Indiana Volunteer Lake Monitoring Report: 2016-2018

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ACKNOWLEDGEMENTS

The chemical analysis of water samples is a labor-intensive process. The total phosphorus and chlorophyll a results in this report would not have been possible were it not for the capable help and skills of many SPEA graduate research assistants who conducted the analyses.

Funds for this program were provided by Section 319 Lake Water Quality Assessment Grants from the U.S. Environmental Protection Agency. Jamie Hosier of the Indiana Department of Environmental Management was the Project Officers.

Most importantly, THANK YOU to all our volunteer lake monitors! Your hard work and dedication contribute greatly to the understanding and sound management of Indiana's lakes.

2016-2018 Primary Volunteers by County

BROWN COUNTY	
Quinn Hetherington	Cordry Lake
David Jarrett	Sweetwater Lake
Howard Webb	Yellowwood Lake
ELKHART COUNTY	
Gordon Mills	Heaton
Jan Folkmeir	Indiana
Dan Ganger	Indiana
Dennis Pedler	Indiana
FRANKLIN COUNTY	
Craig Nobbe	Brookville Reservoir
FULTON COUNTY	
Ray Dausman	Lake Manitou
Christina Overdorf	Nyona & South Mud Lakes
Robert Zawacki	Town
GREENE COUNTY	
William Jones	Airline Lake
HARRISON COUNTY	
Guy Silva	Pinestone Lake
JOHNSON COUNTY	
Tom Houghman	Lamb Lake
KOSCIUSKO COUNTY	
Len Draving	Big & Little Chapman Lakes
Troy Turley	Center Lake
Chuck Brinkman	Irish Lake
Ron Chambers	James, Oswego, & Tippecanoe Lake
Debra Hutnick	Palestine Lake
Diane Tulloh	Lake Papakeechie
Fran Allen	Syracuse Lake
James Shaver	Waubee Lake
Daniel Berkey	Lake Wawasee
Dawn Meyer	Webster Lake
Jim Nichols	Winona Lake
LAGRANGE COUNTY	
Joe Kraft	Adams Lake
Chris Koop	Adams Lake
Steve Singer	Big Long Lake
Tom Henry	Big Turkey Lake
Jonathan Barnes	Little Turkey Lake
Lynn Bowen	Martin, Olin, & Oliver Lakes
Don Merton	North Twin & South Twin Lakes
Ron Kantorak	Pretty Lake
Beth Sholly	Shipshewana
Michael James	South Twin Lake
Richad Kelly	Wall Lake
Don Bonistalli	Witmer Lake
LAKE COUNTY	
Frank Brongiel	Cedar Lake
George Hamnik	Double Tree
Jesse Rodgers	Hermit
Roger Dieckmeyer	Holiday
Mike Talley	Holiday

LAPORTE COUNTY

Don Lode	Hog & Saugany Lakes

MARION COUNTY

Toby Stone	Lake Clearwater
Debra Osborn	Lake Clearwater

MARSHALL COUNTY

Margaret Bonen	Cook Lake
Joe Skelton	Flat, Galbraith, & Lake of the Woods
Adam Thada	Flat & Galbraith Lakes
William Harris	Lost Lake
Dan Baughman	Lake Maxinkuckee
Debbie Palmer	Myers Lake

MONROE COUNTY

Laura Maloney	Griffy Lake
Randi Crim	Griffy Lake
Richard Harris	Lake Monroe (Upper & Lower)
Lee Bridges	Lake Monroe (Upper)

MONTGOMERY COUNTY

Roger Dieckmeyer	Lake Holiday

MORGAN COUNTY

Tim Street	Ole Swimming Hole
Brigitte Schoner	Whippoorwill Lake

NOBLE COUNTY

Chuck Farris	Crooked Lake
Jane Litwiller	High Lake
Nick Stranger	Knapp Lake
Ben Stonebraker	Little Long & Round Lakes
Nancy Lough	Skinner Lake
Stanley Tipton	Upper Long Lake

PORTER COUNTY

Mike Talley	Big Bass Lake
Robert Minarich	Flint, Long, & Loomis Lakes
Dan Fee	Lake Louise

STARKE COUNTY

Phil Woolery	Bass Lake
Tom Camire	Koontz Lake

STEUBEN COUNTY

Peg Zeis	Lake Anne
Bridget Harrison	Clear Lake
Joann Stanley	Clear Lake
Allen Lefevre	Lake Gage
Dennis Mahuren	Lake George
Amber Kimmel	Lake James
Joseph Peck	Silver Lake
Mike Marturello	Snow Lake
John Arthington	Syl-Van Lake
John Williamson	West Otter Lake

VIGO COUNTY

Darrell Althoff	French Lake

WHITLEY COUNTY

Denise Heckman	Goose Lake
Chuck Farris	Little Crooked Lake
Bill MacDonald	Old Lake
Dave Byers	Shriner Lake

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DESCRIPTION OF PROGRAM

The Indiana Volunteer Lake Monitoring Program (VLMP) was created in 1989 as a component of the Indiana Clean Lakes Program (INCLP) administered through the Indiana Department of Environmental Management (IDEM). Indiana University's School of Public and Environmental Affairs (SPEA) implements the program through a grant from IDEM. The INCLP is a comprehensive, statewide public lake management program with five components: public information and education, technical assistance, volunteer lake monitoring, lake water quality assessment, and coordination with other state and federal lake programs.

The VLMP was created to accomplish four main objectives:

1. Collect water quality data to contribute to the understanding of Indiana lakes;
2. Monitor water quality changes to provide an early warning for in lake problems;
3. Encourage citizen involvement in protection and management of lakes;
4. Provide a means for Indiana citizens to learn more about lake ecology and management.

All volunteers collect Secchi depth transparency measurements onlakes. The Secchi disk is one of the oldest and most basic tools used by limnologists. Secchi depth measurements are used as indicators of water quality by measuring the transparency of water (Figure 1). Secchi depth measurements are used as a first, simple check for eutrophication. Water clarity is affected by two main factors: algae and suspended sediments. Color observations are made with the Secchi depth reading to differentiate between these two factors. Algae are a main element in determining trophic status. Sediment is introduced to lakes via runoff from construction sites, agricultural lands, and river banks. Shallow lakes are especially susceptible to sediment resuspension from motor boats, personal watercraft, or strong winds.

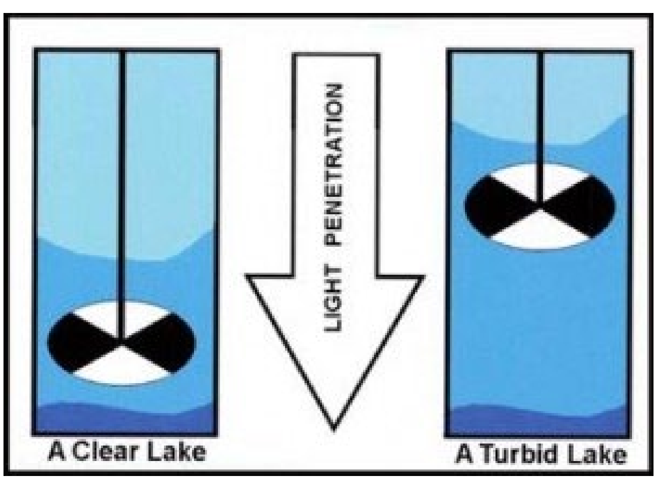


Figure 1. Secchi disk and water quality.

A subset of volunteers collect water samples for total phosphorus and chlorophyll *a* analyses through the Expanded Program. Phosphorus is the primary limiting nutrient required for growth by algae and aquatic plants; therefore most lake management programs measure phosphorus concentrations. Chlorophyll *a* is the primary green pigment in algae and is a direct measure of algal production.

Dissolved oxygen and temperature meters are available to volunteers throughout the state. Dissolved oxygen enters water via two pathways: diffusion into water from the atmosphere and production by algae and aquatic plants as a by-product of photosynthesis. Oxygen is consumed by the respiration of oxygen-breathing aquatic organisms (fish) and through bacterial decomposition. The quantity and distribution of dissolved oxygen in lakes helps determine the importance of these processes, and defines where fish and other aquatic life may survive. Lake zones with extremely low concentrations of dissolved oxygen may not support aquatic life and may instead promote chemical conditions whereby nutrients are released into the water from sediment storage. Temperature can affect where aquatic organisms can live in lakes.

Additional efforts are made to educate volunteers and citizens on aquatic invasive species. The addition of aquatic plant monitoring and zebra mussel early detection were added in 2012. Citizen education and engagement has been the primary success of the program.

MATERIALS AND METHODS

All volunteers are given a training manual, postage paid data cards, access to online data entry, and a Secchi disk with a calibrated measuring tape. Secchi disks are painted and assembled by INCLP staff at SPEA.

Volunteers need access to a boat once every two weeks. Secchi disk measurements are taken on sunny, calm days between the hours of 10:00 a.m. and 4:00 p.m. Measurements are taken at the same site each time, generally over the deepest part of the lake. In addition to Secchi depth measurements, volunteers assign a color to the water. Volunteers choose from a list of: Clear/Blue, Blue/Green, Green, Brown, or Green/Brown. The color selected is the best match to the lake and choices provided. Volunteers quatlitativly select a recreational potential and physical appearance of the lake for the day they are monitoring. Data is submitted to INCLP staff via pre-paid postage cards or electronically: https://clp.indiana.edu/.

Volunteers collect temperature and dissolved oxygen data using meters that can be checked out from INCLP or local soil and water conservation district offices. Temperature and dissolved oxygen change with the seasons, volunteers are encouraged to take monthly profile measurements lake.

Volunteers participating in the Expanded Program collect samples for chlorophyll *a* and total phosphorus at the same location as their Secchi disk measurement. Expanded Program samples are collected once a month during the summer, typically May through August.

The Expanded Program volunteers are provided with a kit, including a PVC 2-meter integrated water column sampler, filters, forceps, a filtering apparatus, hand-held vacuum pump, a pitcher, sample bottles, a storage tote, a Styrofoam mailer, prepaid express mail tags, and an expanded program manual. Phosphorus water samples are poured into 125 ml polyethylene bottles and frozen. A known volume of lake water is filtered through a glass-fiber filter (Whatman GF-F) to trap the algae to analyze for chlorphyll *a*. Filters are folded, placed in a 30 ml opaque bottle, and frozen. Once two months of samples are collected, they are shipped overnight to the SPEA lab in Bloomington for analysis by INCLP staff.

Many of the volunteers monitor lake level. This data is shared with the Department of Natural Resources. While INCLP does not provide analysis of this data it does collect this information.

The aquatic invasive species monitoring program acts as an early detection system for new aquatic invasive plants in Indiana. We train volunteers in workshop lasting 2-3 hours. Volunteers are asked to observe aquatic plants on their lake or in specified areas and report time spent to INCLP staff. In the event that the volunteers find one of the targeted invasive species of concern, including assessment of the zebra mussel artificial substrate, they are encouraged to send to IU for positive identification.

VOLUNTEER RECRUITMENT

Volunteers are recruited via statewide news releases, local newspaper articles, announcements in the quarterly *Water Column* newsletter, word of mouth, information booths at the annual Indiana Lake Management Conference, and the INCLP website (https://clp.indiana.edu/). New volunteers are trained around the state at individual or group training sessions with INCLP staff.

Citizens are critical to the success of the VLMP. Their participation allows IDEM to monitor long term lake water quality and to gather data on many more lakes than would be possible without this program. While volunteers come from a wide variety of backgrounds and have varying interests, they all recognize the importance of lakes as a valuable ecological and recreational asset, and share an interest in protecting or improving water quality. Many volunteers are actively involved in lake or conservation associations, and participate in lake management decisions. By participating in the VLMP, volunteers become better stewards and spokespersons for lakes.

Program Growth

The VLMP began in 1989 with 41 volunteers taking measurements on 51 lakes. From 2016 to 2018, 1,493 observations were made on 87 lakes in Indiana. From 2016 to 2018 32 new volunteers were trained to monitor lakes. Over the past 3 years we have seen a decrease in the number of lakes reporting and observations made on individual lakes. The expanded volunteer monitoring program was at maximum participation during this same time. The decline in Secchi monitoring is primarily from volunteers retiring and not having a replacement. We have been working hard to increase these numbers in the coming summer. The total number of lakes sampled and observations made in the VLMP since its inception are listed in Table 1.

Table 1. Summary of Lakes Monitored with Total Annual Observations.

	Secchi Disk Program		Expanded Program	
Year	Lakes Monitored	Total Observations	Lakes Monitored	Total Observations
1989	51	370	n/a	n/a
1990	73	535	n/a	n/a
1991	74	523	n/a	n/a
1992	85	537	30	90
1993	75	514	31	95
1994	75	677	28	116
1995	85	644	27	130
1996	81	563	27	100
1997	91	668	31	92
1998	87	548	31	111
1999	90	537	31	104
2000	104	618	34	120
2001	84	583	39	132
2002	93	569	41	136
2003	91	611	40	124
2004	94	590	39	132
2005	95	589	40	146
2006	83	514	45	157
2007	91	536	42	149
2008	81	438	37	131
2009	93	568	42	158
2010	80	578	40	144
2011	78	537	48	176
2012	85	561	48	182
2013	78	509	44	153
2014	78	617	36	123
2015	73	593	45	158
2016	75	597	48	181
2017	71	483	51	183
2018	75	455	54	191

THE LAKES

Lakes can be classified based on how they were formed, where they are located (ecoregion) and physical characteristics (depth, surface area, etc.).

Lake Formation

Hutchinson (1957) classified lakes based on how they were formed. Most lakes in Indiana were formed by glacial activity, solution, river channel migration, or by human activity (damming).

The majority of lakes sampled by the Volunteer Monitoring Program are natural lakes located in northern Indiana. Most of these lakes were formed by glacial activity, and are mainly “ice block” or kettle lakes, formed by the large blocks of ice deposited in the glacial outwash plain. In the southern portion of Indiana, limestone is prevalent and lakes were formed in basins created by the solution of the limestone. River channel migration also forms lakes. As a river shifts course, the former channel becomes cut off from the new active channel and can form oxbow lakes. Finally, impoundments have been created by human activity through all parts of Indiana, including farm ponds, millponds, quarry holes, and reservoirs. Seventy of the monitored lakes were natural lakes and eighteen were impoundments.

Ecoregion

Ecoregions were delineated in the late 1980’s to provide a geographic framework for more efficient management of ecosystems and their components (Omernik, 1987). This concept recognizes that land features such as bedrock geology, topography, soil type, vegetation, land use and human impacts interact to form specific ecological regions or ecoregions. The relative importance of individual factors and the complexity with which these factors interact varies from one ecoregion to another.

Indiana is composed of many different land types. The northern portion of the state is relatively flat, while the southern portion of the state is hilly. Land use ranges from row crop agriculture in the northern and central portion of the state to large areas of forest in the south to coal mines in the southwest. The use of ecoregions can help explain the differences among these land types and their lakes. Overall, six ecoregions are located within the state of Indiana (Figure 2). Five of these contain lakes sampled in the Volunteer Monitoring Program during the 2016-2018 sampling seasons (Figure 3). Characteristics of Level III ecoregions within Indiana, as described by Omernik and Gallant (1988), are described in Table 2.

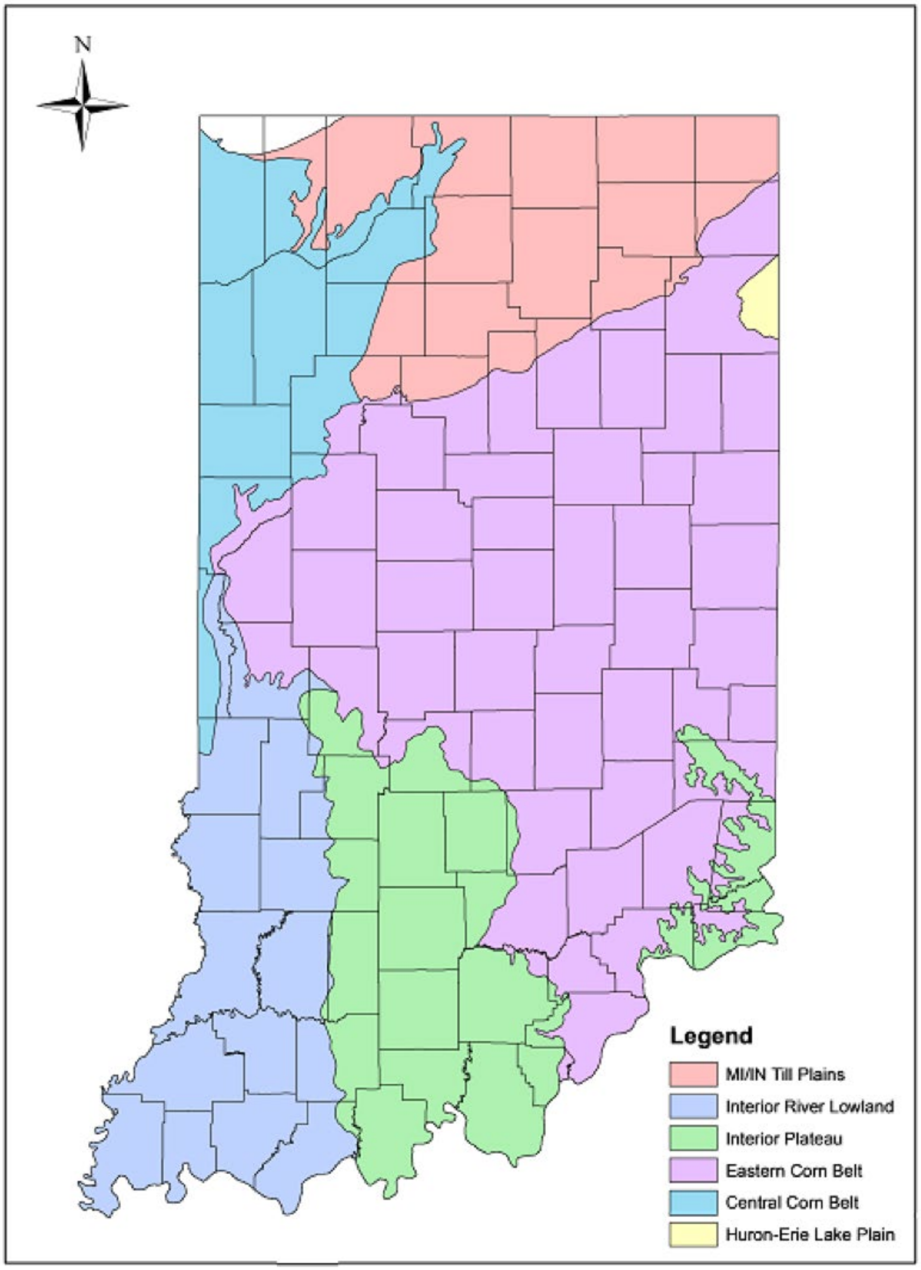


Figure 2. Level III ecoregions in Indiana. After: Omernik and Gallant (1988).

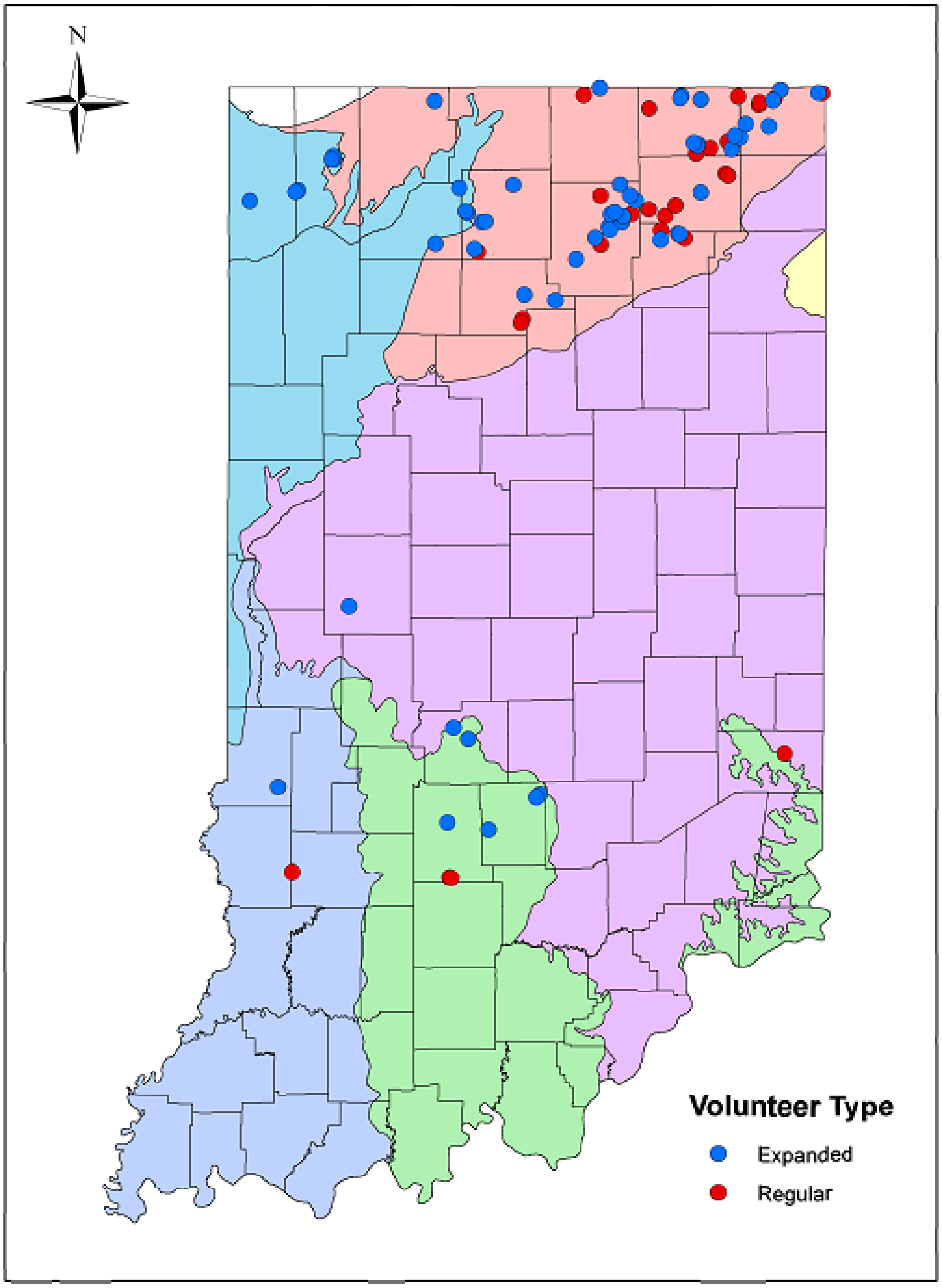


Figure 3. Volunteer Lakes by Level III Ecoregions in Indiana.

Table 2. Indiana Level III ecoregion characteristics and summary statistics for associated lakes sampled in the 2016-2018 as part of the Indiana Clean Lakes Volunteer Monitoring Program.

54 – Central Corn Belt Plains	
Consists of a dissected glacial till plain mantled with loess. Historically, this region was mostly low relief and soils originally developed in tall-grass prairie and oak/hickory forests. Today, almost all of this ecoregion is cultivated for feed crops (corn, soybeans, feed grains and some forage) for livestock. Only 5% of the land remains in woodland. Non-point source pollution in the Central Corn Belt Plains is derived from crop and livestock production.	
Number of Lakes in Program (2016-18)	10
Maximum Surface Area	781 acres
Maximum Depth	67 feet
Median Secchi Disk Transparency	3.8 feet
Number of Expanded Lakes	9
Mean Total Phosphorus Concentration	65.5 µg/L
Median Chlorophyll-a Concentration	11.42 µg/L

55 – Eastern Corn Belt Plains	
Gently rolling glacial till plain broken by moraines and outwash plains. This ecoregion supports a diverse hardwood forest, and approximately 75% is currently in cropland, primarily corn and soybeans. This ecoregion has few natural lakes or reservoirs.	
Number of Lakes in Program (2016-18)	4
Maximum Surface Area	5260 acres
Maximum Depth	100 feet
Median Secchi Disk Transparency	3.0 feet
Number of Expanded Lakes	3
Mean Total Phosphorus Concentration	33.2 µg/L
Median Chlorophyll-a Concentration	4.29 µg/L

56 – Southern Michigan/Northern Indiana Drift Plains	
25,800 square-mile ecoregion including a broad, nearly flat to rolling glaciated plain, deeply mantled by glacial till and outwash, sandy and gravelly beach ridges and flats, belts of morainal hills, and boggy kettle depressions. Land is managed for cropland, livestock, forest and woodland, and urban use. Approximately 25% of the region is urbanized. Lakes are common in some areas; however many depressions are filled with peat deposits or dark mineral soils.	
Number of Lakes in Program (2016-18)	63
Maximum Surface Area	2618 acres
Maximum Depth	123 feet
Median Secchi Disk Transparency	8 feet
Number of Expanded Lakes	39
Mean Total Phosphorus Concentration	28.3 µg/L
Median Chlorophyll-a Concentration	3.69 µg/L

57 – Huron/Erie Lake Plains	
Consists of a broad, nearly level lake plain crossed by beach ridges and low moraines. Most of the area was originally covered by forested wetlands. Local relief is generally only a few feet. The ecoregion covers 11,000 square miles of Indiana, Ohio and Michigan. Cash crop farming is the primary land use in the Huron/Erie lake Plain and soils are often poorly drained. Approximately one-tenth of the regionis urbanized. There are few lakes or reservoirs in this ecoregion.	
Number of Lakes in Program (2016-18)	0

71 – Interior Plateau Ecoregion	
The Interior Plateau includes a till plain of low toographic relief formed from Illinoisan glacial drift materials, rolling to moderately dissected basin terrain, and rolling to deeply dissected plateaus. Layers of limestone, sandstone, siltstone and shale underlie much of this region. Acreage in this ecoregion is managed for cropland, livestock, pasture, woodland and forest. There are numerous quarries and some coal surface mines; natural lakes are few.	
Number of Lakes in Program (2016-18)	9
Maximum Surface Area	10750 acres
Maximum Depth	110 feet
Median Secchi Disk Transparency	7.8 feet
Number of Expanded Lakes	6
Mean Total Phosphorus Concentration	21.0 µg/L
Median Chlorophyll-a Concentration	2.53 µg/L

72 – Interior River Valleys and Hills Ecoregion	
Comprised of a dissected glacial till plain, rolling narrow ridge tops, and hilly to steep ridge slopes and valley sides. Land uses are varied: cropland, livestock, pasture, timber and coal surface mines. About one-third of the region is forested, primarily in oak and hickory. Lakes, reservoirs and numerous ponds are scattered throughout the ecoregion. The greatest land use impacts on stream water quality in the region result from crop and livestock production and surface mining.	
Number of Lakes in Program (2016-18)	2
Maximum Surface Area	24 acres
Maximum Depth	72 feet
Median Secchi Disk Transparency	3.3 feet
Number of Expanded Lakes	1
Mean Total Phosphorus Concentration	86.5 µg/L
Median Chlorophyll-a Concentration	19.90 µg/L

Physical Characteristics
Lakes can also be classified based on their physical characteristics such as surface area, depth, and watershed area. Monitored lakes varied greatly in surface area and depth. Monroe Reservoir in Monroe County had the largest surface area of lakes in the program, 10,750 acres respectively. Lake Wawasee in Kosciusko County and Lake Maxinkuckee in Marshall County were the largest natural lakes in the program with surface areas of 2617 acres and 1853 acres respectively. Conversely, Little Crooked Lake in Whitley county and Syl-van and Anne Lakes in Steuben County had the smallest surface areas, 11, 14, and 15 acres respectively. The majority of the monitored lakes are less in 500 acres in surface area (Figure 4). The deepest monitored lake was Lake Tippecanoe in Kosciusko County at 123 feet, while Lost Lake in Marshall County was the shallowest natural lake at 4.8 feet (Figure 5).

Size of monitored lakes' watersheds also varied greatly. Lake Monroe in Monroe County had the largest watershed, 111,887 acres. Indiana Lake in Elkhart County had the smallest watershed, 161 acres. The majority of the lakes in the program have watersheds between 500 and 2000 acres in size (Figure 6).

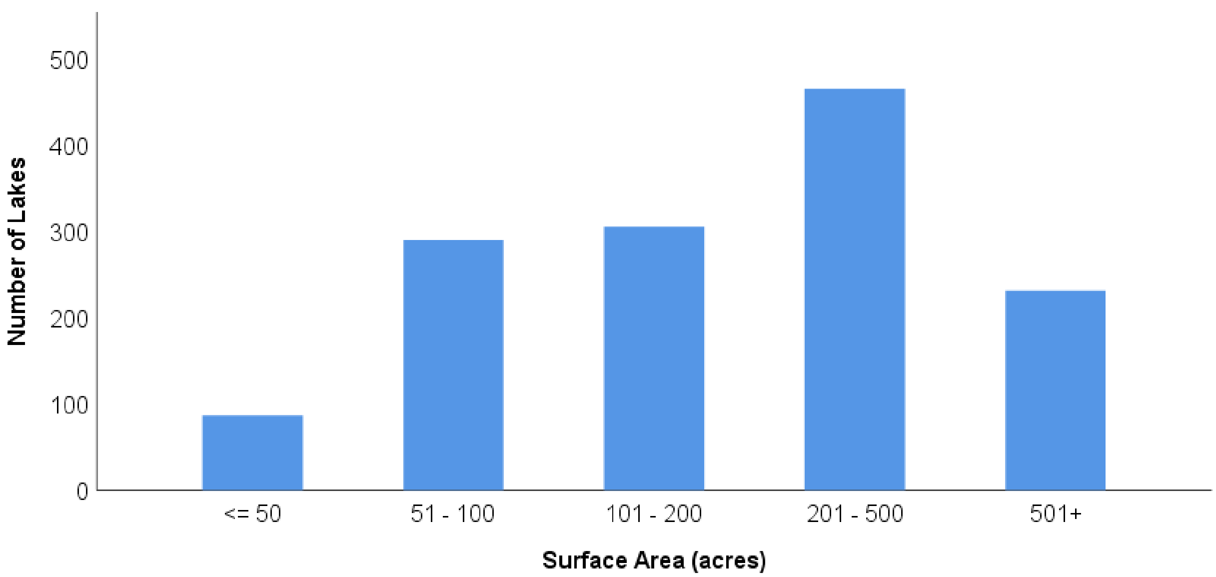


Figure 4. Size distribution of lakes in the Indiana Clean Lakes Volunteer Monitoring Program.

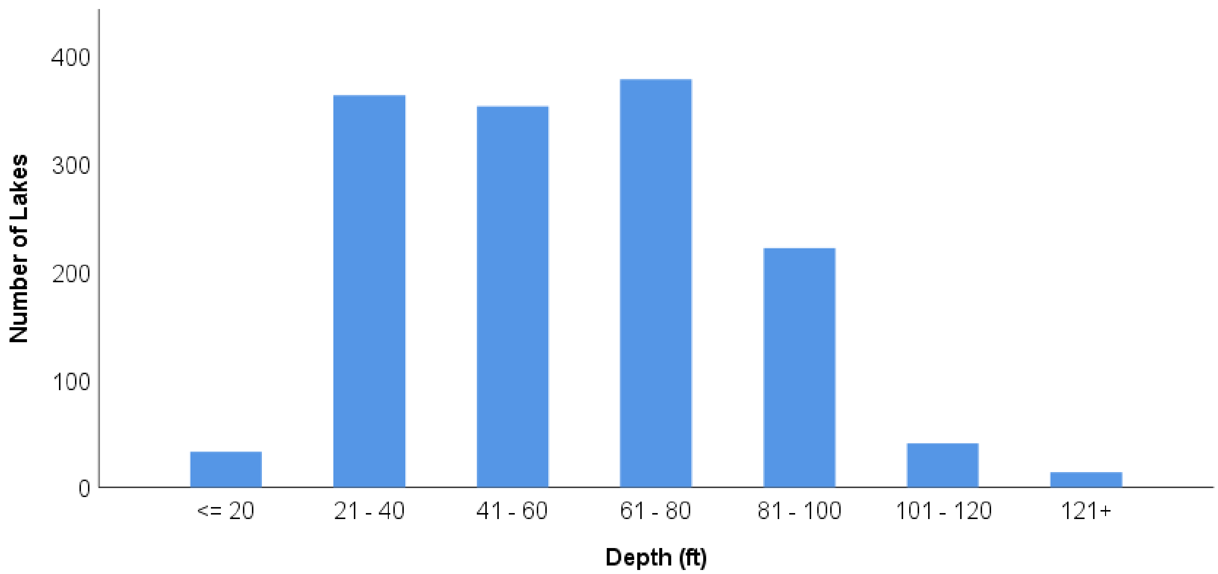


Figure 5. Depth distribution of lakes in the Indiana Clean Lakes Volunteer Monitoring Program.

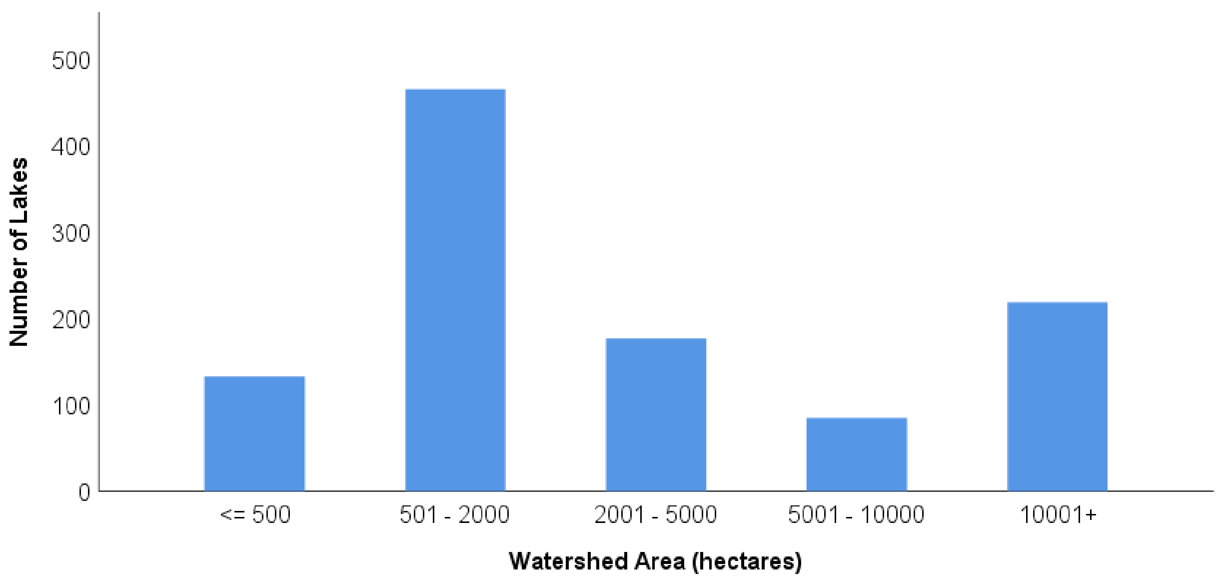


Figure 6. Watershed area distribution for lakes in the Indiana Clean Lakes Volunteer Monitoring Program.

CARLSON'S TROPHIC STATE INDEX

To analyze all of the data collected it is helpful to use an index to normalize the data across many parameters. The most widely used and accepted lake trophic state index (TSI) is Carlson's TSI developed by Bob Carlson (1977). Carlson found statistically significant relationships between summertime total phosphorus, chlorophyll *a*, and Secchi disk transparency for numerous lakes. He then developed mathematical equations to describe the relationships between these three parameters, which are the basis for the Carlson TSI. Using this method a TSI score can be generated for each of the three measurements. Carlson TSI scores range from 0 to 100. Each increase of 10 TSI points (10, 20, 30, etc.) represents a doubling in algal biomass. Data for one parameter are used to make predictions the others.

The Carlson TSI is divided into four main lake productivity categories: *oligotrophic* (least productive), *mesotrophic* (moderately productive), *eutrophic* (very productive), and *hypereutrophic* (extremely productive). The productivity of a lake can be assessed using the TSI score for one or more parameters (Figure 7).

As an example, using the Carlson TSI index, a lake with a mean July/August Secchi disk depth of 7 feet would have a TSI score of 49 points (located in line with the 7 feet) (Figure 7). This lake would be in the mesotrophic productivity category. It would also be expected to have a chlorophyll *a* concentration of 7 µg/L and a total phosphorus concentration of 25 µg/L based on the relationships between these parameters.

It is important to note that the Carlson TSI does not apply equally to all lakes. The relationship between transparency, chlorophyll *a*, and total phosphorus can vary based on factors not observed in Carlson's study lakes. Indiana Lakes are generally more turbid as a result of sediment runoff compared to the lakes Carlson used in his model. High concentrations of suspended sediments will decrease transparency from the predicted value based on total phosphorus and chlorophyll *a* concentrations. Heavy predation of algae by zooplankton can cause chlorophyll *a* values to decrease from the levels that would be expected based on total phosphorus concentrations.

In 2016, 2017 and 2018 the lakes monitored were primarily split between mesotrophic and eutrophic lakes. Few lakes were classified as oligotrophic or hypereutrophic. Minimum and maximum TSI scores ranged from 29 to 69 for chlorophyll *a* (Table 3), 27 to 86 for total phosphorus (Table 4), and 31 to 72 for Secchi transparency (Table 5) during the grant period.

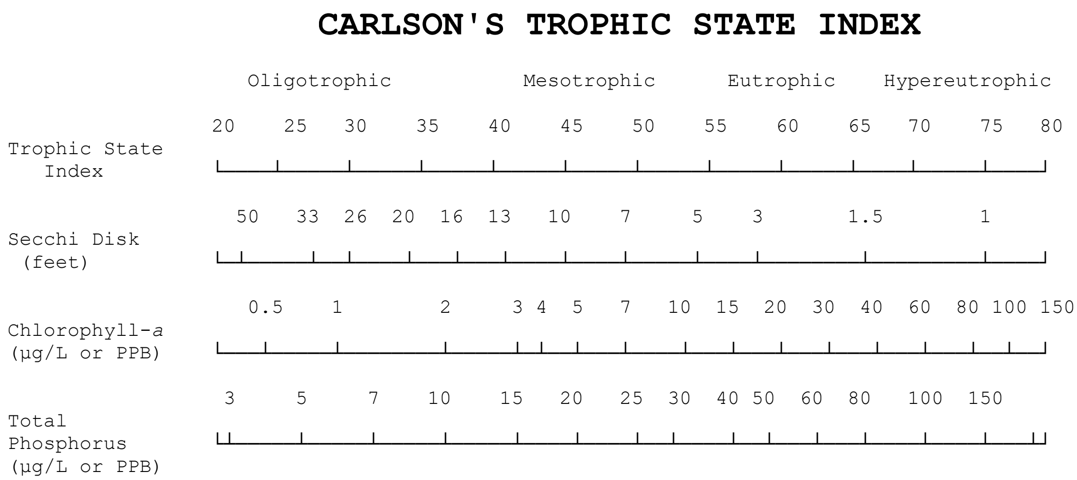


Figure 7. Carlson's Trophic State Index

Table 3. Minimum and maximum Carlson TSI scores for Chlorophyll a from 2016-2018 for lakes in the Indiana Clean Lakes Volunteer Monitoring Program

Chlorophyll a TSI Max or Min	Year	Lake	County	Score
Maximum	2016	Palestine	Kosciusko	69
Minimum	2016	Clearwater	Marion	24
Maximum	2017	Big Bass	Porter	72
Minimum	2017	Cordry	Brown	32
Maximum	2018	Louise	Porter	74
Minimum	2018	Clearwater	Marion	29

Table 4. Minimum and maximum Carlson TSI scores for Total Phosphorus from 2016-2018 for lakes in the Indiana Clean Lakes Volunteer Monitoring Program

TP TSI Max or Min	Year	Lake	County	Score
Maximum	2016	Big Bass	Porter	75
Minimum	2016	South Twin	Lagrange	14
Maximum	2017	Big Bass	Porter	86
Minimum	2017	Olin	Lagrange	27
Maximum	2018	Palestine	Kosciusko	73
Minimum	2018	Olin	Lagrange	27

Table 5. Minimum and maximum Carlson TSI scores for Secchi disk transparency from 2016-2018 for lakes in the Indiana Clean Lakes Volunteer Monitoring Program

Secchi TSI Max or Min	Year	Lake	County	Score
Maximum	2016	Galbraith	Marshall	68
Minimum	2016	Clearwater	Marion	31
Maximum	2017	Shipshewana	Lagrange	72
Minimum	2017	Airline	Greene	32
Maximum	2018	Town	Fulton	72
Minimum	2018	Airline	Greene	30

TRANSPARENCY RESULTS

Secchi disk transparency can vary on individual lakes in as little as a day. It is best to look at transparency results through the summer average rather than one-time measurements. The July/August measurements are used for year-to-year comparisons for consistency. They also represent the “worst-case” scenario for lake conditions as they take into account factors including warm weather, lake stratification, algal blooms and heavy recreational use. Volunteers receive annual summary reports for individual lakes, which include the minimum, maximum, the July/August Secchi depth mean, and Carlson’s TSI. Volunteer monitors also receive an annual summary of all lakes in the program. Summary reports and raw data can be found online at https://clp.indiana.edu/.

The deepest Secchi depth in the 2016-2018 seasons was 34.7 feet at Clearwater Lake in Marion County. The next deepest measurement on Airline Lake in Greene County in June, 2018.

Factors Affecting Lake Transparency

Anything that increases the amount of suspended material in the water affects the Secchi depth transparency. Decreased water transparency is related to increases in sediment or algae in the water column. Sediment enters the water column as a result of runoff from the landscape or is resuspended from the lake bed. Algal growth is directly related to nutrient enrichment of a lake. The location of the lakes, surrounding land use, basin morphometry, basin type, watershed size, ecoregion, and time of week when sampled can all influence transparency.

Variation in lake conditions and Secchi depth transparency can occur as a result from long term events or non seasonal events. Non seasonal events that can affect transparency include, but are not limited to:

1. Major watershed changes that may occur in one year, but not others, for example, clear cutting or large construction projects.
2. Localized storms, droughts or other variable weather events.
3. Major lake events that occur only once every few years, for example, weed treatments or channel dredging.

Basin Morphometry

The physical characteristics of a lake (known as *morphometry*) influence many lake processes. Larger lakes have a greater volume of water to dilute watershed non-point sources. Shallow lakes tend to be more productive than deeper lakes due to the large sediment area to water volume ratio. Sediment resuspension from wind mixing and turbulence caused by boats and personal watercraft are more prevalent in shallow lakes and can lead to a decrease in transparency. Data from 2016-2018 help support this premise. Mean Secchi depth transparency increases with increasing maximum depth, with the exception of the one lake with a maximum depth greater than 121 feet (Tippecanoe Lake in Kosciusko County) (Figure 8). Potential bias in the data trends may be due to uneven distribution of measurements at lakes with different maximum depths (Figure 9).

Basin Type
Impoundments typically have lower Secchi depth transparencies than natural lakes due to their elongated shape (longer wind fetch), and larger watersheds. This results in greater water and sediment runoff. Natural lakes and man-made lakes had similar median transparencies from 2016 to 2018 with median transparencies of 7.2 and 8 feet respectively. Lakes not listed in one of the categories or unknown of lake type, had a median transparency of 2.9 feet (Figure 10).

Surface Area
The surface area of a lake has little effect on the transparency of a lake. Surface area does not help explain much about the volume of the water, the watershed, or the morphometry of the lakes surface. Larger lakes tend to have a greater wind fetch. This allows for more mixing of the surface water of the lake. The Secchi depth results support this finding as no correlation occurs between the lake transparency and the surface area (Figure 11).

Watershed Size
An increase in watershed size means that more land area drains into a lake and this can result in more sediment delivery to the lake. Along with sediment, a larger watershed size also leads to more nutrients entering the lake, which can stimulate algal growth thereby decreasing transparency further. Thus, we'd expect lakes with larger watersheds would have reduced Secchi depth transparency. Data from the Volunteer Lake Monitoring Program supports these relationships. The median Secchi depth transparency was higher for lakes with a watershed less than 500 acres (9.5 feet) and lower for those watersheds greater than 5000 acres (6 feet) (Figure 12).

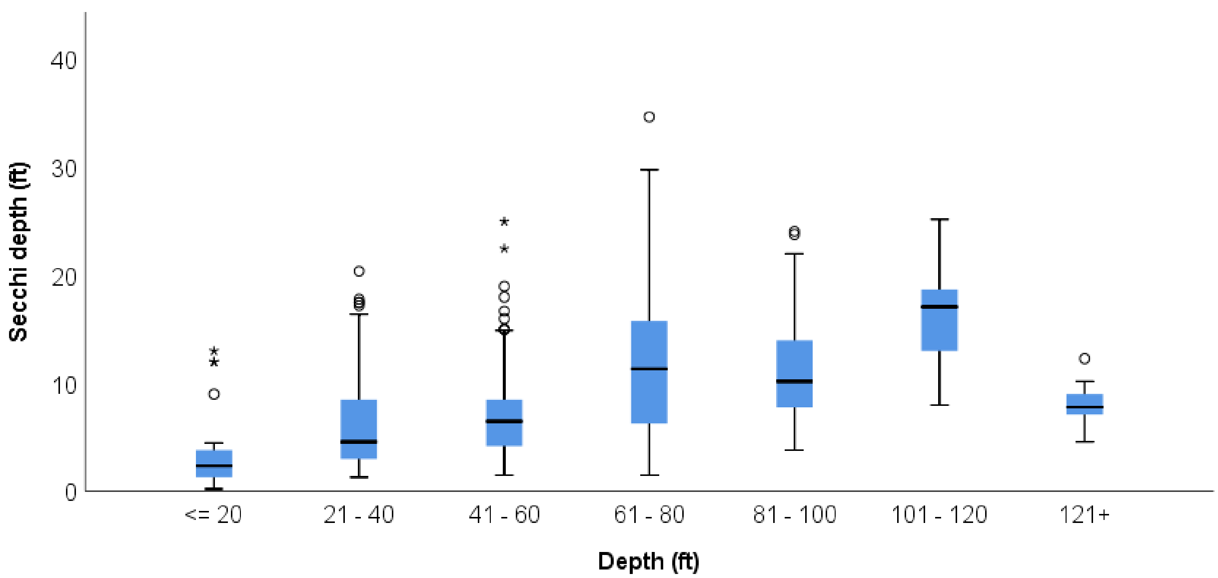


Figure 8. 2016-2018 mean July/August transparency distribution vs. maximum lake depth for lakes in the Indiana Clean Lakes Volunteer Monitoring Program. Median Secchi depth is represented by the line inside the boxes, and the error bars show the minimum and maximum values. The asterisks show outlier values.

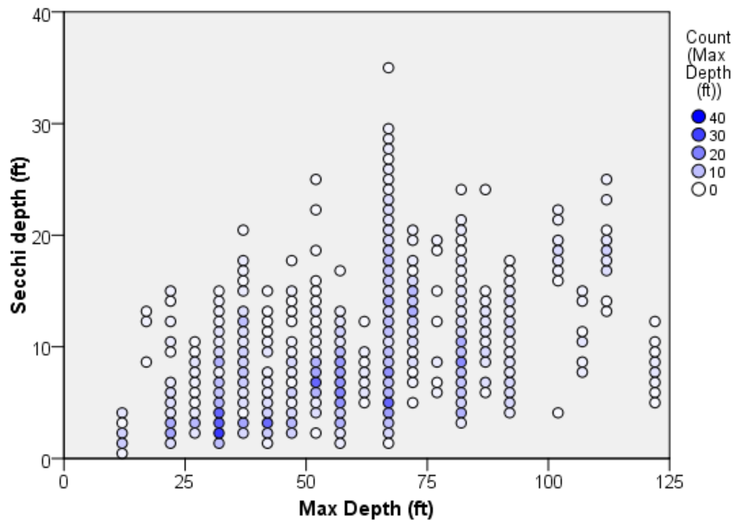


Figure 9. 2016-2018 count of mean July/August transparency measurements vs. maximum lake depth for lakes in the Indiana Clean Lakes Volunteer Monitoring Program. The color scale indicates different counts of observations across the maximum depths.

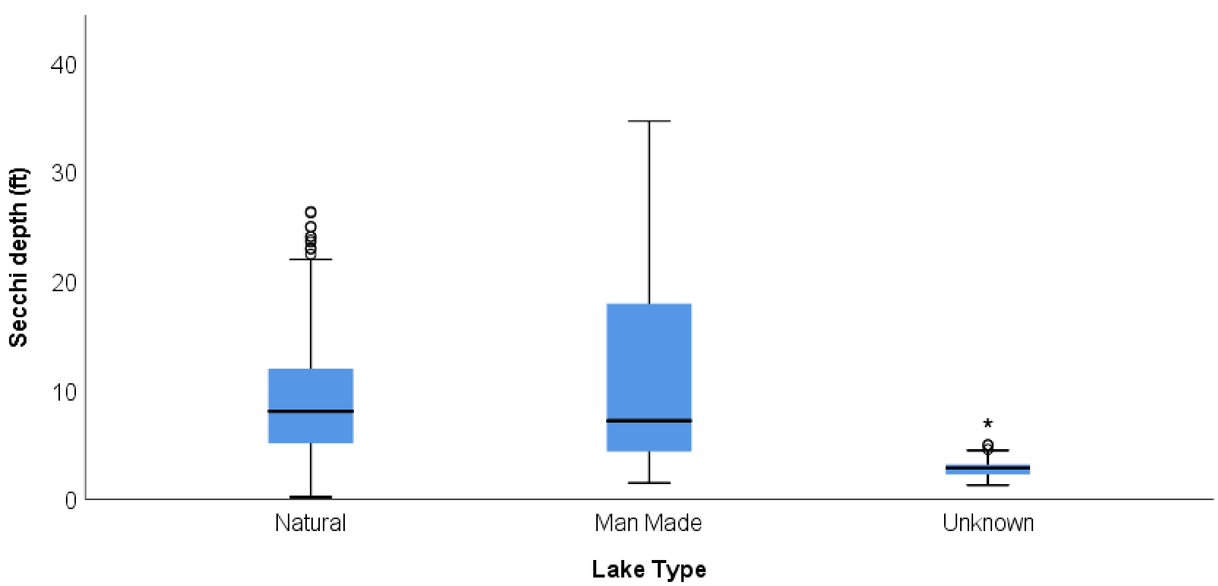


Figure 10. 2016-2018 mean July/August transparency distribution of natural lakes and man made lakes in the Indiana Clean Lakes Volunteer Monitoring Program. Median Secchi depth is represented by the line inside the boxes, and the error bars show the minimum and maximum values. The asterisks show outlier values.

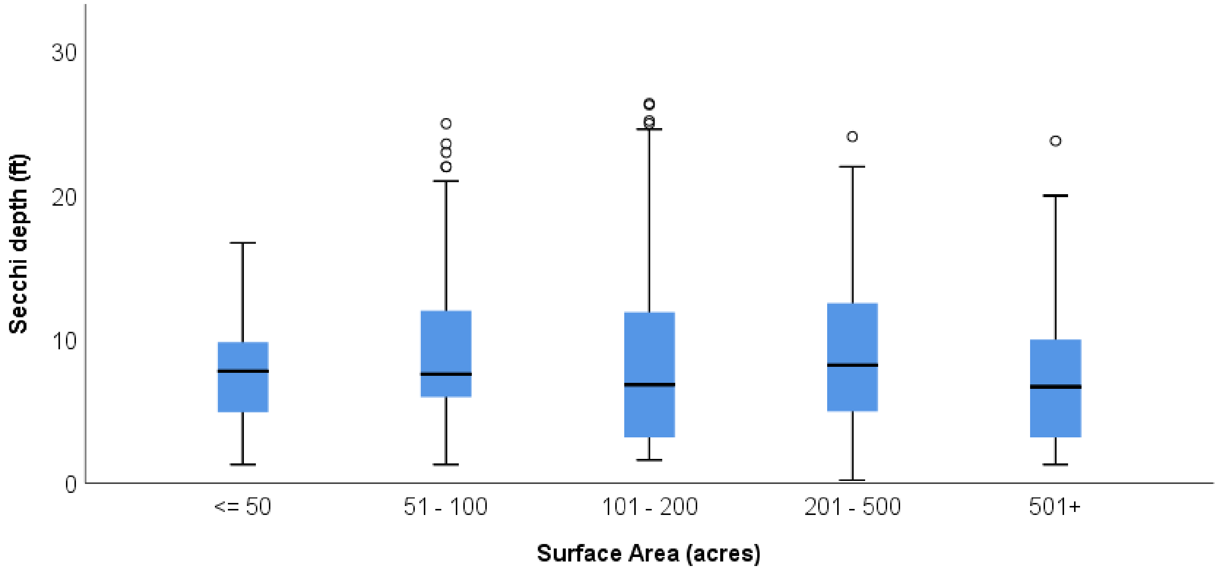


Figure 11. 2016-2018 mean July/August transparency distribution vs. lake surface area for lakes in the Indiana Clean Lakes Volunteer Monitoring program. Median Secchi depth is represented by the line inside the boxes, and the error bars show the minimum and maximum values. The asterisks show outlier values.

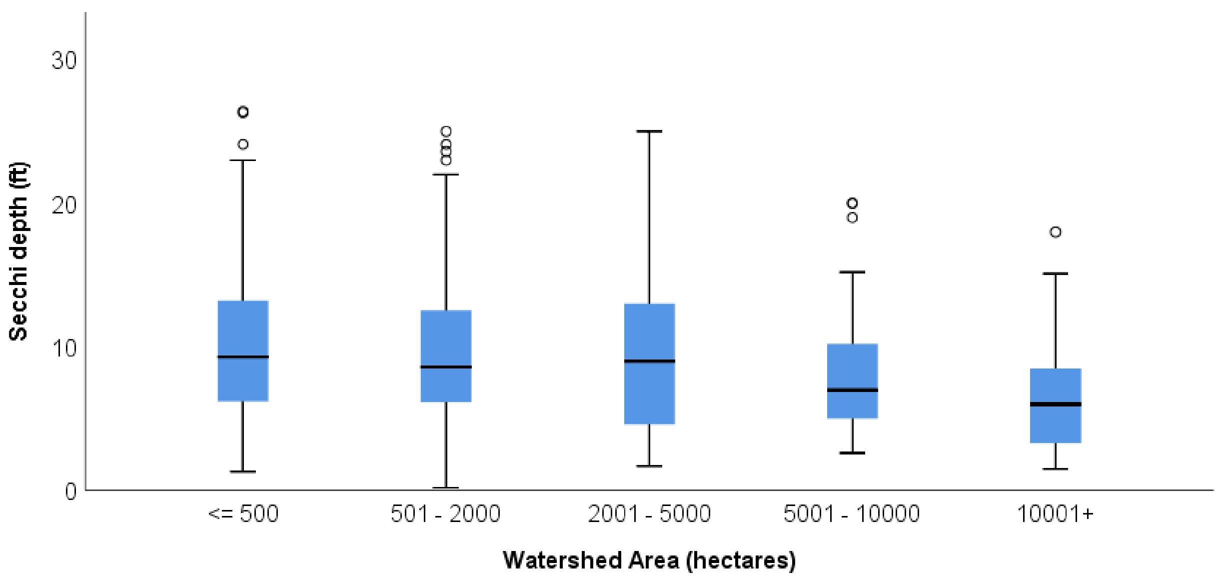


Figure 12. 2016 – 2018 mean July/August transparency distribution vs. watershed size for lakes in the Indiana Clean Lakes Volunteer Monitoring Program. Median Secchi depth is represented by the line inside the boxes, and the error bars show the minimum and maximum values. The asterisks show outlier values.

Ecoregion

Secchi disk transparency varies greatly among the ecoregions of Indiana (Figure 13). The median summertime transparency for monitored lakes in the Central Cornbelt Plains (Ecoregion 54) was 3.8 feet.This ecoregion has a limited number of shallow lakes that are subject to resuspension of sediments. The majority of land in this region is cultivated for feed crops (corn, soybeans, feed grains).

The Eastern Corn Belt (Ecoregion 55) lakes had the lowest median summertime transparency at 3.0 feet. This region has large amounts of cropland (75%) and few natural lakes or reservoirs.

Monitored lakes in the Southern Michigan/Northern Indiana Drift Plains (Ecoregion 56) had a median Secchi disk transparency of 8 feet. This ecoregion contains the majority of the natural, glacial lakes in Indiana. Transparency is expected to be higher in these lakes because they are natural lakes and are deeper than other lakes.

Monitored lakes in the Interior Plateau (Ecoregion 71) had the highest median transparency at 8.2 feet. All of the lakes monitored by volunteers in this ecoregion are impoundments. These would be expected to have lower transparencies because they are impoundments, but these lakes include those located within Hoosier National Forest and in several Indiana State Parks and Forests. The largely forested watersheds provide more protection for the lakes by reducing soil erosion and nutrient loss.

Monitored lakes in the Interior River Valleys and Hills (Ecoregion 72) had a median transparency of 3.3 feet. Land use in this ecoregion varies greatly and includes cropland, livestock, pasture, timber and coal surface mines.
The number of observations at lakes in different ecoregions should be taken into consideration when examining trends and comparing monitored lakes across ecoregions (Figure 14).

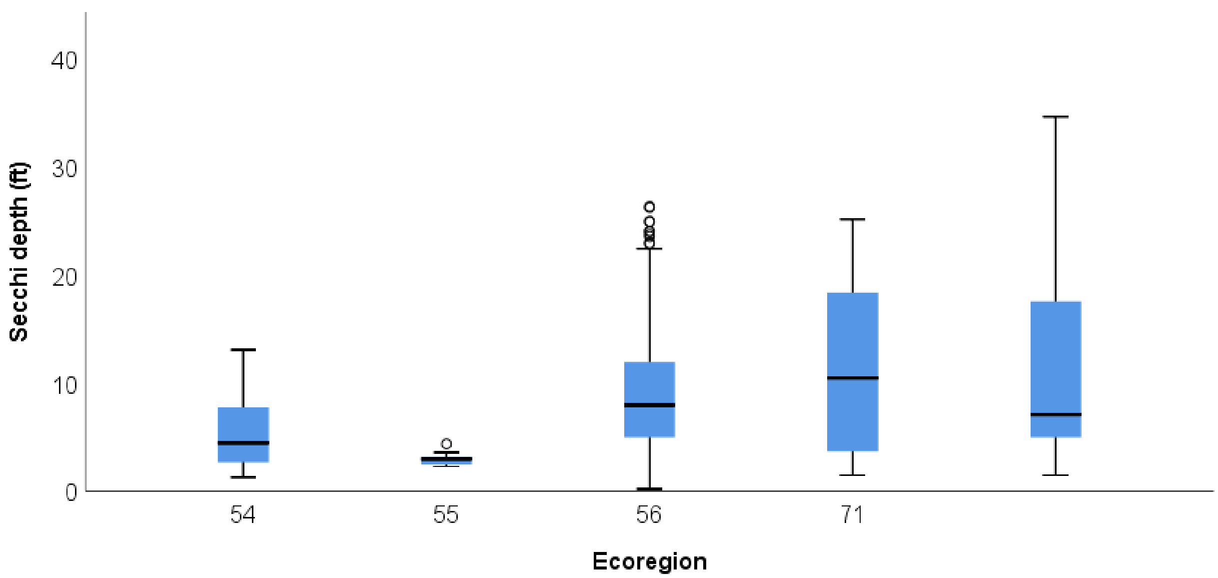


Figure 13. 2016-2018 mean July/August lake transparency among ecoregions for lakes in the Indiana Clean Lakes Volunteer Monitoring Program. Median Secchi depth is represented by the line inside the boxes, and the error bars show the minimum and maximum values. The asterisks show outlier values. Unlabeled category represents lakes with unknown ecoregion.

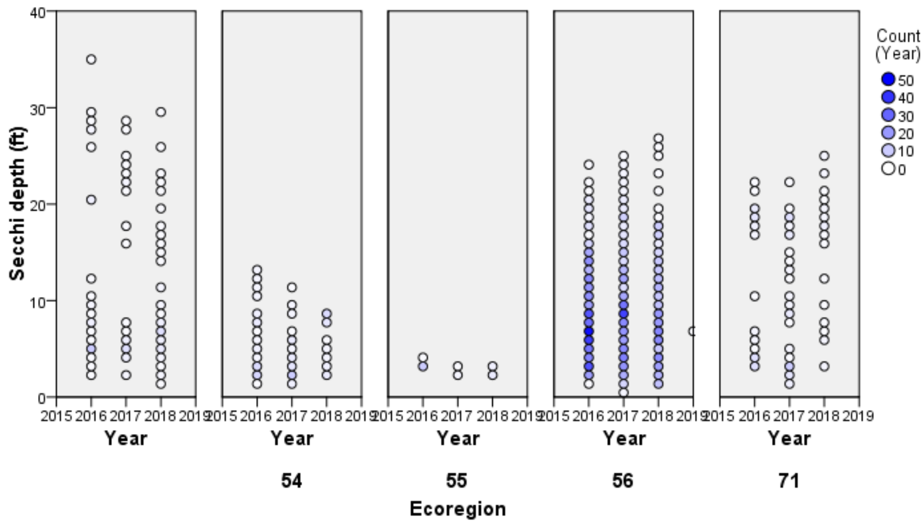


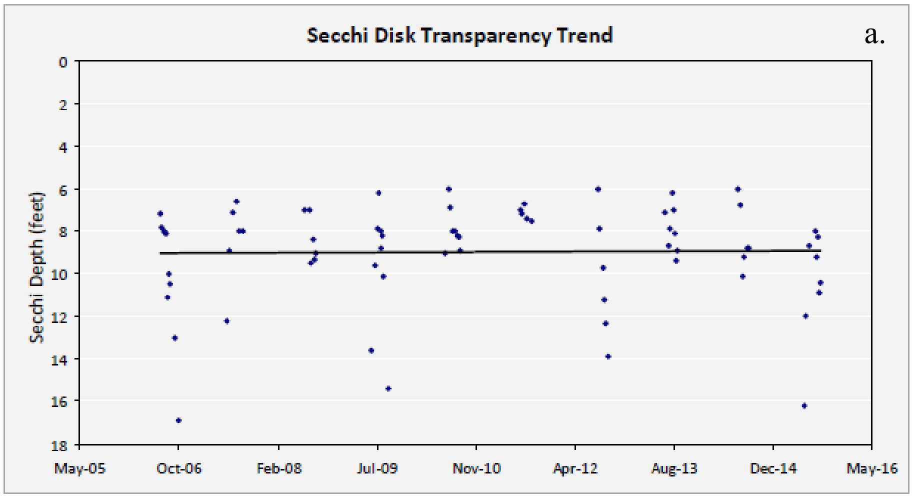
Figure 14. 2016-2018 count of July/August mean transparency measurements across ecoregions for lakes in the Indiana Clean Lakes Volunteer Monitoring Program. The color scale indicates different counts of observations. Unlabeled category represents lakes with unknown ecoregion.

Long-Term Trends

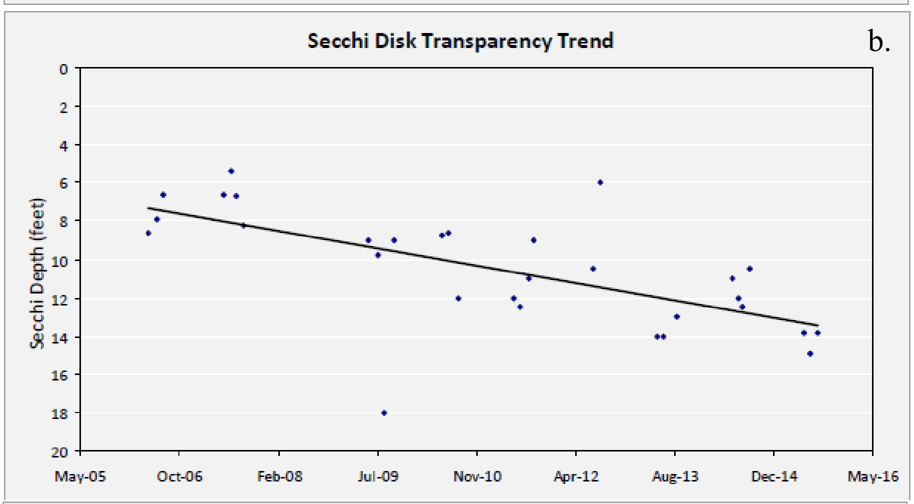
One of the main objectives of the Volunteer Lake Monitoring Program is to establish long-term data on Indiana lakes to assess trends in water quality. Each year volunteers receive a graph of all the measurements taken over the previous 10 years. A computer software program is used to fit a trend-line to the points. This trend line gives information on how the lake has changed over time. The graph is displayed with the lake surface at the top and increasing depth down the vertical axis. A line that appears to be horizontal indicates that transparency has not changed much throughout the sampling period (Figure 15a). An upward sloping line indicates decreasing transparency and a downward sloping line indicates increasing transparency (Figures 15b and c).

Caution should be used when analyzing these trend data because they have not been normalized. As a result, trend lines might not be indicative of a true trend in the condition of the lake. Factors potentially causing the trend line not to reflect a true trend include the number of samples taken during a sampling season, the distribution of samples, and the time period within the season that the samples were taken. For example, average transparency will be overstated if a majority of samples are taken during periods typically having elevated transparency, e.g. early spring or late fall, and if samples are not taken during July and August, when transparency is usually low (Figure 16). Conversely if the majority of samples were taken during July and August and none were taken during the spring and fall, average annual transparency will be underestimated.

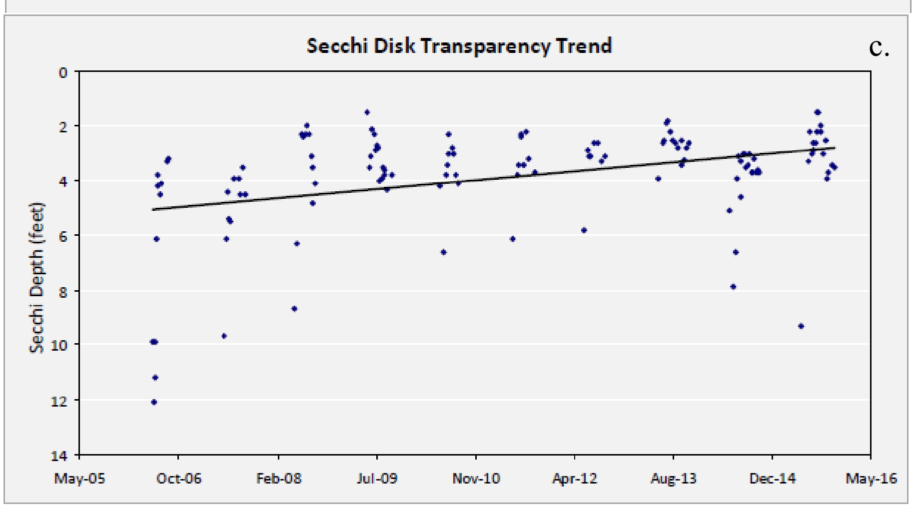
Variation in sample timing among years can also affect data trends. If samples were taken during the spring and fall early in the program, and then taken primarily in July and August in more recent years, it would appear that transparency was dec when that may not be the case. The reverse of that sampling pattern would make it appear that transparency is improving when that may not be accurate.



A trend line showing virtually no change in Secchi disk transparency overtime.



A trend line showing increasing Secchi disk transparency over time.



A trend line showing decreasing Secchi disk transparency over time.

Figures 15a-c. Example of long-term transparency trends.

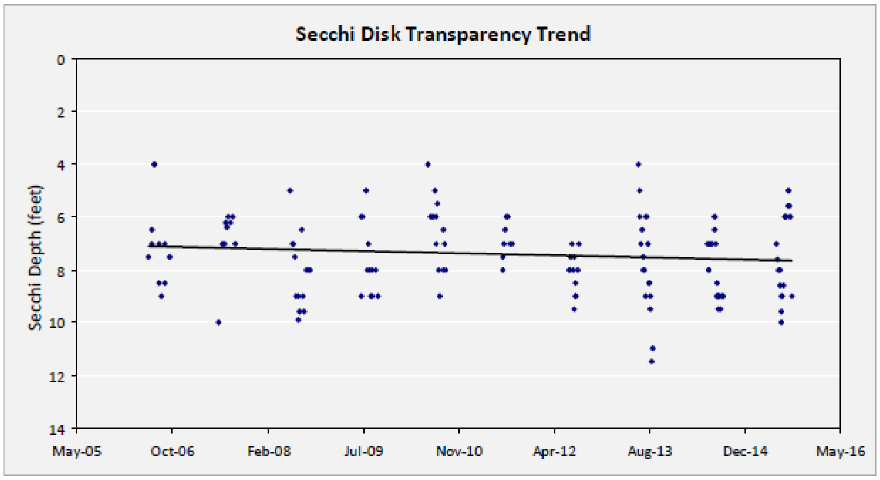


Figure 16. Seasonal variation in Secchi disk transparency

Trophic State Index Analysis

Carlson's TSI provides a means to analyze and compare annual lake data. Long-term trends in TSI values can be a more reliable method of comparison than transparency trends as TSI values are calculated using the July/August means, thereby removing seasonal variations. Based on July/August mean transparency values, the majority of lakes monitored in the program have been mesotrophic or eutrophic (Figure 17). On average less than 10% of lakes were hypereutrophic. A lake's trophic status can however, vary yearly, but long-term data indicates that for many lakes the trophic state is relatively stable.

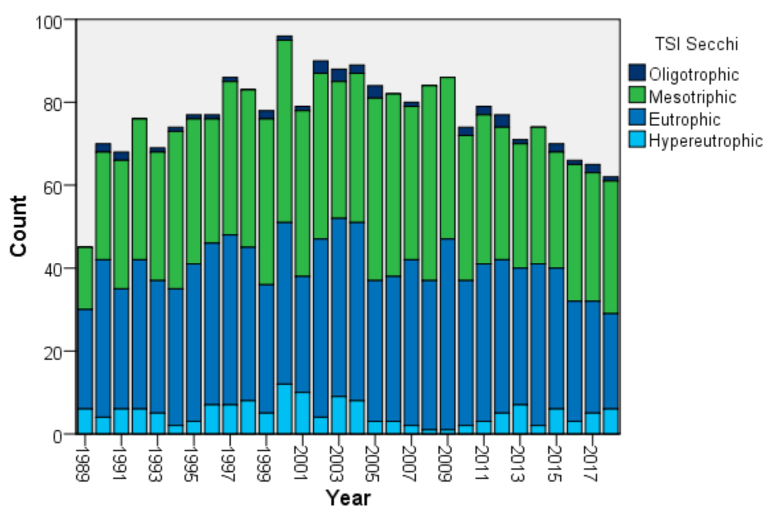


Figure 17. Annual distribution of monitored lakes' trophic classes calculated using July/August summertime means of Secchi depth from 1989-2018.

PHYSICAL APPEARANCE & RECREATION POTENTIAL RESULTS

Volunteers' assessments of physical appearance and recreation potential of lakes provide additional useful information. Hoyer, Brown and Canfield (2004) found significant relationships between lake users perceptions of physical condition of water and associated lake trophic state water chemistry variables. They also found a relationship between recreational or aesthetic value and trophic state.

Physical Appearance

Volunteers are asked to rate the physical appearance of their lake each time they measure transparency. Volunteers rate the lake's physical appearance using the following categories:

1. Crystal Clear
2. Some Algae
3. Definite Algae
4. High Algae
5. Severe Algae

A rating of 1 or 2 indicates enhanced physical appearance. Decreasing transparency generally leads to values of 3, 4, or 5 for physical appearance because sediment and algae that reduce transparency also cause the appearance of the lake to be less desirable. In general, lower transparency is correlated with higher algal levels and therefore more impaired physical appearance (Figure 18).

User perceptions of water quality vary among regions and lakes. Smeltzer and Heiskary (1990) found that expectations of lake users also vary by region. Users in regions of Minnesota and Vermont develop different water quality expectations based upon regional water quality. Areas where mesotrophic lakes predominate generate higher expectations than regions where eutrophic or hypereutrophic lakes predominate.

In the volunteer monitoring program, citizen perceptions of 'crystal clear' lakes showed the widest range of responses of the physical appearance categories. What appears to be excellent transparency to volunteers on some lakes is considered poor transparency on others (Figure 19).

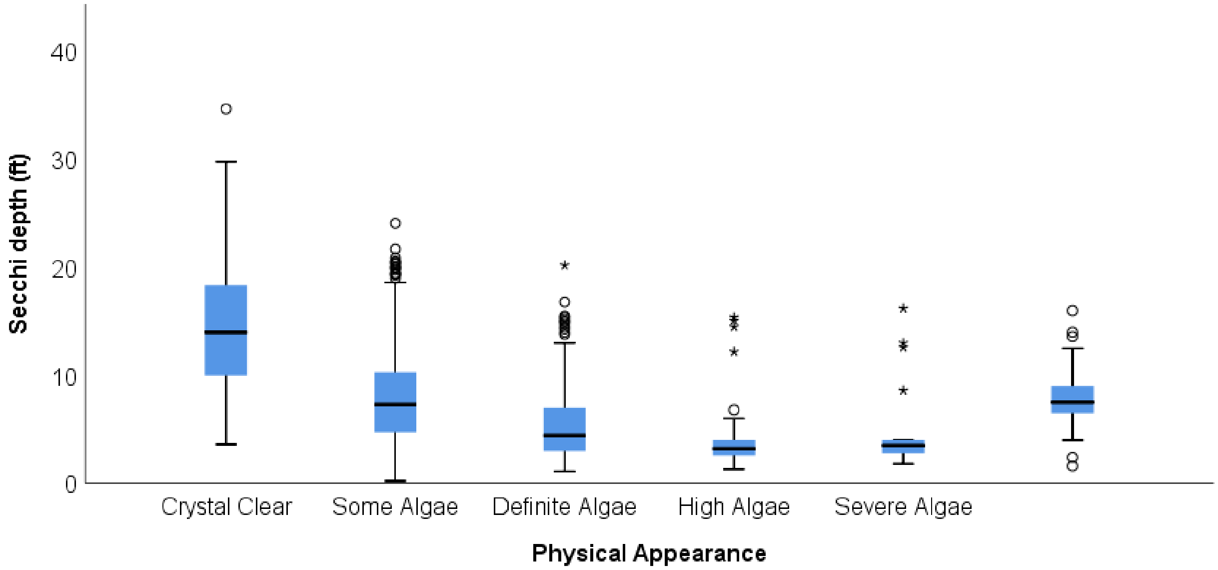


Figure 18. 2016-2018 mean July/August lake transparency distribution across physical appearance categories. Blank category summarizes data with no associated volunteer response to the physical appearance prompt during data collection.

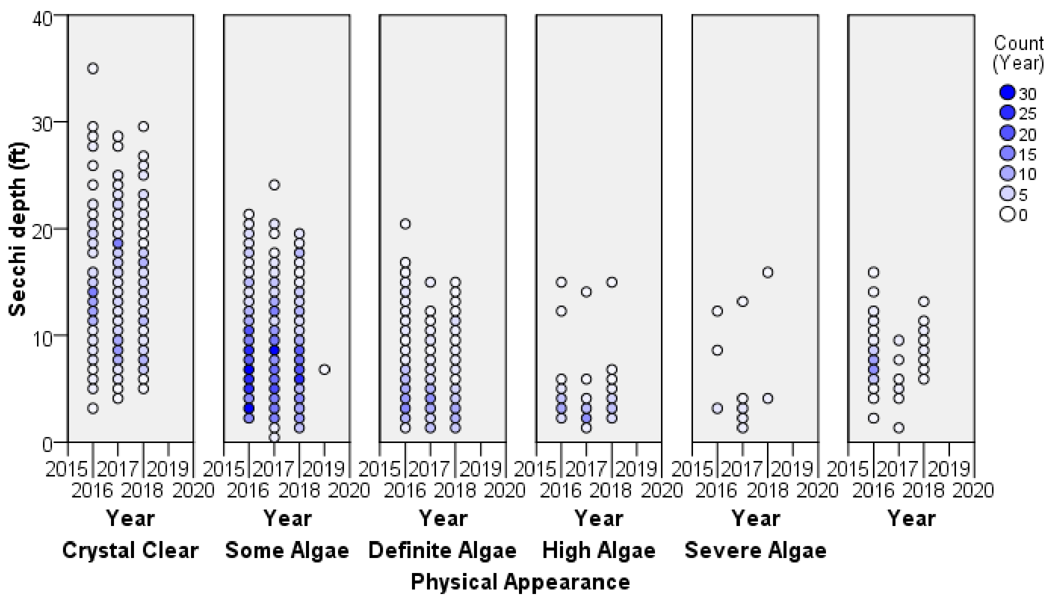


Figure 19. 2016-2018 count of July/August mean transparency measurements across volunteer responses to physical appearance categories. The color scale indicates different counts of observations. Blank category summarizes data with no associated volunteer response to the physical appearance prompt during data collection.

Recreation Potential
Volunteers are also asked to rate recreation potential each time they make a transparency measurement. Volunteer monitors rate recreation potential based on the following five categories:

1. Beautiful – no impairment
2. Minor Aesthetic Problems
3. Swimming Impaired
4. No Swimming
5. No Recreation

Recreation potential ratings were correlated with transparency with the exception of No Swimming and No Recreation ratings (Figure 20). Some lakes do not allow swimming or have limited recreation, which can lead to these responses. Similarl to physical appearance categories, recreation potential categories varied at different lakes with a lot of overlap between "Beautiful – no impairment" and "Minor Aesthetic Problems" (Figure 21).

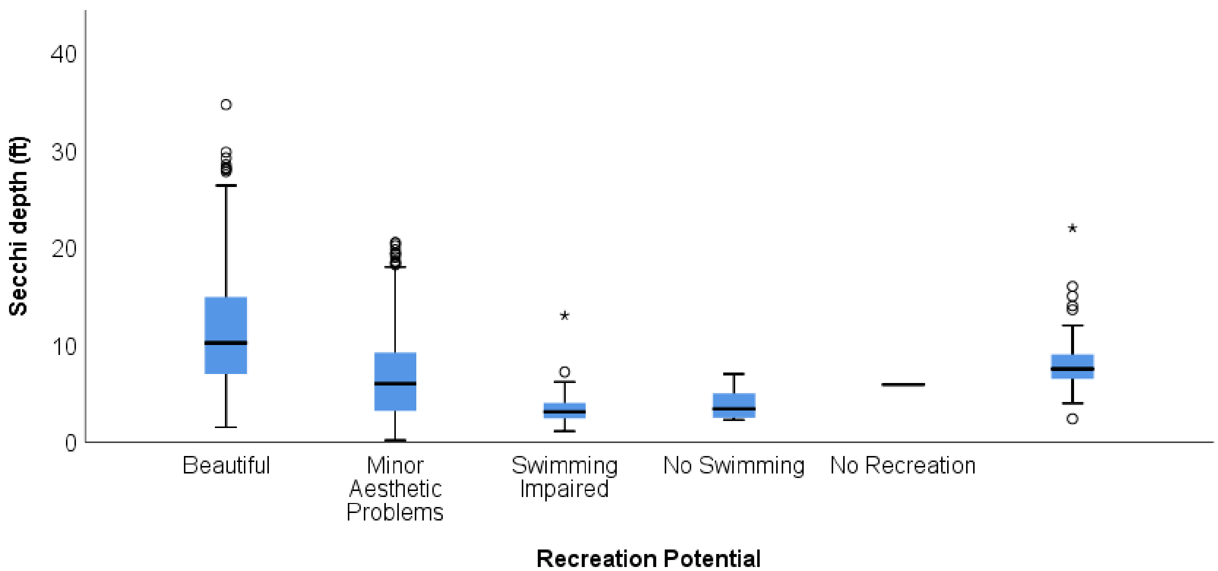


Figure 20. 2016-2018 mean July/August lake transparency distribution across volunteer recreation potential ratings. The blank category summarizes data with no associated volunteer response to the recreation potential prompt during data collection.

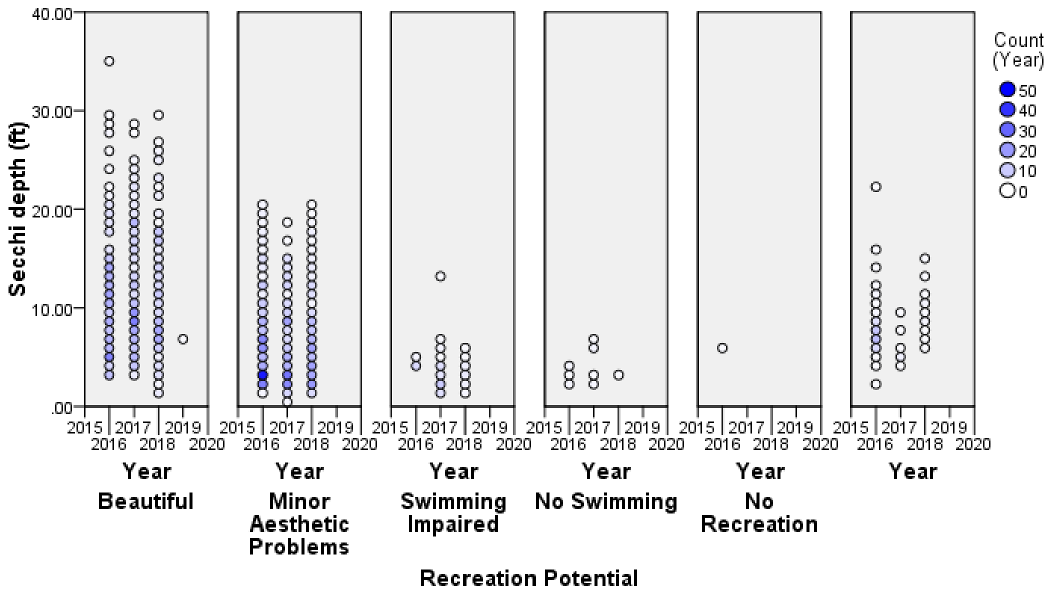


Figure 21. 2016-2018 count of July/August mean transparency measurements across volunteer recreation potential ratings. The color scale indicates different counts of observations. The blank category summarizes data with no associated volunteer response to the recreation portential prompt during data collection.

COLOR RESULTS

Water color can be used as an additional indicator of lake health and to provide insight into the cause of decreasing transparency. Sediment and algae influence the color of a waterbody, with sediments tinting the water brown and algae often causing the water to be various shades of green. Water color can also be a factor of the underlying geology. Limestone overtime and through weathering process creates “marl” lakes that have a blue green hue to them.

Volunteers can report one of the following five color categories:

1. Clear Blue
2. Blue/Green
3. Green
4. Brown
5. Green/Brown

This system allows comparison between the colors and the transparency results. Lakes for which the volunteers select “clear blue” have the highest transparency (Figure 22). The greatest spread of data is for the color choice of “green”. This could be explained by the variation in the density of algal growth that would contribute to the green coloration of the water. The more dense the algal growth, the more turbid the water would appear. The lowest median Secchi depth readings are also for the choices of “brown” and “green/brown” (Figure 22). This is likely a result of suspended sediments contributing to the turbidity of the water.

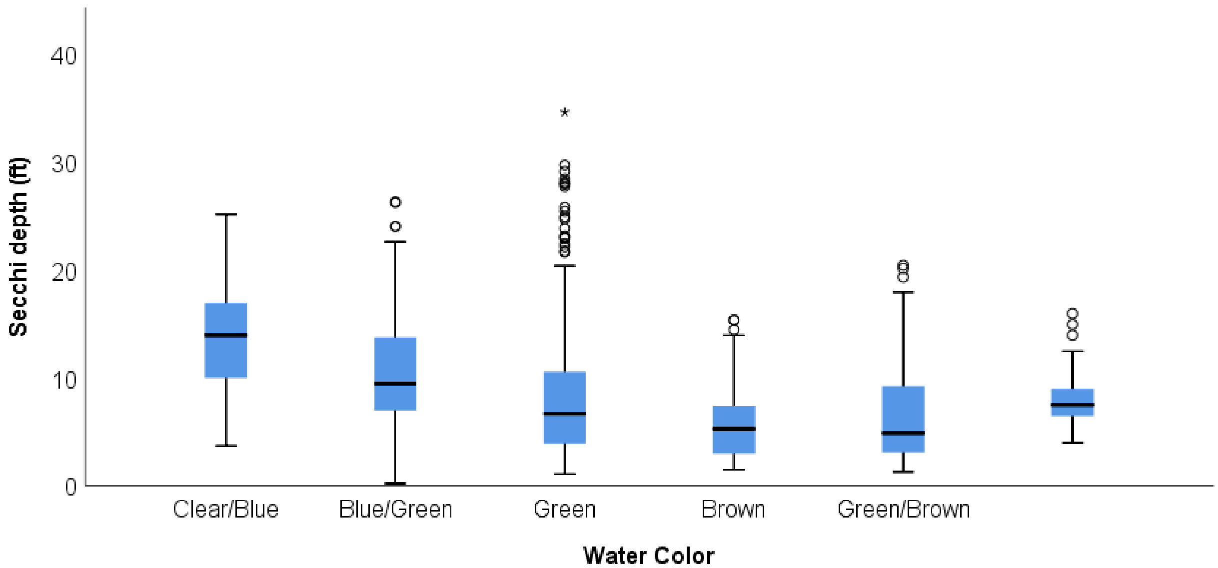


Figure 22. 2016-2018 mean July/August lake transparency distribution across water color responses. The blank category summarizes data with no associated volunteer response to the water color prompt during data collection.

TEMPERATURE AND DISSOLVED OXYGEN RESULTS

Volunteers are able to check out temperature and dissolved oxygen meters from the School of Public and Environmental Affairs in Bloomington, Soil and Water Conservation District offices in Elkhart, Fulton, Kosciusko, LaGrange, Marshall, and Steuben Counties, and Merry Lea Environmental Learning Center (Figure 24). Volunteer use of the meters has increased over the years since the replacement of meters.

From 2016-2018, 204 dissolved oxygen and temperature profiles were made on 21 different lakes (Figure 23). In 2016, 84 profile measurements were collected, the highest number in program history. Dissolved oxygen and temperature profiles can yield very useful information and can indicate:

1. If the lake is thermally stratified or mixing (unstratified)
2. If stratified, the depth of the hypolimnion
3. The position of the metalimnion
4. How much of the lake has sufficient oxygen for fish
5. If the hypolimnion has no oxygen
6. The potential for nutrient release from the bottom sediments

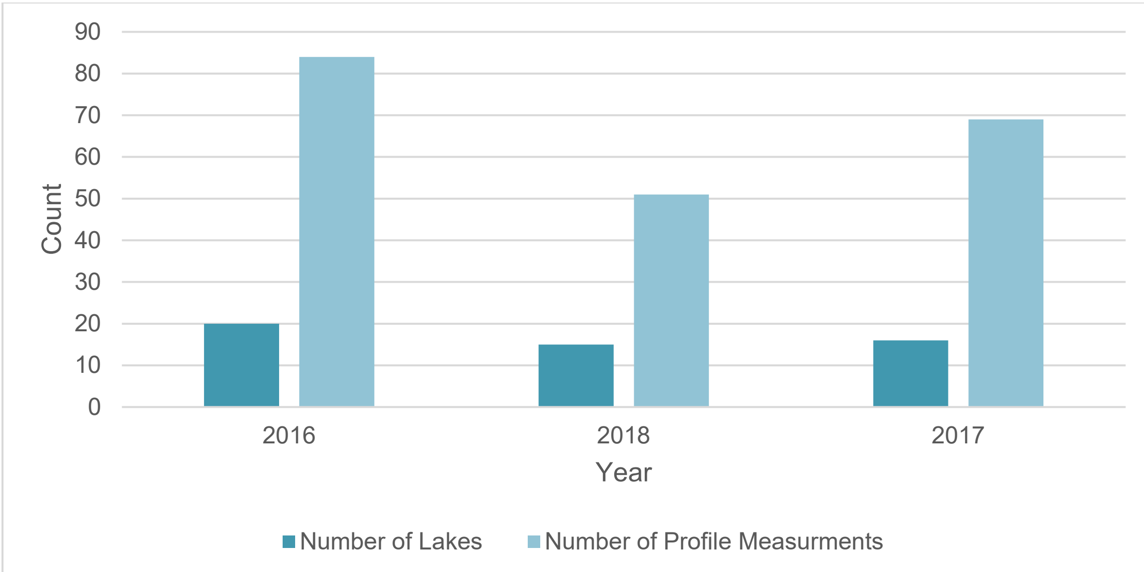


Figure 23. Number of Lakes and profile measurements taken from 2016-2018.

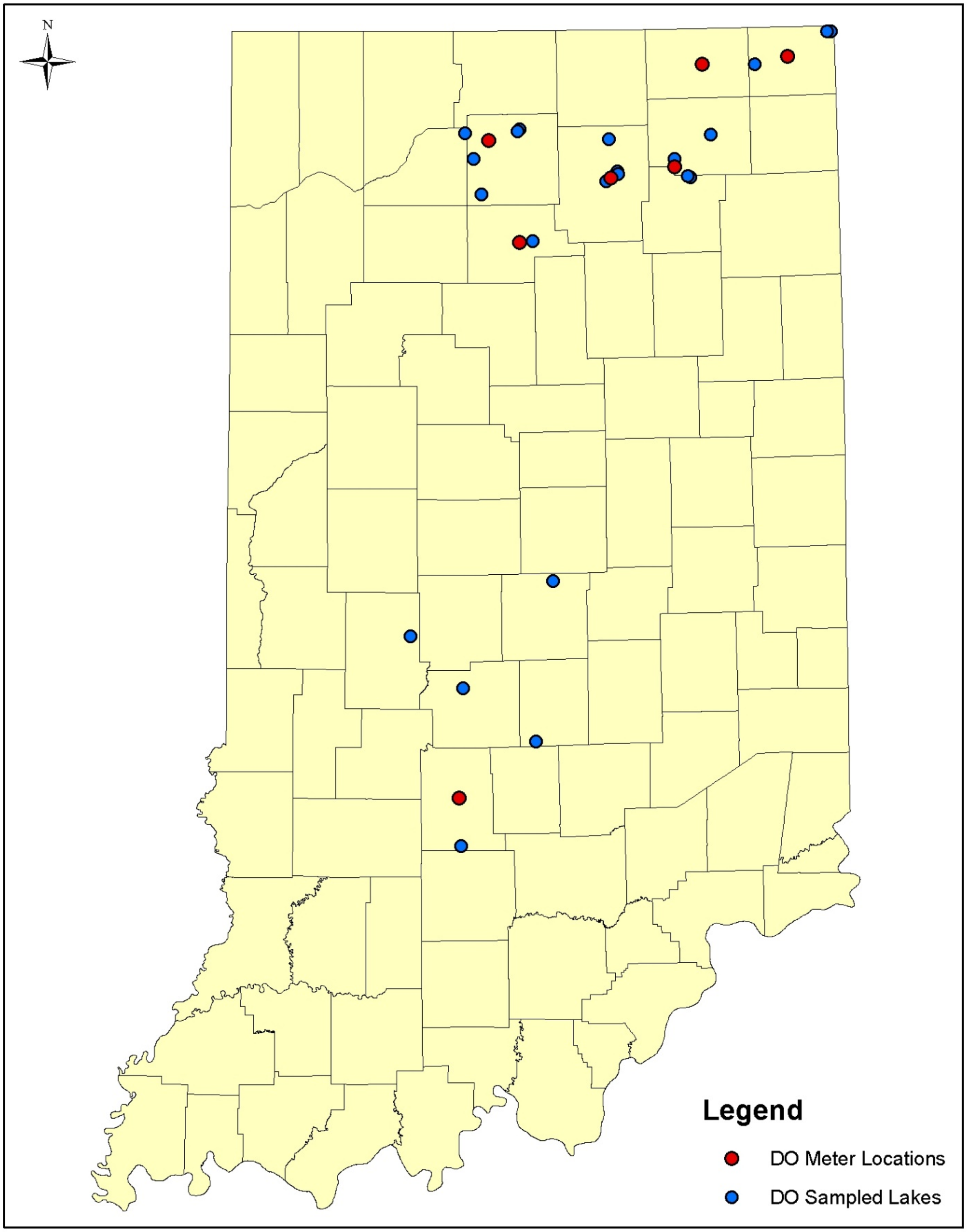


Figure 24. Dissolved oxygen and temperature meter locations and lakes sampled for dissolved oxygen and temperature.

Figures 32 and 33 illustrate an example of changes in a typical temperature and dissolved oxygen profile during the summer season. Waubee Lake was stratified from June to August. The temperature barrier does not allow the lake to mix completely (Figure 25). In early October the surface of the water is beginning to cool and has experienced turnover (complete mixing) by late October. This temperature difference allows for the dissolved oxygen profile to follow the same pattern. The temperature change does not allow oxygen from the top layer of the lake to mix into the bottom creating hypoxic conditions (Figure 32).

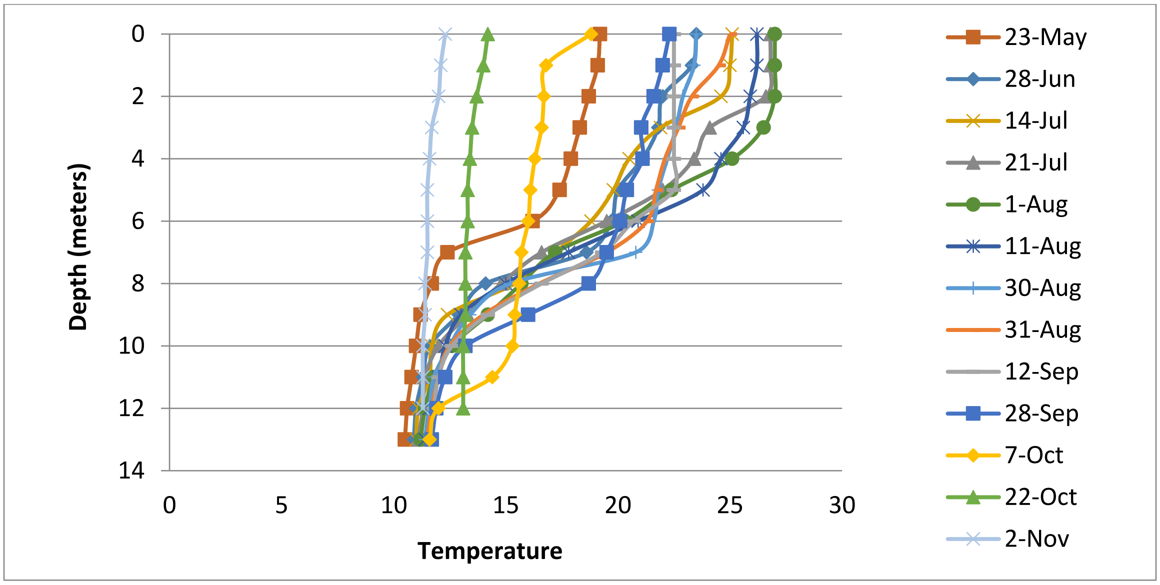


Figure 25. Temperature profile of Waubee Lake from June through October.

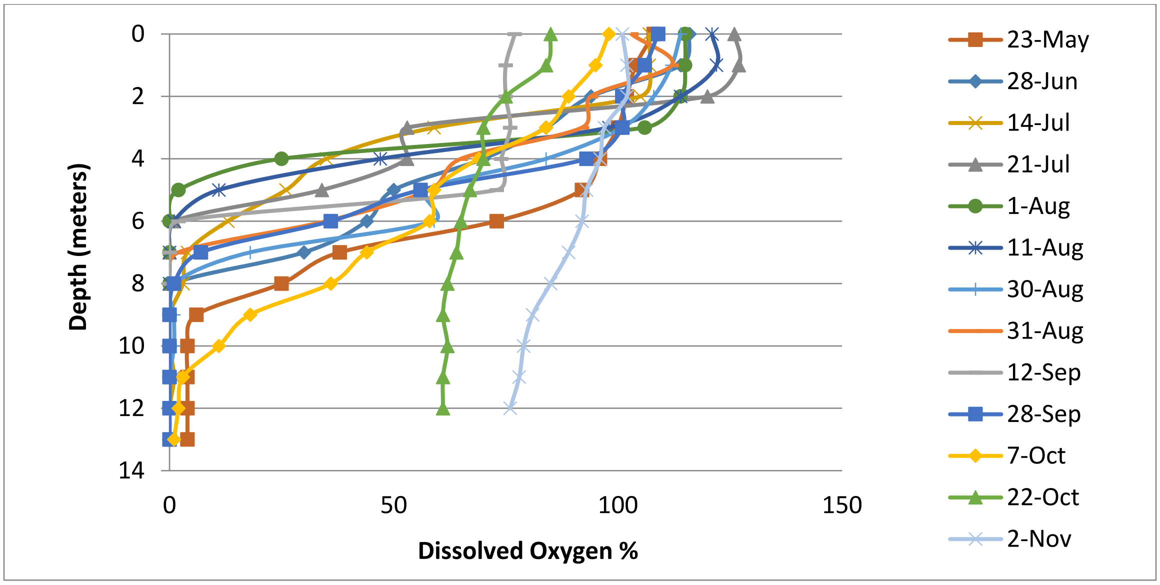


Figure 26. Dissolved oxygen profile of Waubee Lake from June through October.

EXPANDED PROGRAM RESULTS

From 2016-2018 expanded volunteer monitors collected 555 total phosphorus and chlorophyll *a* measurements on 54 lake. The Expanded Program has grown over the past 5 years. While some lakes have come in and out over that time we have overall maintained approximately 50 lakes in all years. We reached our goal of increasing the number from 45 to approximately 50 lakes monitored from the last grant cycle. The expanded lake locations are shown in Figure 2. They are located throughout the state, but are concentrated in the northeast. Annual summary reports that include the minimum, maximum, and July/August mean values for total phosphorus and chlorophyll *a* from 2016 through 2018 can be fourn online at https://clp.indiana.edu/ .

Variation in size and depth of the expanded lakes is similar to the variation in all lakes in the program. Figure 27 and 28 show the size and depth distribution of lakes in the Expanded Program, respectively. Little Crooked Lake in Whitley County had the smallest surface area, 15 acres and is one five lakes less than 50 acres in size. Lake Wawasee in Kosciusko County, 2,617 acres, had the greatest surface area of natural lakes sampled and one of eleven lakes that had a surface area greater than 500 acres. The majority of expanded program lakes had surface areas between 50 and 500 acres. Big Bass Lake in Porter County was the shallowest lake in the Expanded Program, 12 feet. Tippecanoe Lake in Kosciusko County, 123 feet, was the deepest lake. Twenty of the 51 lakes sampled between 2016 and 2018 were between 21 and 40 feet deep. Five lakes were greater than 100 feet deep, while only two were less than 20 feet deep. The remaining lakes were distributed among the remaining classifications; 41-60 feet, 61-80 feet, and 81-100 feet.

Big Bass Lake in Porter County (292 µg/L) and Louise Lake in Porter County (174 µg/L) had the highest mean total phosphorus concentrations from 2016-2018. Nineteen lakes had recorded summertime means below 10 µg/L of total phosphorus.

Louise Lake in Porter County had the highest mean chlorophyll *a* concentration of 112µg/L, from the 2016-2018 sampling period. Skinner Lake in Noble County had the second highest with a mean chlorophyll *a* concentration of 92 µg/L. Twenty lakes had summertime mean chlorophyll *a* concentrations below 2 µg/L.

The data from the Expanded Program agree with expected relationships between total phosphorus and chlorophyll *a*, as total phosphorus increases, chlorophyll *a* increases (Figure 30). Another relationship that is seen in Expanded Program data is as chlorophyll *a* increases, Secchi disk transparency decreases logarithmically (Figure 31). More chlorophyll *a* indicates increased algal biomass that interferes with light penetration and decreases transparency. Secchi disk transparency also decreases exponentially as total phosphorus increases (Figure 32).

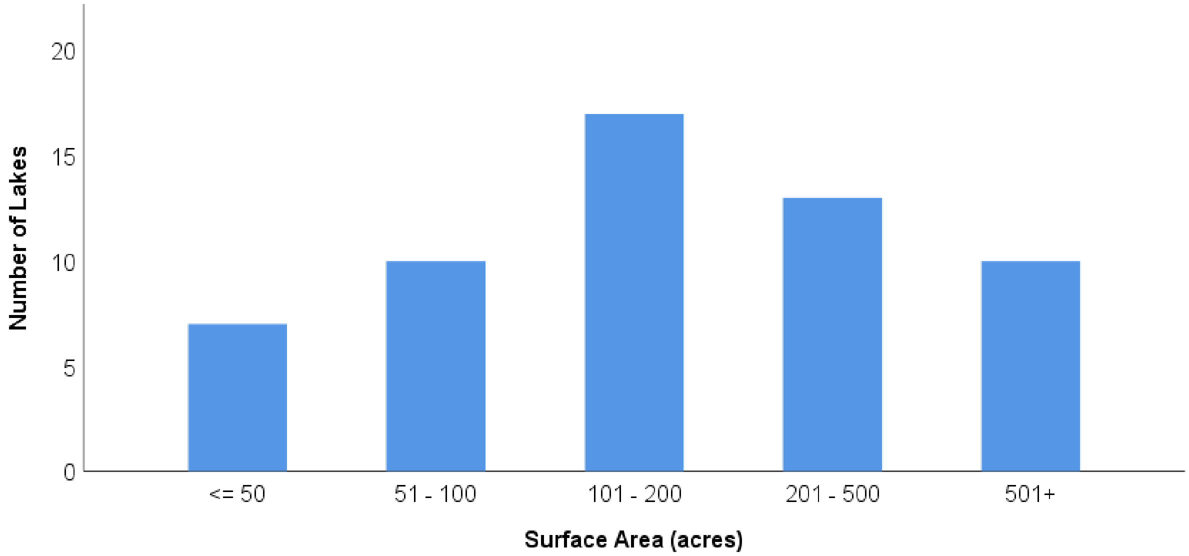


Figure 27. Size distribution of lakes in the Expanded Volunteer Monitoring Program 2016-2018.

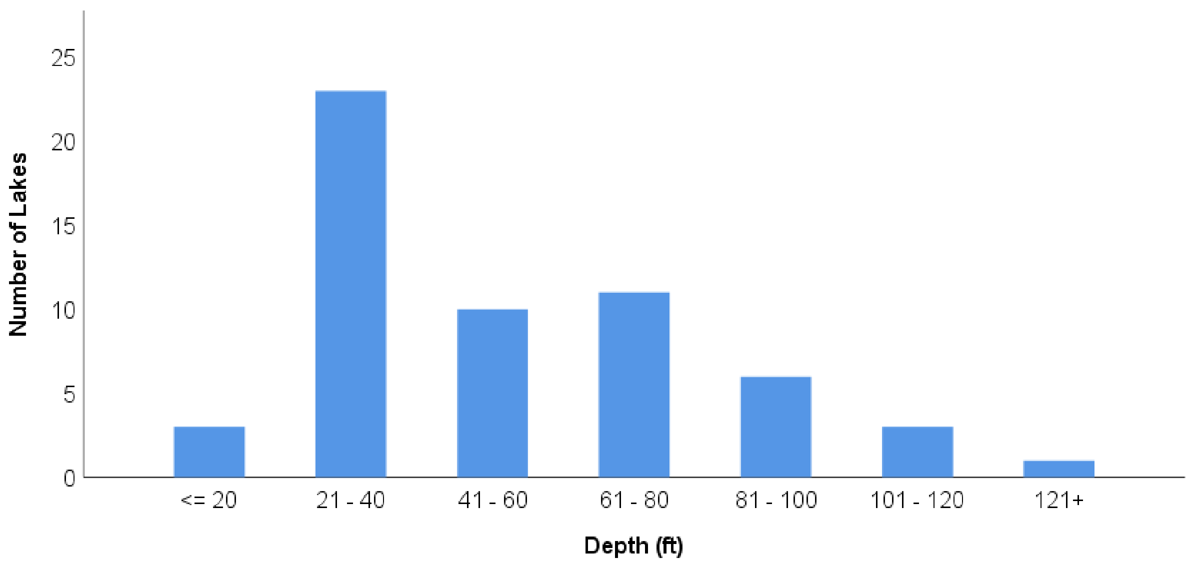


Figure 28. Depth distribution of lakes in the Expanded Volunteer Monitoring Program 2016-2018.

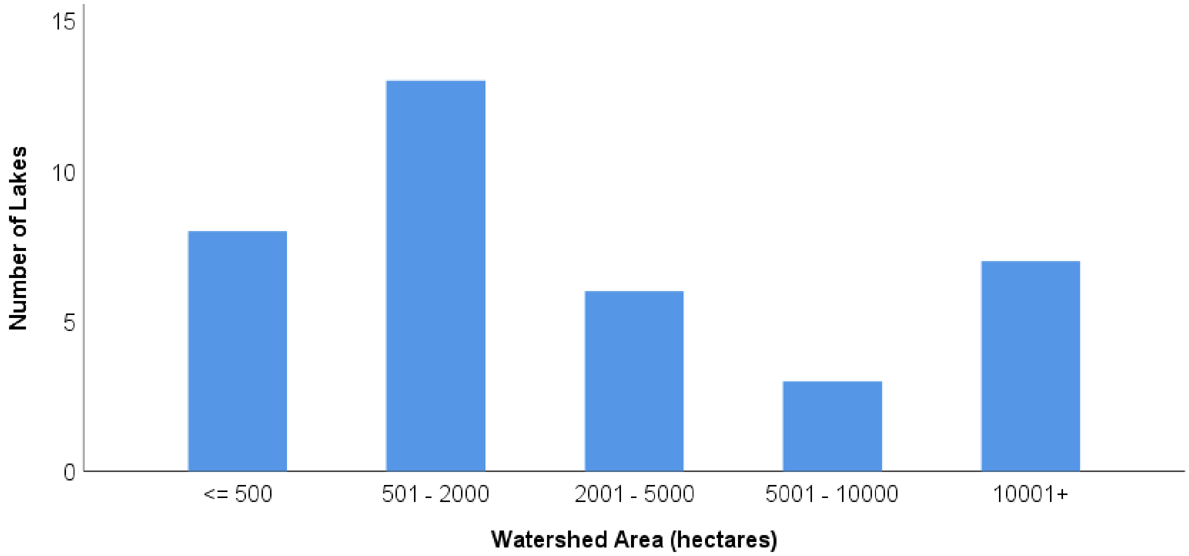


Figure 29. Watershed area distribution of lakes in the Expanded Volunteer Monitoring Program 2016-2018.

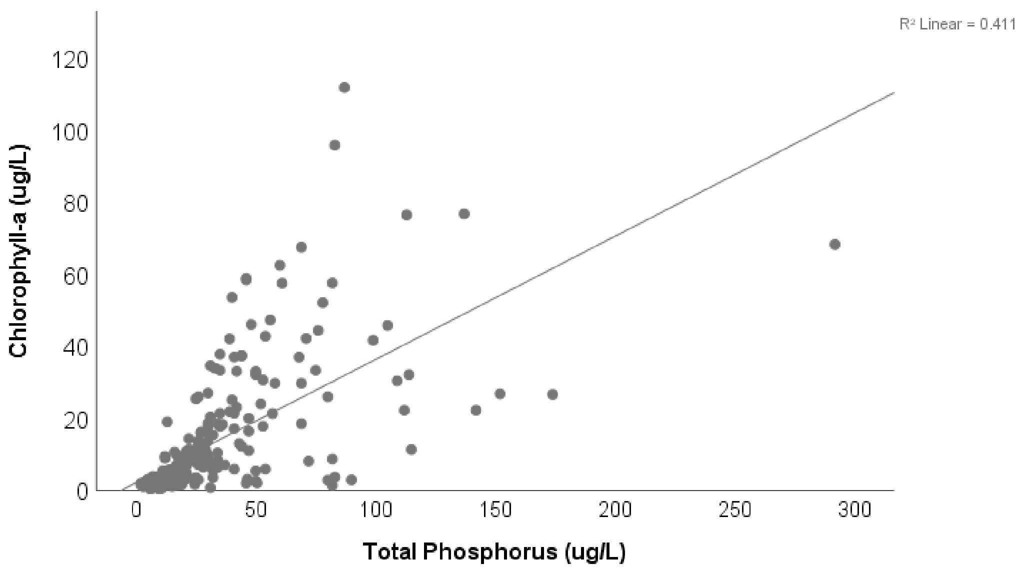


Figure 30. Relationship between July/August summertime means of total phosphorus and chlorophyll *a* in lakes monitored by volunteers from 2016-2018.

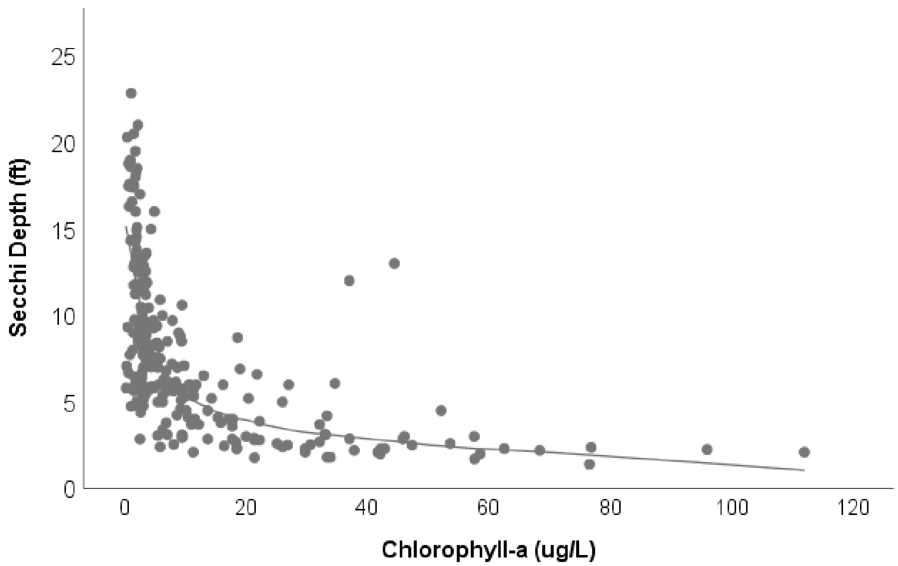


Figure 31. Relationship between July/August summertime means of transparency and chlorophyll *a* from 2016-2018.

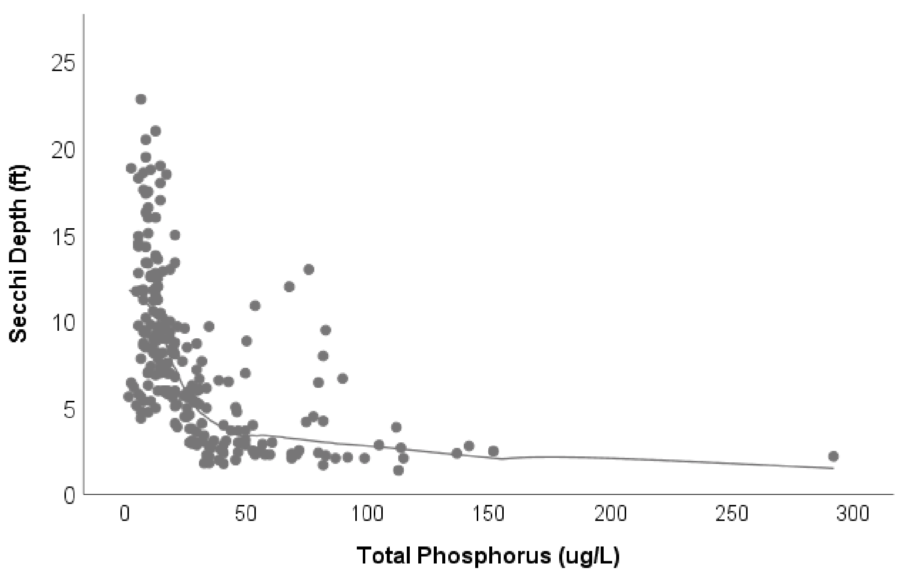


Figure 32. Relationship between July/August summertime means of transparency and total phosphorus from 2016-2018.

Factors Affecting Phosphorus and Chlorophyll *a* Concentrations
Many factors influence total phosphorus concentrations, which subsequently affect chlorophyll *a* concentrations. Phosphorus concentrations are affected by both external and internal factors. Watershed land use is one factor that can be used as a predictor of water quality. Watersheds where agriculture predominates generally have higher phosphorus loads (Novotny, 2003). Watersheds made up of mostly of forests tend to have lower phosphorus loads; therefore the phosphorus concentration in the lake will be lower. Human activities that remove vegetation from land, such as row crop agriculture and construction practices, can increase runoff and nutrient additions to lakes. Other human activities that add phosphorus to lakes include: gardening, fertilizing lawns, some industrial activities, and improperly functioning septic systems or wastewater treatment plants. Once phosphorus enters the lake the dissolved portion is utilized by algae and rooted vegetation, the suspended portion settles attached to sediment particles. Shallower lakes are more prone to wind resuspension of sediments, resuspending phosphorus, releasing it for algal production. Other internal factors that influence phosphorus concentrations include sediment disturbance due to recreational use, surface area and the maximum depth.

Chlorophyll concentrations in lakes are influenced by factors that affect algae growth including: phosphorus availability, light intensity and penetration, water temperature, and algal predation. An increase in total phosphorus, with all other factors held constant, can cause an increase in algae and result in an increase in chlorophyll *a*. Factors that increase turbidity such as heavy runoff or boating may cause chlorophyll *a* concentrations to remain low even when total phosphorus increases because the increased turbidity decreases light availability. A robust zooplankton population may prey on algae sufficiently to reduce algal biomass and thus, chlorophyll *a*.

Characteristics of lakes such as basin morphometry, watershed size, and ecoregion can be used to describe these relationships in Indiana's lakes. Basin morphometry can determine the importance of resuspension of sediments and the availability of light in lakes. Watershed size can provide information about nutrient and sediment delivery while ecoregions help explain land use and human impacts on lakes.

Basin Morphometry
Total phosphorus concentrations are often greater in shallow lakes because bottom sediments, rich in phosphorus, may be resuspended into the water by motorboats or wind activity. The highest phosphorus concentration is associated with Big Bass Lake (Porter County) which is the shallowest lake sampled (12 feet), 292 µg/L (Figure 33).

Chlorophyll *a* concentrations mirrored the total phosphorus concentrations based on maximum depth (Figure 34). The mean chlorophyll *a* concentrations was highest for Louise Lake (Porter County) (92 µg/L). The lowest median chlorophyll *a* concentrations were found in lakes with a depth greater than 81 feet.

The surface area of monitored lakes had little effect on total phosphorus or chlorophyll *a* concentrations (Figures 35 and 36). The median concentrations varied little between different surface areas.

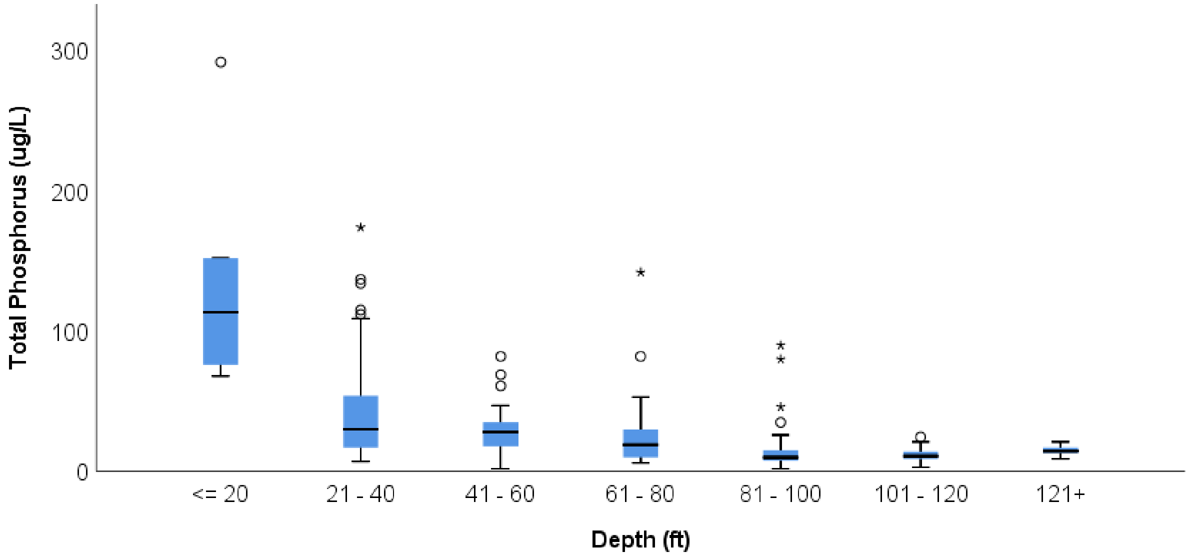


Figure 33. Distribution of July/August summertime mean total phosphorus concentrations (2016-2018) by depth. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

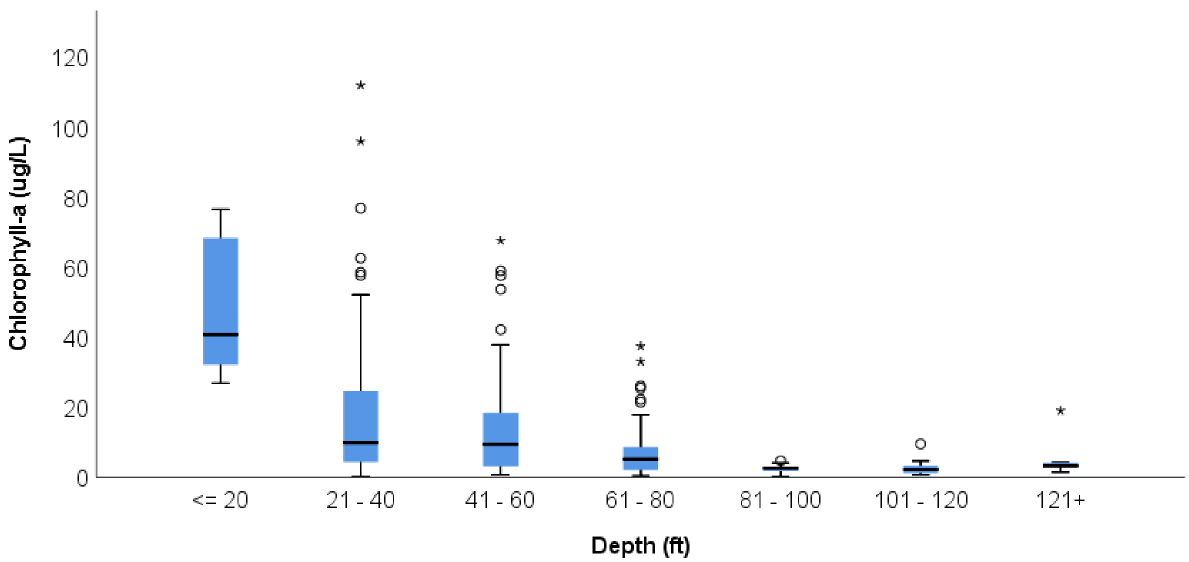


Figure 34. Distribution of July/August summertime mean chlorophyll *a* concentrations (2016-2018) by depth. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

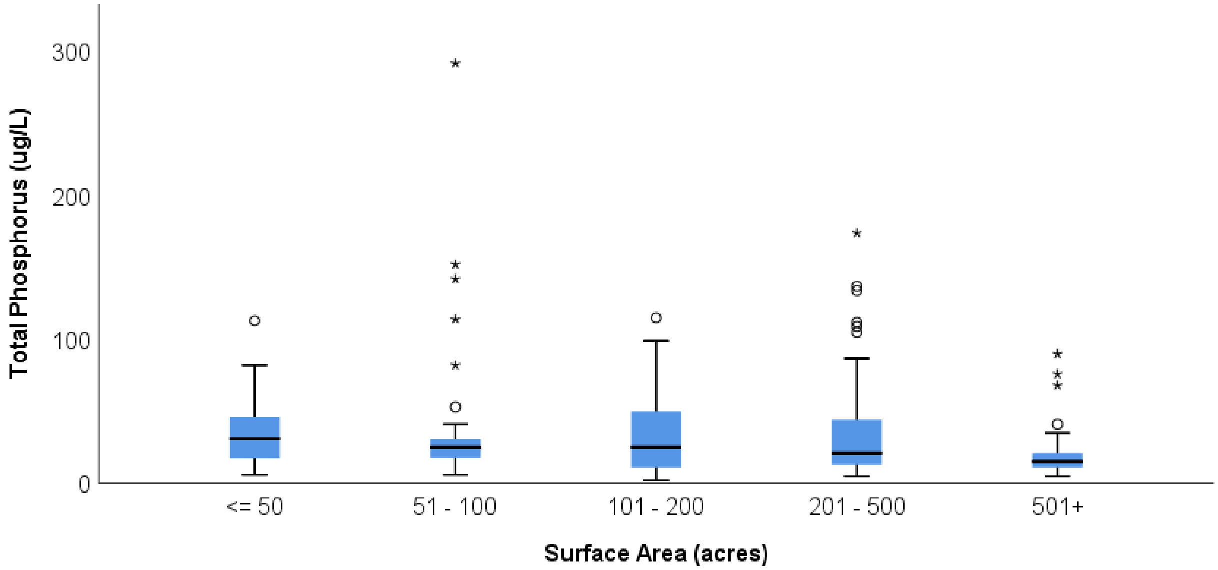


Figure 35. Distribution of July/August summertime mean total phosphorus concentrations (2016-2018) by basin size. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

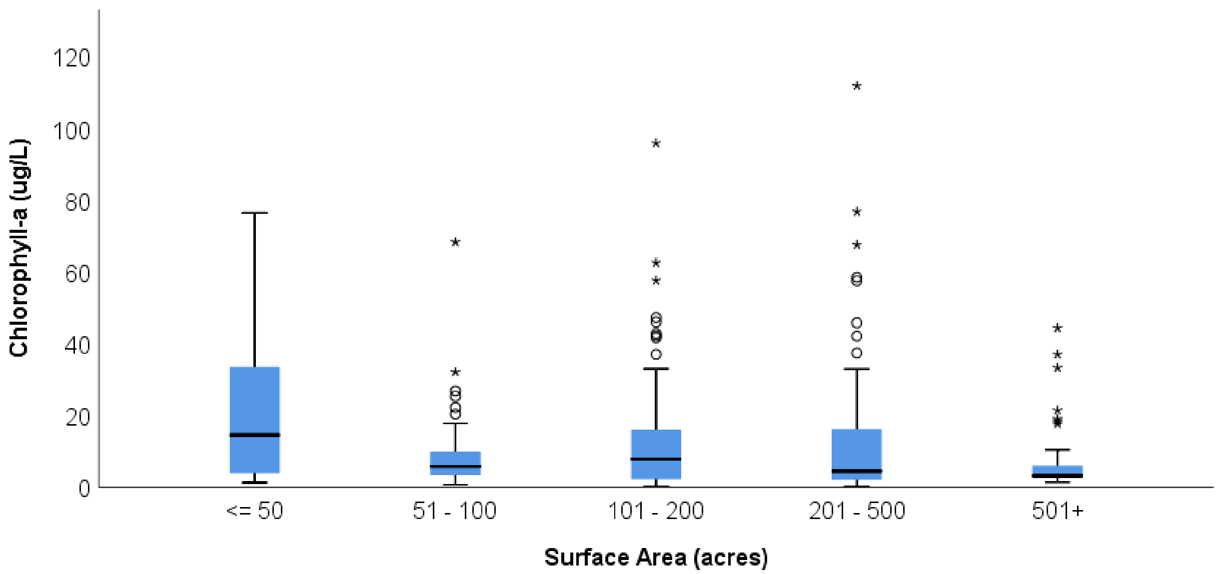


Figure 36. Distribution of July/August summertime mean chlorophyll *a* concentrations (2016-2018) by basin size. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

Watershed Size

Median total phosphorus concentration were highest in lakes with a watershed between 2,000-5,000 acres (39 μg/L) and lowest in lakes with a watershed less than 501-2,000 acres (13 μg/L) (Figure 37). The median chlorophyll *a* concentration was highest in lakes with a watershed between 2,000-5,000 acres (11.9 μg/L) but was lowest in lakes with a watershed area of less than 2,00 acres (3.31 μg/L) (Figure 38).

The median concentrations do not increase with increased size, but we see the greatest concentrations of both phosphorus and chlorophyll *a* in the 2,000 – 5,000 acre range (Figure 37 and 38). Lakes in this size range tend to be of natural origin in Indiana resulting in more turbidity from algal production rather than sediment. Many of the lakes with the largest watershed are reservoirs with increased sediment turbidity that limits algal production.

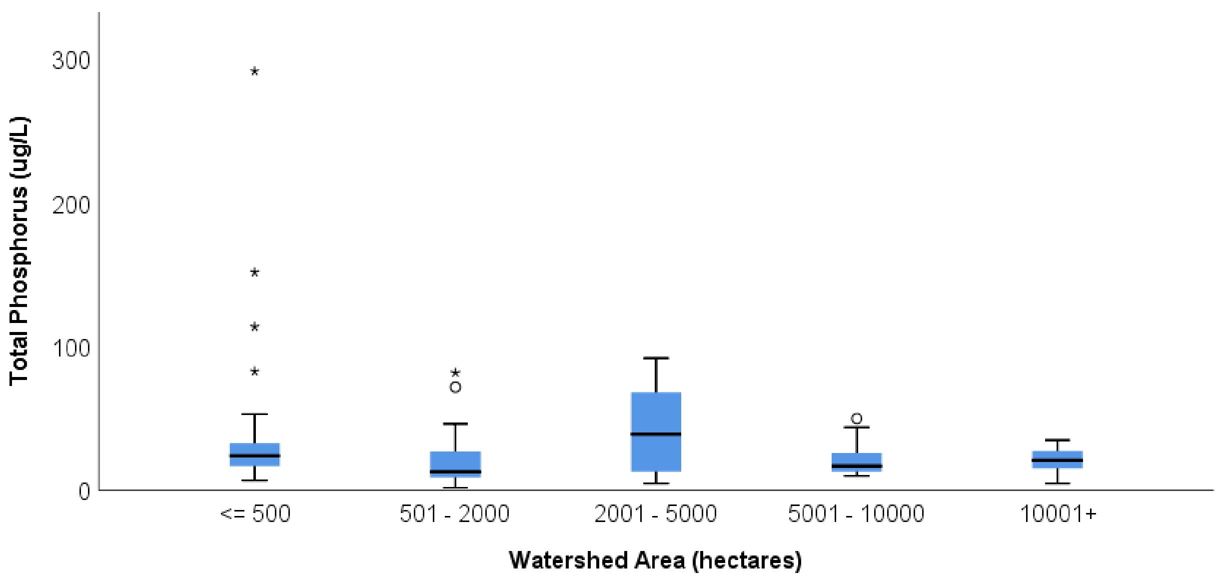


Figure 37. Distribution of mean total phosphorus concentrations (2016-2018) by watershed size. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

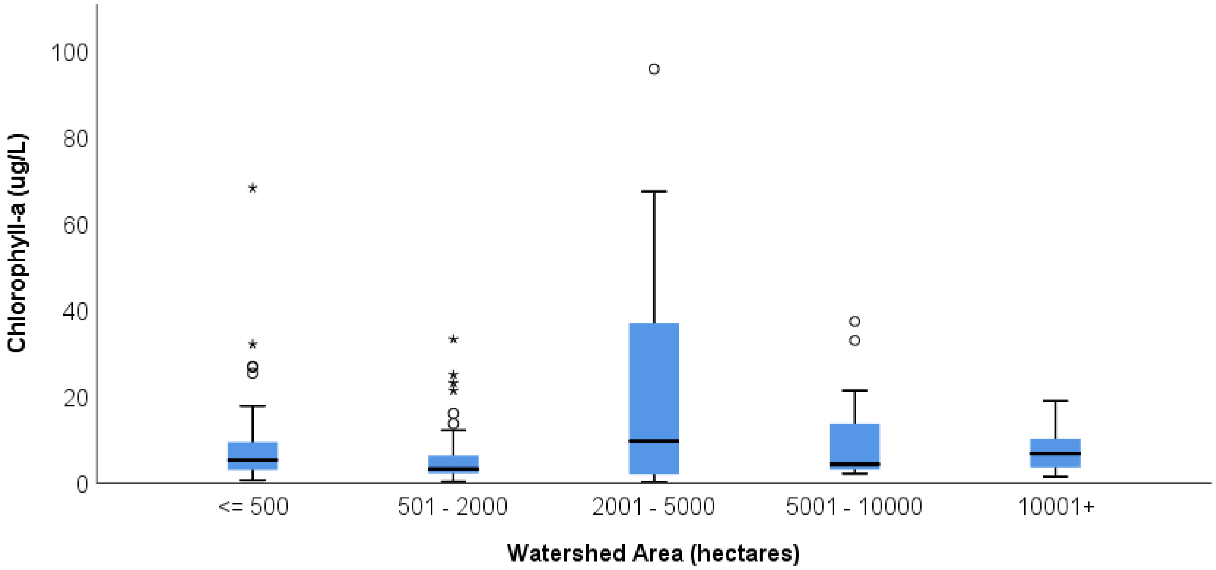


Figure 38. Distribution of mean chlorophyll *a* concentrations (2016-2018) by watershed size. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

Ecoregion

Total phosphorus and chlorophyll *a* concentrations are expected to vary with ecoregion because land use and type vary among ecoregions (Figure 39). Ecoregion 72 (Interior River Valleys and Hills) had the highest median total phosphorus conentrations (112 µg/L), but only one lakes represented this ecoregion that has been known to have high sediment imputs. Ecoregion 55 (Eastern Corn Belt) had the second highest median total phosphorus concentration, 51.0 µg/L. Lakes in this region are surrounded by agriculture which may increase nutrient runoff. The lowest median total phosphorus concentration, 15.0 µg/L, occurred in Ecoregion 71 (Southern Michigan/Northern Indiana Drift Plains). The lakes in Ecoregion 56 had a median concentration of 18 µg/L respectively. These lakes are surrounded by agriculture, but have more lakes collecting data alloweing for better representation of the area.

Chlorophyll *a* concentrations also vary with ecoregion in a similar manner to total phosphorus as expected (Figure 40). Ecoregion 55 (Eastern Corn Belt) had the highest median chlorophyll *a* concentration, 44.5 µg/L. The next highest was 15.5 µg/L in Ecoregion72.The lowest median chlorophyll *a* concentration, 4.06 µg/L, was in Ecoregion 71.

The one lake represented in Ecoregion 72 is a good example of a lake with high total phosphorus inputs from sediment that do not result in high algal productivity due to increased sediment loading from the watershed.

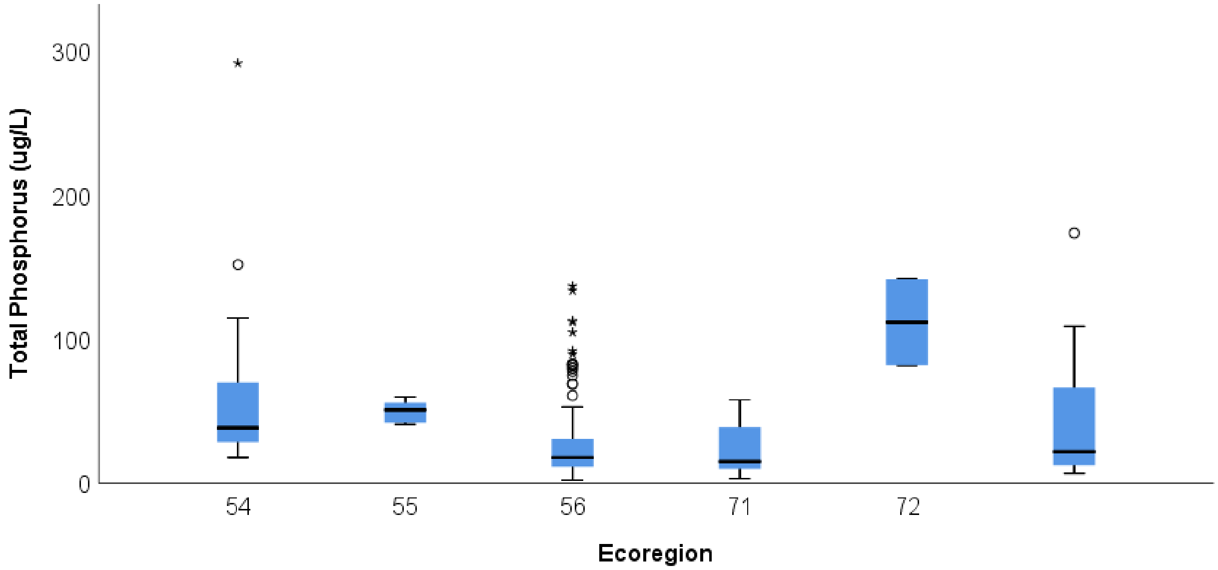


Figure 39. Distribution of mean total phosphorus concentrations (2016-2018) based on ecoregion. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

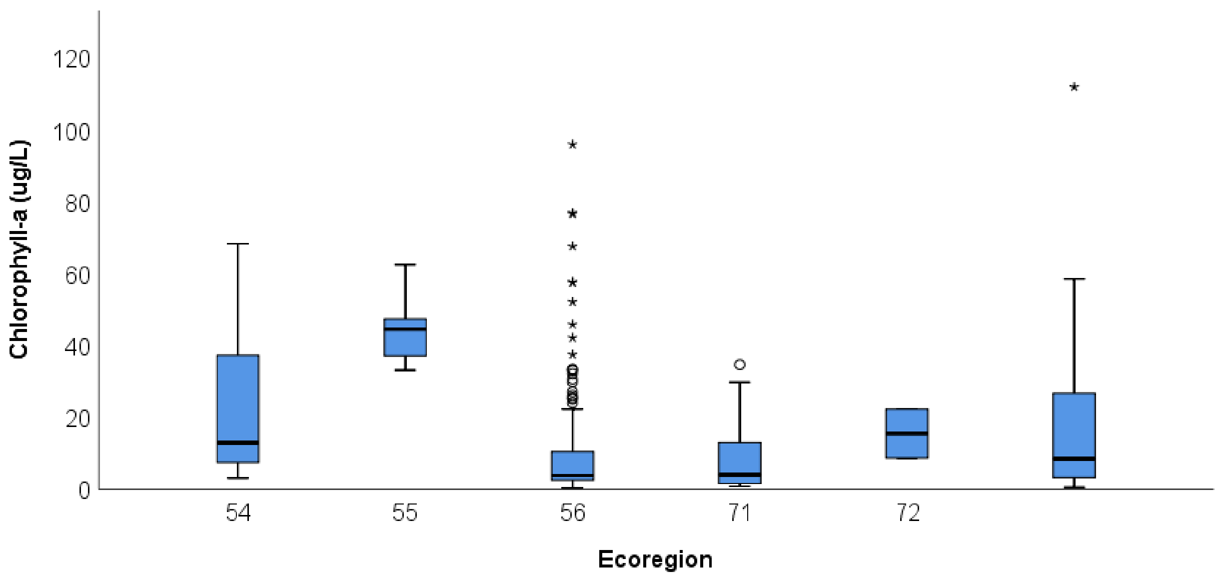


Figure 40. Distribution of mean chlorophyll *a* concentrations (2016-2018) based on ecoregion. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

Trophic State Index Analysis

Carlson's Trophic State Index is used to normalize total phosphorus and chlorophyll a as well as transparency(Figure 4 and 42). The number of lakes in each trophic class did not vary much from year to year; however, it is interesting to see that the two parameters result in different trophic classifications for the same lakes. The trophic states of the same lakes for total phosphorus predict the lakes being more eutrophic than the chlorophyll *a* trophic class. This could be a result of phosphorus being bound to other particles in the water rather than algal biomass. The result is less chlorophyll *a* than we would expect. Secch depth results in a similar trend (Figure 17). The Secchi trophic class predict mostly mesotrophic and eutrophic conditions in the lakes for the past three years.

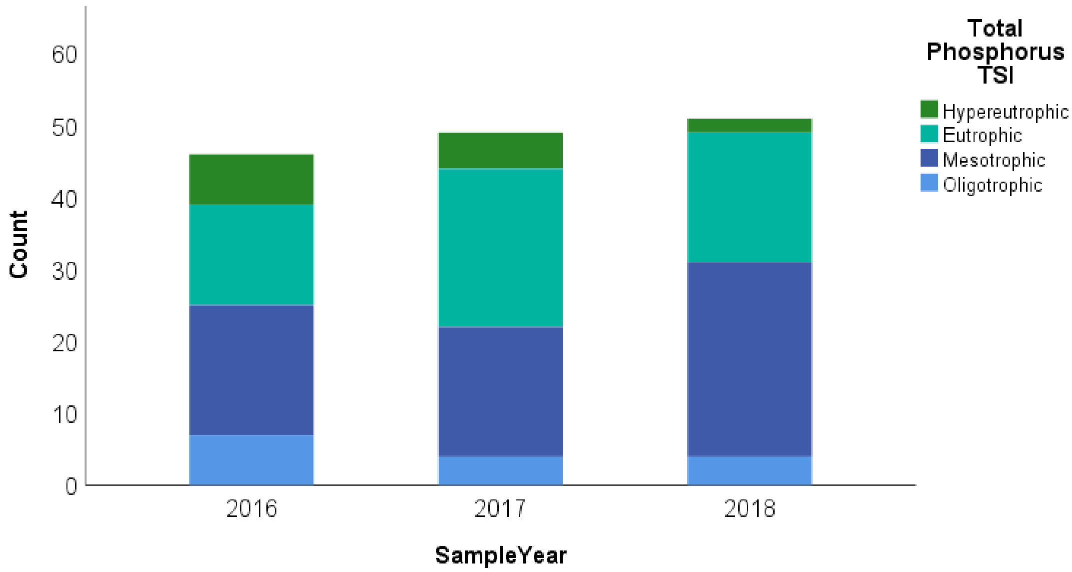


Figure 41. Number of lakes among trophic classes for July/August summertime means of total phosphorus.

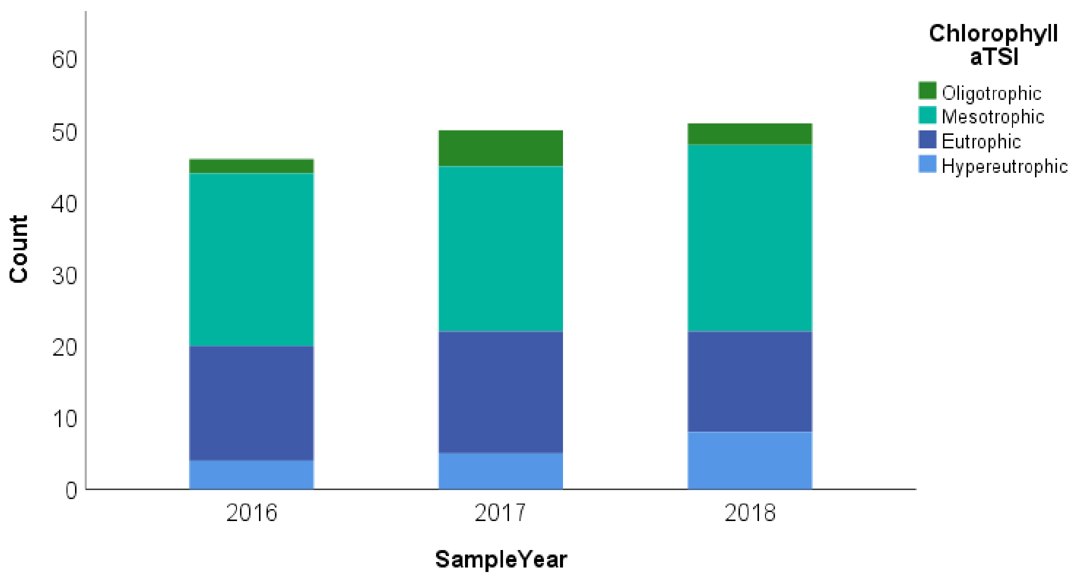


Figure 42. Number of lakes among trophic classes for July/August summertime means of chlorophyll *a*.

Trend Analysis

Volunteer data is best suited for looking at trends on individual lakes. Trend analysis is possible and looking at year to year variation can be helpful (Figure 43 and 44). The data show little change in total phosphorus or chlorophyll *a*

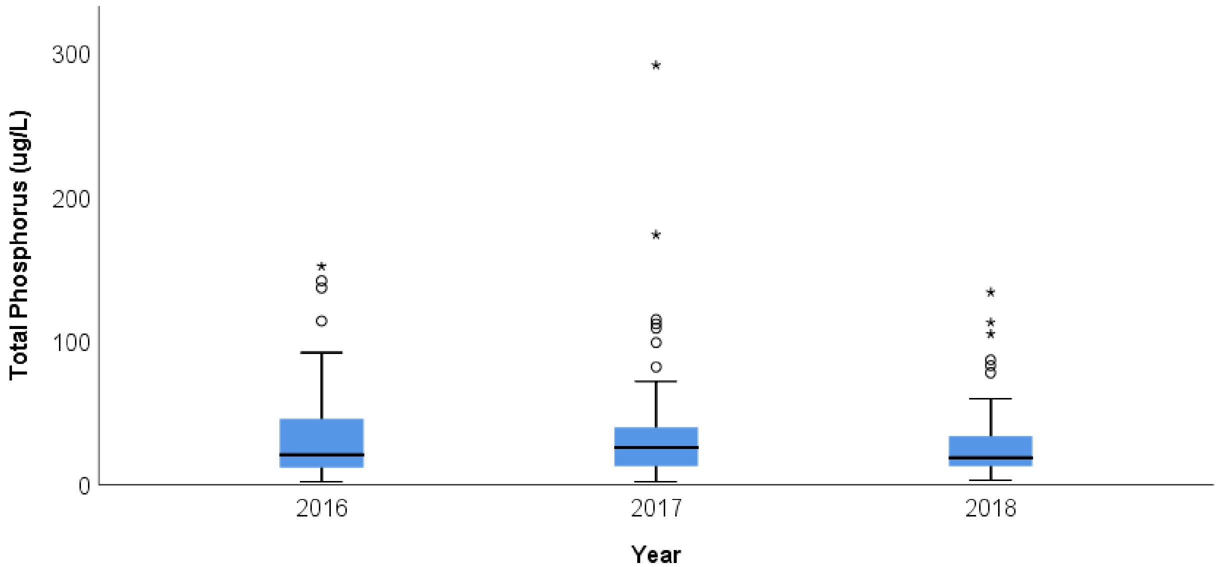


Figure 43. Total phosphorus July/August summertime mean categorized by year. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

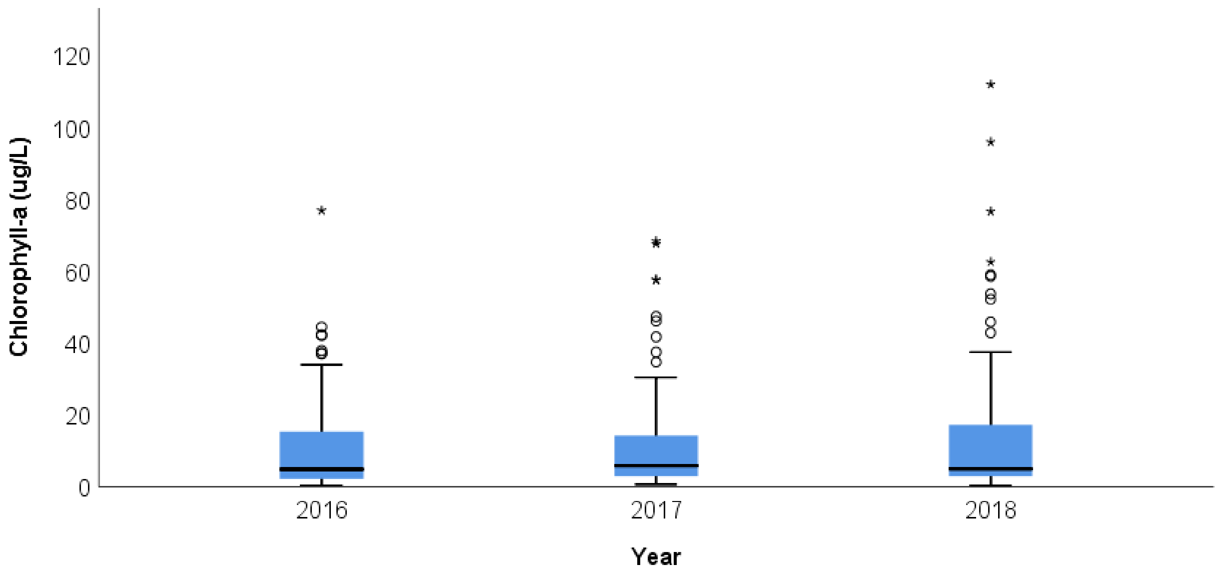


Figure 44. Chlorophyll *a* July/August summertime means categorized by year. The median is the line inside the boxes and the error bars show the minimum and maximum values. The asterisks show the outlier values.

Aquatic Invasive Species Results
By early identification new invasive plants, such as Brazilian elodea and hydrilla, Indiana has been able to keep these invasive plants from spreading. With the help of Volunteer Monitors we can also prevent other invasive plants from becoming a problem in other lakes through early detection. This program furthers the goals of the volunteer monitoring program by adding another dimension to our sampling and education efforts.

In 2012 the training series piloted with one workshop at Pokagon state park to 4 individuals. Since that time we have had an additional 14 workshops focused on aquatic plant identification. We have also passed out 10 invasive mussel monitoring kits.

The greatest challenge that we have had thus far, and seems to be a challenge with other programs of this nature, is the lack of reporting of work done after the workshop. While we hear directly from the volunteers that they continue working on these efforts after they attend a training, they do not submit the information to us. Tracking and success of this program is currently in workshop contacts made with citizens. We continue to offer this program as it offers volunteer engagement.

SURVEY RESULTS
At the end of each sampling season, we request volunteers complete a brief survey concerning their monitoring experience. These questionnaires provide feedback about the program and information on how we can better serve our volunteers and make improvements to the program. The survey also helps us determine how well any new policies and procedures are working for the volunteers.

Each year, respondents are asked “what were the biggest problems affecting your use and enjoyment of your lake this summer? Please check all that apply.” Algal blooms have been a common concern across survey years, with 46% of respondents in 2017 checking them as an issue in the above mentioned question and/or adding specific comments asking if the program can address algal toxins. Algal blooms were also a common concern in 2018 (Figure 45).

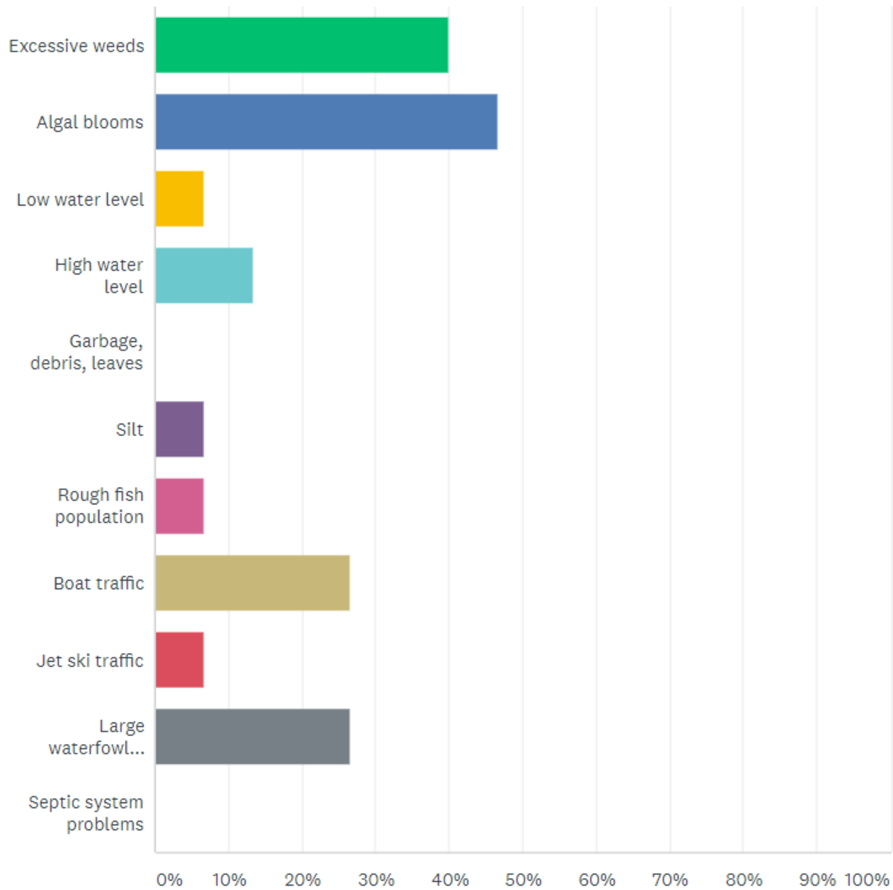


Figure 45. 2018 survey result reporting common issues with monitored lakes.

Many of the questions in the volunteer survey request feedback on the best ways to improve the volunteer lake monitoring program. Suggestions for improvement to the online data entry form have been taken into account, and a new data entry form was implemented in 2018. Follow-up surveys will be sent out in spring 2019 to obtain feedback on the new form and to make continuing improvements to data entry.

PROGRAM CHANGES

The volunteer monitoring program is taking steps to transition to a digital format wherever possible. The change allows faster response time, and will allow volunteers to have access to data in a more timely manner.

Until 2018, year-end summary reports were sent out as paper copies, and many volunteers asked for digital copies of their reports in 2017. Reports were sent out digitally as PDFs in 2018 unless hardcopies were requested. Surveys were sent out primarily in paper form in 2016 and 2017. An online survey was issued in 2018, resulting in a decreased response rate compared to 2016 and 2017. Follow-up surveys will be utilized in early 2019 to obtain more feedback, and we will use a combination of hardcopy and digital format to best reach volunteers. Efforts are being made to determine how volunteers prefer to be contacted, and this information will be collected and taken into account when new volunteers are recruited in the future.

INCLP in conjunction with SPEA is also reformatting and rebuilding the database used to house and access data. Ultimately, we plan to make real-time Secchi depth data available online and implement easy to use data visualization tools on the website. The new database and web-based tools will increase response time, decrease time needed for data processing, and overall improve efficiency for the program and volunteers.

CONCLUSIONS

The VLMP provides invaluable information on Indiana's lakes. The data collected through this program provide long-term data otherwise unachievable by INCLP. The VLMP has continued to change in the past three years, and we look forward to continued growth and improvement in the years to come. Growth of the expanded monitoring program will continue in 2019 as well as the addition of more monitors to the program, with a focus on recruiting volunteers on lakes without current monitors that have been monitored in the past. Overall, the citizen scientists are vital to this program, and we look forward to our continued work with them.

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