| Griffy | Monroe | 42 | 44 | 41 | 42 |
| Hackberry | Sullivan | 40 |  | 37 | 39 |
| Hackenburg | LaGrange | 51 | 49 | 52 | 51 |
| Hamilton | Steuben | 52 | 59 | 54 | 55 |
| Hammond | Greene | 36 | 40 | 37 | 38 |
| Harper | Noble | 44 | 34 | 42 | 40 |
| Henry | Steuben | 52 | 47 | 49 | 49 |
| Hoffman | Kosciusko | 57 | 57 | 54 | 56 |
| Hog | Steuben | 42 | 43 | 45 | 43 |
| Hog | LaPorte | 50 | 39 | 58 | 49 |
| Hogback | Steuben | 57 | 48 | 47 | 51 |
| Hudson | LaPorte | 35 | 27 | 42 | 35 |
| Huntingburg City | Dubois | 70 | 57 | 50 | 59 |
| Indiana | Elkhart | 47 | 25 | 41 | 38 |
| J.C. Murphy | Newton | 73 | 72 | 77 | 74 |
| James | Kosciusko | 52 | 52 | 49 | 51 |
| Jimmerson | Steuben | 44 | 43 | 71 | 53 |
| John Hay | Washington | 46 | 46 | 37 | 43 |
| Jones | Noble | 60 | 66 | 63 | 63 |
| King | Fulton | 67 | 63 | 71 | 67 |
| Kiser | Kosciusko | 47 | 44 | 94 | 62 |
| Knightstown (Big Blue #7) | Henry | 73 | 46 | 72 | 64 |
| Koontz | Starke | 67 | 66 | 59 | 64 |
| Kuhn | Kosciusko | 49 | 40 | 48 | 46 |
| Kunkel | Wells | 65 | 52 | 75 | 64 |
| Lake of the Woods | Marshall | 67 | 64 | 63 | 65 |
| Larwill | Whitley | 67 | 65 | 48 | 60 |
| Latta | Noble | 59 | 37 | 37 | 44 |
| Lemon | Monroe | 77 | 69 | 62 | 69 |
| Little Chapman | Kosciusko | 57 | 48 | 55 | 53 |
| Little Turkey | Steuben | 59 | 62 | 56 | 59 |
| Little Turkey | LaGrange | 51 | 52 | 60 | 54 |

| LAKE NAME | COUNTY | TSI(SD) | TSI(Chl) | TSI(TP_Epi) | TSI(Mean) |
|---|---|---|---|---|---|
| Locust | Sullivan | 40 | 33 | 48 | 40 |
| Long | Wabash | 42 | 43 | 44 | 43 |
| Long | Noble | 52 | 55 | 59 | 55 |
| Long (Dugger) | Sullivan | 36 | 33 | 44 | 38 |
| Long (Pleasant) | Steuben | 59 | 59 | 47 | 55 |
| Loon | Steuben | 51 | 38 | 48 | 46 |
| Lukens | Wabash | 55 | 39 | 40 | 45 |
| Manitou | Fulton | 62 | 58 | 54 | 58 |
| Martin | LaGrange | 41 | 37 | 45 | 41 |
| Mateer | LaGrange | 40 | 35 | 37 | 37 |
| McClures | Kosciusko | 73 | | 59 | 66 |
| Messick | LaGrange | 53 | 50 | 52 | 52 |
| Mill Pond | Marshall | 52 | 59 | 54 | 55 |
| Miller (Chain of Lakes) | Noble | 60 | 40 | 65 | 55 |
| Monroe (Lower) | Monroe | 54 | 53 | 47 | 51 |
| Morse Reservoir | Hamilton | 67 | 70 | 60 | 66 |
| Mud (Chain of Lakes) | Noble | 59 | 62 | 74 | 65 |
| Narrow | Sullivan | 55 | 62 | 37 | 51 |
| Nasby Mill Pond | LaGrange | 60 | 47 | 64 | 57 |
| Norman | Noble | 50 | 55 | 55 | 53 |
| Old | Whitley | 50 | 50 | 55 | 52 |
| Olin | LaGrange | 52 | 32 | 37 | 40 |
| Ontario Mill Pond | LaGrange | 62 | 48 | 60 | 57 |
| Oswego | Kosciusko | 54 | 49 | 47 | 50 |
| Otter | Steuben | 55 | 48 | 42 | 48 |
| Patoka Reservoir | Dubois | 52 | 37 | 44 | 44 |
| Pigeon | LaGrange | 59 | 51 | 55 | 55 |
| Port Mitchell | Noble | 59 | 62 | 56 | 59 |
| Prairie Creek Reservoir | Delaware | 62 | 54 | 51 | 56 |
| Pretty | LaGrange | 39 | | 42 | 41 |
| Prides Creek | Pike | 47 | 33 | 50 | 43 |
| Pump | Sullivan | 41 | 33 | 37 | 37 |
| Reservoir 29 | Sullivan | 45 | 30 | 37 | 37 |
| Rider | Noble | 49 | 47 | 51 | 49 |
| Ridinger | Kosciusko | 57 | 49 | 61 | 56 |
| Robinson | Whitley | 55 | 59 | 65 | 60 |
| Sacrider | Noble | 50 | 58 | 59 | 56 |
| Sand | Noble | 56 | 60 | 59 | 58 |
| Sawmill | Kosciusko | 57 | 52 | 52 | 54 |
| Scales | Warrick | 57 | 44 | 66 | 56 |
| Scheister | Clay | 36 | | 45 | 41 |
| Sechrist | Kosciusko | 52 | 40 | 45 | 46 |
| Shaffer | White | 65 | 72 | 69 | 69 |
| Shakamak | Sullivan | 59 | 63 | 66 | 63 |
| Shake 2 | Greene | 41 | 33 | 59 | 44 |

| LAKE NAME | COUNTY | TSI(SD) | TSI(Chl) | TSI(TP_Epi) | TSI(Mean) |
|---|---|---|---|---|---|
| Simonton | Elkhart | 52 | 28 | 49 | 43 |
| South Mud | Fulton | 65 | 55 | 60 | 60 |
| Spencer | Sullivan | 46 | | 40 | 43 |
| Spurgeon Hollow | Washington | 55 | 52 | 47 | 51 |
| Star | Greene | 45 | 41 | 37 | 41 |
| Starve Hollow | Jackson | 57 | 57 | 54 | 56 |
| Steinbarger | Noble | 52 | 51 | 87 | 63 |
| Stone | LaPorte | 39 | 34 | 44 | 39 |
| Stone | LaGrange | 41 | 41 | 41 | 41 |
| Stump Jumper | Clay | 35 | 38 | 37 | 37 |
| Sullivan | Sullivan | 70 | 66 | 64 | 67 |
| Sycamore | Greene | 42 | 48 | 52 | 47 |
| Sylvan | Noble | 65 | 56 | 59 | 60 |
| Tamarack | LaPorte | 72 | 80 | 71 | 74 |
| Thomas | Marshall | 50 | 38 | 51 | 46 |
| Tipsaw | Perry | 54 | 54 | 47 | 52 |
| Tree | Sullivan | 53 | | 47 | 50 |
| Trout | Sullivan | 54 | 47 | 37 | 46 |
| Troy Cedar | Whitley | 63 | 67 | 68 | 66 |
| Twin Pits, East | Pike | 54 | 51 | 37 | 47 |
| Twin Pits, West | Pike | 60 | 51 | 64 | 58 |
| Upper Long | Noble | 52 | 53 | 52 | 52 |
| Versailles | Ripley | 83 | 76 | 78 | 79 |
| Wall | LaGrange | 40 | 36 | 57 | 44 |
| Wawasee | Kosciusko | 45 | 34 | 47 | 42 |
| West | Greene | 60 | 37 | 37 | 45 |
| Williams | Noble | 65 | 63 | 59 | 62 |

**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 33 shows the Carlson averaged trophic state index for all lakes assessed during 2010 – 2011. 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 160 marks for the lakes spread over the state. To help identify patterns, we will aggregate the data by ecoregion.

Figure 34 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 64, the highest of the five Ecoregions. A TSI score of 64 is within the eutrophic category (51-64) (Table 11). 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 52, which is on the lower end 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 ecoregions have the highest median average total phosphorus concentrations, well into the hypereutrophic range (Figure 35 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. Lakes within Ecoregion 56 have a lower median TP concentration but it is still within the hypereutrophic range. In the southern ecoregions (71 and 72) the median TP concentrations are at the lower end of the eutrophic range.

Havens and Nürnberg (2004) suggest that with increasing total phosphorus concentrations, chlorophyll-a concentrations increase. The excess phosphorus apparent in Figure 35 grows abundant phytoplankton, as shown by chlorophyll-a medians in Figure 36. The two ecoregions with the highest median total phosphorus concentrations had the highest median chlorophyll-a concentrations, as predicted by Havens and Nürnberg.

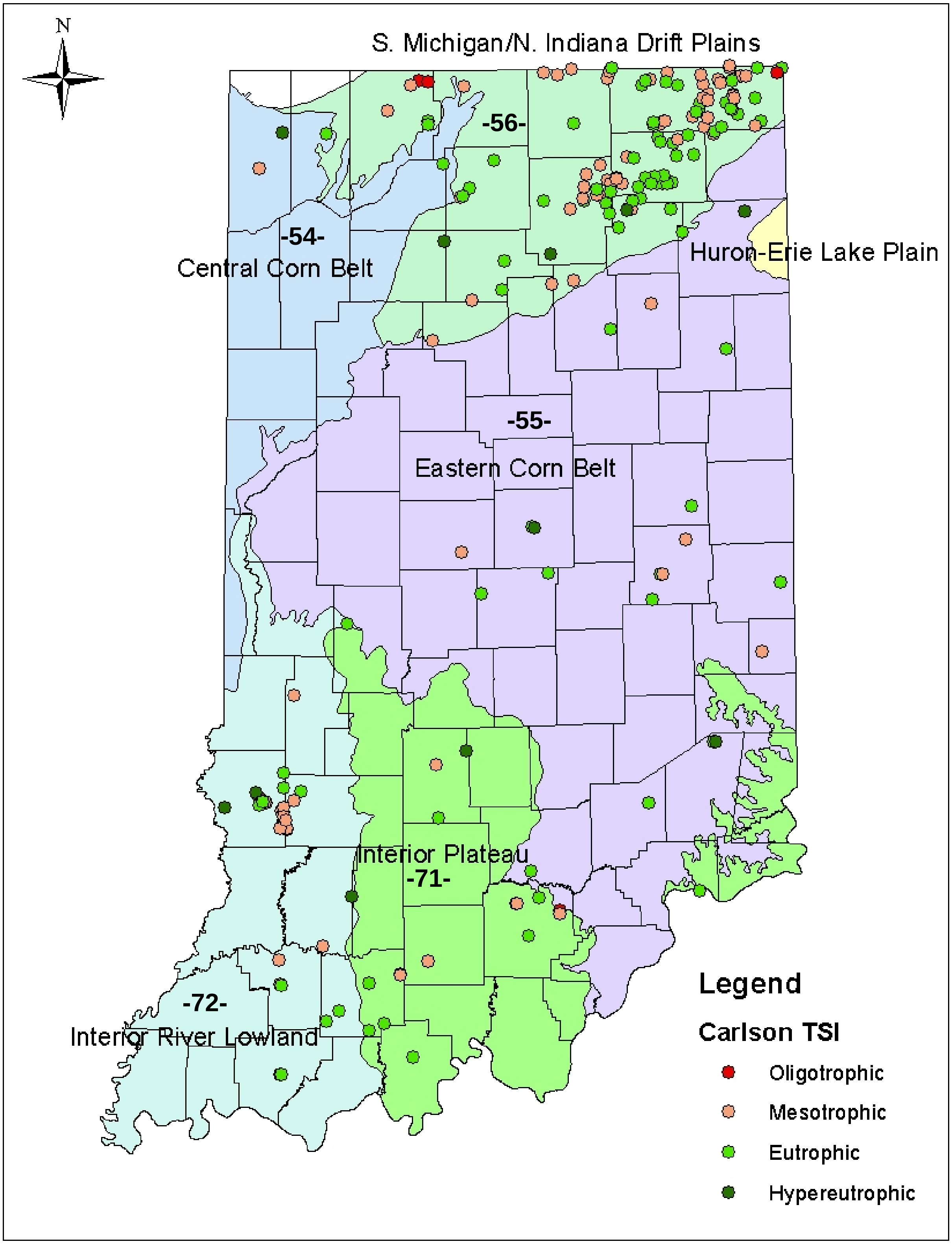



**Figure 33. Carlson mean TSI trophic state for lakes assessed during 2010 – 2011 overlain on Indiana Ecoregions.**

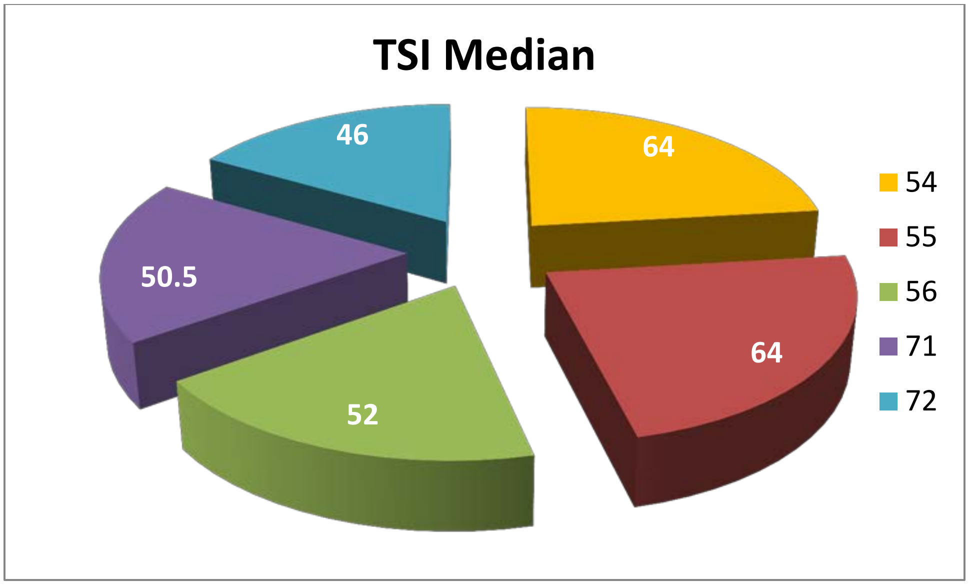



**Figure 34. Mean Carlson TSI of all lakes assessed during 2010 – 2011 aggregated by Ecoregion. Median TSI scores for each Ecoregion are shown in white.**

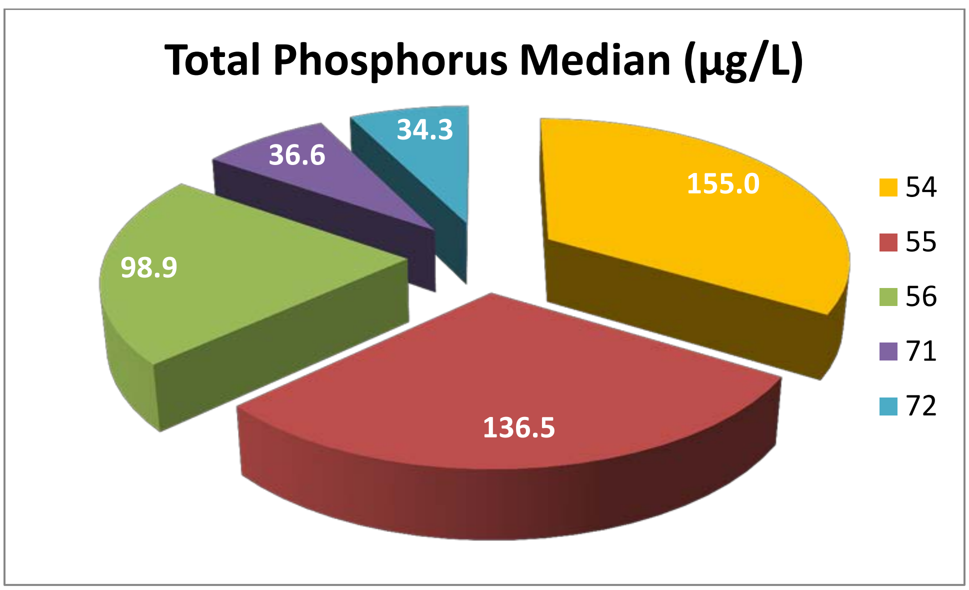



**Figure 35. Mean total phosphorus of all lakes assessed during 2010 – 2011 aggregated by Ecoregion. Median TP concentrations for each Ecoregion are shown in white.**

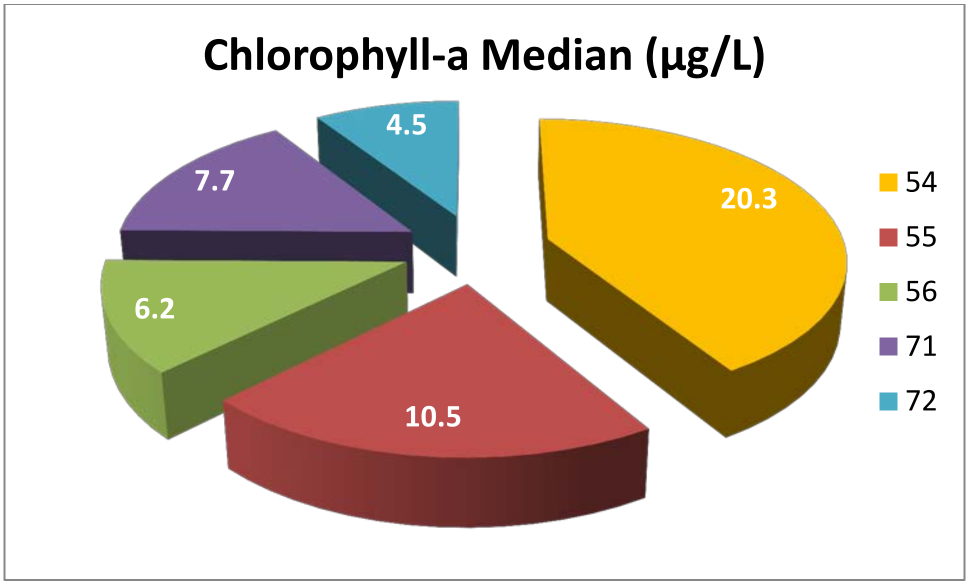



**Figure 36. Chlorophyll-a of all lakes assessed during 2010 – 2011 aggregated by Ecoregion. Median chlorophyll-a concentrations for each Ecoregion are shown in white.**

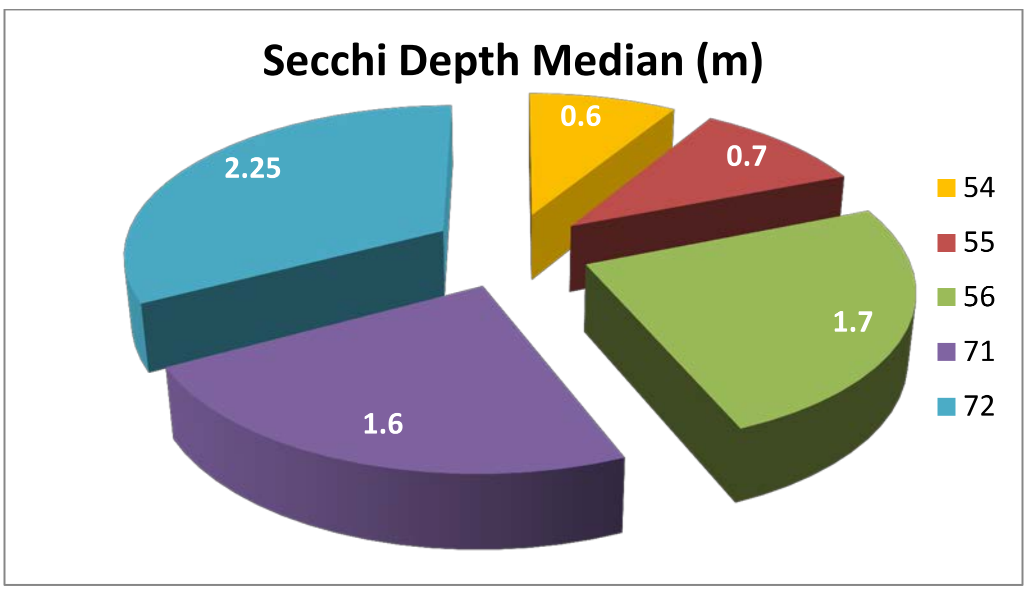



**Figure 37. Secchi disk transparency of all lakes assessed during 2010 – 2011 aggregated by Ecoregion. Median Secchi depths for each Ecoregion are shown in white.**

Abundant phytoplankton contributes to reduced clarity in the lakes (Figure 37). 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 <u>less</u> phytoplankton than what is predicted by the phosphorus available to help grow the phytoplankton (Figure 38).

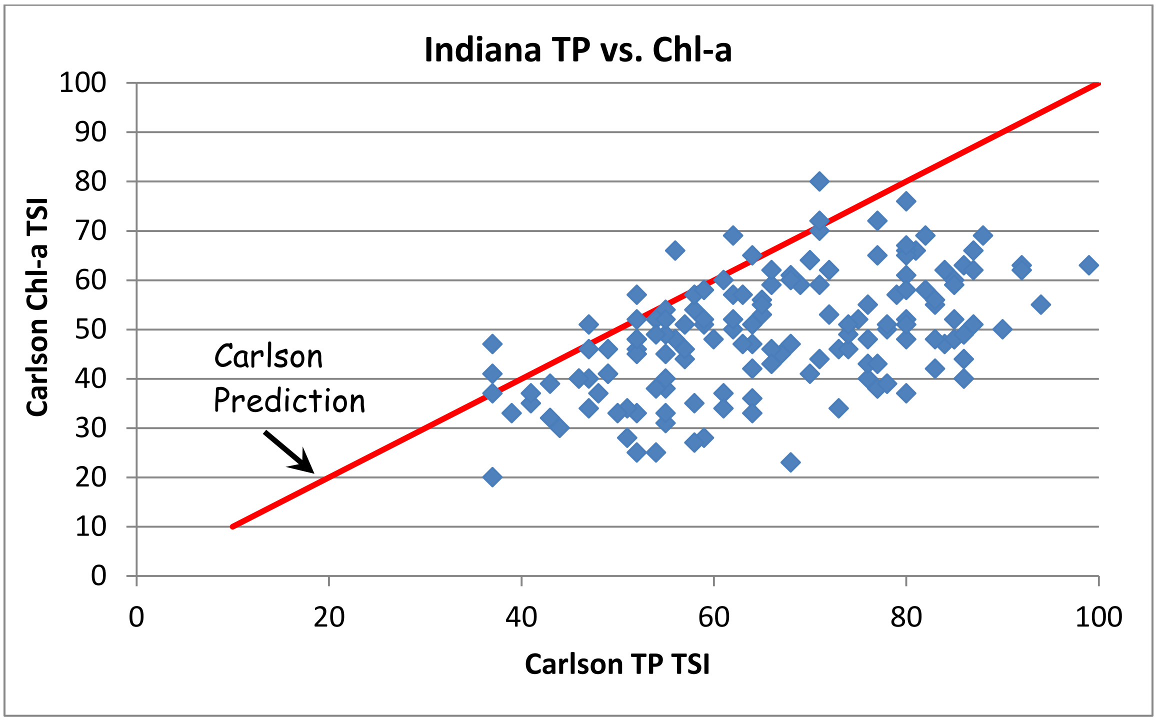



**Figure 38. Carlson TP TSI scores plotted against Carlson Chl-a TSI scores for all 160 lakes assessed during 2010 – 2011. The red line is the predicted relationship between the two parameters.**

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 38 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 all 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 2010 – 2011 data by lake type.

As Figure 39 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.

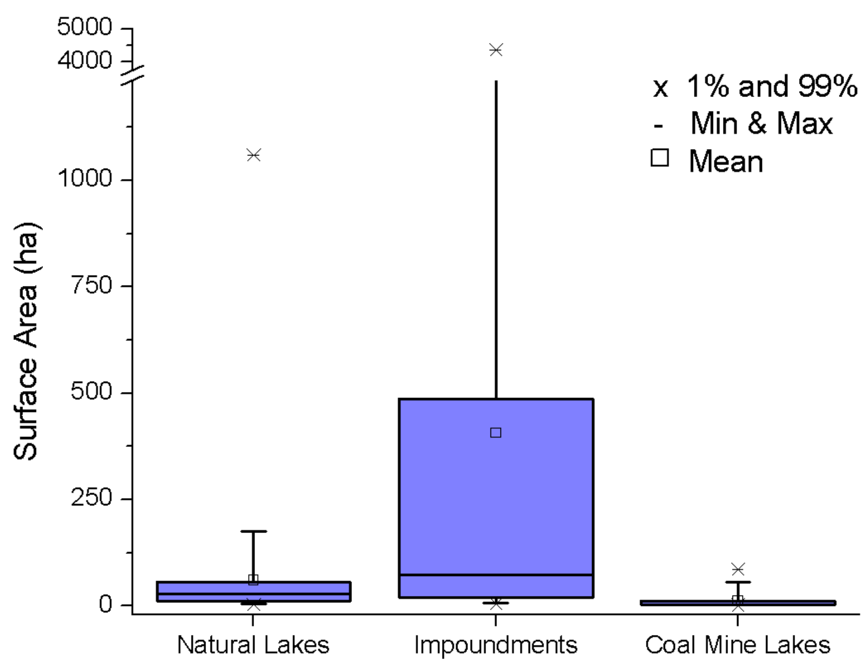



**Figure 39. Box plot of surface areas for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square. A shallow box indicates less variation in the data while a tall box indicates more variation.**

Natural lakes are generally deeper than the impoundments and coal mine lakes in Indiana (Figure 40). 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.

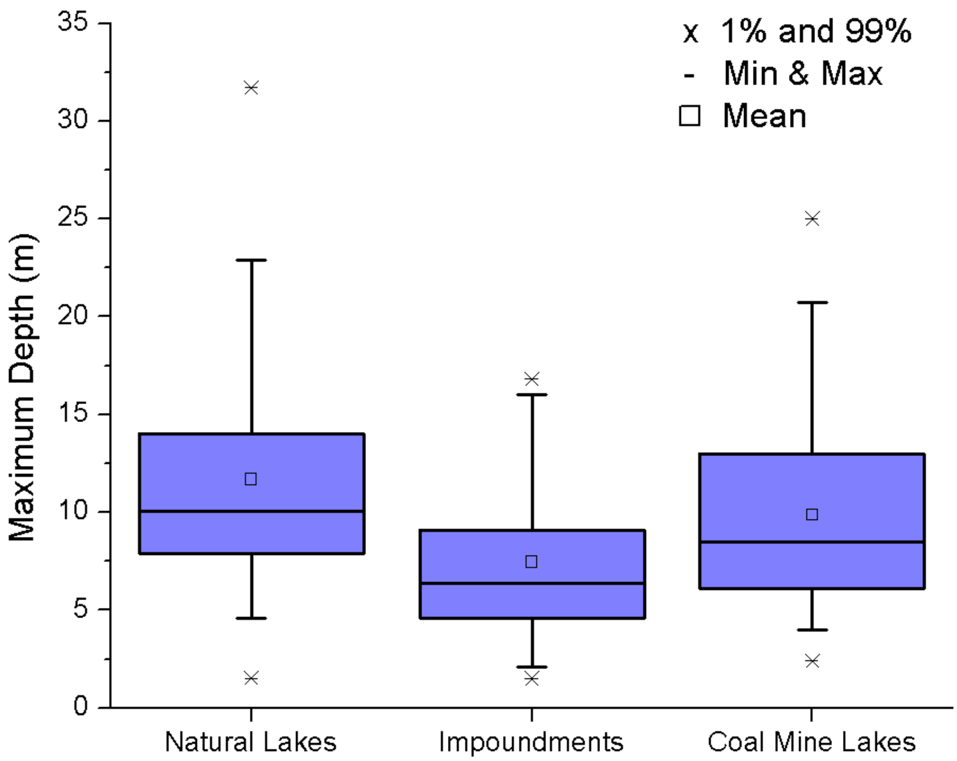



**Figure 40. Box plot of maximum depth for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.**

Figure 41 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 41 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

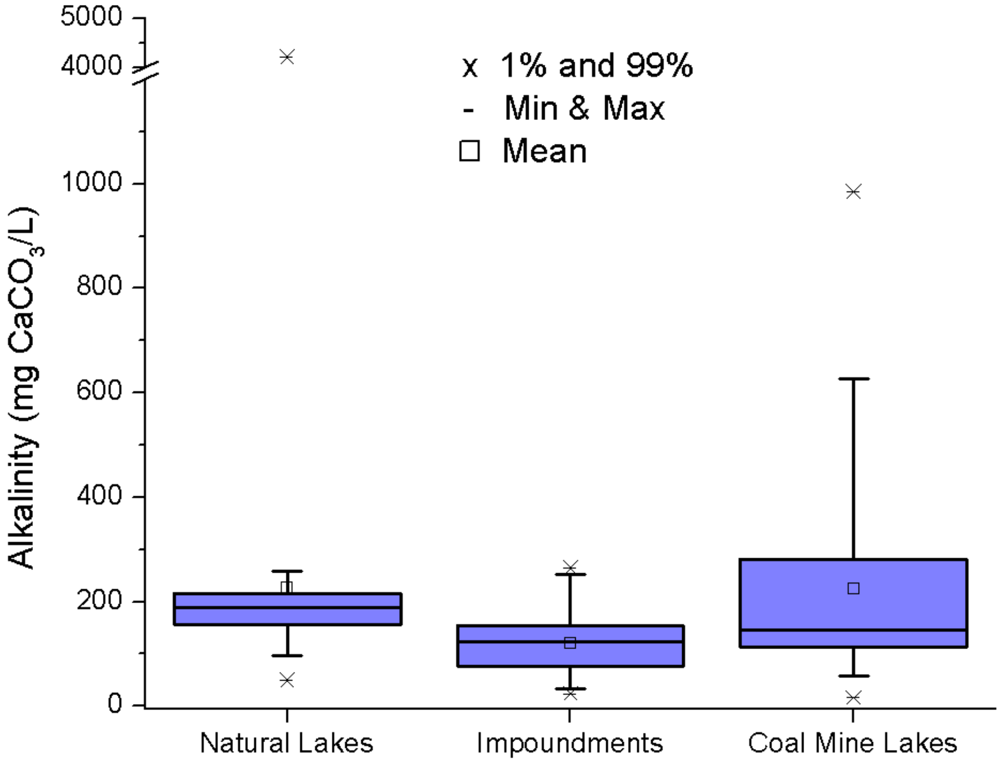



**Figure 41. Box plot of alkalinity for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.**

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 42 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 42 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

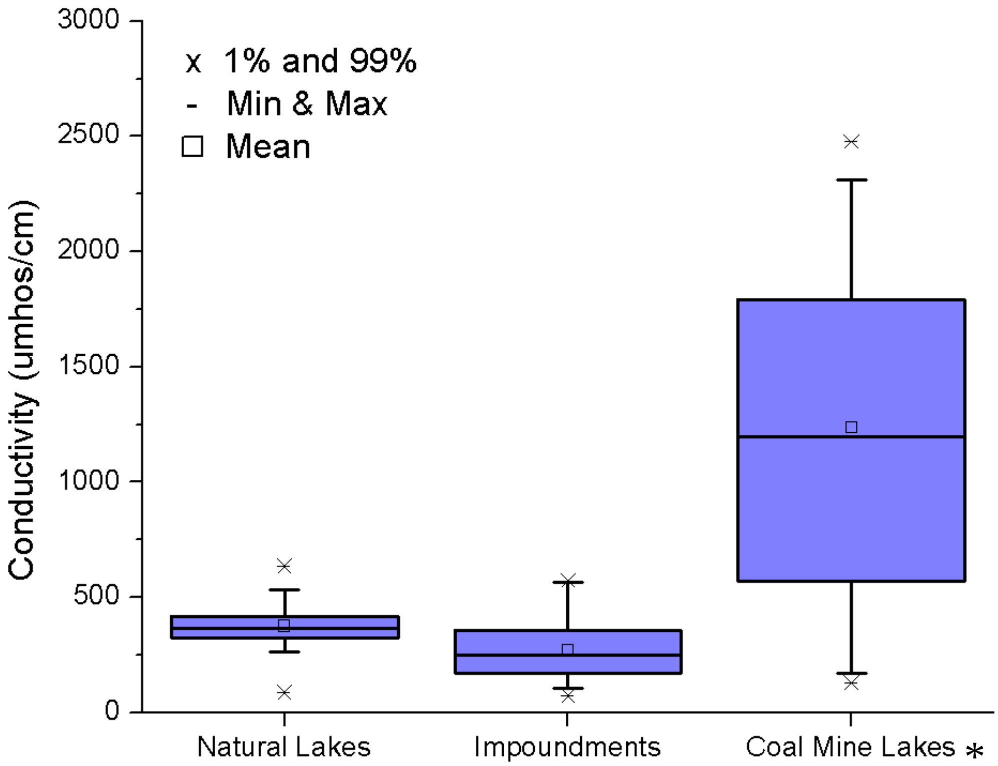



**Figure 42. Box plot of conductivity for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square. An asterisk next to a lake type name indicates that lake type mean is statistically different than the other lake type means.**

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 43 shows the distribution of pH among natural lakes, impoundments and coal mine lakes. The mean for coal mine lakes is statistically lower than that of natural lakes but not for 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 both natural lakes and impoundments have extreme low outliers, the lowest pH values of all the lakes. This occurs at Spurgeon Hollow (Washington Co.) and Canada Lake (Porter Co.). Spurgeon Hollow is within Jackson-Washington State Forest and Canada Lake lies within a bog/wetland area.

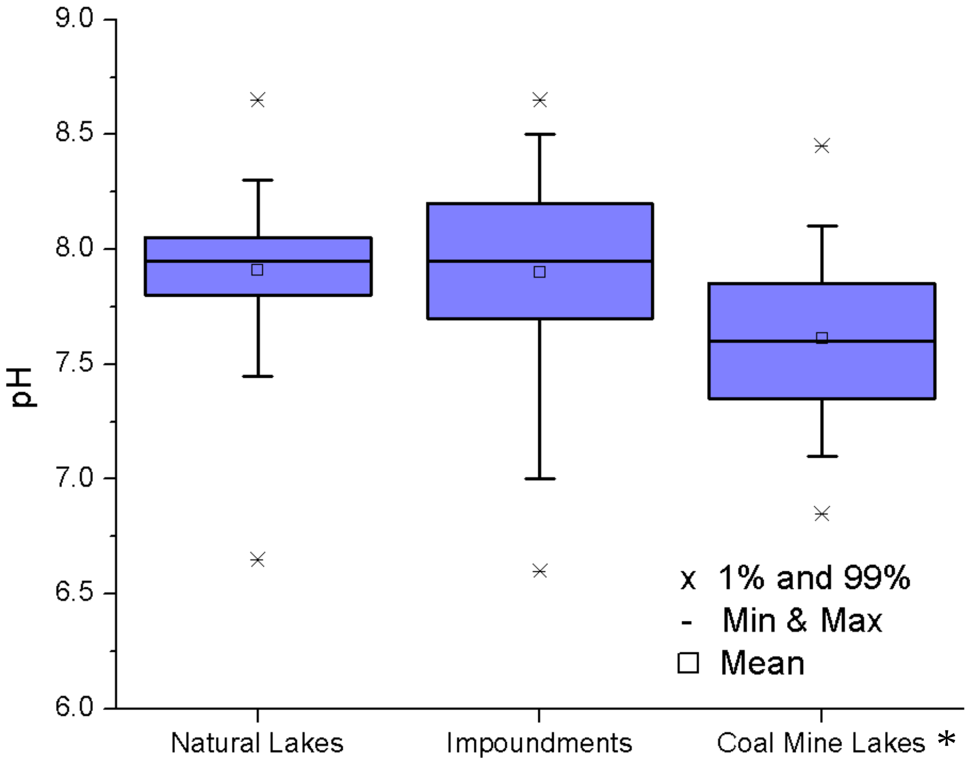



**Figure 43. Box plot of pH for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square. The coal mine lake pH mean is statistically different than the pH mean for natural lakes.**

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 7.4 and 6.3, respectively, by July, 2010 when we sampled it. However, Reservoir 29's pH remains below the average for all the coal mine lakes that were sampled during 2010 - 2011.

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. Figure 44 shows that in Indiana, there is a statistically significant difference in mean Secchi disk transparency among the lake types.

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

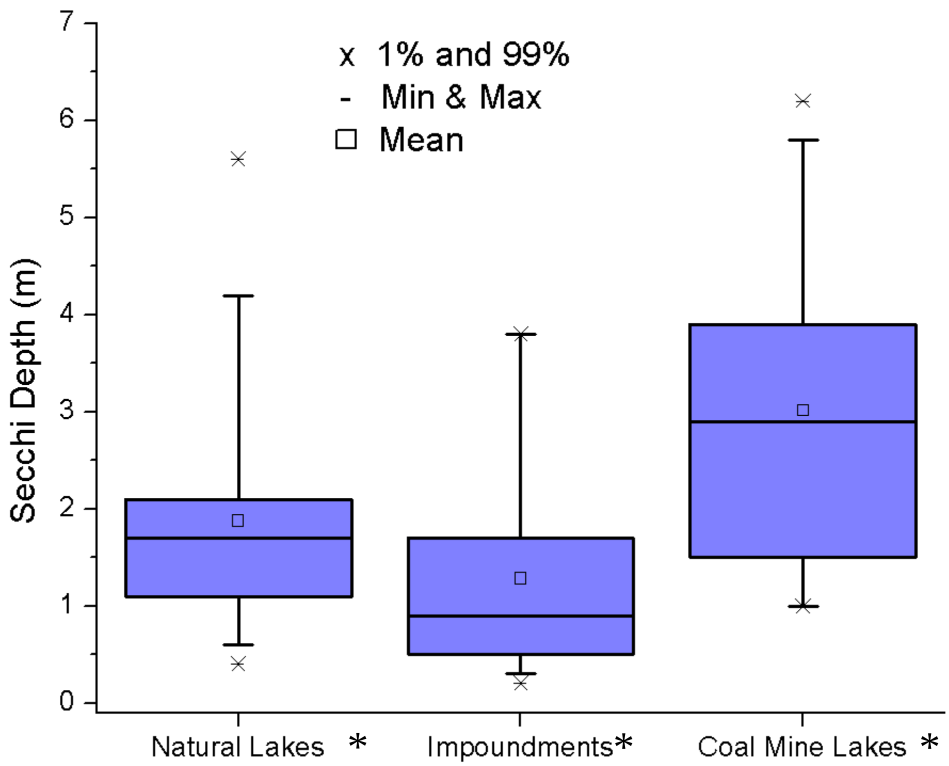



**Figure 44. Box plot of Secchi disk transparency for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square. An asterisk next to a lake type name indicates that lake type mean is statistically different than the other lake type means.**

grow phytoplankton. And it is the phytoplankton growth that most often contributes to poor Secchi disk transparency in natural lakes.

That natural lakes have higher total phosphorus concentrations is illustrated in Figure 45. 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 much greater. One natural lake (Hog Lake, Steuben Co.) also had the highest total phosphorus concentration as shown by the x symbol in Figure 45. 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.

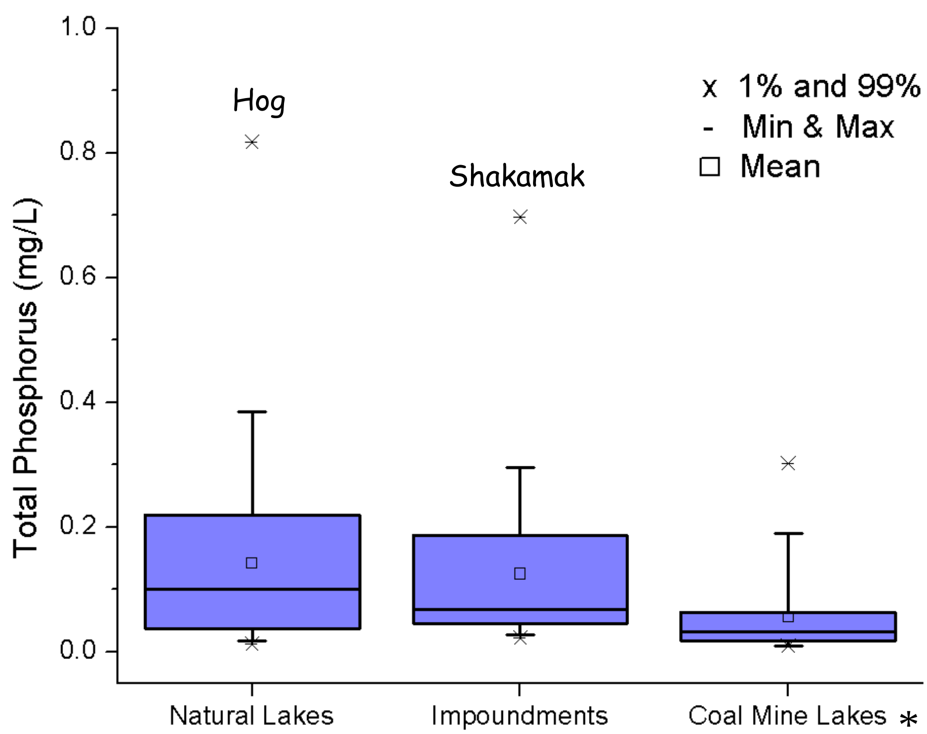



**Figure 45. Box plot of mean total phosphorus for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square. An asterisk next to a lake type name indicates that lake type mean is statistically different than the other lake type means.**

There was little difference in the distributions of nitrate-nitrogen and ammonia-nitrogen among the three lake types (Figures 46 and 47). 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 Little Turkey Lake (Steuben Co.) for the natural lakes and Knightstown Reservoir (Henry Co.) for the impoundments.

The highest mean ammonia-nitrogen concentration occurred at Airline Pit (Greene Co.) a coal mine lake. Another coal mine lake (Trout Lake in Sullivan Co.) had the next highest ammonia-nitrogen concentration. These two anomalies skewed the mean upward for the coal mine lakes, which typically had low ammonia-nitrogen concentrations. McClures Lake (Kosciusko Co.) was the high ammonia-nitrogen concentration outlier for the natural lakes.

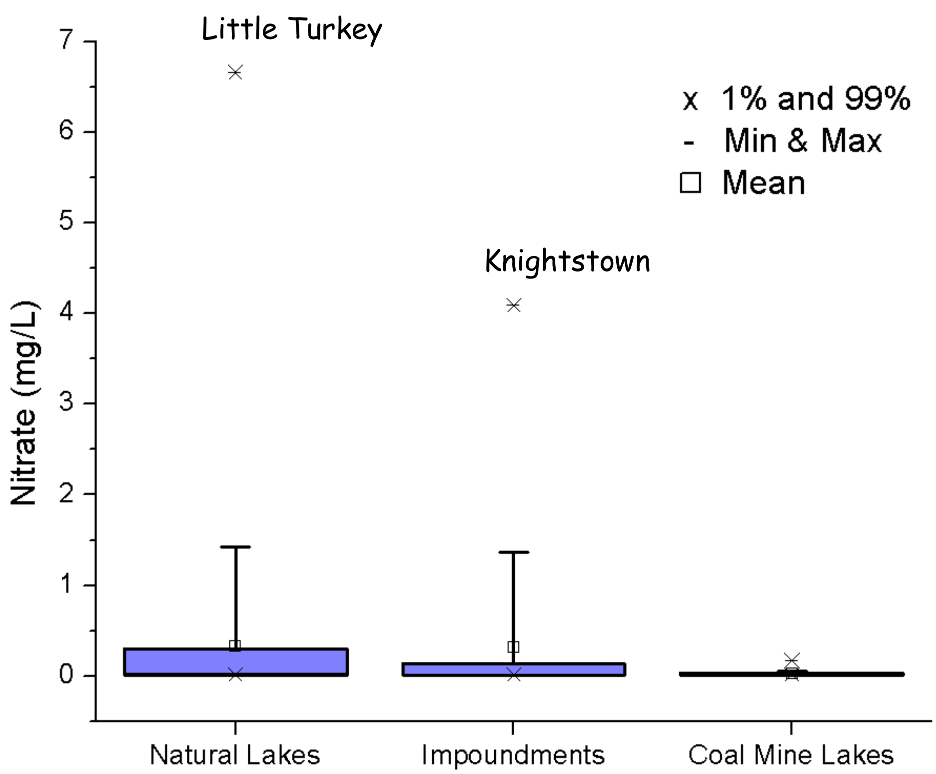



**Figure 46. Box plot of mean nitrate-nitrogen for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.**

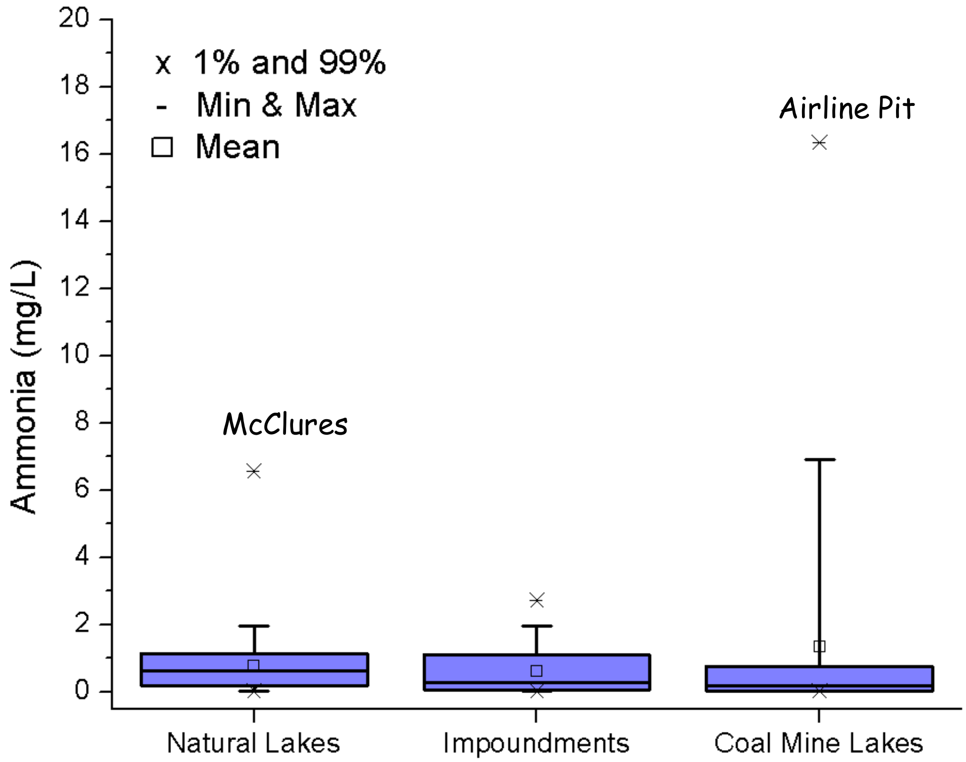



**Figure 47. Box plot of mean ammonia-nitrogen for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square.**

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 natural lakes and impoundments were at Tamarack Lake, a shallow lake in Porter Co. and Versailles Lake, a reservoir in Ripley Co.

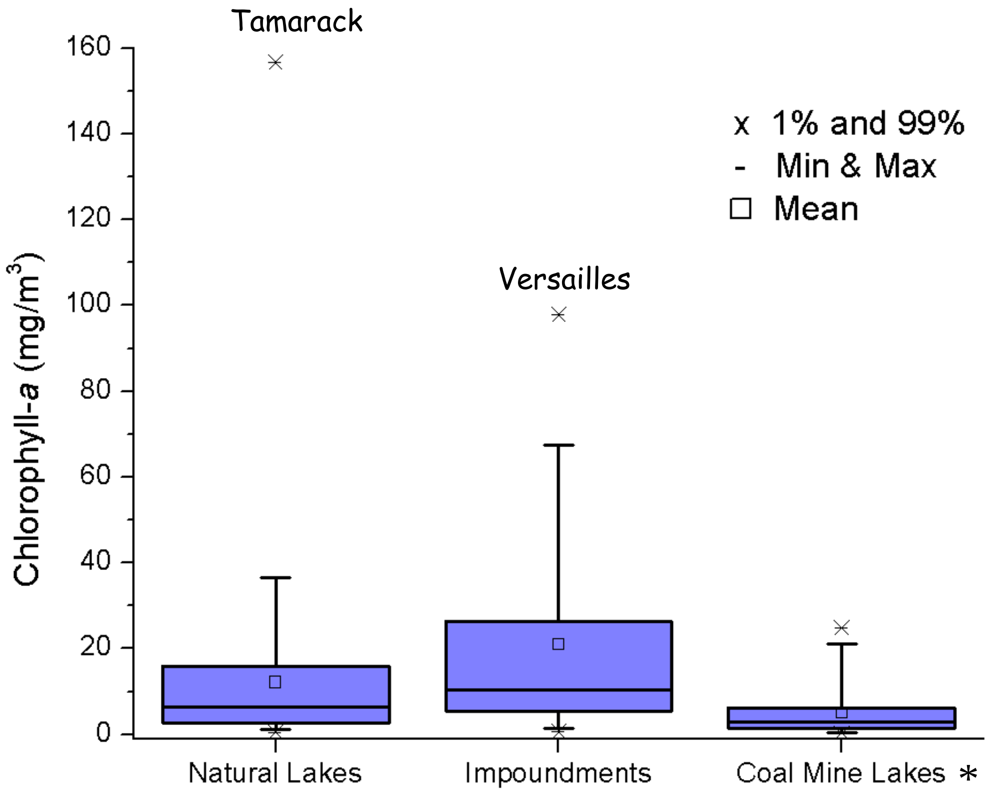



**Figure 48. Box plot of chlorophyll-a for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square. An asterisk next to a lake type name indicates that lake type mean is statistically different than the other lake type means.**

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 49). 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.

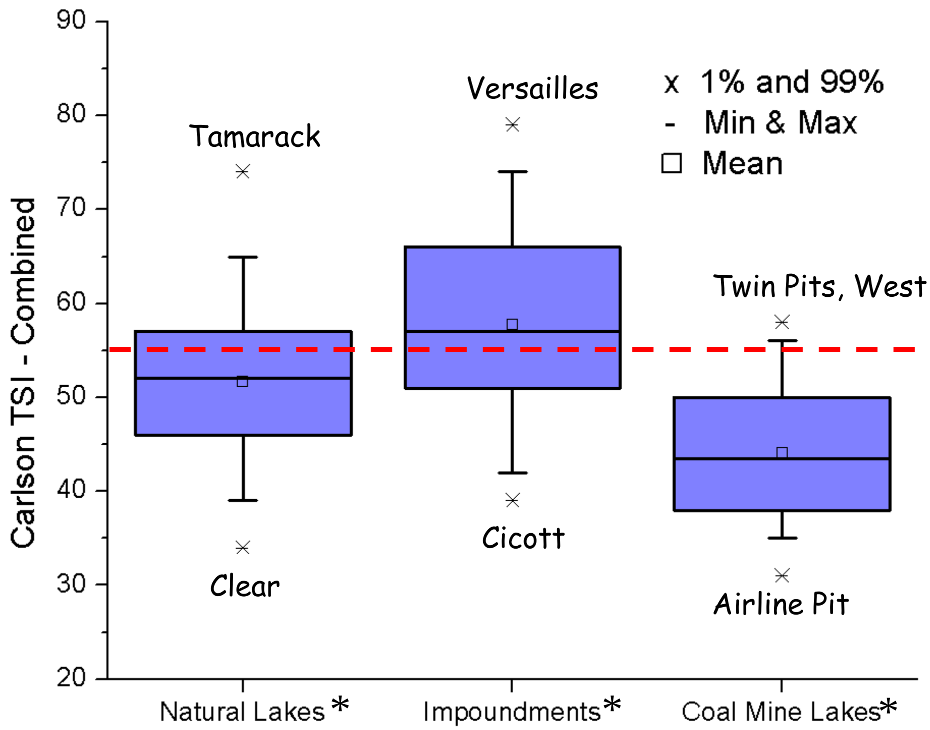



**Figure 49. Box plot of mean Carlson's TSI for the three lake types. The median value is shown by the horizontal line within the box. The mean is shown by the small square. An asterisk next to each lake type label indicates that each lake type mean TSI is statistically different from the other lake types. The dashed red line is the lower limit of the eutrophic classification.**

## CONCLUSION

Summary conclusions from the 2009 – 2011 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 61% of lakes assessed.
- Most Indiana lakes are eutrophic and the number of eutrophic lakes is increasing; 55% of all lakes assessed during 2009 – 2011 vs. 46% of all lakes assessed during 2004 – 2008.
- Impoundments are most eutrophic, natural lakes are next, and coal mine lakes are least eutrophic.
- Changes in our plankton sampling, analysis, and reporting protocols implemented for the 2010 – 2011 assessments are consistent with prevailing methods currently used in limnology, but these changes could not be adapted for use in the Indiana Trophic State Index.
- Carlson's Trophic State Index is a useful measure of overall trophic state in Indiana lakes.
- The randomized lake selection process used in 2010 – 2011 generates data more representative of all Indiana lakes than the geographical sampling pattern use in twenty previous years.

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## APPENDIX A:

## INFORMATION ABOUT LAKES SAMPLED DURING 2009 AND 2011-11

Sources: Clark (1980); IDNR (1993); CLP (2011)

Key

Natural Lake = Glacial origin

Impoundment = Reservoir

SML = Coal mine Lake

Borrow Pit = excavation hole created by construction

**INDIANA CLEAN LAKES PROGRAM - 2009 Sampling List**

School of Public & Environmental Affairs, Bloomington

| LAKE NAME | COUNTY | LOCATION | AREA (ac) | MAX DEPTH (ft) | LAKE TYPE |
|---|---|---|---|---|---|
| Cedarville Res. | Allen | At Cedarville | 245 | 15 | impoundment |
| Everett | Allen | 3 mi N of Aarcola | 43 | 44 | impoundment |
| Dogwood (Glendale) | Daviess | 1 1/2 mi. S.W. of Glendale | 1414 | 40 | impoundment |
| Story (lower) | Dekalb | 4 1/2 mi. W. of Ashley | 77 | 30 | Natural Lake |
| Story (Upper) | Dekalb | 4 1/2 mi. W. of Ashley | | 29 | Natural Lake |
| Prairie Creek Res. | Delaware | 6 mi. S.E. of Muncie | 1216 | 30 | impoundment |
| Beaver Creek Res. | Dubois | 4 mi. E. of Jasper | 173 | 31 | impoundment |
| Ferdinand City | Dubois | in Ferdinand St. Forest | 36 | 21 | impoundment |
| Ferdinand City New | Dubois | 2 mi. E of Ferdinand | 10 | 15 | impoundment |
| Holland 2 | Dubois | N. edge of Holland | 20 | 16 | impoundment |
| Huntingburg City | Dubois | 1.5 mi. W of Huntingburg | 181 | 23 | impoundment |
| Patoka Res. | Dubois | 3 mi. N of Birdseye | 8880 | 52 | impoundment |
| Goshen Dam Pond | Elkhart | S edge of Goshen | 142 | 8 | impoundment |
| Heaton | Elkhart | 3 mi. N. of Elkhart, 4 mi. E. of SR 19 | 87 | 22 | Natural Lake |
| Hunter | Elkhart | 4 mi. N. of Middlebury | 99 | 27 | Natural Lake |
| Simonton | Elkhart | 4 mi. N. of Elkhart | 282 | 20 | Natural Lake |
| Morse Res. | Hamilton | 3 mi. NW of Noblesville | 1500 | 45 | impoundment |
| Big Blue #13 (Westwood) | Henry | | 173 | 44 | impoundment |
| Knightstown (Big Blue #7) | Henry | 2.5 mi. W of Dunreith | 40 | 16 | impoundment |
| Summit | Henry | 4 mi. SW of Mt. Pleasant | 815 | 42 | impoundment |
| Clair | Huntington | East Edge of Huntington | 43 | 54 | quarry |
| Huntington Res. | Huntington | | 900 | 24 | impoundment |
| Salamonie Res. | Huntington | E. of Wabash | 2800 | 60 | impoundment |
| Starve Hollow | Jackson | in Jackson State Forest | 145 | 17 | impoundment |
| Crosley | Jennings | 2 mi. S. Vernon | 14 | 20 | impoundment |
| Appleman | LaGrange | 2 1/2 mi. N.N.W. of Elmira | 52 | 29 | Natural Lake |
| Cedar | LaGrange | 4 mi. E.N.E. of Howe | 120 | 31 | Natural Lake |
| Saugany | LaPorte | 5 mi. N.E. Rolling Prairie | 74 | 66 | Natural Lake |
| Geist Res. | Marion | 3 mi. N. of McCordsville | 1800 | 22 | impoundment |
| West Boggs Res. | Martin | 2.5 mi. N of Loogootee | 622 | 26 | impoundment |
| Griffy | Monroe | 1/4 mi. E. of Bloomington | 130 | 36 | impoundment |
| Springs Valley(Tucker) | Orange | 6 mi. S.E. of French Lick | 141 | 29 | impoundment |
| Hovey | Posey | 9 mi. S.W. of Mt. Vernon | 242 | 7 | impoundment |
| Bischoff Res. | Ripley | 2 mi. SE of Batesville | 200 | 21 | impoundment |
| Molenkramer Res. | Ripley | 1 1/2 mi. S. of Batesville | 93 | 8 | impoundment |
| Versailles | Ripley | in Versailles State Park | 230 | 30 | impoundment |
| Ball | Steuben | 1 1/2 mi. N.W. Hamilton | 87 | 66 | Natural Lake |
| Barton | Steuben | 5 1/2 mi. N.E. of Orland | 94 | 30 | Natural Lake |
| Beaver Dam | Steuben | 3 mi. SW of Orland | 11 | 26 | Natural Lake |
| Big Otter | Steuben | 5 mi. N of Angola | 69 | 39 | Natural Lake |
| Bower | Steuben | 3 mi. N.W. Pleasant Lake | 25 | 22 | Natural Lake |

| LAKE NAME | COUNTY | LOCATION | AREA (ac) | MAX DEPTH (ft) | LAKE TYPE |
|---|---|---|---|---|---|
| Fish | Steuben | 1 mi. N. of Fremont | 59 | 25 | Natural Lake |
| Gage | Steuben | 3 mi. S.E. of Orland | 327 | 66 | Natural Lake |
| Hog | Steuben | 5 mi. E.of Orland | 48 | 26 | Natural Lake |
| Lime (Gage) | Steuben | 1/4 mi. N. of Lake Gage | 30 | 26 | Natural Lake |
| Little Otter | Steuben | 5 mi. N. Angola | 34 | 37 | Natural Lake |
| Little Turkey | Steuben | 1 1/2 mi. W. Hudson | 58 | 28 | Natural Lake |
| Long (Clear) | Steuben | 1/2 mi. E. of Clear Lake | 154 | 30 | Natural Lake |
| Long (Pleasant) | Steuben | at Pleasant Lake | 92 | 32 | Natural Lake |
| Loon | Steuben | 4 mi. N.W. of Angola | 138 | 18 | Natural Lake |
| Marsh | Steuben | 6 mi. N. of Angola | 56 | 38 | Natural Lake |
| McClish | Steuben | 1 mi. N.W. of Helmer | 35 | 57 | Natural Lake |
| Otter | Steuben | 9 mi. W. of Angola | 118 | 31 | Natural Lake |
| Pigeon | Steuben | 3 mi. E. of Angola | 61 | 38 | Natural Lake |
| Stayner/Gannon | Steuben | 5 mi S. of Orland | 5 | 19 | Natural Lake |
| Island | Sullivan | Minnehaha F&W Area | 19 | 48 | SML |
| Sullivan | Sullivan | at Sullivan | 507 | 23 | impoundment |
| Turtle Creek Reservoir | Sullivan | 1 mi E. of Merom (Hoosier Energy) | 1550 | 33 | impoundment |
| Whitewater | Union | 1 1/2 mi. S. of Liberty in Whitewater SP | 199 | 46 | impoundment |
| Scales | Warrick | in Scales Lake State Park | 66 | 20 | SML |
| Elk Creek #9 | Washington | 2 mi. E of Georgetown | 48 | 35 | impoundment |
| John Hay | Washington | at Salem | 210 | 28 | impoundment |
| Salinda | Washington | 1 mi. S. of Salem | 126 | 23 | impoundment |
| Spurgeon Hollow | Washington | Jackson-Washington State Forest | 12 | 28 | impoundment |
| Middlefork Res. | Wayne | 2 mi. N. of Richmond | 277 | 30 | impoundment |
| Kunkel | Wells | in Wabash State Recreation Area | 25 | 19 | impoundment |
| Old | Whitley | 1 mi. E of Etna | 32 | 42 | Natural Lake |
| Troy Cedar | Whitley | 8 mi. NW of Columbia City | 93 | 88 | Natural Lake |

**INDIANA CLEAN LAKES PROGRAM - 2010 Sampling List**

School of Public & Environmental Affairs, Bloomington

| LAKE NAME | COUNTY | LOCATION | AREA (ac) | MAX DEPTH (ft) | LAKE TYPE |
|---|---|---|---|---|---|
| Cicott | Cass | 9 mi. W. of Logansport on SR 24 | 65 | 53 | impoundment |
| Scheister | Clay | Chinook F&W Area | 10 | 52 | SML |
| Prairie Creek Res. | Delaware | 6 mi. S.E. of Muncie | 1216 | 30 | impoundment |
| Huntingburg City | Dubois | 1.5 mi. W of Huntingburg | 181 | 21 | impoundment |
| Patoka Res. | Dubois | 3 mi. N of Birdseye | 8880 | 55 | impoundment |
| Indiana | Elkhart | 3 mi. N.W. of Bristol | 122 | 65 | Natural Lake |
| Simonton | Elkhart | 4 mi. N. of Elkhart | 282 | 20 | Natural Lake |
| Kings | Fulton | 1 mi. S. Delong | 19 | 35 | Natural Lake |
| South Mud | Fulton | 4 mi. N.E. of Fulton | 94 | 27 | Natural Lake |
| Airline | Greene | in Greene-Sullivan State Forest | 25 | 68 | SML |
| Corky | Greene | in Greene-Sullivan State Forest | 12 | 53 | SML |
| Hammond | Greene | in Greene-Sullivan State Forest | 6 | 28 | SML |
| Knightstown (Big Blue #7) | Henry | 2.5 mi. W of Dunreith | 40 | 16 | impoundment |
| Brush Creek Res | Jennings | 1 mi. N. Butlerville | 167 | 32 | impoundment |
| Barrel 1/2 | Kosciusko | in Tri-Co. Fish & Game Area | 7 | 48 | natural lake |
| Goldeneye | Kosciusko | Tri-Co. FWA | 20 | 15 | impoundment |
| Hoffman | Kosciusko | 1 1/2 mi. N.W. of Atwood | 187 | 34 | Natural Lake |
| Kuhn | Kosciusko | 3 mi. SW of North Webster | 118 | 27 | Natural Lake |
| Little Chapman | Kosciusko | 3 mi NE of Warsaw | 120 | 30 | Natural Lake |
| McClures | Kosciusko | 3 1/2 mi. W. ofSilver Lake | 32 | 27 | Natural Lake |
| Ridinger | Kosciusko | 4 mi. W. of Warsaw | 136 | 42 | Natural Lake |
| Sawmill | Kosciusko | 2 1/2 mi. S.W. of North Webster | 27 | 26 | Natural Lake |
| Sechrist | Kosciusko | 2 1/2 mi. S.W. of North Webster | 99 | 59 | Natural Lake |
| Wawasee | Kosciusko | at Syracuse | 2618 | 77 | Natural Lake |
| Appleman | LaGrange | 2 1/2 mi. N.N.W. of Elmira | 52 | 29 | Natural Lake |
| Buck | LaGrange | 1 1/2 mi. S.E. ofSeybert | 18 | 20 | Natural Lake |
| Dallas | LaGrange | 4 1/2 mi. N.W. ofWolcottville | 283 | 100 | Natural Lake |
| Mateer | LaGrange | 2 mi. E of Howe | 18 | 16 | Natural Lake |
| Nasby Mill Pond | LaGrange | 2.5 mi. W of Mongo | 35 | 5 | impoundment |
| Olin | LaGrange | 2 1/2 mi. N.W. of Wolcottville | 103 | 80 | Natural Lake |
| Ontario Mill Pond | LaGrange | at Ontario on Pigeon R FWA | 38 | 9 | impoundment |
| Pretty | LaGrange | 3 mi. W. of Stroh | 184 | 80 | Natural Lake |
| Fancher | Lake | In Crown Pt @ Lake Co. Fairgrounds | 7 | 32 | impoundment |
| Lake George (Hobart) | Lake | W. of Hobart in city limits | 270 | 9 | impoundment |
| Hog | LaPorte | 2.5 mi. N of Rolling Prairie | 64 | 45 | Natural Lake |
| Hudson | LaPorte | 1 1/2 mi. W. of Carlisle | 432 | 42 | Natural Lake |
| Stone | LaPorte | in LaPorte | 125 | 40 | Natural Lake |
| Eagle Creek Res. | Marion | NW edge of Indianapolis | 1510 | 40 | impoundment |
| Lake of the Woods | Marshall | 5 mi. S.W. of Bremen | 416 | 48 | Natural Lake |
| Thomas | Marshall | 6 mi. S.W. Plymouth | 16 | 44 | Natural Lake |
| Lake Lemon | Monroe | 6 mi. W. of Bean Blossom | 1650 | 28 | impoundment |
| J.C. Murphy | Newton | 3 1/2 mi. N.W. of Morocco | 1200 | 8 | impoundment |

| LAKE NAME | COUNTY | LOCATION | AREA (ac) | MAX DEPTH (ft) | LAKE TYPE |
|---|---|---|---|---|---|
| Big | Noble | 8 mi. N. of Columbia City | 228 | 75 | Natural Lake |
| Bixler | Noble | E. edge of Kendallville | 117 | 38 | Natural Lake |
| Duely | Noble | 3 mi. NE of Wilmot | 21 | 19 | Natural Lake |
| Dock | Noble | Chain of Lakes State Park | 16 | 22 | Natural Lake |
| Eagle | Noble | 2 mi. N. of Kimmel | 81 | 45 | Natural Lake |
| Engle | Noble | 2 mi. S. Ligonier | 48 | 25 | Natural Lake |
| Harper | Noble | 4 1/2 mi. N.W. of Ormas | 11 | 25 | Natural Lake |
| Latta | Noble | 3 mi. E. of Rome City | 42 | 35 | Natural Lake |
| Miller (Chain-O) | Noble | Chain of Lakes State Park | 11 | 25 | Natural Lake |
| Mud (Chain-O) | Noble | Chain of Lakes State Park | 8 | 25 | Natural Lake |
| Norman | Noble | Chain of Lakes State Park | 14 | 45 | Natural Lake |
| Sylvan | Noble | at Rome City | 630 | 30 | impoundment |
| Twin Pits, East | Pike | 3 mi. N of Winslow | 31 | 16 | SML |
| Twin Pits, West | Pike | 3 mi. N of Winslow | 18 | 8 | SML |
| Bischoff Res. | Ripley | 2 mi. SE of Batesville | 200 | 23 | impoundment |
| Clear | Steuben | 6 mi. E. Fremont | 800 | 106 | Natural Lake |
| Fish | Steuben | 1 mi. N. of Fremont | 59 | 25 | Natural Lake |
| Henry | Steuben | 1 1/2 mi. S.E. of Wildwood | 20 | 20 | Natural Lake |
| Hogback | Steuben | 5 1/2 mi. W. of Angola | 146 | 22 | Natural Lake |
| Long (Pleasant) | Steuben | at Pleasant Lake | 92 | 32 | Natural Lake |
| Loon | Steuben | 4 mi. N.W. of Angola | 138 | 18 | Natural Lake |
| Dogwood | Sullivan | in Greene-Sullivan State Forest | 5 | 33 | SML |
| Downing | Sullivan | in Greene-Sullivan State Forest | 32 | 44 | SML |
| Front | Sullivan | Hillenbrand II F&W Area | 11 | 27 | SML |
| Hackberry | Sullivan | in Greene-Sullivan State Forest | 5 | 31 | SML |
| Narrow | Sullivan | in Greene-Sullivan State Forest | 9 | 25 | SML |
| Reservoir 29 | Sullivan | in Greene-Sullivan State Forest | 140 | 20 | SML |
| Spencer | Sullivan | in Greene-Sullivan State Forest | 6 | 20 | SML |
| Sullivan | Sullivan | at Sullivan | 507 | 20 | impoundment |
| Tree | Sullivan | in Greene-Sullivan State Forest | 6 | 20 | SML |
| Trout | Sullivan | in Greene-Sullivan State Forest | 5 | 20 | SML |
| West | Sullivan | Dugger Unit, 2 mi South of Dugger | | 82 | SML |
| Long | Wabash | 1/2 mi. N. of Laketon | 48 | 39 | Natural Lake |
| Luken | Wabash | 4 mi. N. of Roann | 46 | 41 | Natural Lake |
| Scales | Warrick | in Scales Lake State Park | 66 | 20 | SML |
| Goose | Whitley | 3.5 mi. SE of Etna | 84 | 66 | Natural Lake |
| Larwill | Whitley | 0.25 mi. S of Larwill | 10 | 35 | Natural Lake |

**INDIANA CLEAN LAKES PROGRAM - 2011 Sampling List**

School of Public & Environmental Affairs, Bloomington

| LAKE NAME | COUNTY | LOCATION | AREA (ac) | MAX DEPTH (ft) | LAKE TYPE |
|---|---|---|---|---|---|
| Boones Pond | Boone | 5.5 mi. SE of Lebanon | 8 | 28 | borrow pit |
| Stump Jumper | Clay | Chinook F&W Area | 6 | 34 | SML |
| Ferdinand City Old | Dubois | 1 mi. E of Ferdinand | 15 | 17 | impoundment |
| Fletcher | Fulton | 6 mi. S.E. Grass Creek | 45 | 40 | Natural Lake |
| Manitou | Fulton | 1 mi. E. Rochester | 713 | 45 | Natural Lake |
| Crystal | Greene | Hillenbrand II F&W Area | 8 | 36 | SML |
| Shake 2 | Greene | in Greene-Sullivan State Forest | 5 | 18 | SML |
| Star | Greene | in Greene-Sullivan State Forest | 5 | 22 | SML |
| Sycamore | Greene | in Greene-Sullivan State Forest | 7 | 27 | SML |
| Morse Res. | Hamilton | 3 mi. NW of Noblesville | 1500 | 45 | impoundment |
| Big Blue #13 (Westwood) | Henry | | 173 | 43 | impoundment |
| Starve Hollow | Jackson | in Jackson State Forest | 145 | 17 | impoundment |
| Big Chapman | Kosciusko | 3 mi NE of Warsaw | 414 | 38 | Natural Lake |
| Center | Kosciusko | At Warsaw | 120 | 41 | Natural Lake |
| Dewart | Kosciusko | 3 mi. N. of Oswego | 357 | 77 | Natural Lake |
| James | Kosciusko | 1 1/2 mi. W. of North Webster | 267 | 63 | Natural Lake |
| Kiser | Kosciusko | 2 mi E of North Webster | 9 | 20 | Natural Lake |
| Oswego | Kosciusko | at Oswego | 41 | 36 | Natural Lake |
| Fish Lake (Scott) | LaGrange | 4 mi. W. of Scott | 139 | 57 | Natural Lake |
| Green | LaGrange | 6 mi. S.E. of Mongo | 62 | 12 | Natural Lake |
| Hackenberg | LaGrange | 6 mi. N.W. of Wolcottville | 42 | 36 | Natural Lake |
| Little Turkey | LaGrange | 1/2 mi. W. of Elmira | 135 | 33 | Natural Lake |
| Martin | LaGrange | 3 mi. N.W. of Wolcottville | 26 | 55 | Natural Lake |
| Messick | LaGrange | 6 mi. W.N.W. of Wolcottville | 68 | 55 | Natural Lake |
| Pigeon | LaGrange | 3 mi. W.S.W. of Howe | 61 | 30 | Natural Lake |
| Stone | LaGrange | 5 mi. W. of Scott | 116 | 30 | Natural Lake |
| Wall | LaGrange | 2 mi. W. of Orland | 141 | 34 | Natural Lake |
| Fish (Lower) | LaPorte | 3 mi. E. of Stillwell | 134 | 16 | Natural Lake |
| Fish (Upper) | LaPorte | 3 mi. E. of Stillwell | 139 | 23 | Natural Lake |
| Tamarack | LaPorte | Kingsbury Fish & Wildlife Area | 12 | 5 | Natural Lake |
| Dixon | Marshall | 1 1/2 mi. S.W. Plymouth | 27 | 33 | Natural Lake |
| Mill Pond (Zehner) | Marshall | 5 mi. S.W. Plymouth | 168 | 16 | Natural Lake |
| Griffy | Monroe | 1/4 mi. E. of Bloomington | 130 | 36 | impoundment |
| Monroe Res. (lower basin) | Monroe | 1 1/2 mi. E. of Harrodsburg | 10750 | 55 | impoundment |
| Bartley | Noble | 3 mi. S.W. of Albion | 34 | 31 | Natural Lake |
| Bear Lake | Noble | 1 1/2 mi. S.W. Wolfe Lake | 136 | 59 | Natural Lake |
| Cree | Noble | 4 mi. N. of Kendallville | 58 | 26 | Natural Lake |
| Jones | Noble | 2 mi. W. of Rome City | 115 | 23 | Natural Lake |

| LAKE NAME | COUNTY | LOCATION | AREA (ac) | MAX DEPTH (ft) | LAKE TYPE |
|---|---|---|---|---|---|
| Long | Noble | Chain of Lakes State Park | 40 | 30 | Natural Lake |
| Port Mitchell | Noble | 3 mi. N.E. of Wolf Lake | 15 | 28 | Natural Lake |
| Rider | Noble | 1 mi SE of Indian Village | 5 | 15 | Natural Lake |
| Sacrider | Noble | 3 mi. S.W. of Kendallville | 33 | 54 | Natural Lake |
| Sand | Noble | Chain of Lakes State Park | 47 | 49 | Natural Lake |
| Steinbarger | Noble | 2 1/2 mi. S.W. of Rome City | 73 | 36 | Natural Lake |
| Upper Long | Noble | 1 1/4 mi. N. & 1 mi. E. of Wolf Lake | 86 | 50 | Natural Lake |
| Williams | Noble | 2 mi. E. of Wolf Lake | 46 | 44 | Natural Lake |
| Tipsaw | Perry | 2 mi. S of Apalona | 131 | 15 | impoundment |
| Prides Creek | Pike | SE edge of Petersburg | 90 | 25 | impoundment |
| Canada | Porter | 4 mi. N of Valparaiso | 10 | 22 | Natural Lake |
| Glen Flint | Putnam | 1 mi. E of Clinton Falls | 379 | 36 | impoundment |
| Versailles | Ripley | in Versailles State Park | 230 | 20 | impoundment |
| Dale reservoir | Spencer | 1.5 mi. NE of Dale | 33 | 30 | impoundment |
| Bass (N. Chain) | St. Joseph | 5 mi. W. of South Bend | 88 | 32 | Natural Lake |
| Koontz | Starke | 3 mi. S of Walkerton | 346 | 30 | Natural Lake |
| Ball | Steuben | 1 1/2 mi. N.W. Hamilton | 87 | 66 | Natural Lake |
| Big Bower | Steuben | 3 mi. N.W. Pleasant Lake | 25 | 22 | Natural Lake |
| Buck | Steuben | 2 mi. W. Angola | 20 | 41 | Natural Lake |
| Gage | Steuben | 3 mi. S.E. of Orland | 327 | 67 | Natural Lake |
| Golden | Steuben | 4 mi. S.W. of Angola | 119 | 28 | Natural Lake |
| Hamilton | Steuben | at Hamilton | 802 | 70 | Natural Lake |
| Hog | Steuben | 5 mi. E.of Orland | 48 | 26 | Natural Lake |
| Jimmerson | Steuben | 7 mi. N.W. of Angola | 283 | 56 | Natural Lake |
| Little Turkey | Steuben | 1 1/2 mi. W. Hudson | 58 | 28 | Natural Lake |
| Otter | Steuben | 9 mi. W. of Angola | 118 | 31 | Natural Lake |
| Bass | Sullivan | Dugger Unit, 2 mi south of Dugger | 211 | 54 | SML |
| Big Fry | Sullivan | in Greene-Sullivan State Forest | 5 | 12 | SML |
| Bobcat | Sullivan | Dugger Unit, 2 mi south of Duger | | 30 | SML |
| Fox | Sullivan | Dugger Unit, 2 mi south of Dugger | | 34 | SML |
| Locust | Sullivan | in Greene-Sullivan State Forest | 7 | 16 | SML |
| Long (Dugger) | Sullivan | Dugger Unit, 2 mi South of Dugger | 38 | 72 | SML |
| Pump | Sullivan | Dugger Unit, 2 mi South of Dugger | 22 | 60 | SML |
| Shakamak | Sullivan | in Shakamak SP | 56 | 24 | impoundment |
| Elk Creek #9 | Washington | 2 mi. E of Georgetown | 48 | 20 | impoundment |
| John Hay | Washington | at Salem | 210 | 28 | impoundment |
| Spurgeon Hollow | Washington | Jackson-Washington State Forest | 12 | 28 | impoundment |
| Kunkel | Wells | Wabash St Recrea. Area | 25 | 15 | impoundment |
| Shaffer | White | at Monticello | 1291 | 30 | impoundment |

| LAKE NAME | COUNTY | LOCATION | AREA (ac) | MAX DEPTH (ft) | LAKE TYPE |
|---|---|---|---|---|---|
| Blue | Whitley | 2 mi. NW of Churubusco | 239 | 46 | Natural Lake |
| Old | Whitley | 1 mi. E of Etna | 32 | 42 | Natural Lake |
| Robinson | Whitley | 4 mi. NW of Larwill | 59 | 49 | Natural Lake |
| Troy Cedar | Whitley | 8 mi. NW of Columbia City | 93 | 88 | Natural Lake |