LAKE LEMON MONITORING PROGRAM
2012 RESULTS

Prepared for:

Lake Lemon Conservancy District

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CONTENTS

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 2012 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 4/17/12, 6/14/12, and 7/31/12 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.

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 4/17/12 and 7/31/12, 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
- alkalinity
- conductivity
- dissolved oxygen
- temperature
- total phosphorus
- soluble reactive phosphorus
- nitrate+nitrite
- ammonia
- total organic nitrogen
- total suspended solids
- 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 ¾ of the way down the main channel (Chitwood #2), Bear Creek and the North side Marina drainage inlet to Lake Lemon.

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 nannoplankton 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 ^{o}F (23.7 ^{o}C) by more than 3 ^{o}F (1.7 ^{o}C). June temperatures should not exceed 90 ^{o}F (32.2 ^{o}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:

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

***Fecal Coliform* Bacteria -** 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. *Fecal coliforms* 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, fecal coliform 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 Utermoehl settling chambers. Either 25-ml or 50-ml of sample is concentrated to insure sufficient cell density. Settled concentrate is transferred into a 2-mL micro-centrifuge tube for storage. Counts are made using a 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. 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 1. 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

Just following spring turnover, when the lake temperatures are the same throughout the water column, the temperature profile in April is almost isothermal with the surface temperature slightly warmer. Temperature profiles for June and July indicated slight thermal stratification at Riddle Point, while Reed Point primarily illustrates no stratification (Figures 2 and 3). In most Indiana lakes, thermal stratification is weakest in the spring and gets stronger as summer progresses. The April temperatures at Riddle Point range less than 2°C, with the warmer surface 17.3°C surface temperature and 15.4°C bottom temperature. By June, the Riddle Point temperature profile was stratified with the hypolimnion starting at 3m deep. The whole water column continued to warm with the July surface temperature reaching 28.9°C and the hypolimnion reaching 23.8°C. Reed Point basically was isothermal throughout the whole summer, with a slight temperature decrease in at the 3m depth, 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 well mixed.

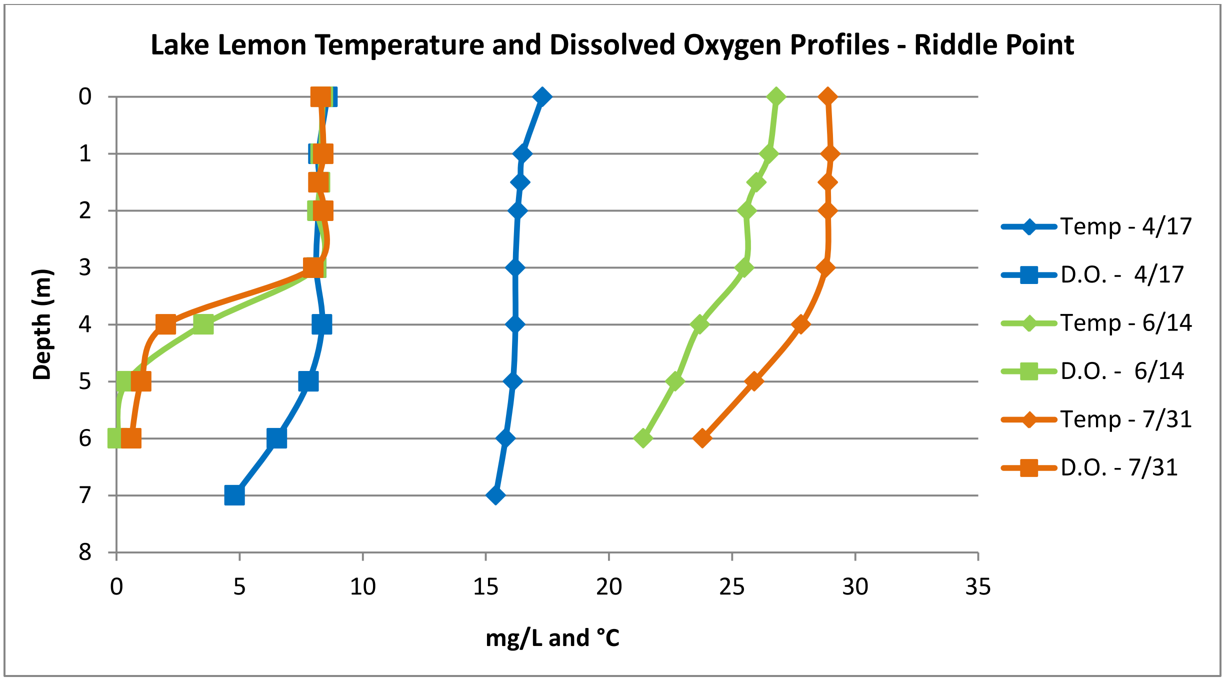

Figure 2. Temperature and dissolved oxygen profiles for Lake Lemon at Riddle Point on 4/17/12, 6/14/12, and 7/31/12.

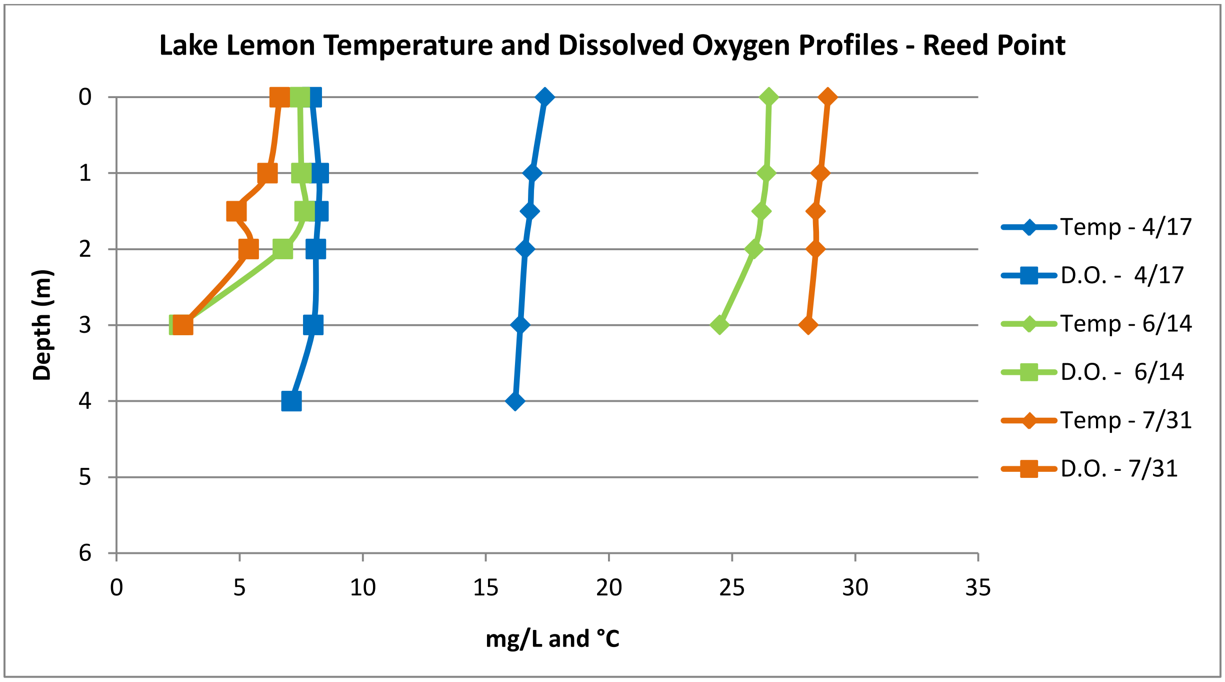

Figure 3. Temperature and dissolved oxygen profiles for Lake Lemon at Reed Point on 4/17/12, 6/14/12, and 7/31/12.

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. This profile was illustrated at both Riddle and Reed Points April. There was a slight oxygen decrease in the bottom 3m of Riddle Point, but that portion of the water column still had 4.8 mg/L dissolved oxygen. 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 4 meters of water remained oxygenated during both June and July sampling at Riddle Point (Figures 2). The July dissolved oxygen concentrations averaged 8.3 mg/L in the epilimnion, which was above 100% saturation. Anoxic conditions develop below 4 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 3).

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 4). Soluble phosphorus (SRP) concentrations are lower than total phosphorus because algae rapidly take up and use soluble phosphorus. Mean SRP concentrations were below the method detection (0.01 mg/L) limit in all samples with exception of the July Riddle Point sample (0.0.62 mg/L). Summer (June and July) TP concentrations were greater than the level indicative of eutrophication (0.030 mg/L).

Typically we only detect low concentrations of nitrate-nitrogen throughout the sampling season. The 2012 spring sampling event captured spring runoff following spring fertilizer application, which resulted in elevated nitrate concentrations during April and June. Nitrate concentrations decreased to the minimum detection level (0.013 mg/L) in June and July at Riddle and Reed Points (Figure 5). 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 increased throughout the summer in the hypolimnion from 0.018 mg/L to 0.952 mg/L (Figure 6). 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, however in 2012 the spring and late summer concentrations were much higher, 0.433 mg/L and 0.485 mg/L, respectively. Sufficient mixing within the shallower waters of Reed Point usually keep 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, 4/17/12.

Parameter	**Riddle**		**Reed**
	Epilimnion	Hypolimnion	Epilimnion
Secchi (m)	1.5	--	0.9
Light trans @ 3' (%)	21.3	--	12
1% Light Level (ft)	13.5	--	9.5
% Water Column Oxic	100	--	100
pH	7.5	7.4	7.5
Conductivity (uS/cm))	125.4	123.4	135.1
Alkalinity (mg/L)	53	54	62
Total Suspended Solids (mg/L)	5.6	6.2	9.6
Nitrate (mg/L)	0.108	0.101	0.099
Ammonia (mg/L)	0.018*	0.035	0.433
Total Organic Nitrogen (mg/L)	0.289	0.260	0.212
Soluble Reactive Phosphorus (mg/L)	0.010*	0.010*	0.010*
Total Phosphorus (mg/L)	0.02	0.025	0.033
Chlorophyll-*a* (ug/L)	5.015	--	7.42
Plankton (Cells/ml)			
Plankton (#/L)			
Blue-green dominance NU (%)			
Blue-green dominance – cells/ml (%)			

* Method Detection Limit

Table 2. Water Quality Characteristics of Lake Lemon – Riddle Point and Reed Point, 6/14/12.

Parameter	Riddle		Reed
	Epilimnion	Hypolimnion	Epilimnion
Secchi (m)	1.3	--	1.05
Light trans @ 3' (%)	20.3	--	66.6
1% Light Level (ft)	12.5	--	10
% Water Column Oxic	83	--	100
pH	7.1	7.1	7.35
Conductivity (uS/cm))	169.2	183.2	173.3
Alkalinity (mg/L)	64.5	66.0	72.5
Total Suspended Solids (mg/L)	4.5	18.5	15.6
Nitrate (mg/L)	0.043	0.013*	0.013*
Ammonia (mg/L)	0.018*	0.131	0.018*
Total Organic Nitrogen (mg/L)	0.308	0.318	0.355
Soluble Reactive Phosphorus (mg/L)	0.010*	0.010*	0.010*
Total Phosphorus (mg/L)	0.029	0.048	0.029
Chlorophyll-*a* (ug/L)	6.9	--	6.7
Plankton (Cells/ml)	180,708		160,716
Plankton (#/L)	7,267,555		33,083,302
Blue-green dominance NU (%)	54.9		85.9
Blue-green dominance – cells/ml (%)	91.6		83.5

* Method Detection Limit

Table 3. Water Quality Characteristics of Lake Lemon – Riddle Point and Reed Point, 7/31/12.

Parameter	**Riddle**		**Reed**
	Epilimnion	Hypolimnion	Epilimnion
Secchi (m)	0.55	--	1.05
Light trans @ 3' (%)	5	--	2.6
1% Light Level (ft)	6.5	--	10
% Water Column Oxic	67	--	100
pH	7.7	7.1	7.3
Conductivity (uS/cm))	0.201	0.26	208
Alkalinity (mg/L)	86	122	87
Total Suspended Solids (mg/L)	14.0	7.2	14.3
Nitrate (mg/L)	0.013*	0.013*	0.013*
Ammonia (mg/L)	0.018*	0.952	0.018*
Total Organic Nitrogen (mg/L)	1.239	0.808	0.949
Soluble Reactive Phosphorus (mg/L)	0.010*	0.062	0.010*
Total Phosphorus (mg/L)	0.051	0.086	0.334
Chlorophyll-*a* (ug/L)	40.51	--	34.88
Plankton (Cells/ml)			
Plankton (#/L)			
Blue-green dominance NU (%)			
Blue-green dominance – cells/ml (%)			

* Method Detection Limit

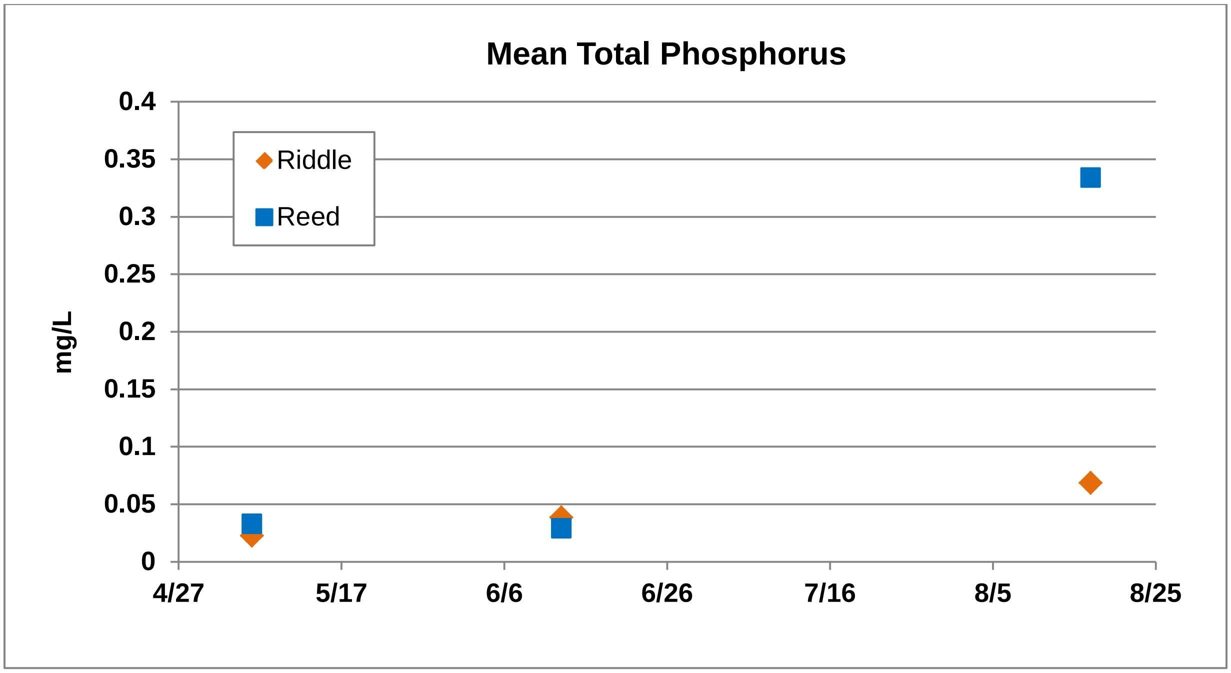

Figure 4. Mean total phosphorus concentrations at Riddle and Reed Point during summer 2012.

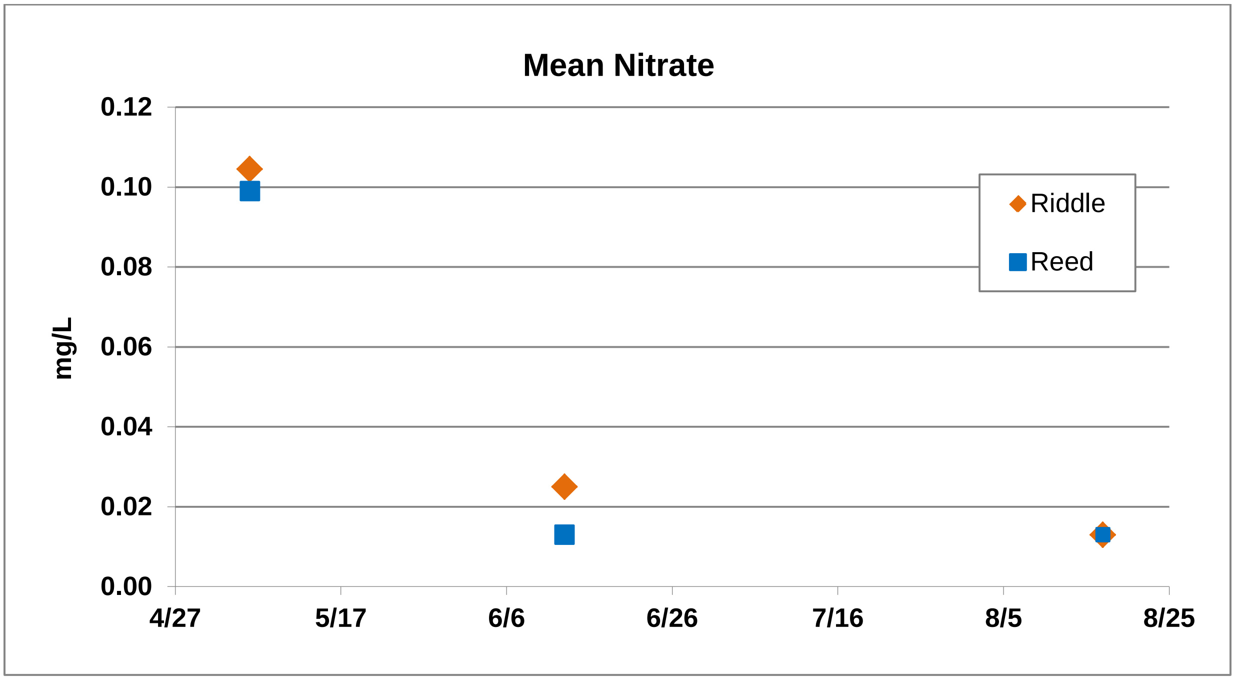

Figure 5. Mean nitrate concentrations at Riddle and Reed Point during summer 2012.

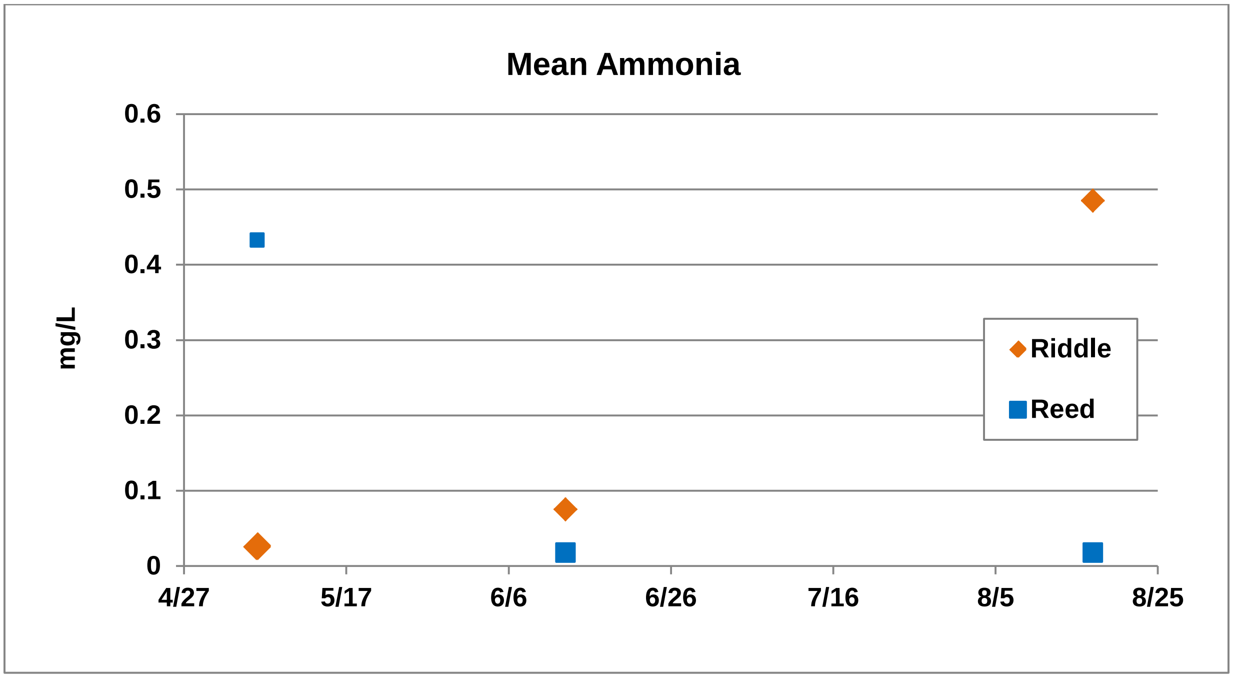

Figure 6. Mean ammonia concentrations at Riddle and Reed Point during summer 2012.

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 2012, Riddle and Reed plankton counts increased by over 6-fold by mid-June (Table 4). Reed plankton counts were elevated on all sample dates (Table 5). Typically, the plankton assemblage shifted towards a strongly dominant blue-green algae proportion by August, which is definitely the case with blue-green dominating both August samples at >99%. 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.

Green algae typically decrease throughout the summer (Figure 7). By late July, both Riddle and Reed Point green algal counts have decreased <1% of the plankton assemblage. These algae, as a rule, make great food for the zooplankton, however the green algae cannot compete well with the blue-greens for resources (light, nutrients, carbon dioxide) necessary for continued growth in the summer. Green algae are usually outcompeted by blue-green algae. 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.

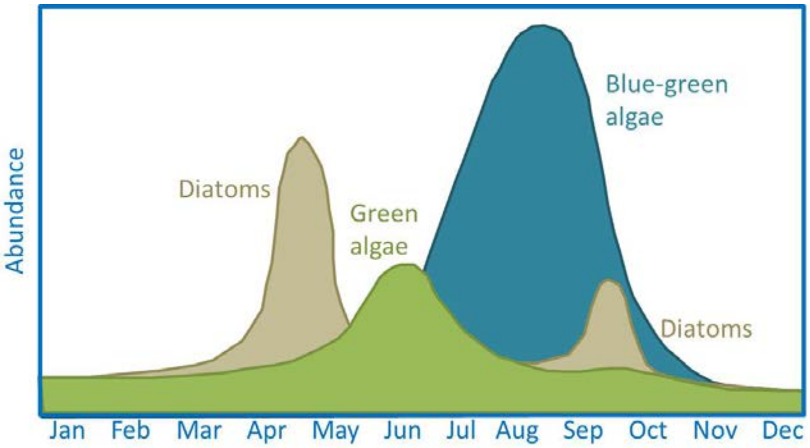

Figure 7. Generic seasonal phytoplankton succession.

Diatoms typically have higher concentrations early in the sampling season, which falls closer to spring turnover (Figure 7). Diatom numbers increase with turnover because of the increased supply of available dissolved silica (Kalff and Watson, 1986). The diatom numbers generally decrease throughout the growing season (Tables 4 and 5), which could result from less available silica. Diatom densities typically are barely represented by the end of the growing season. Plankton diversity typically decreases in Lake Lemon in regard to Phylum throughout the summer.

Zooplankton,which are microscopic animals equivalent to cows grazing in the pasture, feed on phytoplankton (Figure 8). Zooplankton densities significantly increased by late July. Both Riddle and Reed Point samples were dominated by rotifer populations. Many rotifer populations have a population peak in late summer in conjunction with peaked blue-green algae populations.

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. Transparencies closely matched the concentrations of suspended material. The transparencies for Reed Point remain fairly stable around 1m depth. Riddle Point transparency decreased while the total suspended solids (TSS) and the TP concentrations increased (Figure 9 and 10). 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.

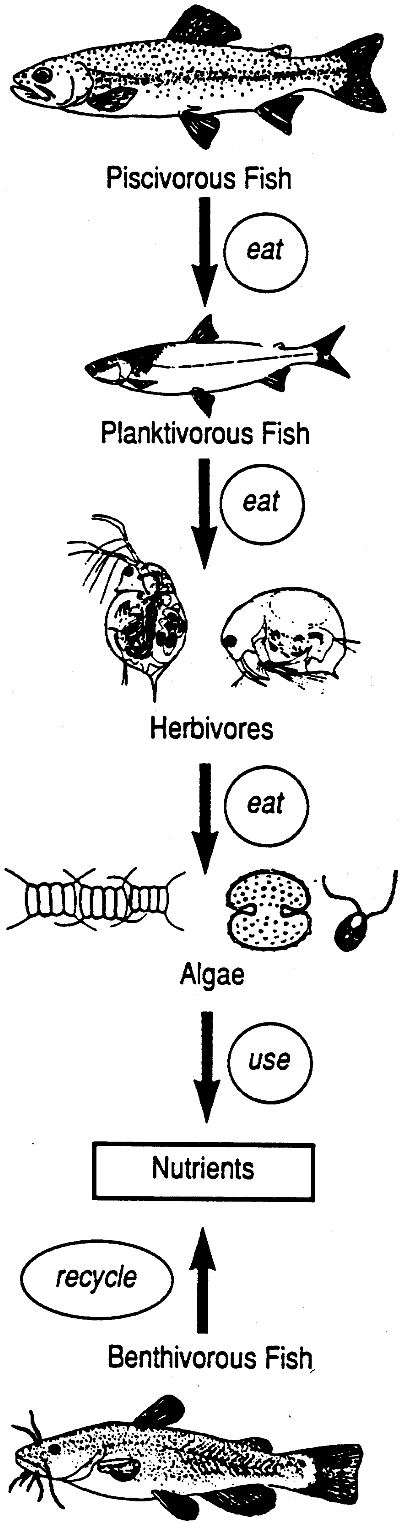

Figure 8. Generalized aquatic food chain. Tiny shrimp-like animals called zooplankton eat algae. Zooplankton, in turn, are eaten by small plankton-eating fish such as minnows, gizzard shad and young sunfish.

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.

	4/17/12		6/14/12		7/31/12	
Phytoplankton (Algae)	**Total (Cells/ml)**	**%**	**Total (Cells/ml)**	**%**	**Total (Cells/ml)**	**%**
Blue-greens	26,326	85.8%	165,559	91.6%	108,176	99.55%
Greens	1,951	6.4%	11,383	6.3%	216	0.20%
Diatoms	1,003	3.3%	1,541	0.9%	54	0.05%
Other algae	1,400	4.6%	2,225	1.2%	217	0.20%
Total Phytoplankton	30,680		180,708		108,663	
Zooplankton	**Total (#/L)**		**Total (#/L)**		**Total (#/L)**	
Rotifers	24		2		2,301	
Zooplankton*	26		46		866	

*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.

	4/17/12		6/14/12		7/31/12	
Phytoplankton (Algae)	**Total (Cells/ml)**	**%**	**Total (Cells/ml)**	**%**	**Total (Cells/ml)**	**%**
Blue-greens	100,629	95.8%	134,175	83%	129,932	99.4%
Greens	3,956	3.8%	20,056	12%	684	0.5%
Diatoms	326	0.3%	1,842	1%	144	0.1%
Other algae	118	0.1%	4,643	3%		
Total phytoplankton	105,029		160,716		130,760	
Zooplankton	**Total (#/L)**		**Total (#/L)**		**Total (#/L)**	
Rotifers	0		13		1,388	
Zooplankton*	10		23		723	

*Zooplankton counts include Cladocera and Copepods.

Chlorophyll-*a,* which is a measure of the primary pigment in algae, 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 5.015 µg/L in April to 40.51 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 9 and 10).

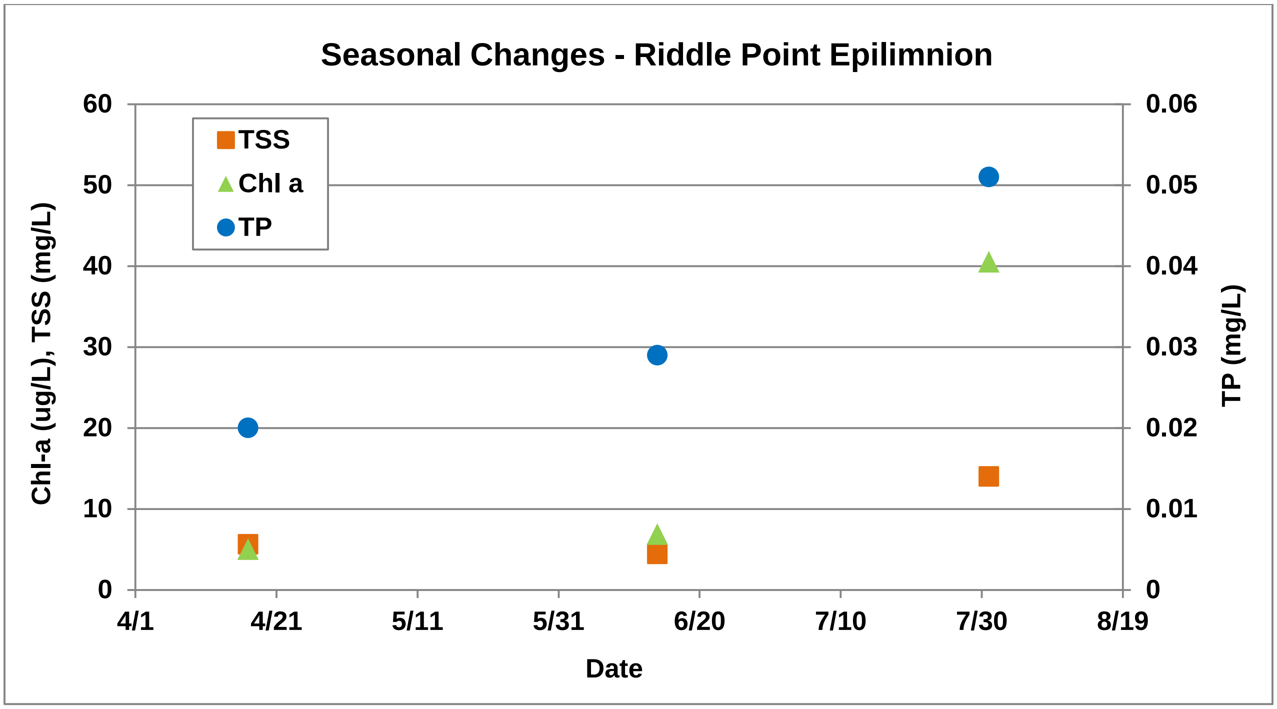

Figure 9. Seasonal changes in total phosphorus, total suspended solids, and chlorophyll-*a* in the surface waters (epilimnion) at Riddle Point in Lake Lemon in 2012.

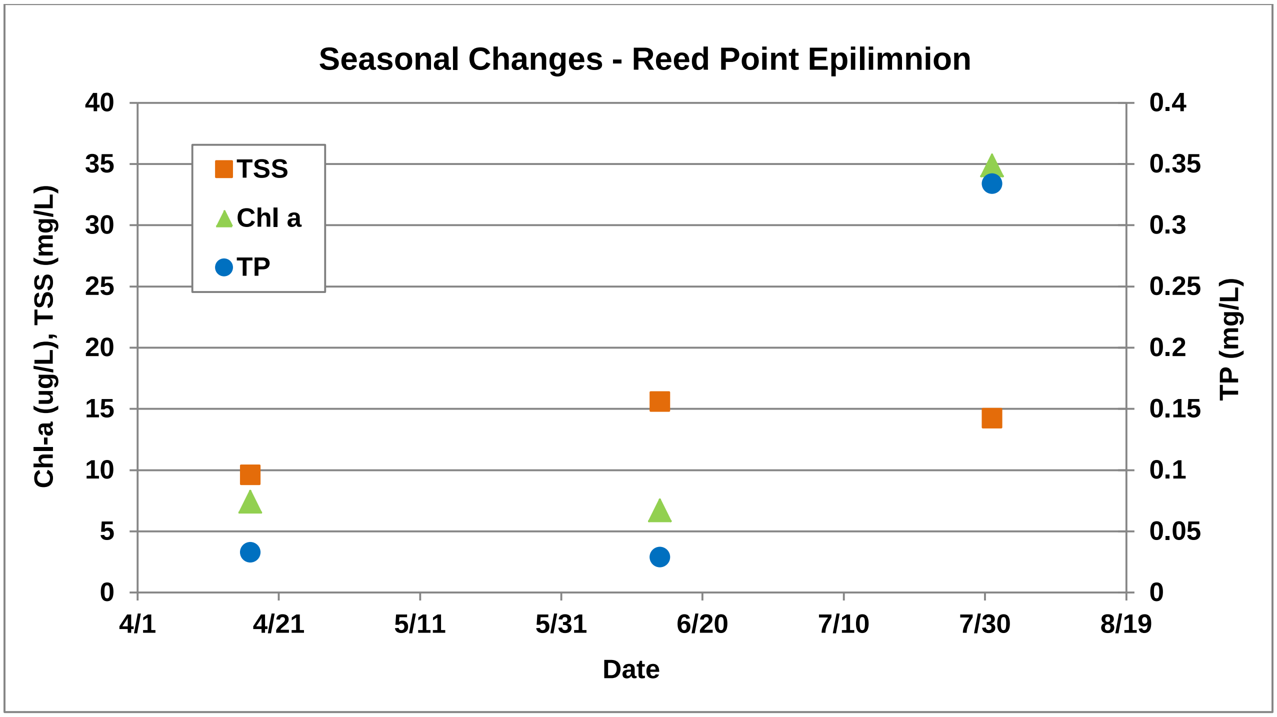

Figure 10. Seasonal changes in total phosphorus, total suspended solids, and chlorophyll-*a* in the surface waters (epilimnion) at Reed Point in Lake Lemon in 2012.

3.2 Comparison with Other Indiana

Table 6 gives values of water quality parameters determined for 355 Indiana lakes during July-August 1998-2010 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, TP, SRP and chlorophyll-*a* exceeded the median values for these 355 lakes, but fell well below the maximum concentrations.

Table 6. July-August Water Quality Characteristics of 355 Indiana Lakes Sampled From 1998 thru 2010 by the Indiana Clean Lakes Program compared to Riddle Point of Lake Lemon (7/31/12). Means of epilimnion and hypolimnion samples were used for Lake Lemon.

	Secchi Disk (m)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	TP (mg/L)	SRP (mg/L)	Chl. *a* (μg/L)
Median	1.7	0.046	0.455	1.199	0.082	0.028	4.42
Maximum	16	16.679	16.348	20.873	4.894	1.427	380.38
Minimum	0.1	0.013*	0.018*	0.230*	0.010*	0.010*	0.010
Mean Values for Riddle Pt. (7/31/12)	**0.55**	**0.013***	**0.485**	**1.509**	**0.069**	**0.036**	**40.51**

* 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. This trend continued with the exception of dissolved oxygen concentrations and fecal coliform counts which were slightly higher in April compared to July. Solubility of oxygen in water is influenced by temperature, with less dissolved oxygen dissolving in warmer water. Beanblossom Creek's late July temperature (29.8°C) resulted in a decreased dissolved oxygen concentration (6.5 mg/L).

In addition to collecting fecal coliform bacteria at Riddle Point and Reed Point, two locations adjacent to the Chitwood neighborhood and three stream locations within 1) Bear Creek, 2) the North Shore Marina tributary, and 3) Beanblossom Creek (Table 8). All samples were below the state standard of 200 colonies per 100 ml threshold. These data illustrate a marked improvement from historic records. The summer drought conditions most likely contributed to the lower concentrations. The lack of precipitation reduced the possibility of surface runoff and groundwater inputs to carry bacteria into the streams and lake.

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

Table 7. Water Quality Characteristics of Beanblossom Creek, Bear Creek, and the small stream that enters Lake Lemon from the North Shore Marina in 2012. Bear Creek and the North Shore Marina Creek only included TSS and F. coliform bacteria analysis.

	Beanblossom Creek		**Bear Creek**		**North Shore Marina Creek**	
	4/17	**7/31**	**4/17**	**7/31**	**4/17**	**7/31**
pH	7.3	7.6				
Conductivity (mS/cm)	127.8	285.0				
Alk (mg/L)	61	107				
Temperature	14.2	29.8				
D.O. (mg/L)	8.5	6.5				
% D.O. Saturation	89.6	82.3				
TSS (mg/L)	8.8	10.8	2.4	12.0	4.0	3.0
NO_3^- (mg/L)	0.111	0.013*				
NH_4^+ (mg/L)	0.018*	0.018*				
TKN (mg/L)	0.283	0.570				
SRP (mg/L)	0.010*	0.010*				
Total Phos (mg/L)	0.028	0.048				
Fecal Coliform (col/100ml)	110	50	38	24	50	0

* Method Detection Limit

Table 8. Fecal coliform bacteria summary for 2012 Lake Lemon samples. The state standard for full body contact and recreation is 200 colonies per 100mls.

	Fecal Coliform Bacteria (#/100mls)	
	4/17/12	**7/31/12**
Riddle Point	64	6
Reed Point	74	4
Chitwood #1	148	52
Chitwood #2	28	122
Beanblossom Creek	110	50
Bear Creek	38	24
N. Shore Marina Creek	50	0

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
Oligotrophic	clear	Low TP < 6 µg/L	few algae	Hypo has D.O.	can support salmonids (trout and salmon)
Mesotrophic	Less clear	Moderate TP 10-30 µg/L	healthy populations of algae	Less D.O. in hypo	lack of salmonids
Eutrophic	transparency <2 meters	High TP > 35 µg/L	abundant algae and weeds	No D.O. in the hypo during the summer	
Hypereutrophic	transparency <1 meter	extremely high TP > 80 µg/L	thick algal scum Dense weeds	No D.O. in the hypo during the summer	

The changes in a lake from oligotrophy to a 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 (Figure11). 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.

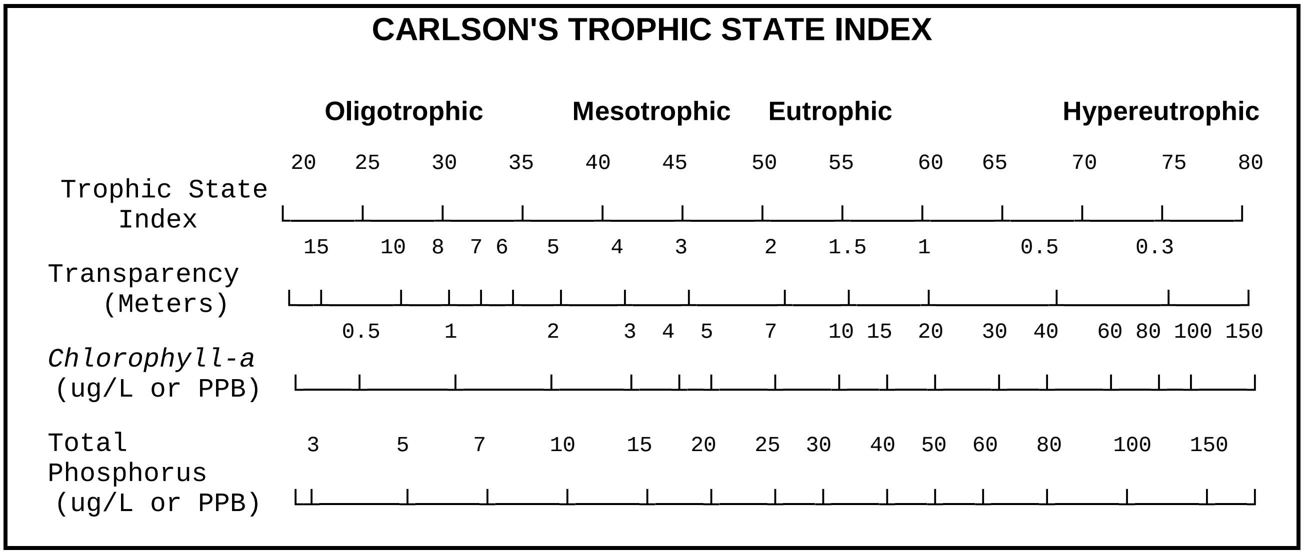

Figure 11. Carlson's trophic state index.

3.4.3 Trophic State Scores

Using Carlson's TSI for the April, June, and July data, Lake Lemon varied by parameter and month, and ranged from mesotrophic to hypereutrophic (Table 10). The earlier April TSI scores start the growing season with eutrophic conditions. Except the June chlorophyll classification, 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 2012 Water Quality Data for Riddle/Reed Points.

DATE	Carlson's Secchi Disk TSI	Carlson's Total Phosphorus TSI	Carlson's Chlorophyll TSI
April	54/62	49/54	46/50
	Eutrophic	Mesotrophic/Eutrophic	Mesotrophic/Eutrophic
June	53/59	53/54	37/49
	Eutrophic	Eutrophic	Mesotrophic
July	69/59	65/88	67/82
	Eutrophic	Eutrophic/Hypereutrophic	Eutrophic/Hypereutrophic

How to read:

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

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 generally hoovers around eutrophic conditions. Figures 12-14 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 significantly lower (less eutrophic) while increasing during the late summer months to a hypereutrophic status. While there is an overall slight decrease in TP concentrations over the last 14 years, the last 5 years showed a greater decreasing trend (Figure 13).

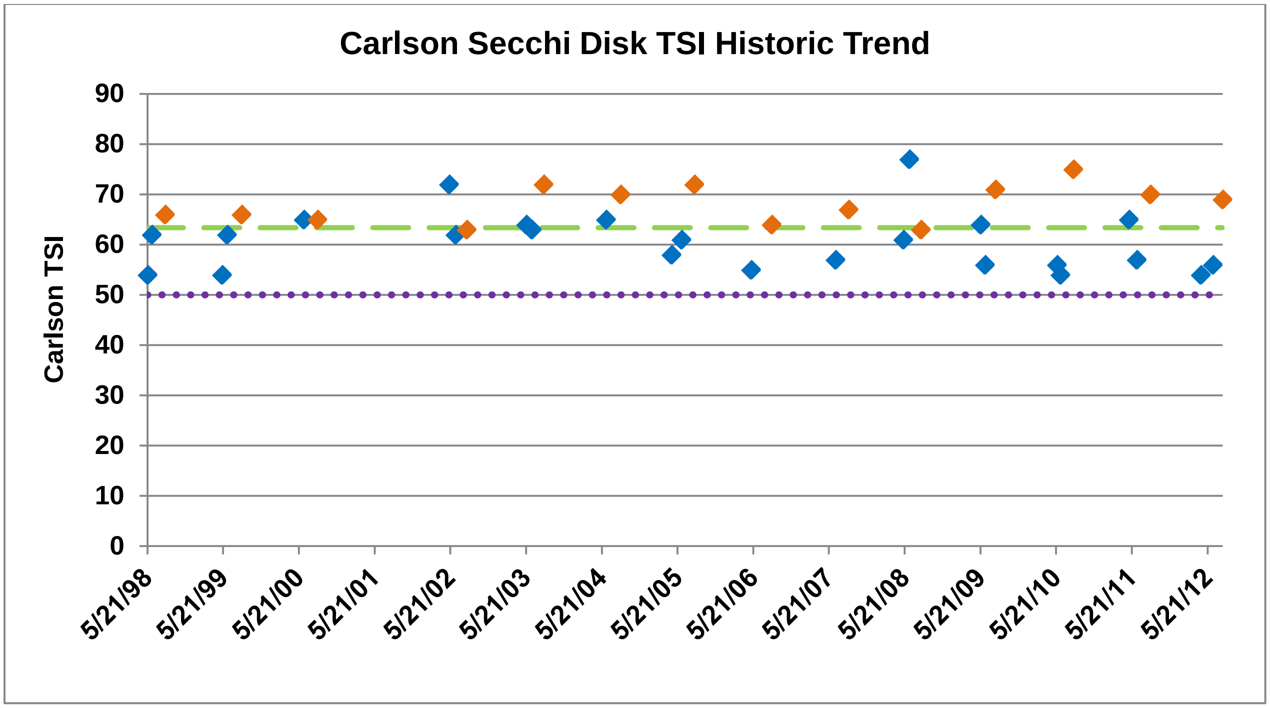

Figure 12. The 14-year historic trend for Carlson Secchi disk TSI scores. All but three late summer (August) samples, shown in orange, scored above the mean for eutrophic status. The green dashed line illustrates the 14-year mean. The purple dotted line illustrates eutrophic status for the Carlson TSI.

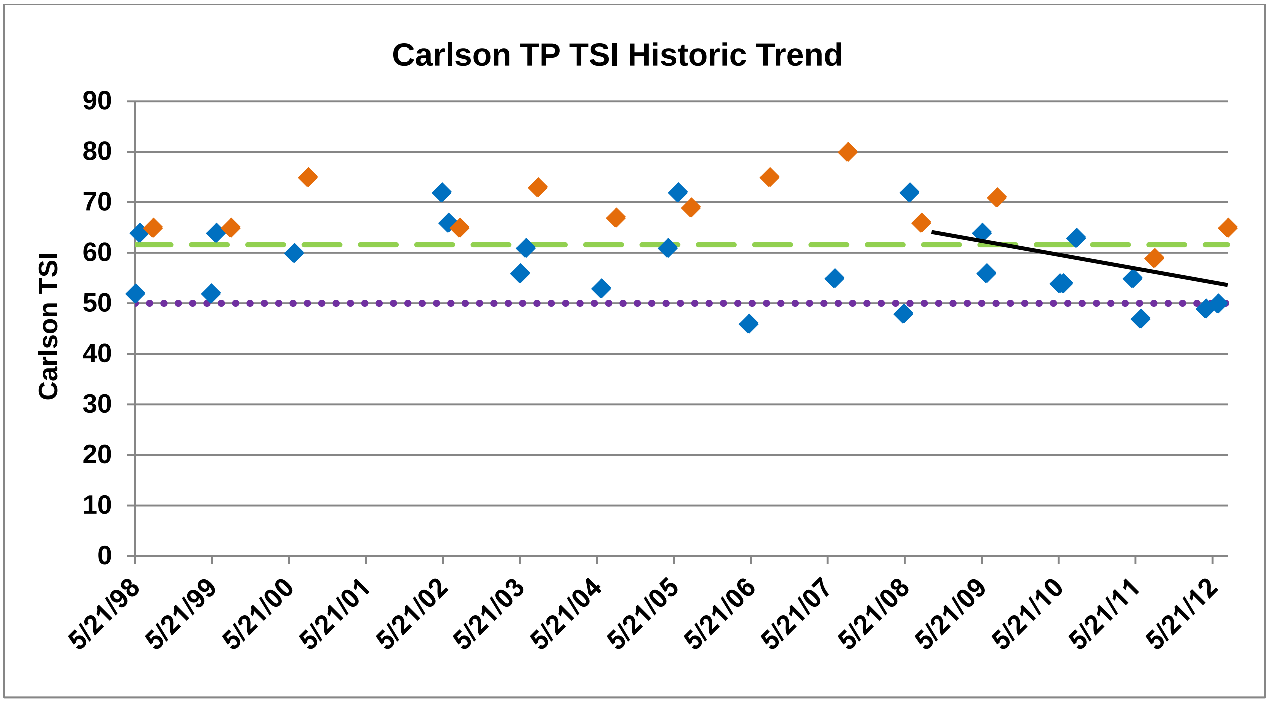

Figure 13. The 14-year historic trend for Carlson total phosphorus TSI scores. All August samples, shown in orange, score above the mean for eutrophic status. The green dashed line illustrates the 14-year mean. The purple dotted line illustrates eutrophic status for the Carlson TSI. The black line shows a decreasing trend for the last 5 years.

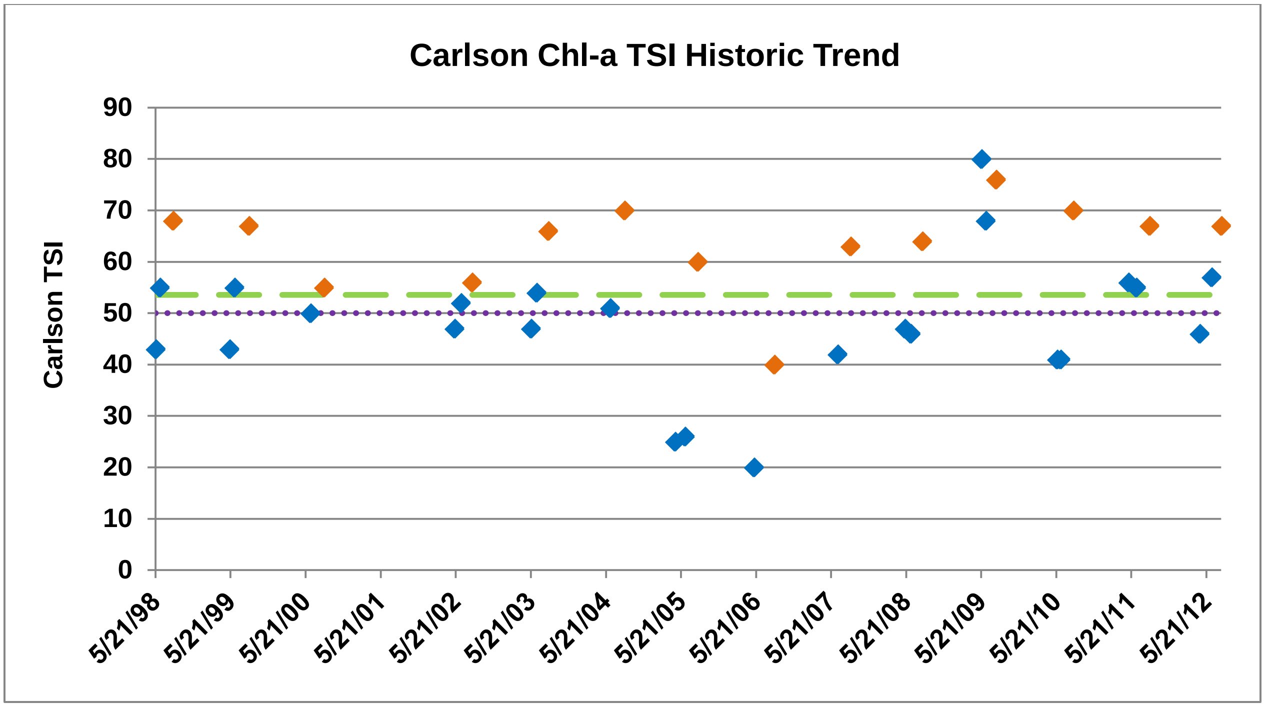

Figure 14. The 14-year historic trend for Carlson chlorophyll-*a* TSI scores. Most August samples, shown in orange, score above the mean for eutrophic status. The 14-year mean is just above the Carlson TSI eutrophic status score of 50 (purple dotted line).

5.0 WATER QUALITY TRENDS

Compiled Secchi disk transparency data from volunteer monitors and SPEA monitoring studies over the past 19 years are shown in Figure 15. 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 19 years at Lake Lemon's Riddle Point sampling site (Figure 16). There is little visible long-term trend. Most of the values were above the eutrophic threshold of 0.030 mg/L. The earlier April and June 2012 samples were below this threshold, but exceed the concentration by late July. The variable concentrations have tightened over the years with the average just about 0.030 mg/L.

Epilimnetic total phosphorus concentrations at Riddle Point are mostly in the eutrophic range but the resulting chlorophyll-*a* concentrations (Figure 17) do not always reach the eutrophic range of greater than 7 µg/L; however, the majority of the August chlorophyll-*a* samples over the eighteen years do fall above the eutrophic classification. 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 shade out the photic zone.

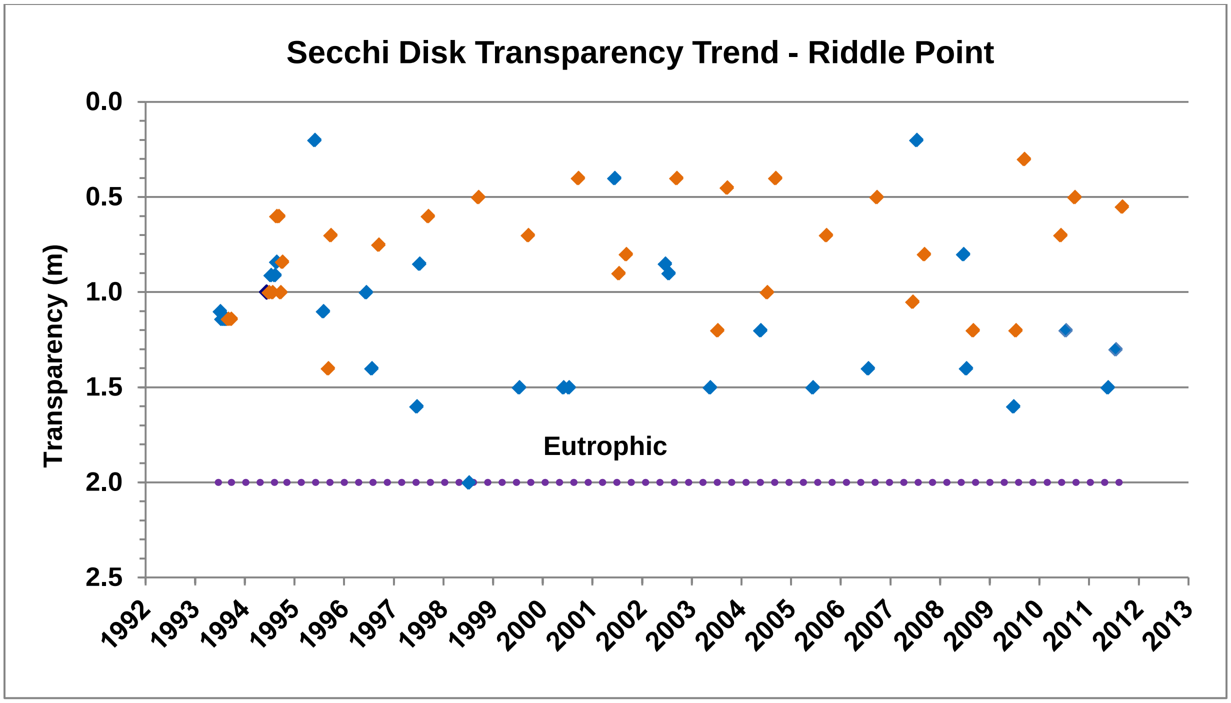

Figure 15. Historic Secchi disk transparency data for Lake Lemon. All data are less than the general eutrophic indicator of 2 meters (dotted line). Orange markers indicate August or late July samples.

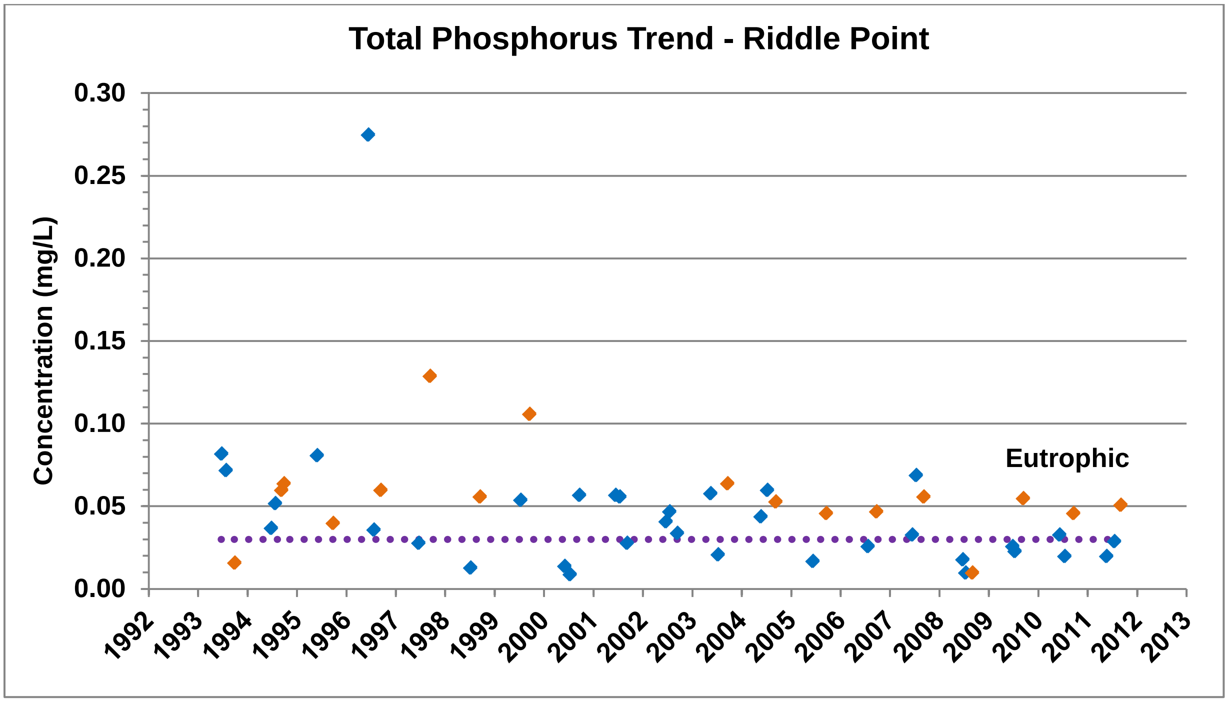

Figure 16. Historic epilimnetic total phosphorus trend for Lake Lemon. Most concentrations are higher than 0.030 mg/L (dotted line), the level generally considered high enough to support eutrophic conditions. Orange markers indicate August or late July samples.

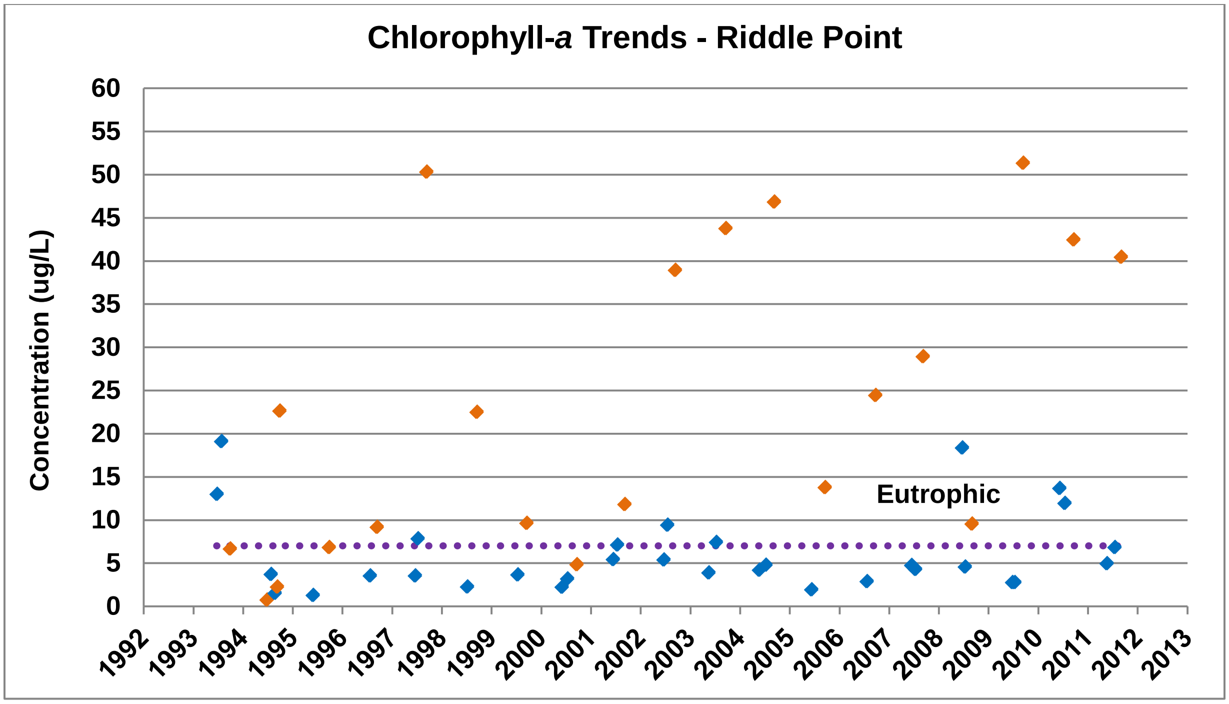

Figure 17. Historic chlorophyll-*a* data for Lake Lemon. The dotted line illustrates concentrations indicative of eutrophic conditions. Orange markers indicate August or late July samples.

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 18). 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. The extreme drought conditions of 2012 impacted all lakes and reservoirs throughout Indiana. 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. This makes this reservoir very responsive to watershed inputs. The drought conditions reduced the watershed inputs, which lengthen the residence time and decreased nutrient deliver.

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 18 years (Figures 15-17). 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.

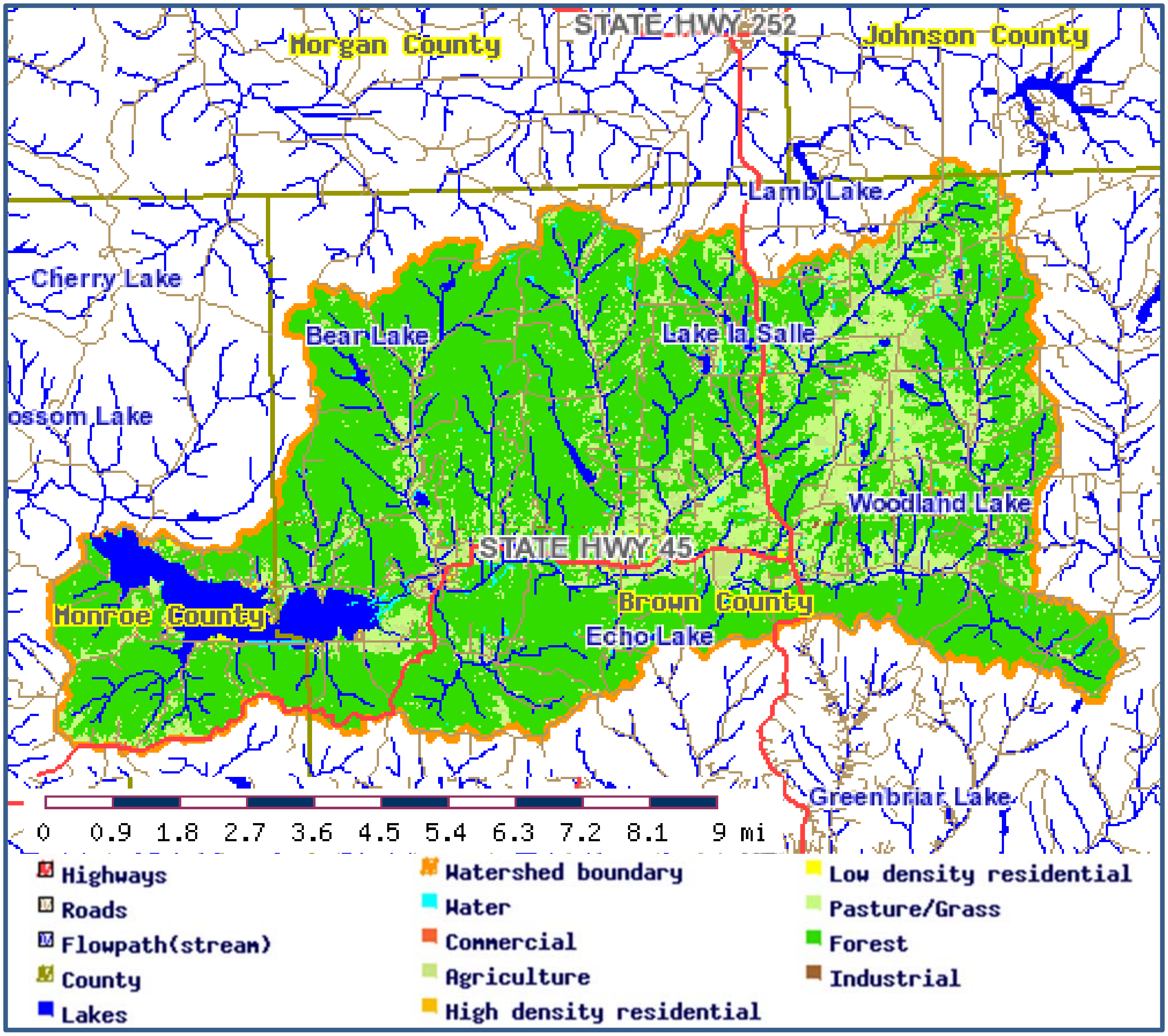

Figure 18. Lake Lemon watershed. Source: Choi and Engel (2005).

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 most recently dredging, watershed sedimentation continues to deliver excessive suspended solids.

Sedimentation and its consequences are likely the most pervasive problems continuing to face Lake Lemon. The LLCD initiated a dredging program at Lake Lemon. Dredging, along with controlling the watershed sources of sediment delivery, continue to be the most needed lake management activities.

While Lake Lemon continues to face watershed and lake challenges ranging from eutrophic water conditions that peak towards the end of the summer season due to watershed land uses, there has been no significant change over the last 19-years. Key eutrophy parameters (total phosphorus, chlorophyll-*a*, Secchi disk transparency) have produced similar annual trends. While Lake Lemon’s eutrophy status has shown a slight decrease for the TP trophic state index, it has not significantly deviated from the 14-year average.

7.0 **REFERENCES**

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