

LAKE LEMON MONITORING PROGRAM 2015 RESULTS



Prepared for:

Lake Lemon Conservancy District

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Contents

1.0 INTRODUCTION	1
2.0 METHODS	1
3.0 RESULTS	5
3.1 Water Quality	5
3.2 Comparison with Other Indiana.....	16
3.3 Stream Results	16
3.4 Trophic State.....	19
3.4.1 Introduction.....	19
3.4.2 Trophic State Indices	19
3.4.3 Trophic State Scores	21
4.0 TROPHIC STATE TRENDS	21
5.0 WATER QUALITY TRENDS	23
6.0 CONCLUSIONS.....	25
7.0 REFERENCES	29

1.0 INTRODUCTION

The Lake Lemon Conservancy District (LLCD) has entered into a lease agreement with the City of Bloomington Utilities Service Board (USB) to maintain Lake Lemon in such condition necessary to protect the lake's water quality consistent with its potential use as a drinking water source. LLCD also agreed to maintain the lake in such condition to meet all state and federal requirements for recreational waters and to maintain the quality of the water in the lake at least at its present level.

The LLCD has contracted with Indiana University's School of Public & Environmental Affairs (SPEA) to evaluate the condition of Lake Lemon since 1997. This report is the result of SPEA's 2015 monitoring efforts.

2.0 METHODS

The water sampling and analytical methods used for Lake Lemon were consistent with those used in IDEM's Indiana Clean Lakes Program and IDNR's Lake and River Enhancement Program. We collected water samples for various parameters on 5/19/15, 6/22/15, and 7/29/15 from over the point of maximum depth off Cemetery Island near Riddle Point and in the channel off Reed Point in the eastern end of Lake Lemon (Figure 1).



Figure 1. Sampling locations for the Lake Lemon Water Monitoring Program, 2015.

We collected water samples from one meter below the surface (*epilimnion*) and from one meter above the bottom (*hypolimnion*) at each lake site that was thermally stratified, except the Chitwood site where we only sampled the epilimnion due to the very shallow channel. These samples were preserved as needed, placed in coolers and transported to our laboratory for

analysis. Chlorophyll was determined only for the epilimnetic sample. Other parameters such as Secchi disk transparency, light transmission, and oxygen saturation are single measurements. In addition, dissolved oxygen and temperature were measured at one-meter intervals from the surface to the bottom. A tow to collect zooplankton was made from the 1% light level to the water surface. An integrated sampler was used to collect phytoplankton within the first two meters of the water column.

Because Lake Lemon's condition is heavily influenced by runoff from its watershed, it was also important to monitor the main inlet to the lake - Beanblossom Creek. Therefore, we sampled Beanblossom Creek on 5/19/15, 6/22/15 and 7/29/15 during base flow conditions and 8/6/15 to capture a high flow event, at one location at mid-depth near its discharge point to the lake.

The following parameters were measured for both the lake and stream samples:

- | | |
|--------------------|-------------------------------|
| - pH | - soluble reactive phosphorus |
| - alkalinity | - nitrate+nitrite |
| - conductivity | - ammonia |
| - dissolved oxygen | - total organic nitrogen |
| - temperature | - total suspended solids |
| - total phosphorus | - fecal coliform bacteria |

In addition to the water sampling stations described above, we also monitored several other locations for fecal coliform bacteria. At the Chitwood addition, we collected water samples from just inside the entrance (Chitwood #1) and $\frac{3}{4}$ of the way down the main channel (Chitwood #2), Bear Creek and Knob Creek (Figure 1 and 2).



Figure 2. Zoomed in eastern section of Lake Lemon for the two Chitwood sampling locations.

All sampling techniques and laboratory analytical methods were performed in accordance with procedures in *Standard Methods for the Examination of Water and Wastewater*, 21th Edition (APHA, 2005). Phytoplankton counts were made using a nanoplankton chamber (PhycoTech, Inc.) and a phase contrast light microscope and zooplankton counted using a standard Sedgewick-Rafter counting cell. Fifteen fields per cell were counted for phytoplankton and the entire slide was counted for zooplankton. Plankton identifications were made according to: Wehr and Sheath (2003), Prescott (1982), Ward and Whipple (1959) and Whitford and Schumacher (1984).

The comprehensive evaluation of lakes and streams require collecting data on a number of different, and sometimes hard-to-understand, water quality parameters. Some of the more important parameters that we analyze include:

Temperature. Temperature can determine the form, solubility, and toxicity of a broad range of aqueous compounds. Likewise, life associated with the aquatic environment in any location has its species composition and activity regulated by water temperature. Since essentially all aquatic organisms are 'cold-blooded' the temperature of the water regulates their metabolism and ability to survive and reproduce effectively (EPA, 1976). The Indiana Administrative Code (327 IAC 2-1-6) sets maximum temperature limits to protect aquatic life for Indiana streams. For example, temperatures during the month of May should not exceed 80 °F (23.7 °C) by more than 3 °F (1.7 °C). June temperatures should not exceed 90 °F (32.2 °C).

Dissolved Oxygen (D.O). D.O. is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3-5 mg/L of D.O. Cold-water fish such as trout generally require higher concentrations of D.O. than warm water fish such as bass or Bluegill. The IAC sets minimum D.O. concentrations at 6 mg/L for cold-water fish. D.O. enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth can over-saturate (greater than 100% saturation) the water with D.O. Conversely, dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

Conductivity. Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions: on their total concentration, mobility, and valence (APHA, 1998). During low discharge, conductivity is higher than during storm water runoff because the water moves more slowly across or through ion containing soils and substrates during base flow. Carbonates and other charged particles (ions) dissolve into the slow-moving water, thereby increasing conductivity measurements.

pH. The pH of water is a measure of the concentration of acidic ions (specifically H⁺) present in the water. The pH also determines the form, solubility, and toxicity of a wide range of other aqueous compounds. The IAC establishes a range of 6-9 pH units for the protection of aquatic life.

Alkalinity. Alkalinity is a measure of the acid-neutralizing (or buffering) capacity of water. Certain substances, if present in water, like carbonates, bicarbonates, and sulfates can cause the water to resist changes in pH. A lower alkalinity indicates a lower buffering capacity or a decreased ability to resist changes in pH. During base flow conditions, alkalinity is usually high because the water picks up carbonates from the bedrock. Alkalinity measurements are usually lower during storm flow conditions because buffering compounds are diluted by rainwater and the runoff water moves across carbonate-containing bedrock materials so quickly that little carbonate is dissolved to add additional buffering capacity.

Nitrogen. Nitrogen is an essential plant nutrient found in fertilizers, human and animal wastes, yard waste, and the air. About 80% of the air we breathe is nitrogen gas. Nitrogen gas diffuses into water where it can be “fixed”, or converted, by Blue-green algae to ammonia for their use. Nitrogen can also enter lakes and streams as inorganic nitrogen and ammonia. Because of this, there is an abundant supply of available nitrogen to aquatic 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. It is found in streams and runoff when dissolved oxygen is present, usually in the surface waters. Ammonia applied to farmland is rapidly oxidized or converted to nitrate and usually enters surface and groundwater as nitrate. The Ohio EPA (1999) found that the median nitrate-nitrogen concentration in wadeable streams that support modified warmwater habitat (MWH) was 1.6 mg/L. Modified warmwater habitat was defined as: aquatic life use assigned to streams that have irretrievable, extensive, man-induced modification that preclude attainment of the warmwater habitat use (WWH) designation; such streams are characterized by species that are tolerant of poor chemical quality (fluctuating dissolved oxygen) and habitat conditions (siltation, habitat amplification) that often occur in modified streams (Ohio EPA, 1999). Nitrate concentrations exceeding 10 mg/L in drinking water are considered hazardous to human health (Indiana Administrative Code IAC 2-1-6).

Ammonia (NH_4^+) – Ammonia is a form of dissolved nitrogen that is the preferred form for algae use. It is the reduced form of nitrogen and is found in water where dissolved oxygen is lacking. Important sources of ammonia include fertilizers and animal manure. In addition, bacteria produce ammonia as a by-product as they decompose dead plant and animal matter. Both temperature and pH govern the toxicity of ammonia for aquatic life.

Organic Nitrogen (Org N) – Organic nitrogen includes nitrogen found in plant and animal materials. It may be in dissolved or particulate form. In the analytical procedures, total Kjeldahl nitrogen (TKN) was analyzed. Organic nitrogen is TKN minus ammonia.

Phosphorus. Phosphorus is an essential plant nutrient, and the one that most often controls aquatic plant (algae and macrophyte) growth in freshwater. It is found in fertilizers, human and animal wastes, and yard waste. There are few natural sources of phosphorus to streams other than what is attached to soil particles, and there is no atmospheric (vapor) form of phosphorus. For this reason, 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 inputs to receiving waterways because: (a) it can be managed and (b) reducing phosphorus can reduce algae production. Two common forms of phosphorus are:

Orthophosphate (OP) – OP is dissolved phosphorus readily usable by algae. OP is often found in very low concentrations in phosphorus-limited systems where the phosphorus is tied up in the algae themselves. Because phosphorus is cycled so rapidly through biota, OP concentrations as low as 0.005 mg/L are enough to maintain eutrophic or highly productive conditions in lake systems (Correll, 1998). Sources of OP include fertilizers, animal wastes, and septic systems.

Total phosphorus (TP) – TP includes dissolved and particulate phosphorus. TP concentrations greater than 0.03 mg/L (or 30µg/L) can cause algal blooms in lakes and reservoirs. The Ohio EPA (1999) found that the median TP in Wadeable streams that support MWH for fish was 0.28 mg/L.

Total Suspended Solids (TSS). A TSS measurement quantifies all particles suspended and dissolved in stream water. Closely related to turbidity, this parameter quantifies sediment particles and other solid compounds typically found in stream water. In general, the concentration of suspended solids is greater during high flow events due to increased overland flow. The increased overland flow erodes and carries more soil and other particulates to the stream. Although the State of Indiana sets no standard for TSS, total dissolved solids should not exceed 750 mg/L. In general, TSS concentrations >80 mg/L have been found to be deleterious to aquatic life (Waters, 1995).

E. coli - is used as an indicator organism to identify the potential for the presence of pathogenic organisms in a water sample. Pathogenic organisms can present a threat to human health by causing a variety of serious diseases, including infectious hepatitis, typhoid, gastroenteritis, and other gastrointestinal illnesses. *E. coli* can come from the feces of any warm-blooded animal. Wildlife, livestock, and/or domestic animal defecation, manure fertilizers, previously contaminated sediments, and failing or improperly sited septic systems are common sources of the bacteria. The IAC sets the maximum standard at 200 colonies/100 ml in any one sample within a 30-day period or a geometric mean of 125 colonies per 100 ml for five samples collected in any 30-day period. In general, *E. coli* bacteria have a life expectancy of less than 24 hours.

Secchi Disk Transparency. This refers to the depth to which the black & 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 (for example, soil or dead leaves) may be introduced into the water by either runoff from the land or from sediments already on the bottom of the lake. Many processes may introduce sediments from runoff; examples include erosion from construction sites, agricultural lands, and riverbanks. Bottom sediments may be resuspended by bottom feeding fish such as carp, or in shallow lakes, by motorboats or strong winds.

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

Plankton. Plankton are important members of the aquatic food web. The plankton include the algae (microscopic plants) and the zooplankton (tiny shrimp-like animals that eat algae). The zooplankton net is towed up through the lake's water column from the one percent light level to the surface utilizing a 80-micron mesh on the net and bucket. Beginning in 2010, phytoplankton were sampled using a 2-meter integrated sampler and in the lab whole water samples of phytoplankton were concentrated using Utermöhl 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 nanoplankton chamber (PhycoTech, Inc.) and a phase contrast light microscope. Historically in our analysis of Lake Lemon algae are 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. According to the literature, (Ward and

Whipple, 1959; Prescott, 1982; Whitford and Schumacher, 1984; Wehr and Sheath, 2003; and St. Amand, 2010) in order to provide a more accurate representation of lake algal community composition, in 2011, we have also included counts of only individual cells. For example, the previous method would count a single filamentous green algae (ie: *Ulothrix*) with 20 cells or 10 cells as one unit, whereas the new method would default to a count of 20 or 15 individual cells (Figure 3). Ten to thirty (based on variability of cells per *natural unit*) representative specimens were selected at random and a mean number of cells per natural unit was calculated. Final counts of each genera appear lower however, because they are reported as # of cells per milliliter as opposed to natural units per L. In this report we report only cell counts in replacement of *natural units*. Of the many different algal species present in the water, we are particularly interested in the blue-green algae. Blue-green algae are those that most often form nuisance blooms and their dominance in lakes may indicate poor water conditions.

Chlorophyll-a. The plant pigments of algae consist of the chlorophylls (green color) and carotenoids (yellow color). Chlorophyll-a is by far the most dominant chlorophyll pigment and occurs in great abundance. Thus, chlorophyll-a is often used as a direct estimate of algal biomass.

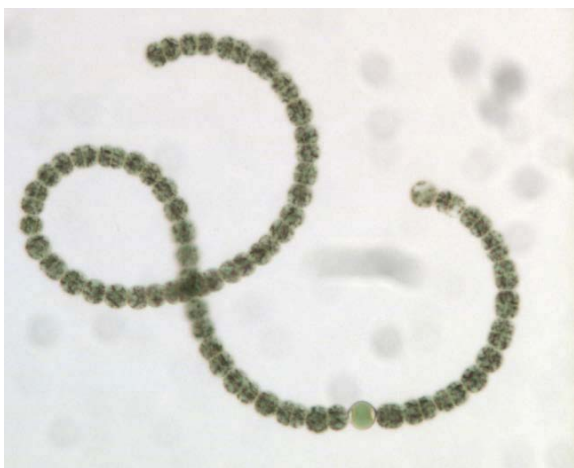


Figure 3. Phytoplankton can be counted with two techniques: natural unit per liter (N.U./L) and cells per milliliter (cells/ml). Colonial species, like this blue-green algae can be enumerated using both methods. This *Anabaena* is counted as one (1) N.U./L, whereas it would be also counted as 74 cells/ml.

3.0 RESULTS

3.1 Water Quality

Temperature – Temperature profiles for June and July indicated slight thermal stratification at Riddle Point, while Reed Point primarily illustrates no stratification (Figures 4 and 5). In most Indiana lakes, thermal stratification is weakest in the spring and gets stronger as summer progresses. The May temperatures at Riddle Point indicate thermal stratification, with 19.9°C surface temperature and 16.8°C bottom temperature. In June, the Riddle Point temperature profile was more strongly stratified with the hypolimnion starting at 4m deep. The whole water column continued to warm with the July surface temperature reaching 31.2°C and the hypolimnion reaching 19.3°C and the hypolimnion extending to the depth of 5m respectively. Reed Point was isothermal throughout the whole summer, with a slight temperature decrease in the July sampling, which is likely due

to calm water conditions reducing the mixing of this shallow sampling site. Reed Point is shallow enough that turbulence from winds and boating activity usually keeps it relatively well mixed.

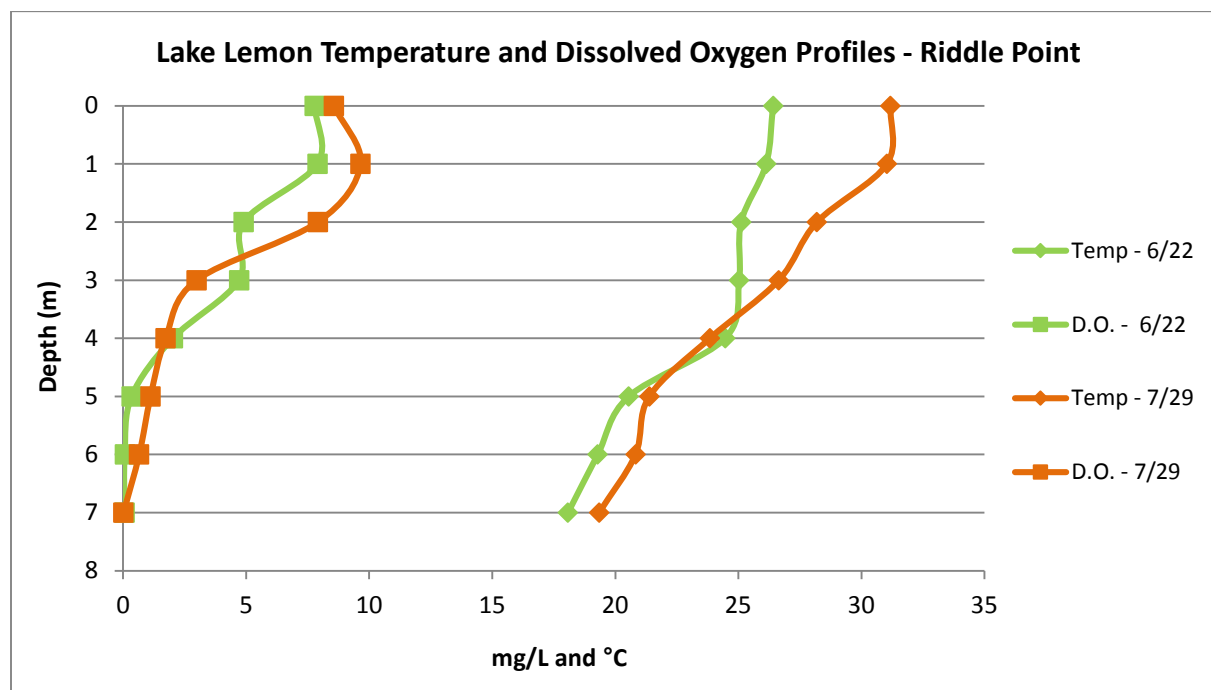


Figure 4. Temperature and dissolved oxygen profiles for Lake Lemon at Riddle Point on 5/19/15 (not collected due to meter malfunction), 6/22/15, and 7/29/15.

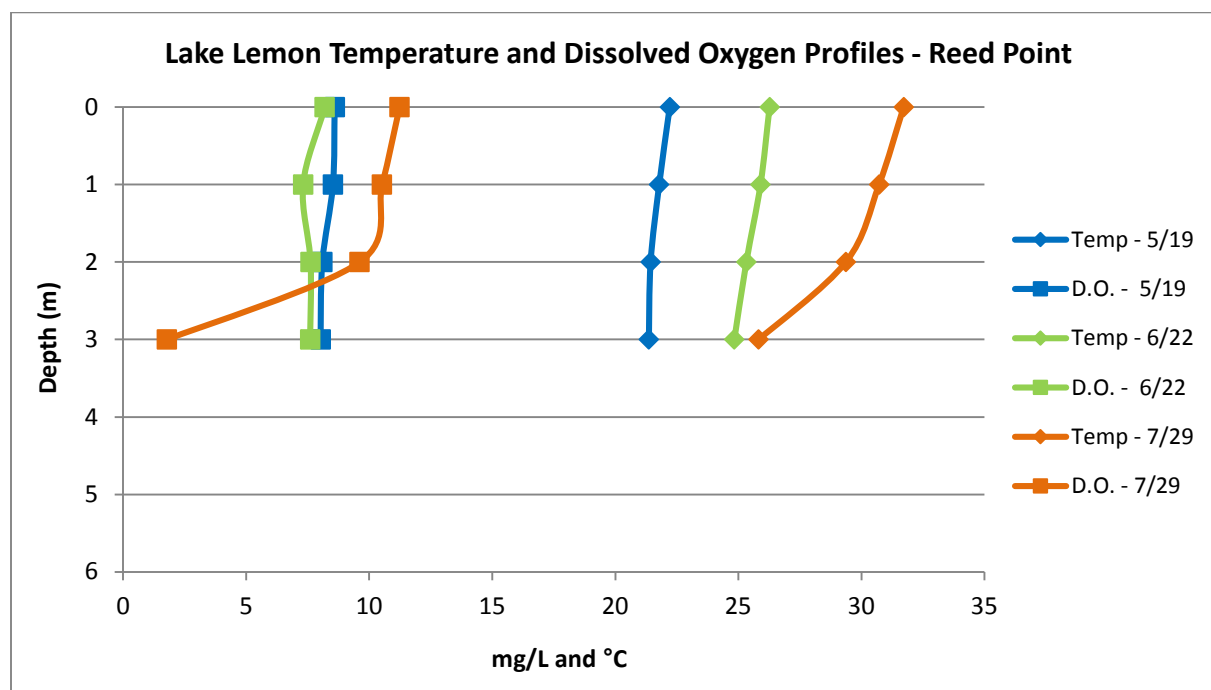


Figure 5. Temperature and dissolved oxygen profiles for Lake Lemon at Reed Point on 5/19/15, 6/22/15, and 7/29/15.

Dissolved Oxygen – Dissolved oxygen (D.O.) profiles generally follow the temperature profiles. Typically, early spring profiles are characterized by an orthograde oxygen profile, where the oxygen concentrations remain uniform throughout the water column because of recent spring turnover. While neither site illustrated this orthograde profile, the May profile was not collected as the meter malfunctioned. While this is typical in some lakes it is not been historically seen in Lake Lemon. Riddle Point was characterized by a clinograde oxygen profile by June, where oxygen levels decrease below the thermocline and continue to decrease rapidly. The upper 3 meters of water remained oxygenated during both June and July sampling at Riddle Point (Figures 4). The July dissolved oxygen concentrations averaged 7.3 mg/L in the epilimnion, a decrease of approximately 1 mg/L respectively from 2014. Anoxic conditions develop below 3 meters depth, which are likely due to significant organic matter on the lake bottom, creating a biochemical oxygen demand (BOD) that results in decomposition processes consuming all the available oxygen. Because stratification does not allow surface water to mix into this deeper water, oxygen is not replenished. The shallow depth of Reed Point and lake turbulence keep this portion of the lake well-mixed and oxygenated (Figure 5). The decreased dissolved oxygen at 3m at Reed is likely the consequence of a very calm night, which allowed that shallow area to slightly thermally stratify and permitted the bottom meter to near anoxia due to decomposition. This has been typical of the Reed location for many sampling years and indicates that the bottom water may be stratifying during the latter part of the summer.

Phosphorus – Water quality data for Lake Lemon are presented in Tables 1- 3. Phosphorus and nitrogen are the primary plant nutrients in lakes. Typically, mean total phosphorus (TP) concentrations increase throughout the summer within Lake Lemon due to watershed inputs (Figure 6). Orthophosphate (OP) concentrations are lower than total phosphorus because algae rapidly take up and use this soluble form of phosphorus. Mean OP concentrations were below the method detection (0.010 mg/L) limit in all samples with exception of the June and July Riddle Point hypolimnion sample (0.033 and 0.028 mg/L). All spring and summer TP concentrations were greater than the level indicative of eutrophication (0.030 mg/L), except the May Riddle Point epilimnetic sample.

Nitrogen – Typically we only detect low concentrations of nitrate-nitrogen throughout the sampling season. The 2015 sampling events did not capture any nitrate (Table 1,2, &3). Typically we will sometimes capture spring runoff following spring fertilizer application, which resulted in elevated nitrate concentrations during May. Nitrate concentrations were measured at the minimum detection level (0.013 mg/L) in all samples in 2015 (Figure 7). Nitrate, an oxidized form of inorganic nitrogen, is highly soluble in water and is carried into the lake from fertilized agricultural fields, livestock, and other sources by watershed runoff. Ammonia, a reduced form of inorganic nitrogen, is the primary by-product of bacterial decomposition of organic matter and is also found in animal wastes. Riddle Point ammonia concentrations were initially low in the lake near detection level of 0.018 mg/L and increased as stratification of the lake increased throughout the summer in the hypolimnion to 1.44 mg/L in July (Figure 8). The increased ammonia concentrations are due to thermal stratification and anoxic conditions within the hypolimnion coupled with significant decomposition of organic matter, which generates

ammonia as a by-product. The Reed Point ammonia concentrations typically remain lower throughout the summer. Sufficient mixing within the shallower waters of Reed Point usually keeps the water column oxygenated preventing the concentration of the chemically-reduced ammonia. Very calm water and wind conditions can allow short-term and temporary thermal stratification within the bottom 2 meters. During these periods ammonia concentrations can increase due to the reduced environment, then mixing throughout when turbulence returns.

Table 1. Water Quality Characteristics of Lake Lemon – Riddle Point and Reed Point, 5/19/2015.

Parameter	Riddle		Reed
	Epilimnion	Hypolimnion	Epilimnion
Secchi (m)	1.2	--	0.6
Light trans @ 3' (%)	17.76	--	7.32
1% Light Level (ft)	13.78	--	6.56
% Water Column Oxic	--	--	100
pH	8	7.2	7.7
Conductivity (uS/cm))	--	--	182
Alkalinity (mg/L)	66	63	63
Total Suspended Solids (mg/L)	8.4	11.9	17.3
Nitrate (mg/L)	0.013*	0.013*	0.013*
Ammonia (mg/L)	0.018*	0.223	0.018*
Total Organic Nitrogen (mg/L)	0.495	0.403	--
Orthophosphate (mg/L)	0.010*	0.010*	0.010*
Total Phosphorus (mg/L)	0.016	0.036	0.046
Chlorophyll-a (ug/L)	6.89	--	17.22
Plankton (Cells/ml)	99	--	2314
Plankton (#/L)	26,535	--	40,710
Blue-green dominance NU (%)	12	--	67
Blue-green dominance – cells/ml (%)	35.4	--	99.2

* Method Detection Limit

Table 2. Water Quality Characteristics of Lake Lemon – Riddle Point and Reed Point, 6/22/15.

Parameter	Riddle		Reed
	Epilimnion	Hypolimnion	Epilimnion
Secchi (m)	1	--	0.9
Light trans @ 3' (%)	15.77	--	6.99
1% Light Level (ft)	8.856	--	4.92
% Water Column Oxic	57.14	--	100
pH	7.75	7.1	7.7
Conductivity (uS/cm)	196	230	195
Alkalinity (mg/L)	67.5	81	65
Total Suspended Solids (mg/L)	8.5	24	12
Nitrate (mg/L)	0.013*	0.013*	0.013*
Ammonia (mg/L)	0.018*	0.018*	0.018*
Total Organic Nitrogen (mg/L)	0.467	0.570	0.543
Orthophosphate (mg/L)	0.010*	0.033	0.010*
Total Phosphorus (mg/L)	0.056	0.120	0.056
Chlorophyll-a (ug/L)	16.8	--	32.96
Plankton (Cells/ml)	18,567	--	5,465
Plankton (#/L)	67,294	--	100,742
Blue-green dominance NU (%)	89	--	92
Blue-green dominance – cells/ml (%)	99.9	--	95.9

* Method Detection Limit

Table 3. Water Quality Characteristics of Lake Lemon – Riddle Point and Reed Point, 7/29/15.

Parameter	Riddle		Reed
	Epilimnion	Hypolimnion	Epilimnion
Secchi (m)	0.8	--	0.8
Light trans @ 3' (%)	11.1	--	3.74
1% Light Level (ft)	8.2	--	5.248
% Water Column Oxic	68.5	--	100
pH	9.2	6.8	9
Conductivity (uS/cm))	160	206	166
Alkalinity (mg/L)	59	80	66
Total Suspended Solids (mg/L)	6.7	20	5.4
Nitrate (mg/L)	0.013*	0.013*	0.013*
Ammonia (mg/L)	0.018*	0.636	0.018*
Total Organic Nitrogen (mg/L)	0.629	0.777	0.7375
Orthophosphate (mg/L)	0.010*	0.028	0.010*
Total Phosphorus (mg/L)	0.054	0.124	0.067
Chlorophyll-a (ug/L)	18.57	--	21.88
Plankton (Cells/ml)	567	--	2,238
Plankton (#/L)	117,900	--	236,785
Blue-green dominance NU (%)	87	--	80
Blue-green dominance – cells/ml (%)	95.9	--	96.9

* Method Detection Limit

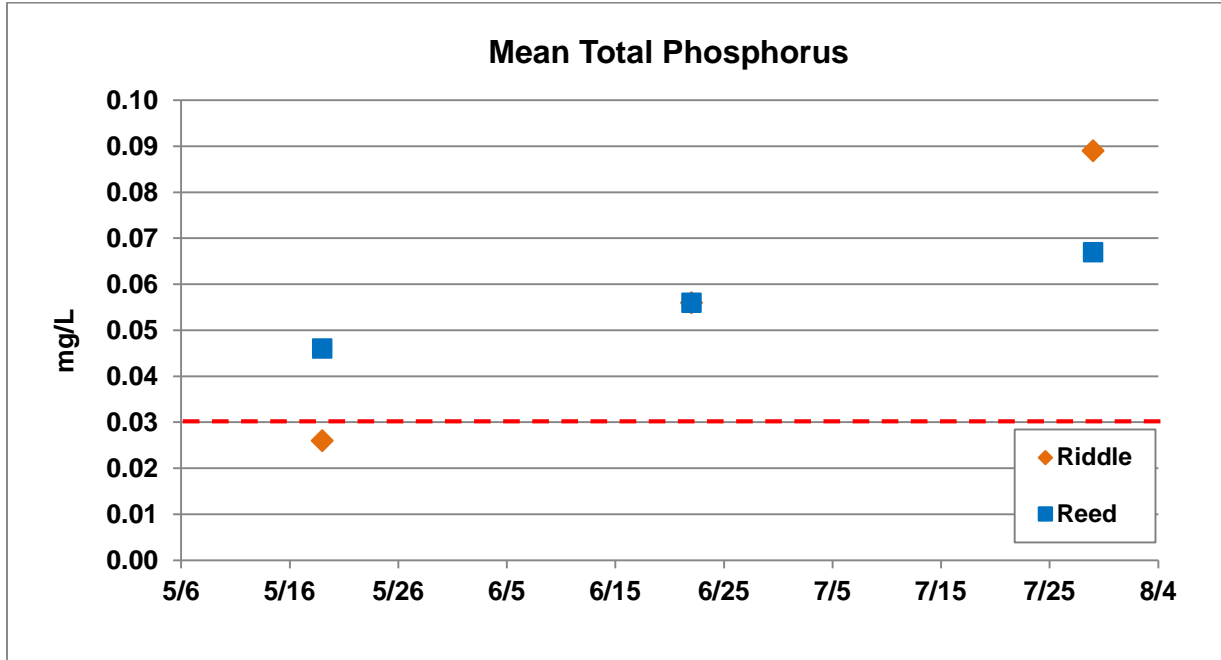


Figure 6. Mean total phosphorus concentrations at Riddle and Reed Point during summer 2015. The dashed red line represents the threshold for eutrophic conditions that is typically characterized by algal blooms.

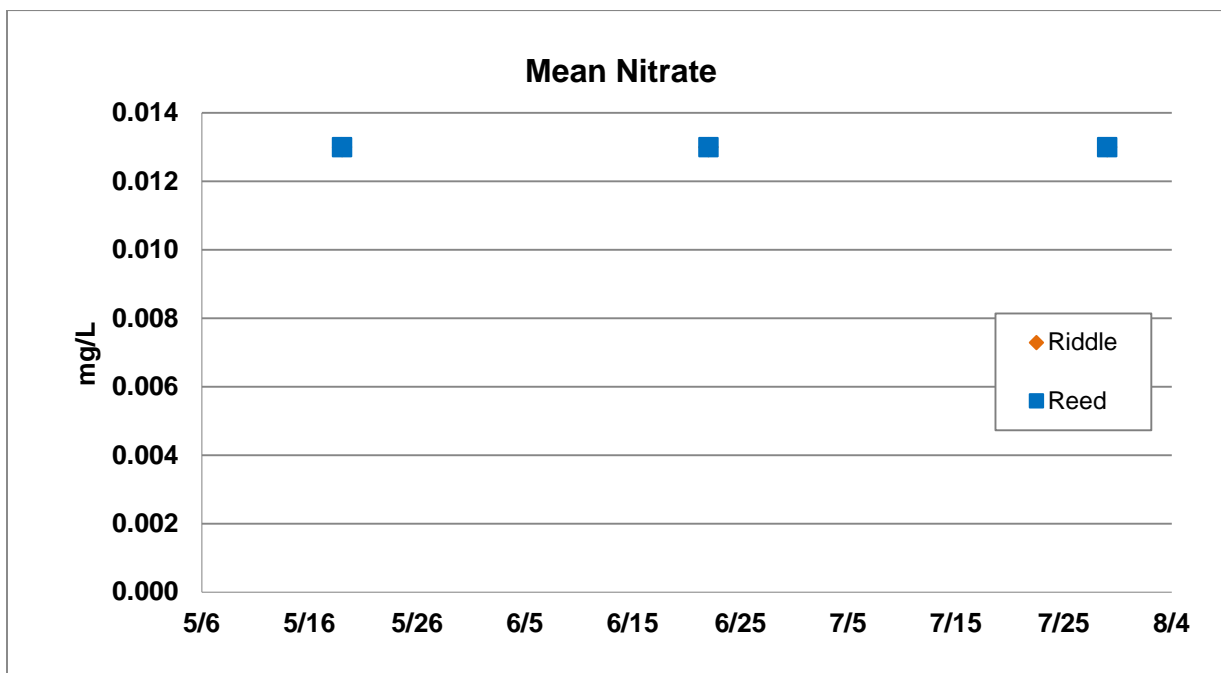


Figure 7. Mean nitrate concentrations at Riddle and Reed Point during summer 2015.

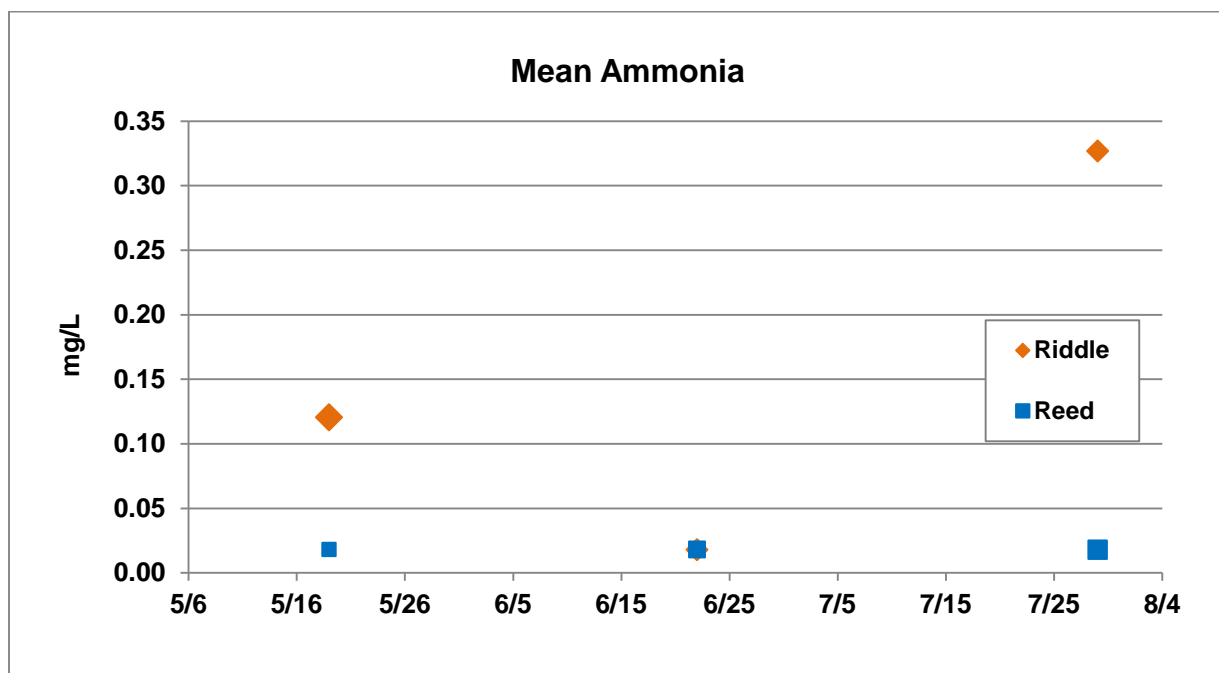


Figure 8. Mean ammonia concentrations at Riddle and Reed Point during summer 2015.

Plankton – Lake Lemon is characterized by relatively low to average plankton densities. Usually, Lake Lemon is characterized by lower spring densities that increase by July and August. In 2015 Riddle and Reed plankton followed this typical seasonal increase (Table 4). Reed plankton counts were generally higher in densities (Table 5). Typically, the plankton assemblage shifted towards a strongly dominant blue-green algae proportion by July, which is definitely the case with blue-green dominating both late July samples at approximately 96% and 97% respectively (Table 4 and 5). Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers. Blue-green algae usually have an advantage over other plankton tend to dominate reaching nuisance proportions. These competitive advantages include: 1) ability to regulate buoyancy and thus stay up in the light, 2) nitrogen fixation, and 3) more efficient use of nutrients. Dominant blue-green algae populations are typical of temperate lakes with high nutrient availability, especially from a large watershed that is predominately agriculture.

Zooplankton, which are microscopic animals equivalent to cows grazing in the pasture, feed on phytoplankton (Figure 10). Zooplankton density decreased throughout the summer (Table 4 & 5). Typically, rotifer populations (small zooplankton) dominate at both Riddle and Reed Point samples over Cladocera and Copepod populations (large zooplankton).

Transparency – The low Secchi disk transparencies in Lake Lemon are a reflection of the relatively high amount of suspended material (sediments, algae, etc.) in the water. Both Riddle and Reed start the season with transparencies just over 1 m and decrease to approximately half a meter by end of July. Sources of suspended sediments to Lake Lemon include soils washed in from the watershed, resuspended lake sediments, and algal cells produced within the lake. The fine clays and silts of the sediments (Zogorski et al., 1986) can be suspended in the shallow east end of the lake by wind directed along the main west-east axis of the lake. In addition, turbulence from motorboats is capable of resuspending fine clay sediments from a depth exceeding ten feet (Yousef et al., 1978). All of these actions likely contribute to the poor clarity of Lake Lemon and of shallow lakes in general.

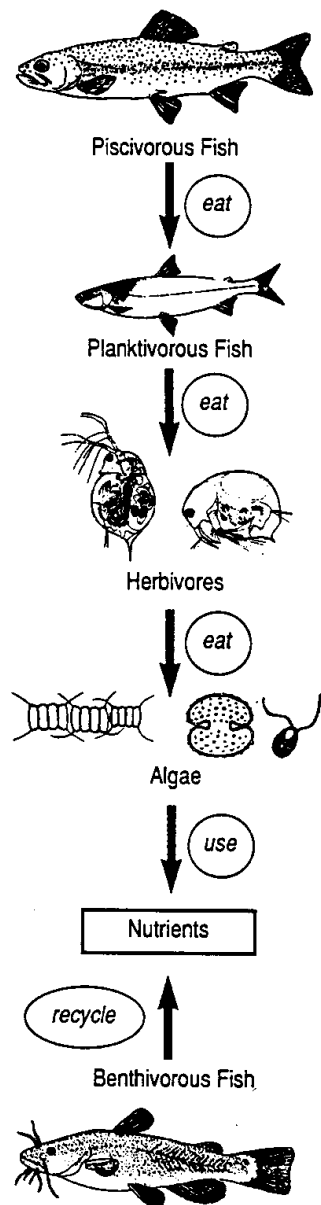


Figure 10. Generalized aquatic food chain. Tiny shrimp-like animals called zooplankton eat algae. Zooplankton, in turn, are eaten by small plankton-eating fish such as minnows, gizzard shad and young sunfish.

Table 4. Phytoplankton and Zooplankton Community for Lake Lemon at Riddle Point, enumerated as # cells/ml for phytoplankton and # Natural Units per liter for zooplankton.

	5/19/2015		6/22/2015		7/29/2015	
Phytoplankton (Algae)	Total (Cells/ml)	%	Total (Cells/ml)	%	Total (Cells/ml)	%
Blue-greens	35	35%	4,375	100%	790	97%
Greens	19	19%	1	0%	14	2%
Diatoms	39	39%	10	0%	5	1%
Other algae	6	6%	0	0%	4	0%
Total Phytoplankton	99		4,386		813	
Zooplankton	Total (#/L)		Total (#/L)		Total (#/L)	
Rotifers	1,355		181		302	
Zooplankton*	441		24		232	

*Zooplankton counts include Cladocera and Copepods.

Table 5. Phytoplankton and Zooplankton Community for Lake Lemon at Reed Point, enumerated as # cells/ml for phytoplankton and # Natural Units per liter for zooplankton.

	5/19/2015		6/22/2015		7/29/2015	
Phytoplankton (Algae)	Total (Cells/ml)	%	Total (Cells/ml)	%	Total (Cells/ml)	%
Blue-greens	2,295	99%	5,243	96%	2,169	97%
Greens	16	1%	218	4%	8	0%
Diatoms	2	0%	4	0%	35	2%
Other algae	0	0%	0	0%	26	1%
Total phytoplankton	2,314		5,465		2,238	
Zooplankton	Total (#/L)		Total (#/L)		Total (#/L)	
Rotifers	1684		293		643	
Zooplankton*	170		102		99	

*Zooplankton counts include Cladocera and Copepods.

Chlorophyll-a – Chlorophyll-a, which is a measure of the primary pigment in algae, it is a direct measure of algal productivity. In the integrated samples from the surface to the 2-meter depth, the chlorophyll-a concentrations ranged from 6.89 µg/L in May to 32.98 µg/L in July. Chlorophyll-a concentrations >7 µg/L are indicative of eutrophic lake conditions. Overall, we see a seasonal pattern of nutrient increase by late summer, which is characteristic of Lake Lemon. This pattern is mirrored by increases in chlorophyll-a concentrations. This suggests that conditions exist for increasing growth of algae (Figure 11 and 12).

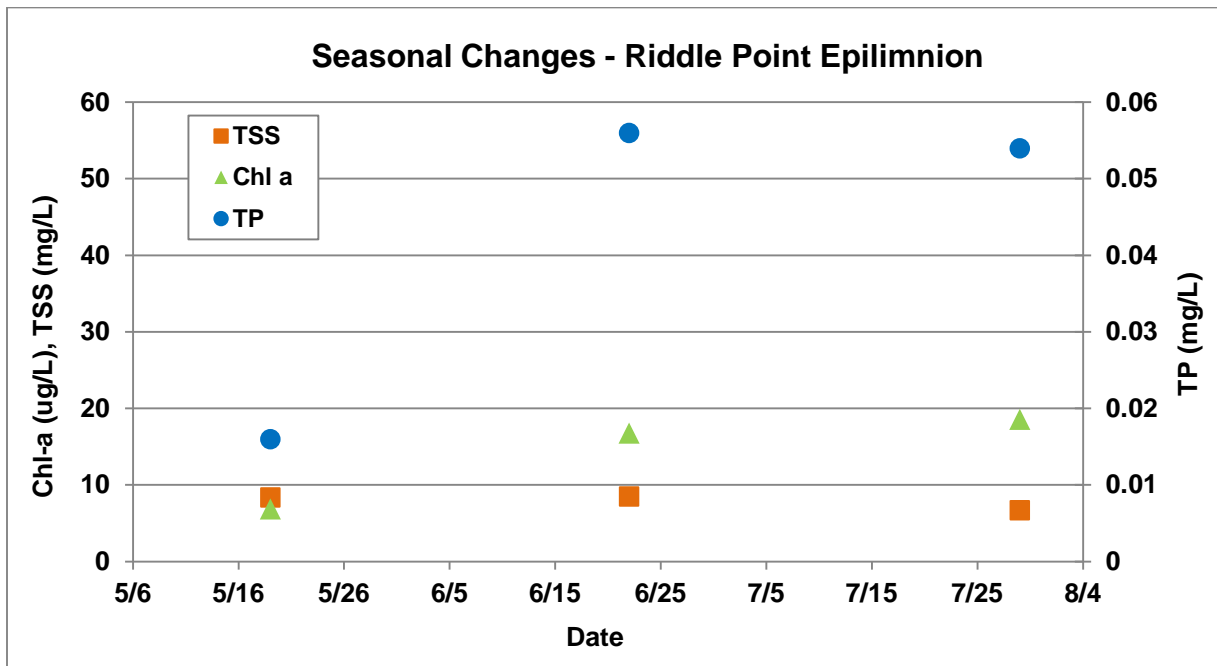


Figure 11. Seasonal changes in total phosphorus, total suspended solids, and chlorophyll-a in the surface waters (epilimnion) at Riddle Point in Lake Lemon in 2015.

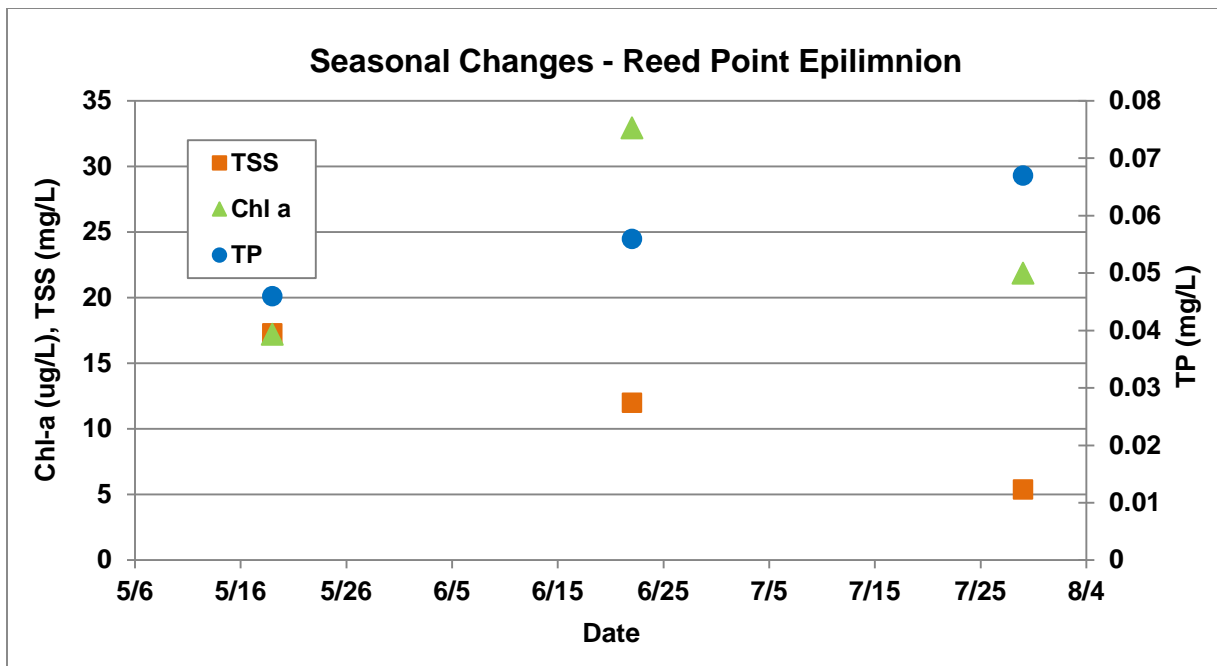


Figure 12. Seasonal changes in total phosphorus, total suspended solids, and chlorophyll-a in the surface waters (epilimnion) at Reed Point in Lake Lemon in 2015.

3.2 Comparison with Other Indiana

Table 6 gives values of water quality parameters determined for 357 Indiana lakes during July-August 2012-2015 by the Indiana Clean Lakes Program. This table can be used to compare values determined for Lake Lemon with other Indiana lakes. Table 6 shows that ammonia, organic N, OP, TP, and chlorophyll-*a* exceeded the median values for these 355 lakes, but fell well below the maximum concentrations. Secchi transparency was below the median which indicates less clarity than the median for the rest of the state.

Table 6. July-August Water Quality Characteristics of 357 Indiana Lakes Sampled From 2012 thru 2015 by the Indiana Clean Lakes Program compared to Riddle Point of Lake Lemon (7/31/15). Means of epilimnion and hypolimnion samples were used for Lake Lemon.

	Secchi Disk (m)	NO ₃ (mg/L)	NH ₄ (mg/L)	OrgN (mg/L)	TP (mg/L)	OP (mg/L)	Chl. <i>a</i> (µg/L)
Median	1.7	0.016	0.133	0.942	0.051	0.010*	6.89
Maximum	9.5	5.281	12.367	9.258	1.842	0.667	292.03
Minimum	0.1	0.013*	0.018*	0.230*	0.010*	0.010*	1.33
Mean Values for Riddle Pt. (7/29/15)	0.8	0.013*	0.327	0.703	0.089	0.019	18.57

* Method Detection Limit

3.3 Stream Results

Results from the Beanblossom Creek samples are given in Table 7. Stream values generally fell within the range of lake parameters. Variation among the sample parameters was slight. Historically, most of the parameters increased throughout the summer. Solubility of oxygen in water is influenced by temperature, with less dissolved oxygen dissolving in warmer water, which we do not see in 2015. Storm event samples were collected on August 6th (Figure 13). There was no increase in the expected parameters following the storm events relative to the other sampling dates. However, as it can be seen in Figure 13, many of the other sampling dates followed longer rain events of both longer duration and magnitude. The June 22nd sampling events had some of the highest concentrations of bacteria and phosphorus and we also see the typical decrease in alkalinity and conductivity that is representative of storm events.

Table 7. Water Quality Characteristics of Beanblossom Creek.

	Beanblossom Creek			
	5/19	6/22	7/29	8/6 (storm)
pH	7.4	7.4	7.4	7.9
Conductivity (mS/cm)	279	86.1	271	283
Alk (mg/L)	103	71	106	109.5
Temperature (°C)	19.68	21.8	26.51	24.79
D.O. (mg/L)	6.27	6.6	7.78	8.58
TSS (mg/L)	6.9	21	17	
NO ₃ ⁻ (mg/L)	0.118*	0.350	0.169	0.137
NH ₄ ⁺ (mg/L)	0.161	0.046	0.082	0.039
TKN (mg/L)	0.189	0.285	0.278	0.341
SRP (mg/L)	0.010*	0.014	0.010*	0.010*
Total Phos (mg/L)	0.010*	0.063	0.061	0.056
<i>E. coli</i> (col/100ml)	--	1190	120	152

* Method Detection Limit

** TNTC = Too Numerous To Count

In addition to collecting *E. coli* at Riddle Point and Reed Point, two locations adjacent to the Chitwood neighborhood and three stream locations within 1) Bear Creek, 2) Knob Creek, and 3) Beanblossom Creek were collected (Table 8). All June samples exceeded the state standard of 200 colonies per 100 ml threshold, except for Chitwood site #2. Multiple days of rainfall in the days leading up to sampling likely contributed to increased bacteria. July samples were under the threshold values except for Knob Creek. The storm event concentrations exceeded state standards as well, with the sample from Knob Creek that enters the lake east of the North Shore Marina that were 17,400 colonies/100 ml.

Total suspended solids (TSS) were sampled at the three stream sites. While the concentrations increased during times of increased rainfall, the values are significantly below the cautionary value of 80 mg/L, considered harmful to aquatic life (Waters, 1995).

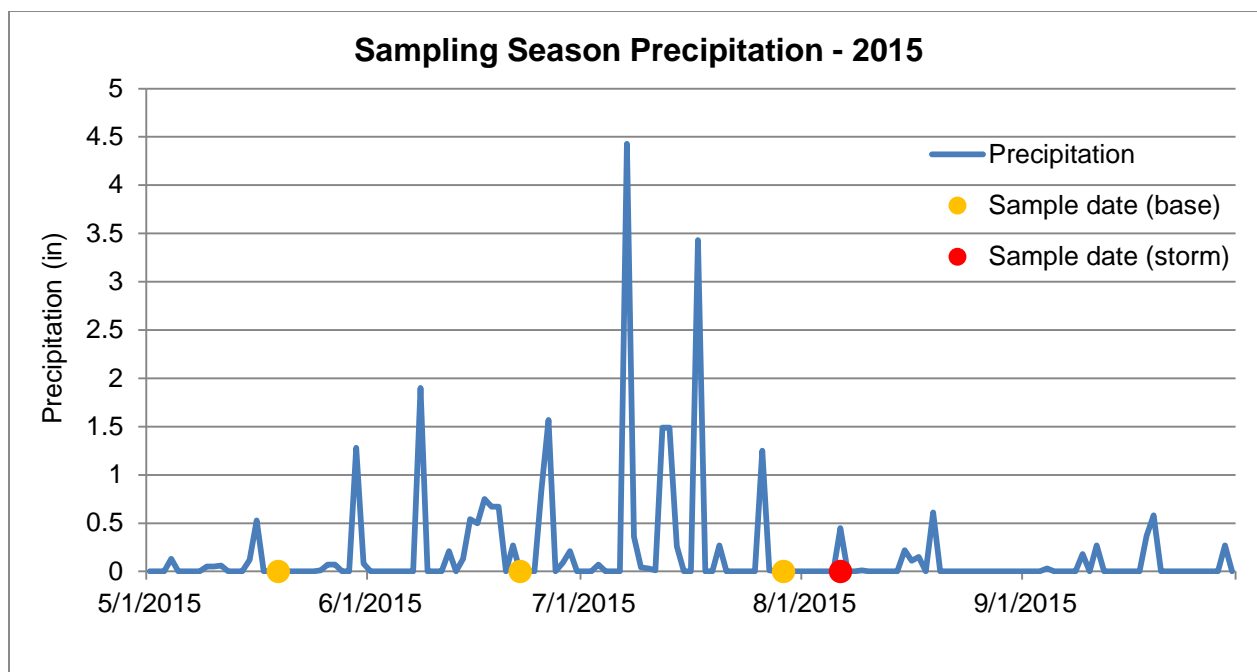


Figure 13. Precipitation amounts during the 2015 sampling season.

Table 8. Fecal coliform bacteria summary for 2015 Lake Lemon samples. The state standard for full body contact and recreation is 200 colonies per 100mls.

	<i>E. coli</i> (#/100mls)				TSS (mg/L)			
	5/19	6/22	7/29	8/6	5/19	6/22	7/29	8/6
Riddle Point	\	130	8	\	9.4	10.7	11.1	\
Reed Point	\	500	0	\	17.3	11.4	5.4	\
Chitwood #1	\	170	68	\	\	\	\	\
Chitwood #2	\	80	32	\	\	\	\	\
Beanblossom Creek	\	1190	120	152	7	21	13	\
Bear Creek	\	370	100	268	7	3	10	\
Knob Creek	\	470	540	17,400	2	5	1	\

\ indicate samples not collected or processed

3.4 Trophic State

3.4.1 Introduction

The most widely used standard for assessing the condition of a lake is by considering its *trophic state*. The trophic state of a lake refers to its overall level of nutrition or biological productivity. Trophic categories include: *oligotrophic*, *mesotrophic*, *eutrophic* and *hypereutrophic*, with productivity increasing from oligotrophic to eutrophic (Table 9).

Table 9. Some characteristics of the different trophic state index classifications. Note, that while those salmonid fisheries, which have higher oxygen requirements, are lost in more eutrophic lakes, there are still many fish species present.

Classification	Transparency	Nutrients	Algae	D.O.	Fish
<i>Oligotrophic</i>	clear	Low TP < 6 µg/L	few algae	Hypo has D.O.	can support salmonids (trout and salmon)
<i>Mesotrophic</i>	Less clear	Moderate TP 10-30 µg/L	healthy populations of algae	Less D.O. in hypo	lack of salmonids
<i>Eutrophic</i>	transparency <2 meters	High TP > 35 µg/L	abundant algae and weeds	No D.O. in the hypo during the summer	Warm-water fisheries only. Bass may dominate.
<i>Hypereutrophic</i>	transparency <1 meter	extremely high TP > 80 µg/L	thick algal scum Dense weeds	No D.O. in the hypo during the summer	Rough fish dominate; summer fish kills possible

The changes in a lake from oligotrophy to eutrophy (higher trophic state) is called *eutrophication*. Eutrophication is defined as the excessive addition of inorganic nutrients, organic matter and silt to lakes and reservoirs at rates sufficient to increase biological production and to lead to a decrease in lake volume. By this definition, high phosphorus alone does not make a lake eutrophic. The phosphorus levels must also cause an increase or potential increase in plant production and/or sedimentation.

3.4.2 Trophic State Indices

The large amount of water quality data collected during lake water quality assessments can be confusing to evaluate. Because of this, Indiana and many other states use a trophic state index (TSI) to help evaluate water quality data. A TSI condenses water quality data into a single, numerical index. Different index (or eutrophy) points are assigned for various water quality concentrations. The index total, or TSI, is the sum of individual eutrophy points for a lake.

The most widely used and accepted TSI is one developed by Bob Carlson (1977) called the Carlson TSI (Figure 14). Carlson analyzed total phosphorus, chlorophyll-*a*, and Secchi disk transparency data for numerous lakes and found statistically significant relationships among the three parameters. He developed mathematical equations for these relationships that form the basis for the Carlson TSI. Using this index, a TSI value can be generated by one of three measurements: Secchi disk transparency, chlorophyll-*a* or total phosphorus. Data for one parameter can also be used to predict a value for another. The TSI values range from 0 to 100. Each major TSI division (10, 20, 30, etc.) represents a doubling in algal biomass.

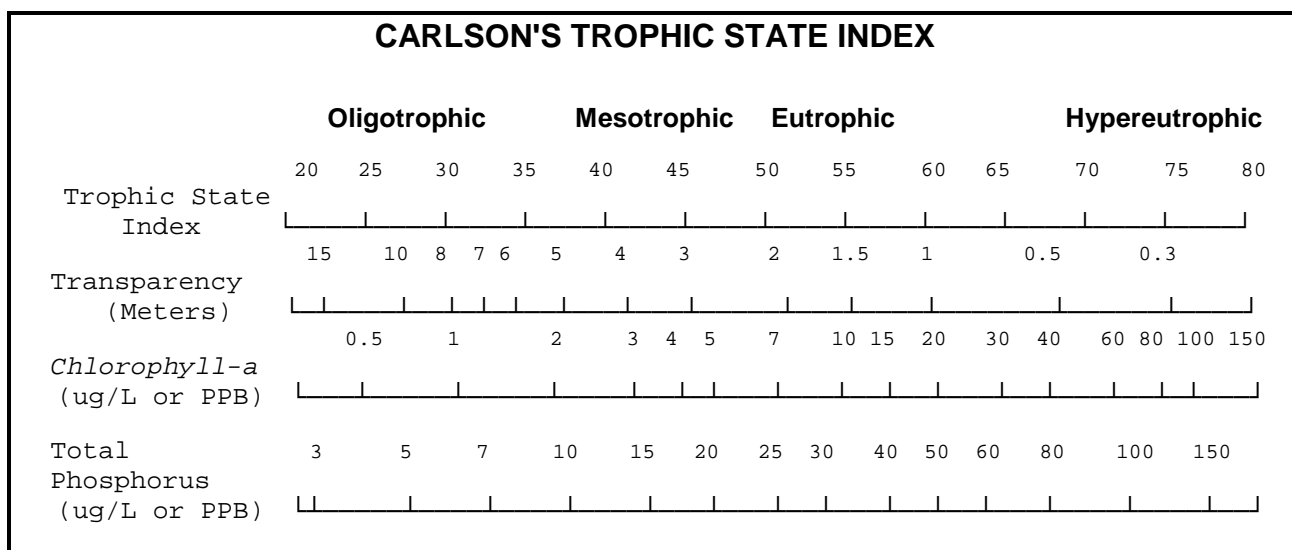


Figure 14. Carlson's trophic state index.

3.4.3 Trophic State Scores

Using Carlson's TSI for the May, June, and July data, Lake Lemon varied slightly by parameter and month but was mostly characterized by the eutrophic classification (Table 10). The earlier May TSI scores start the growing season with eutrophic conditions. All the TSI scores increased throughout the growing season, which is the historic trend for Lake Lemon.

Table 10. Summary of Trophic State Index Scores Using Mean 2015 Water Quality Data for Riddle/Reed Points.

DATE	Carlson's Secchi Disk TSI	Carlson's Total Phosphorus TSI	Carlson's Chlorophyll TSI
May	57/67	51/59	50/58
	Eutrophic	Eutrophic	Eutrophic
June	60/62	62/62	58/65
	Eutrophic	Eutrophic	Eutrophic
July	63/63	69/65	59/61
	Eutrophic	Hypereutrophic/Eutrophic	Eutrophic

Riddle Pt. TP = 0.051mg/L = 51ug/L
 ↓
 Graph on Carlson's TP scale
 ↓
 Carlson's TSI value

How to read:

Carlson's TP TSI

65/88

Eutrophic/Hypereutrophic

Reed Pt. TP = 0.334mg/L = 334ug/L
 ↓
 Graph on Carlson's TP scale
 ↓
 Carlson's TSI value

4.0 TROPHIC STATE TRENDS

Using Riddle Point Carlson TSI scores to look at the historic trend for Lake Lemon shows that the lake is generally characterized as eutrophic conditions. Figures 14-16 illustrate the Carlson TSI historic trends for Secchi disk, total phosphorus, and chlorophyll-a. Overall, a pattern is seen within the seasonal variation with the late spring months scoring lower (less eutrophic) while increasing during the late summer months to a eutrophic/hypereutrophic status.

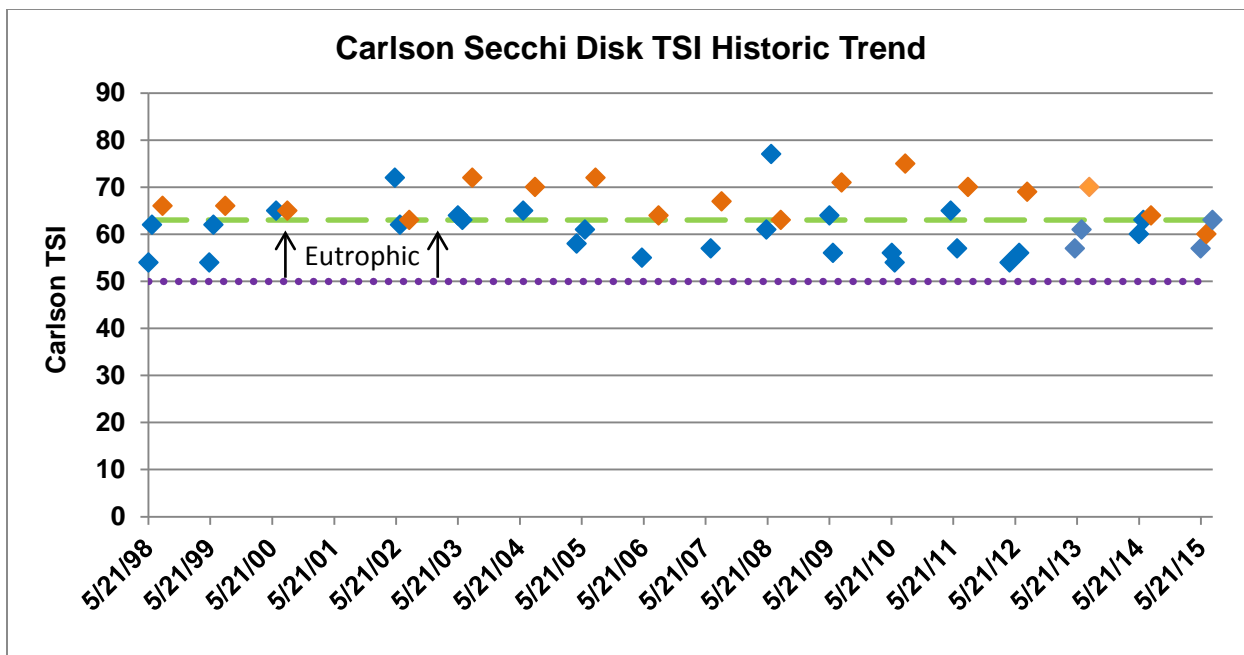


Figure 14. The 17-year historic trend for Carlson Secchi disk TSI scores. All but three late summer (August) samples, shown in orange, scored above the mean for eutrophic status. The green dashed line illustrates the 17-year mean. The purple dotted line illustrates eutrophic status for the Carlson TSI.

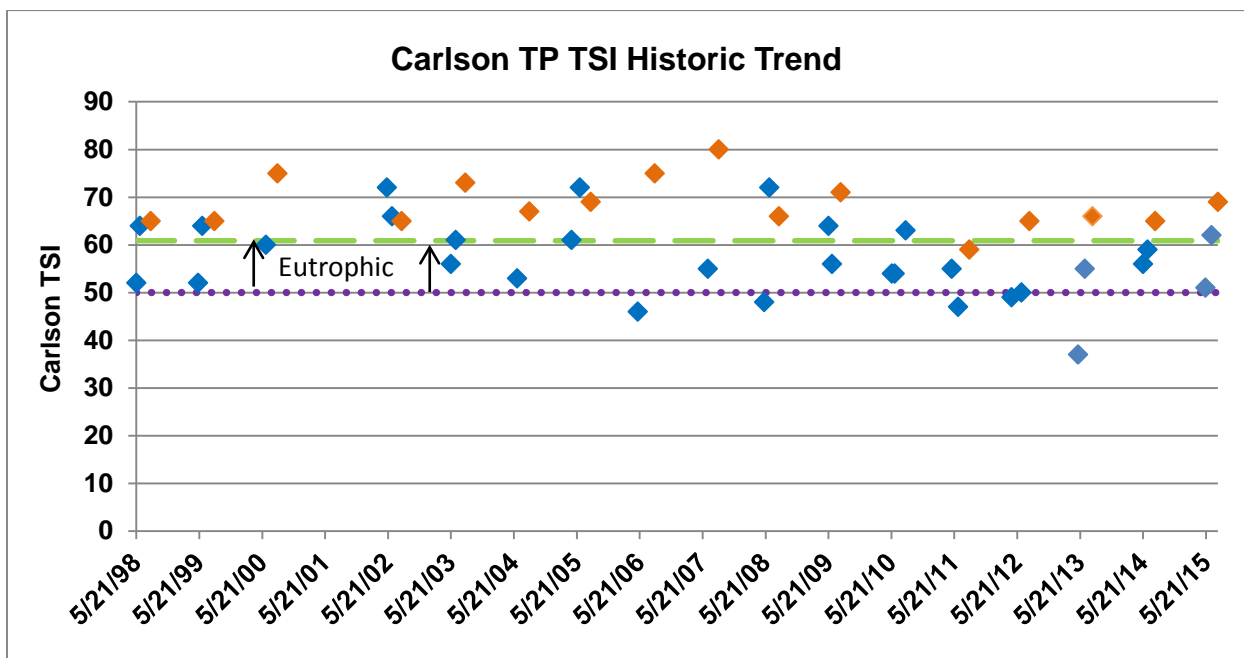


Figure 15. The 17-year historic trend for Carlson total phosphorus TSI scores. All August samples, shown in orange, score above the mean for eutrophic status. The green dashed line illustrates the 17-year mean. The purple dotted line illustrates eutrophic status for the Carlson TSI.

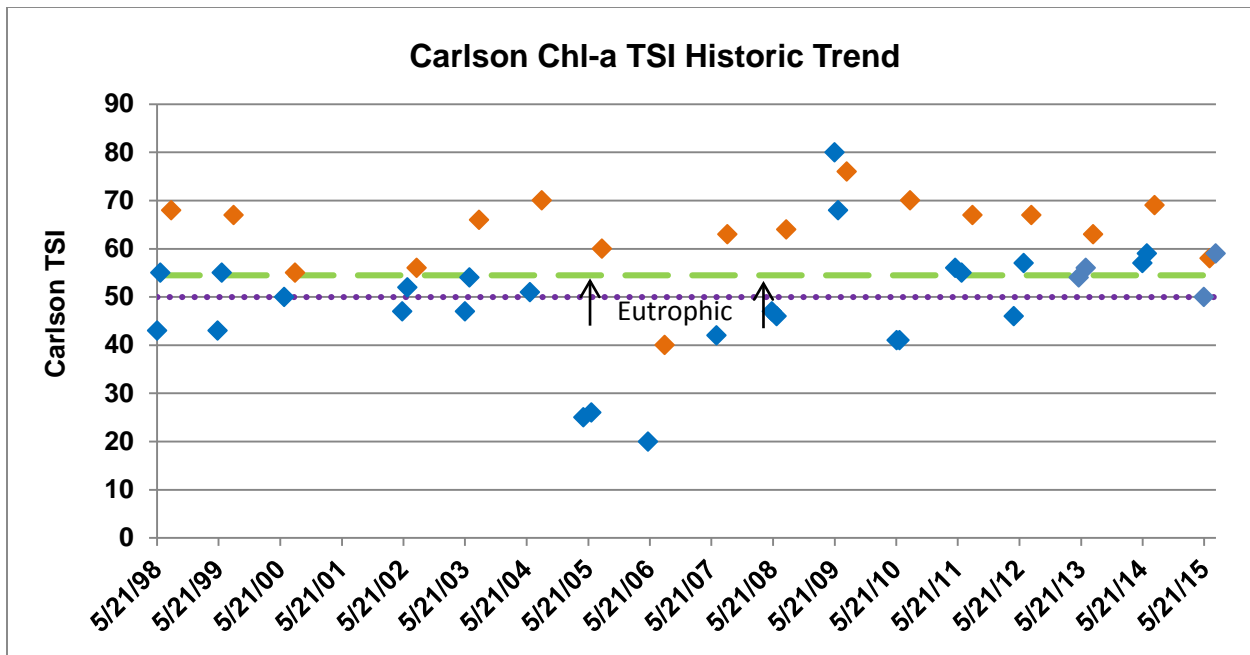


Figure 16. The 17-year historic trend for Carlson chlorophyll-a TSI scores. Most August samples, shown in orange, score above the mean for eutrophic status. The 14-year mean is just above the Carlson TSI eutrophic status score of 50 (purple dotted line).

5.0 WATER QUALITY TRENDS

Compiled Secchi disk transparency data from volunteer monitors and SPEA monitoring studies over the past 20 years are shown in Figure 17. There is no apparent long-term trend in transparency except that late July and August samples are generally lower in transparency. All measures of record would be considered indicative of eutrophic conditions.

Total phosphorus (TP) concentrations are quite variable over the past 20 years at Lake Lemon's Riddle Point sampling site (Figure 18). There is little visible long-term trend. Most of the values were above the eutrophic threshold of 0.030 mg/L. The May sample was at the threshold, but exceeded the concentration in June and July. The variable concentrations have tightened over the years with the average of 0.040 mg/L just above the level of eutrophic conditions.

Epilimnetic total phosphorus concentrations at Riddle Point are mostly in the eutrophic range but the resulting chlorophyll-a concentrations (Figure 19) do not always reach the eutrophic range of greater than 7 µg/L; however, the majority of late summer chlorophyll-a samples over the 20 years do fall above the eutrophic classification. In the past 2 years the chlorophyll-a concentrations have been higher earlier in the spring, but overall lower throughout the season. It is typical that the chlorophyll-a concentrations would align with the TP concentrations; however, Lake Lemon watershed inputs of

suspended solids contribute and elevate the TP concentrations, which also can shade out the photic zone.

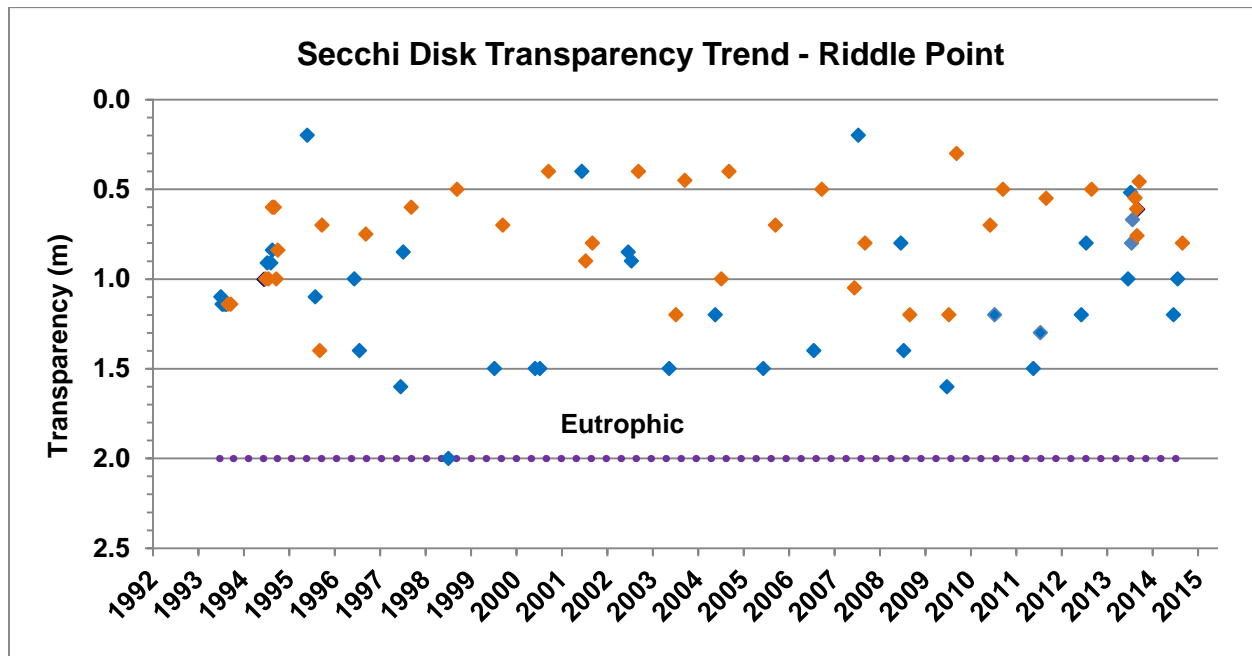


Figure 17. Historic Secchi disk transparency data for Lake Lemon. All data are less than the general eutrophic indicator of 2 meters (dotted line). Orange markers indicate August or late July samples.

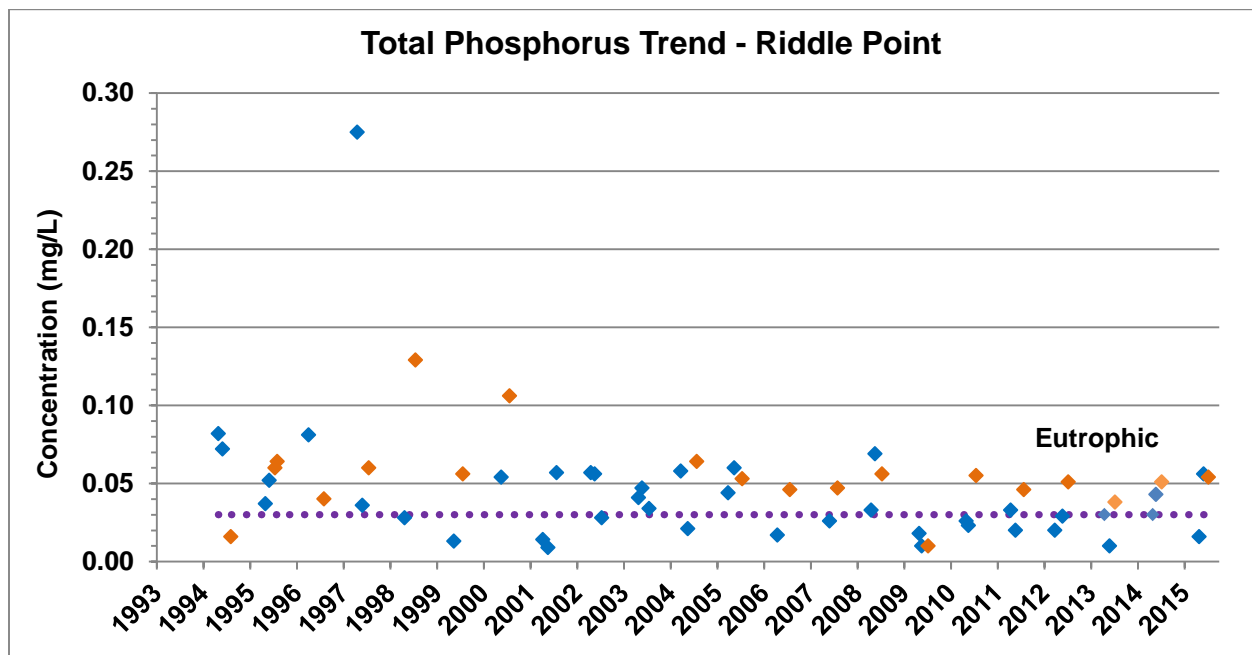


Figure 18. Historic epilimnetic total phosphorus trend for Lake Lemon. Most concentrations are higher than 0.030 mg/L (dotted line), the level generally considered high enough to support eutrophic conditions. Orange markers indicate August or late July samples.

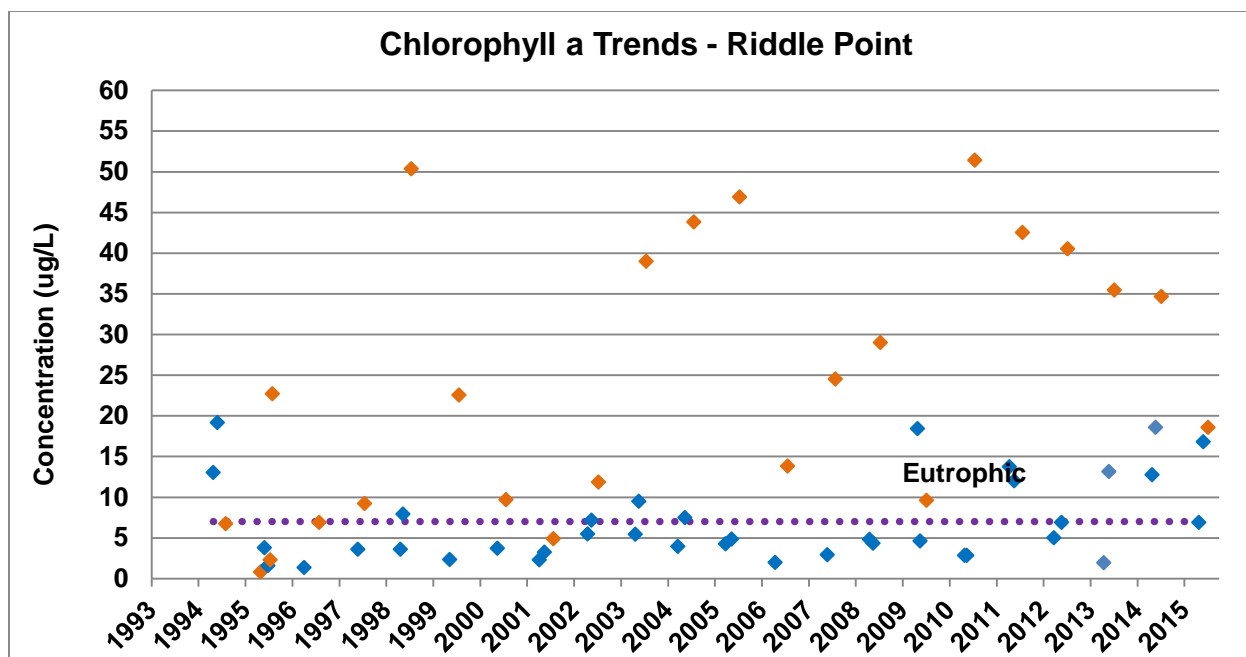


Figure 19. Historic chlorophyll-a data for Lake Lemon. The dotted line illustrates concentrations indicative of eutrophic conditions. Orange markers indicate August or late July samples.

6.0 CONCLUSIONS

The water characteristics of Lake Lemon are highly variable due, in large part, to runoff from the very large watershed that can replace the entire lake volume in a relatively short time (Figure 20). This causes difficulties in monitoring because the water conditions at any particular time depend on several immeasurable variables, including: time since the last major storm and the intensity and duration of that storm. All base flow samples were following rain events so there was likely significant flushing of algal cells (Figure 13). While these variables affect other Indiana lakes and reservoirs, they have a much greater influence at Lake Lemon because of its very large watershed and short residence time. The watershed drainage area to lake area ratio is very large at 31:1 for Lake Lemon. While the flushing rate will need to be recalculated once the dredging work is complete, previously Lake Lemon had a hydraulic flushing rate of 5/yr, meaning the whole lake volume replaces itself 5 times per year. This makes this reservoir very responsive to watershed inputs.

Lake Lemon suffers from seasonally high levels of phosphorus, and suspended sediments and relatively low Secchi disk transparency throughout the year; however, the overall trend for Lake Lemon has not changed in over 20 years (Figures 17-19). Current water conditions unquestionably place the lake into the 'eutrophic' or over-productive trophic category. Eutrophic lakes produce more algae and rooted plants than the bacteria and microbes can decompose annually. As a result, decaying organic matter accumulates

on the sediments where it contributes to low dissolved oxygen levels and decreased lake volume.

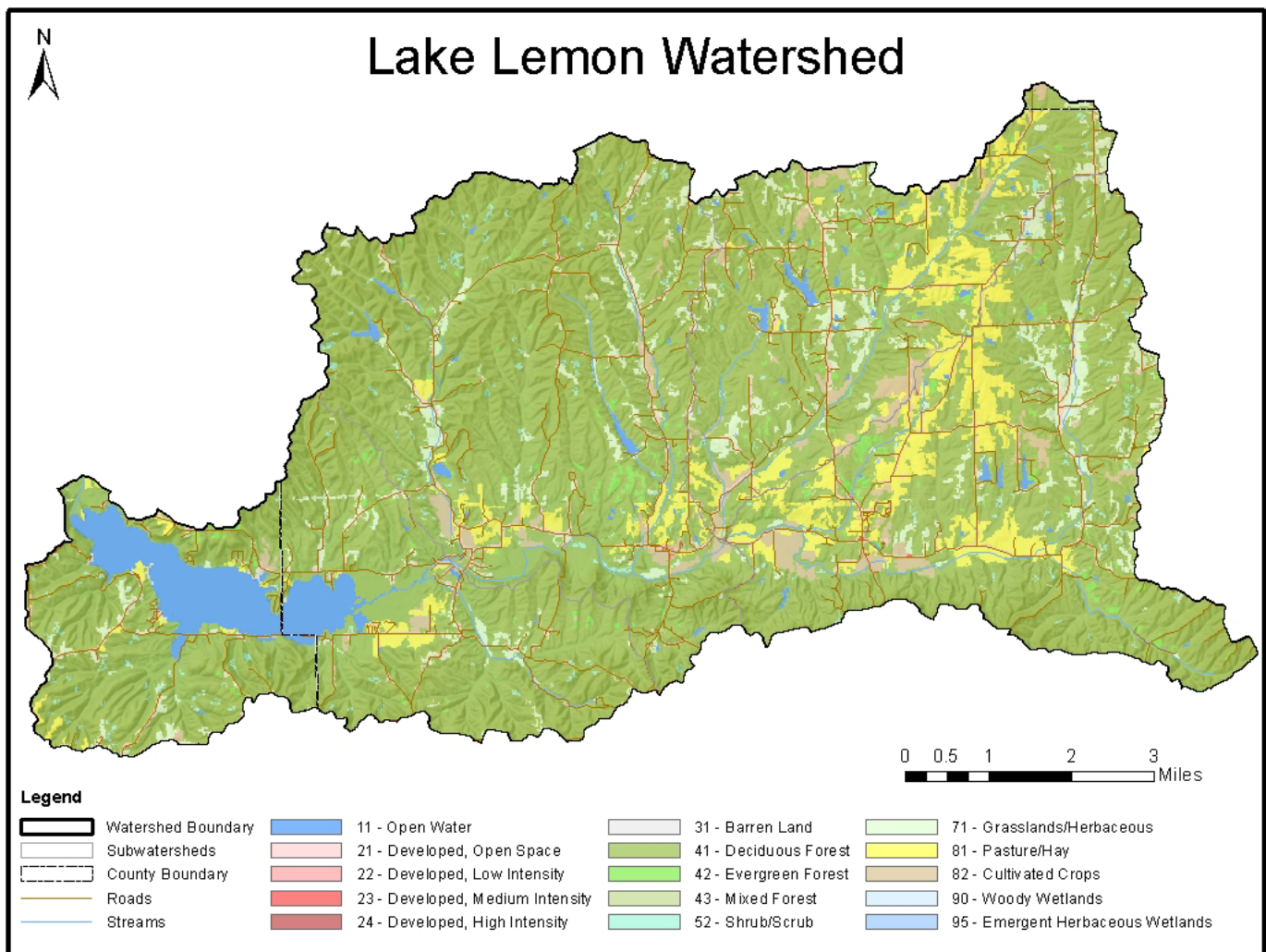


Figure 20. Lake Lemon watershed.

The delivery of eroded watershed soils to the lake has created bars and shallow water depths in the eastern end of the lake. In addition to posing navigation problems, sediment accumulations provide more potential habitat for rooted aquatic plants. The abundant shallow water and freshly deposited sediments in Lake Lemon provide ideal conditions for the growth of rooted plants. These rooted aquatic plants then provide additional hydraulic resistance encouraging sedimentation, which exacerbates the siltation in the eastern end of the lake. While the overabundance of macrophytes has decreased over the years by active harvesting and recent dredging, watershed sedimentation continues to deliver excessive suspended solids.

Sedimentation and its consequences are likely the most pervasive and historic problems of Lake Lemon. Since the LLCDD has initiated a dredging program, controlling the watershed sources of sediment delivery, are the most needed lake management activities currently at the lake. While nutrient mitigation is not the primary objective of the current sediment dredging, removing those nutrient rich lake sediments will impact the nutrient release and resuspension, consequently reducing nutrients in the lake. However, since most lake sediments were dredged from the epilimnetic sediments, the nutrient release is chemically limited but fully susceptible to boat wave action. It is well documented that a 50 horse power recreational boat motor can resuspend silt sized lake sediment particles in 10 feet of water. While there are a many idle speed areas within the lake, a large portion of the lake area that is 10 feet deep and shallower permits high speed motor boating (Figure 21). This certainly contributes to the high sediment resuspension in addition to watershed inputs.

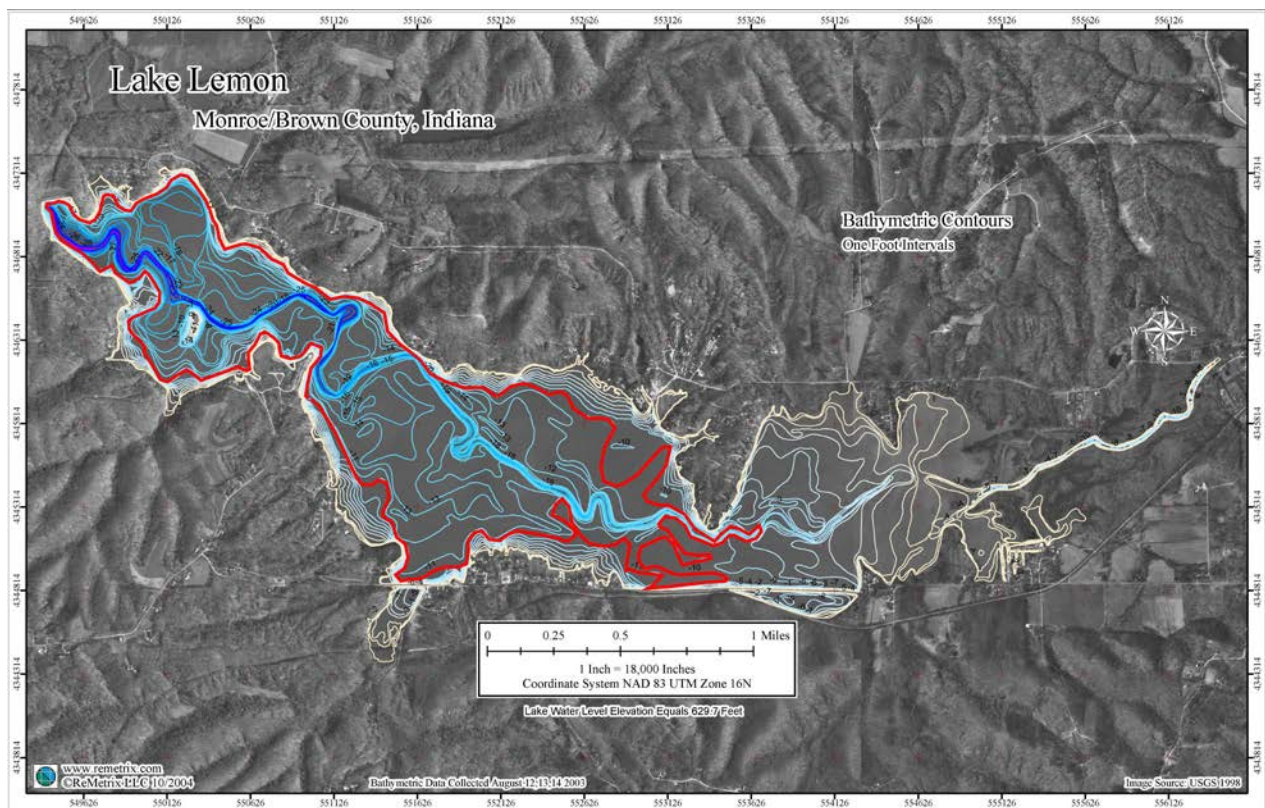


Figure 21. Lake Lemon 2004 Bathymetry. The red line follows the 10 foot depth contour.

While Lake Lemon continues to face watershed and lake challenges ranging from eutrophic water conditions that usually peak towards the end of the summer season to watershed land uses, there has been no significant change over the last 17 years. Key eutrophy parameters (total phosphorus, chlorophyll-a, Secchi disk transparency) have produced similar yearly results. Additional time is needed to discover if the multiple benefits of dredging significantly contribute to nutrient reduction.

The conservancy has done a great job of focusing efforts on in lake management issues through the dredging project and plant management. The focus on in lake management has contributed countless benefits to the waterbody. However, the problems of high sediment loading and bacteria cannot be addressed within the lake. In 2014, 2015, and 2016 we began the collection of *E. coli* samples that have allowed us to show even more definitively that Lake Lemon has an issue with human or animal waste. Studies have shown that swimming in waters impaired with *E. coli* can cause gastrointestinal issues in as much as 38% of swimmers and even greater when swimmers ingest water, which is more likely for children (Ackman et al. 1997). High levels of both fecal coliform historically and high *E. coli* counts in the past three summers indicate that further analysis and time needs to be dedicated to this issue.

In previous years high counts have typically only been seen in the targeted sample areas of the stream sites; however, this past summer levels of *E.coli* were above the recreation standard of 200 colonies/100ml in lake samples (Table 8). Reed Point sample was taken multiple days after a rain event, show that even after rain has subsided bacteria are still moving through the lake. This indicates that there is an issue that needs to be addressed, whether the issue is failing septic systems, animal waste or a combination of both needs to be determined. Watershed assessment for areas of concern is important and should be a first step in dealing with the issue.

The greatest limitation to dealing with failing septic systems is the ability to determine which systems are failing. Distributing information on maintenance procedures and visual assessment of what to look for in a failing system could be a cost effective method of reducing the problem. While visual inspections can sometimes be valuable, professional assessment are usually necessary. Implementing a septic care incentive program would be an even more effective method of helping property owners have systems inspected and routine maintenance performed. Finding local partners and grant funding would be critical to the operation of this type of program.

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