LAKE LEMON MONITORING PROGRAM
2006 RESULTS

Prepared for:

Lake Lemon Conservancy District

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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 2006 monitoring efforts.

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 5/10/06 and 8/17/06 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. 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, 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 plankton was made from the 1% light level to the water surface.

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 in early and late summer of 2006, May 10th and August 17th, 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).

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:

Phosphorus. An essential plant nutrient, most often controls aquatic plant growth. Found in fertilizers, human and animal wastes, and yard waste. There are few natural sources of phosphorus to lakes and there is no atmospheric (vapor) form of phosphorus. For this reason, phosphorus is often a ***limiting nutrient*** in lakes. This means that the relative scarcity of phosphorus in lakes may limit the ultimate growth and production of algae and rooted aquatic plants. Therefore, lake management efforts often focus on reducing phosphorus inputs to lakes because: (a) it can be managed and (b) reducing phosphorus can reduce algae production.

Soluble reactive phosphorus (SRP) - dissolved phosphorus readily usable by algae. SRP is often in very low concentrations in lakes with dense algae populations where it is tied up in the algae themselves. May be released from storage in sediments when dissolved oxygen is lacking.

Total phosphorus (TP) - includes dissolved and particulate phosphorus. TP concentrations greater than 0.03 mg/L (or 30 μg/L) may cause algal blooms.

Nitrogen. 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. This nitrogen can diffuse into water where it can be "fixed", or converted, by blue-green algae 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 lakes.

Nitrate (NO_3) - dissolved nitrogen that is converted to ammonia by algae. Found in lakes when dissolved oxygen is present, usually the surface waters.

Ammonia (NH_4) - dissolved nitrogen, preferred form for algae use. Also produced by bacteria as they decompose dead plant and animal matter. Found where dissolved oxygen is lacking, often in the hypolimnia of eutrophic lakes.

Organic Nitrogen (Org N) - includes nitrogen found in plant and animal materials. May be in dissolved or particulate form. In our analytical procedures, we analyze total Kjeldahl nitrogen (TKN). Organic nitrogen is TKN minus ammonia.

Dissolved Oxygen (DO). Dissolved gas essential for respiration of fish and other aquatic organisms. Fish need at least 3-5 parts per million (ppm) of D.O. Affects chemical reactions in water. For example, the lack of D.O. near the bottom sediments may allow dissolved phosphorus (SRP) to be released from the sediments into the water. If less than 50% of a lake’s water column has oxygen, you may also see greater hypolimnetic concentrations of SRP and ammonia as well. 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. Dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

Secchi Disk Transparency. This refers to the depth to which the black & white Secchi disk can be seen in the 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 water column. Another important light transmission measurement is 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.

Plankton. Plankton are important members of the aquatic food web. Include the algae (microscopic plants) and the zooplankton (tiny shrimp-like animals that eat algae). Determined by filtering water through a net having a very fine mesh (63 micron openings = 63/1000 millimeter). The plankton net (63 μm mesh) is towed up through the water column from the one percent light level to the surface. This small mesh size allow us to sample all but the nanoplankton. 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. Our data are reported as natural units per litter (N.U./L). A natural unit is a single, viable organism. For example, a solitary cell is 1 N.U. but a filamentous colony of 10 cells joined together is also 1 N.U.

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.

RESULTS

Water Quality

Temperature profiles indicated slight to strong stratification at Riddle Point, while Reed Point primarily illustrates weaker stratification (Figures 1–4). In most Indiana lakes, thermal stratification is weakest in the spring and gets stronger as summer progresses. Riddle Point, however, was most stratified in May with the epilimnion at approximately 21°C and steadily decreased to 16.6°C in the hypolimnion. The August measurements (Figure 2) illustrated an increase in warmer water in the top meter, reaching 28.8°C. Reed Point was weakly stratified in May and August due to the shallow water depth there.

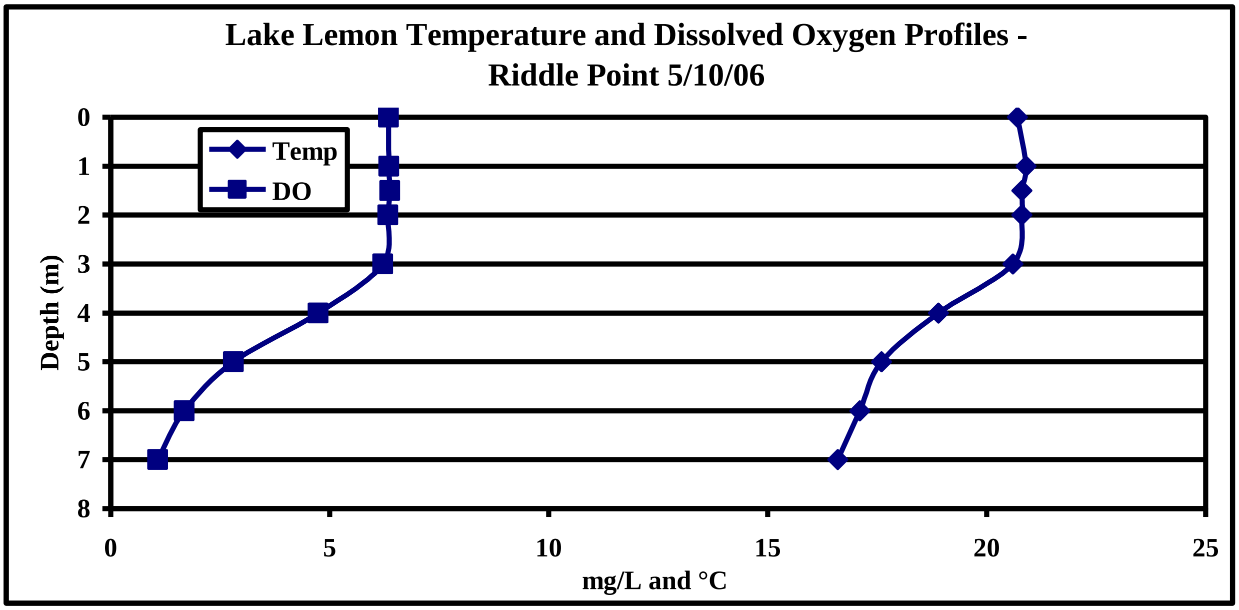

FIGURE 1. Temperature and dissolved oxygen profiles for Lake Lemon at Riddle Point on 5/10/06.

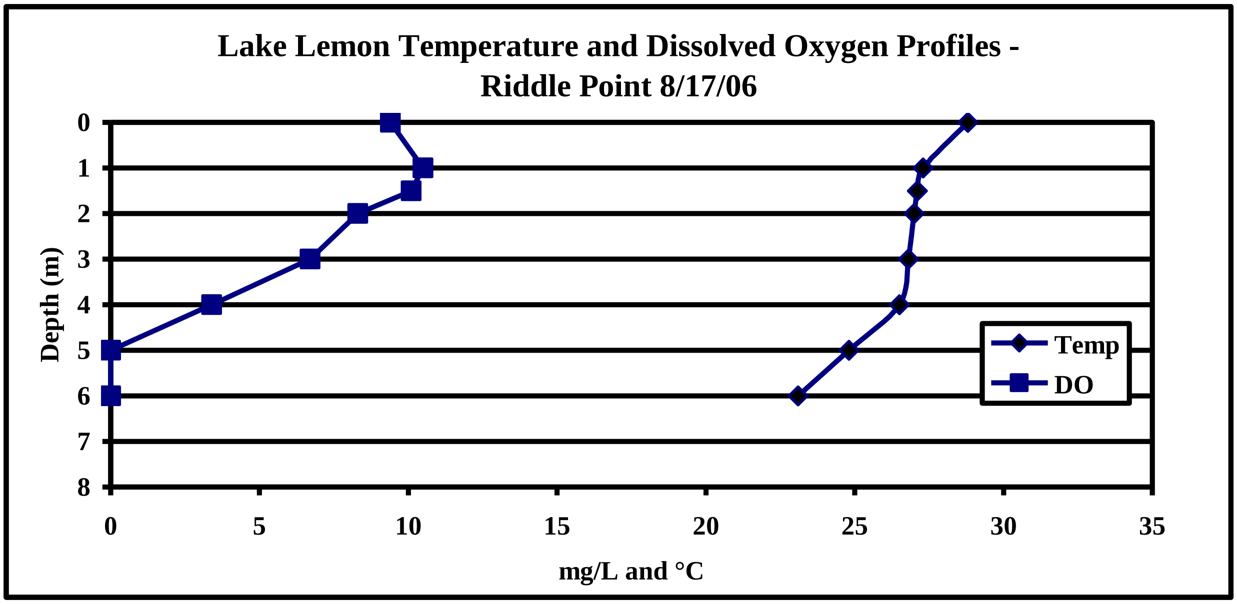

FIGURE 2. Temperature and dissolved oxygen profiles for Lake Lemon at Riddle Point on 8/17/06.

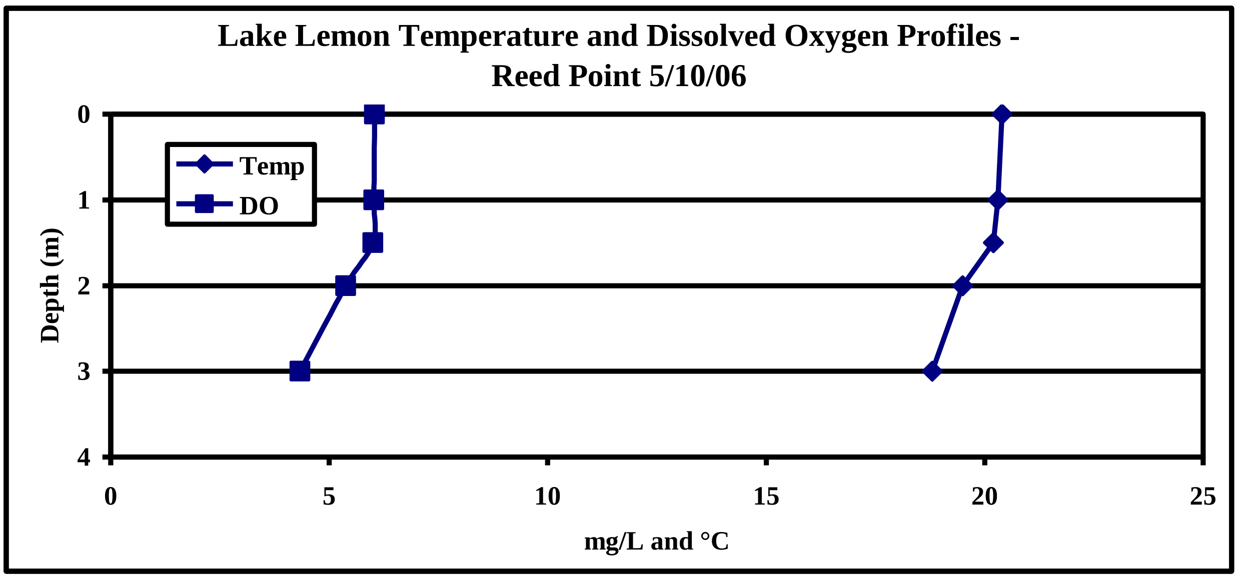

FIGURE 3. Temperature and dissolved oxygen profiles for Lake Lemon at Reed Point on 5/10/06.

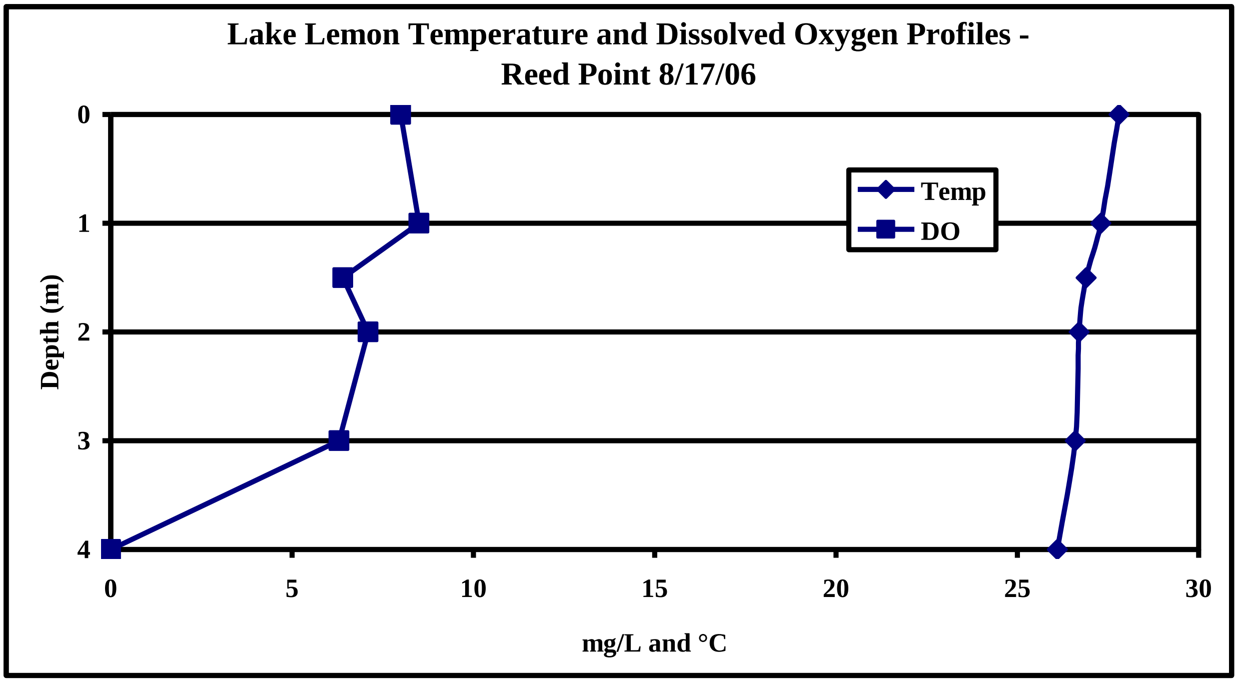

FIGURE 4. Temperature and dissolved oxygen profiles for Lake Lemon at Reed Point on 8/17/06.

Dissolved oxygen (D.O.) profiles generally follow the temperature profiles. Typically, early spring samples are characterized by an orthograde oxygen profile, where the oxygen concentrations remain uniform throughout the water column. Even though D.O. at Riddle Point decreased near the lake bottom in May (Figure 1), it remained oxic throughout the top 4 meters of the water column, averaging 6.32 mg/L, then decreasing to 1.07 mg/L, matching the thermal stratification. The August Riddle Point measurements reached anoxic conditions below 4 meters depth. There is likely 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 August sample at Riddle Point (Figure 2) showed a metalimnetic oxygen maximum, which is illustrated by the oxygen peak at 1 meter. This spike occurs when there is an increased density of photosynthesizing algae within that layer of the water column. Because Reed Point never fully stratifies none of the measurements were anoxic except along the lake sediments in the August sample. This is due to the shallower morphology of Reed Point and lake turbulence.

Water quality data for Lake Lemon are presented in Tables 1- 4. Phosphorus and nitrogen are the primary plant nutrients in lakes. Typically, mean total phosphorus concentrations increase throughout the summer within Lake Lemon due to watershed inputs. Summer 2006 mean total phosphorus concentrations at Riddle Point increased by nearly an order of magnitude in August. Reed Point mean total phosphorus in August was about twice that of May (Figure 5). Soluble phosphorus (SRP) concentrations are lower than total phosphorus because algae rapidly take up and use soluble phosphorus. SRP concentrations were below the method detection limit in all samples except during the August hypolimnion sample, likely due to phosphorus release from the sediments under the anoxic conditions.

We only detected concentrations of nitrate-nitrogen following spring turnover in the Riddle Point hypolimnion in May. The remaining samples were below the detection limit of 0.013 mg/L. Nitrate, an oxidized form of inorganic nitrogen, is highly soluble in water and is carried into the lake from fertilized farm fields 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. Ammonia follows an opposite trend, increasing throughout the summer in the hypolimnion. Riddle Point increased from 0.113 mg/L to 1.034 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 generated ammonia as a by-product. Ammonia was only detected at Reed Point in May, averaging 0.031 mg/L. Sufficient mixing within the shallower waters of Reed Point kept the water column oxygenated preventing the concentration of the chemically-reduced ammonia.

TABLE 1. Water Quality Characteristics of Lake Lemon – Riddle Point, 5/10/06.

Parameter	**Epilimnetic Sample (1m)**	**Hypolimnetic Sample (6m)**	**Indiana TSI Points (based on mean values)**
pH	7.9	7.2	-
Alkalinity	52.5 mg/L	53.5 mg/L	-
Conductivity	150 μmhos	140 μmhos	-
Secchi Disk Transp.	1.5 m	-	6
Light Transmission @ 3 ft	18.4 %	-	4
1% Light Level	11.5 ft	-	-
Total Suspended Solids	2.9 mg/L	5.8 mg/L	-
Total Phosphorus	0.017 mg/L	0.024 mg/L	0
Soluble Reactive Phos.	0.010* mg/L	0.010* mg/L	0
Nitrate-Nitrogen	0.013* mg/L	0.021 mg/L	0
Ammonia-Nitrogen	0.018* mg/L	0.113 mg/L	0
Organic Nitrogen	0.405 mg/L	0.321 mg/L	0
Oxygen Saturation @ 5 ft.	70.8 %	-	0
% Water Column Oxic	65.6 %	-	1
Fecal Coliform Bacteria	14 per 100mls	-	-
Chlorophyll *a*	1.99 μg/L	-	-
Plankton Density	2899 N.U./L	-	0
Blue-Green Dominance	3.5 %	-	0
* Method Detection Limit		TSI Score	11

TABLE 2. Water Quality Characteristics of Lake Lemon – Riddle Point, 8/17/06.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (6m)	Indiana TSI Points (based on mean values)
pH	8.8	7.3	-
Alkalinity	72 mg/L	110 mg/L	-
Conductivity	190 μmhos	226 μmhos	-
Secchi Disk Transp	0.7 m	-	6
Light Transmission @ 3 ft	8 %	-	4
1% Light Level	7.6 ft	-	-
Total Suspended Solids	9.4 mg/L	7.6 mg/L	-
Total Phosphorus	0.046 mg/L	0.218 mg/L	3
Soluble Reactive Phos.	0.010* mg/L	0.142 mg/L	3
Nitrate-Nitrogen	0.013* mg/L	0.013* mg/L	0
Ammonia-Nitrogen	0.018* mg/L	1.034 mg/L	2
Organic Nitrogen	0.828 mg/L	0.858 mg/L	2
Oxygen Saturation @ 5 ft.	126.3 %	-	2
% Water Column Oxic	66.7 %	-	1
Fecal Coliform Bacteria	6 per 100mls	-	-
Chlorophyll *a*	13.8 μg/L	-	-
Plankton Density	16651 N.U./L	-	3
Blue-Green Dominance	98 %	-	10
* Method Detection Limit		TSI score	36

TABLE 3. Water Quality Characteristics of Lake Lemon – Reed Point, 5/10/06.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	7.7	7.1	-
Alkalinity	55 mg/L	52 mg/L	-
Conductivity	158 μmhos	150 μmhos	-
Secchi Disk Transp	1.0 m	-	6
Light Transmission @ 3 ft	12.4 %	-	4
1% Light Level	4.9 ft	-	-
Total Suspended Solids	4.8 mg/L	8 mg/L	-
Total Phosphorus	0.019 mg/L	0.036 mg/L	0
Soluble Reactive Phos.	0.010* mg/L	0.010* mg/L	0
Nitrate-Nitrogen	0.013* mg/L	0.013* mg/L	0
Ammonia-Nitrogen	0.021 mg/L	0.040 mg/L	0
Organic Nitrogen	0.442 mg/L	0.368 mg/L	0
Oxygen Saturation @ 5 ft.	65.7 %	-	0
% Water Column Oxic	100 %	-	0
Fecal Coliform Bacteria	0 per 100mls	-	-
Chlorophyll *a*	3.08 μg/L	-	-
Plankton Density	7574 N.U./L	-	2
Blue-Green Dominance	0 %	-	0
* Method Detection Limit		TSI Score	12

TABLE 4. Water Quality Characteristics of Lake Lemon – Reed Point, 8/17/06.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	8.5	8.3	-
Alkalinity	75 mg/L	78 mg/L	-
Conductivity	195 μmhos	196 μmhos	-
Secchi Disk Transp	0.6 m	-	6
Light Transmission @ 3 ft	4 %	-	4
1% Light Level	5.4 ft	-	-
Total Suspended Solids	13.5 mg/L	16 mg/L	-
Total Phosphorus	0.067 mg/L	0.069 mg/L	3
Soluble Reactive Phos.	0.010* mg/L	0.010* mg/L	0
Nitrate-Nitrogen	0.013* mg/L	0.013* mg/L	0
Ammonia-Nitrogen	0.018* mg/L	0.018* mg/L	0
Organic Nitrogen	0.901 mg/L	0.827 mg/L	2
Oxygen Saturation @ 5 ft.	87.4 %	-	0
% Water Column Oxic	75 %	-	1
Fecal Coliform Bacteria	2 per 100mls	-	-
Chlorophyll *a*	4.85 μg/L	-	-
Plankton Density	11622 N.U./L	-	2
Blue-Green Dominance	90 %	-	10
* Method Detection Limit		TSI score	28

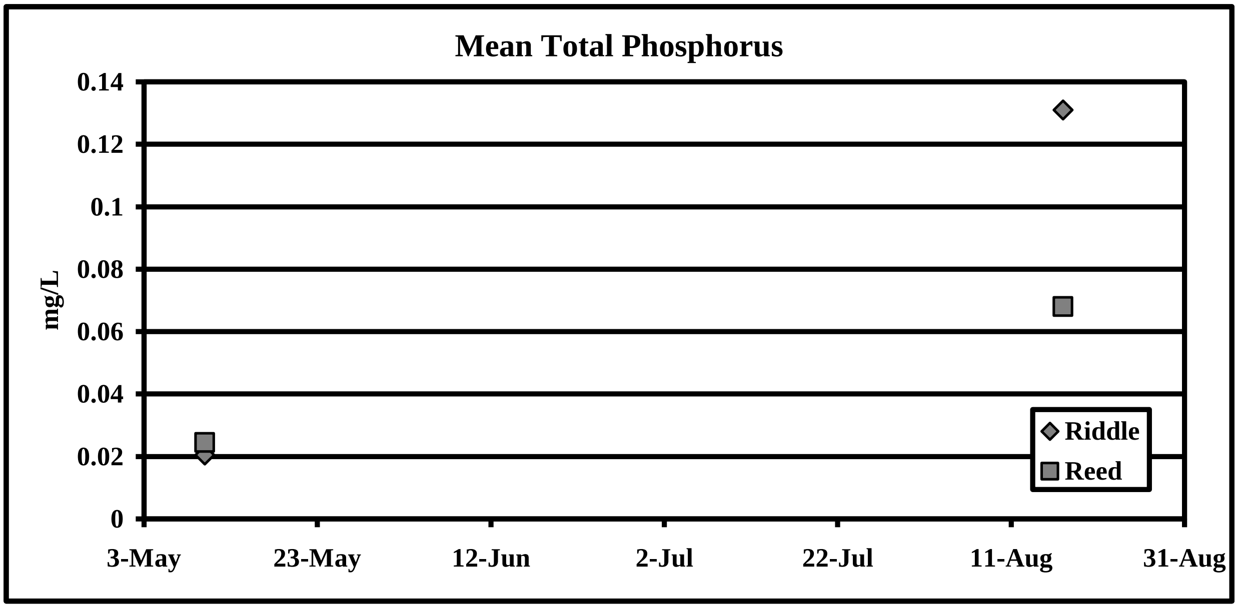

FIGURE 5. Mean total phosphorus concentrations at Riddle and Reed Point during summer 2006.

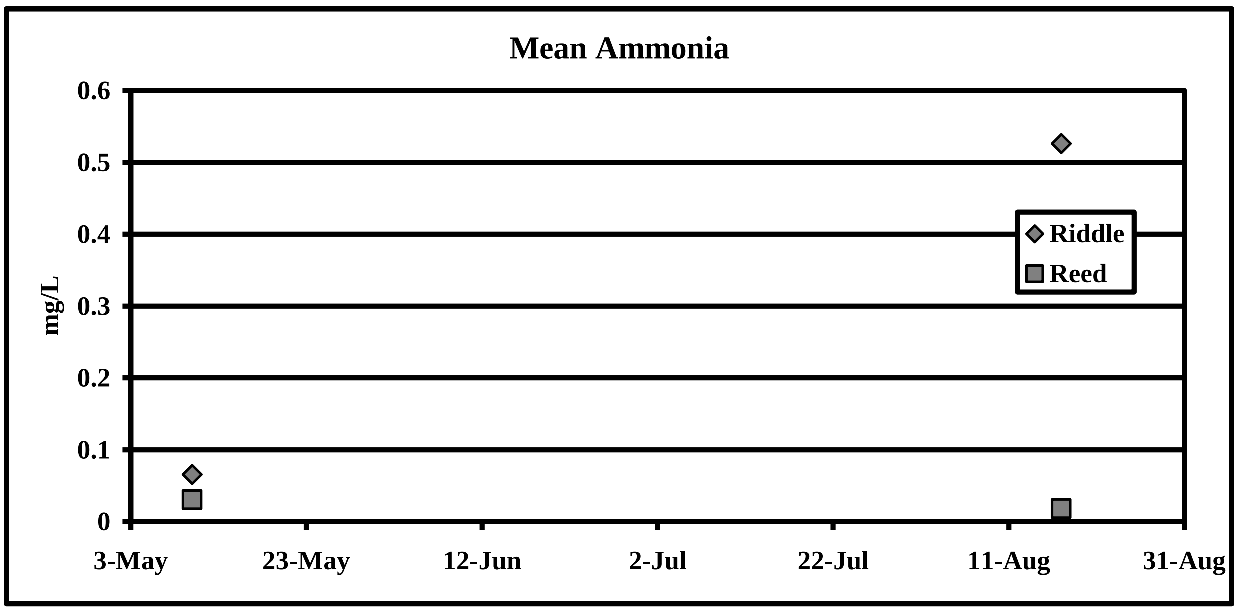

FIGURE 6. Summer 2006 mean concentrations of ammonia. The high ammonia concentration at Riddle Point in August was driven by a high hypolimnetic ammonia concentration, likely created by bacterial decomposition in the anoxic environment.

Plankton include algae (microscopic green plants) and zooplankton (microscopic, primarily crustacean animals). Ecologically, the algae are the chief primary producers in lakes and form the base of the aquatic food chain. Zooplankton are the primary consumers of algae and are, in turn, preyed upon by many fish (Figure 7). Ecologically healthy lakes need healthy, balanced plankton populations.

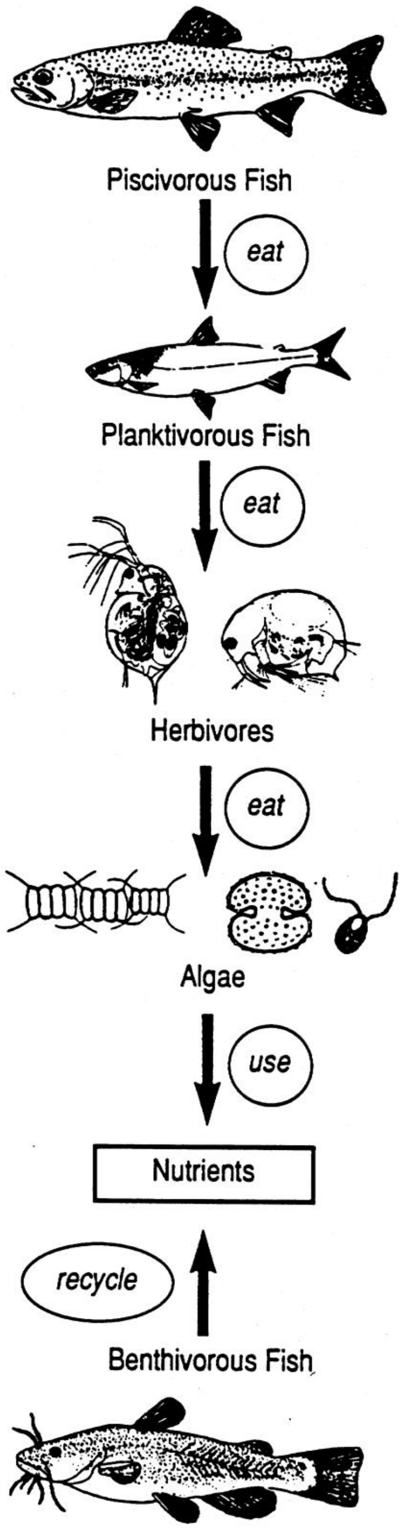

FIGURE 7. Generalized aquatic food chain. Tiny shrimp-like animals called zooplankton eat algae. Zooplankton, in turn, are eaten by small plankton-eating fish such as minnows, gizzard shad and young sunfish.

Lake Lemon is characterized by relatively low to average plankton densities. In 2006, both Riddle Point and Reed Point samples were lower in May (early in the growing season) and quite higher in August (Table 5 and 6). Riddle Point achieved a plankton density of 16,651 N.U. per liter in August, while Reed Point had 11,623 N.U. per liter. The relative proportion of blue-green algae increased substantially at both sites by the August sampling. Blue-greens accounted for 98% of all plankton at Riddle and 90% at Reed on August 17. 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.

TABLE 5. Phytoplankton and Zooplankton Community for Lake Lemon at Riddle Point.

	5/10/06		8/17/06	
Species Classification	**Total #**	**%**	**Total #**	**%**
Blue-green Algae	102	4%	16301	97.9%
Green Algae	204	7%	45	0.3%
Diatoms	245	8%	248	1.5%
Other Algae	2124	73%	23	0.1%
Rotifers	184	6%	0	0.0%
Zooplankton	40	1%	34	0.2%
Total Number	2899		16651	

TABLE 6. Phytoplankton and Zooplankton Community for Lake Lemon at Reed Point.

	5/10/06		8/17/06	
Species Classification	**Total #**	**%**	**Total #**	**%**
Blue-green Algae	0	0%	10461	90.0%
Green Algae	435	6%	911	7.8%
Diatoms	2797	37%	186	1.6%
Other Algae	3977	53%	0	0.0%
Rotifers	249	3%	21	0.2%
Zooplankton	115	2%	44	0.4%
Total Number	7573		11623	

Green algae decreased throughout the summer, having very low presence in the August sample. 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.

Diatoms typically have higher concentrations early in the sampling season, which falls closer to spring turnover. 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, which could result from less available silica. The spring samples resulted in a much more diverse assemblage of plankton, with diatoms taking a high presence at Reed Point, averaging 37% of the total plankton assemblage. Both Riddle and Reed Point diatom densities decreased below 2% of the total plankton assemblage by August. The August plankton were dominated by a blue-green algae known as *Aphanizomenon*. Blue-green algae often dominate lakes in late summer and their abundance may reach nuisance proportions. Blue-greens have a number of competitive advantages that allow them to dominate the summer algae communities of productive lakes. These advantages include: 1) ability to regulate buoyancy and thus stay up in the light, 2) nitrogen fixation, and 3) more efficient use of nutrients. Lake Lemon was not dominated by blue-green algae during April, but by the August sample, blue-greens accounted for 98% of all algae in the lake. Dominant blue-green algae populations are typical of temperate lakes with high nutrient availability, especially from a large watershed that is predominately agriculture.

The low Secchi disk transparencies in Lake Lemon (0.6 to 1.45 meters) are a reflection of the relatively high amount of suspended material in the water. Suspended solids concentrations increased throughout the summer and ranged up to 16 mg/L (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.

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 4.9 μg/L in April to 13.8 μg/L in August. Chlorophyll *a* concentrations >7 μg/L are indicative of eutrophic lake conditions.

Overall, we see a seasonal pattern of nutrient increase by late summer. This pattern is mirrored by increases in plankton abundance and chlorophyll *a* concentrations (Figures 9 and 10). This suggests that conditions exist for promoting increased growth of algae. The increased total phosphorus concentrations support this increased blue-green algal growth.

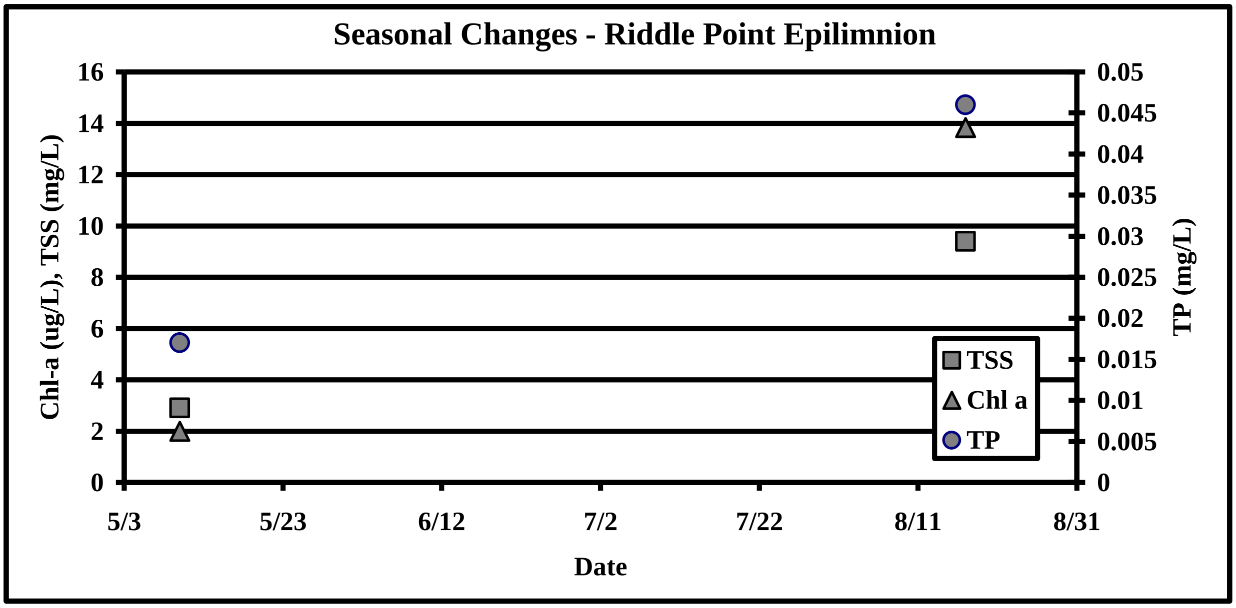

FIGURE 9. Seasonal changes in total phosphorus, total suspended solids, and chlorophyll *a* in the surface waters (epilimnion) at Riddle Point in Lake Lemon in 2006.

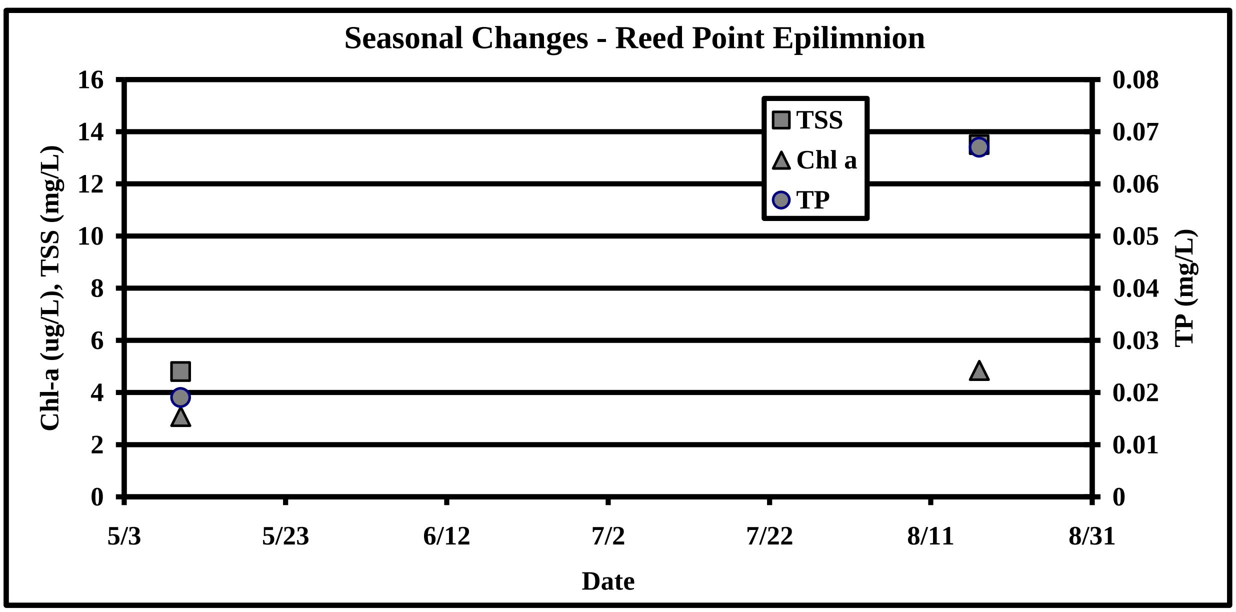

FIGURE 10. Seasonal changes in total phosphorus, total suspended solids, and chlorophyll *a* in the surface waters (epilimnion) at Reed Point in Lake Lemon in 2006.

COMPARISON WITH OTHER INDIANA LAKES

Table 7 gives values of water quality parameters determined for 355 Indiana lakes during July-August 1994-2004 by the Indiana Clean Lakes Program. This table can be used to compare values determined for Lake Lemon with other Indiana lakes. Table 7 shows that all of the Lake Lemon parameters, except NO_3, exceeded the median values for these 355 lakes.

TABLE 7. July-August Water Quality Characteristics of 355 Indiana Lakes Sampled From 1994 thru 2004 by the Indiana Clean Lakes Program compared to Riddle Point of Lake Lemon (8/17/06). Means of epilimnion and hypolimnion samples were used.

	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	0.069	0.513	1.312	0.095	0.035	4.35
Maximum	10.0	16.679	13.666	14.228	4.894	1.427	380.38
Minimum	0.1	0.013*	0.018*	0.230*	0.01*	0.01*	0.01
Mean Values for Riddle Pt. (8/17/06)	**0.7**	**0.013***	**0.526**	**1.369**	**0.131**	**0.076**	**13.83**

* Method Detection Limit

STREAM RESULTS

Results from the Beanblossom Creek samples are given in Table 11. Stream values generally fell within the range of lake parameters. Two moderate flow samples were collected on May 10th, 2006 and August 17th, 2006.

Variation among the sample parameters was slight. Most of the parameters increased throughout the summer. Stream temperature increased, while dissolved oxygen decreased from 6 mg/L to 4.9 mg/L. Both nitrate and ammonia increased slightly, while total organic nitrogen increased from 0.172mg/L to 0.502mg/L. Fecal coliform bacteria results for all lake and stream sites are summarized in Table 9. All the samples, including the 4 lake samples, fell below Indiana's standard of 200 fecal coliform colonies per 100 mls.

TABLE 8. Water Quality Characteristics of Lake Lemon - Beanblossom Creek.

Parameter	**Beanblossom Creek 5/10/06**	**Beanblossom Creek 8/17/06**
pH	7.7	7.5
Alkalinity	104 mg/L	125 mg/L
Temperature	18.4 °C	25.3 °C
Dissolved Oxygen	6 mg/L	4.9 mg/L
Conductivity	210 μmhos	298 μmhos
Total Suspended Solids	3.4 mg/L	10.6 mg/L
Fecal Coliform Bacteria	132 per 100mls	50 per 100mls
Total Phosphorus	0.020 mg/L	0.060 mg/L
Soluble Reactive Phos.	0.010* mg/L	0.010* mg/L
Nitrate-Nitrogen	0.055 mg/L	0.114 mg/L
Ammonia-Nitrogen	0.032 mg/L	0.083 mg/L
Organic Nitrogen	0.172 mg/L	0.502 mg/L

* Method Detection Limit

TABLE 9. Fecal coliform bacteria summary for 2006 Lake Lemon samples.

	Fecal Coliform Bacteria (#/100mls)	
Site	**5/10/06**	**8/17/06**
Riddle Point	14	6
Reed Point	0	2
Chitwood #1	118	54
Chitwood #2	54	16
Beanblossom Creek	132	50

TROPHIC STATE

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. Some characteristics of these trophic states are:

> *Oligotrophic* - clear water, dissolved oxygen is present in the hypolimnion (bottom waters), can support salmonid fisheries.
>
> *Mesotrophic* - water less clear, decreasing dissolved oxygen in the hypolimnion, loss of salmonids.
>
> *Eutrophic* - transparency less than two meters, no dissolved oxygen in hypolimnion during summer, weeds and algae abundant.

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.

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 11). 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 and these for 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.

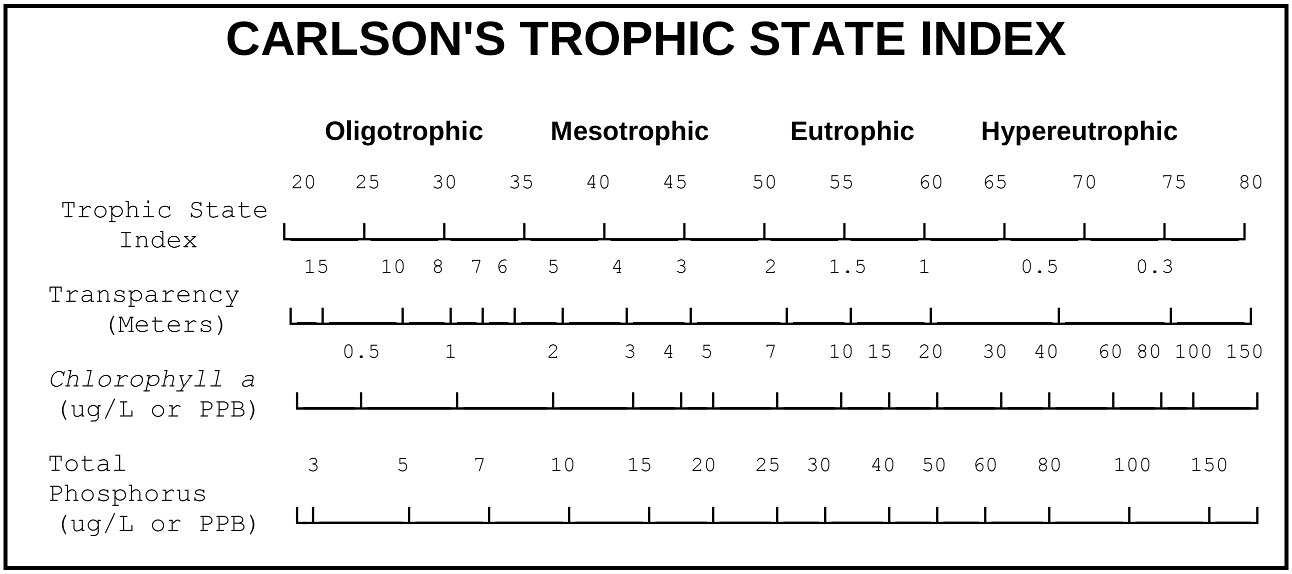

FIGURE 11. Carlson's trophic state index.

In the early 1970's, biologists with the Indiana State Board of Health developed a multi-parameter TSI for use in understanding water quality differences between two particular lakes (IDEM, 1976; IDEM, 1986). While values for this index have not been statistically validated as with Carlson's TSI, the Indiana TSI has nonetheless been used since that time to evaluate changes in all Indiana lakes. The Indiana TSI ranges from 0 to 75 total points.

The Indiana TSI totals are grouped into the following four lake quality classifications:

Indiana TSI Total	Water Quality Classification
0-15	oligotrophic
16-30	mesotrophic
31-45	eutrophic
>45	hypereutrophic

Indiana TSI scores are calculated from ten water quality parameters (Table 10). Eutrophy points are assigned according to the value of the measured parameter. The mean of an epilimnetic and hypolimnetic water sample is used to calculate the parameter value from which the eutrophy points for phosphorus and nitrogen are assigned. For example, a total phosphorus concentration of 0.043 ppm would be assigned 2 eutrophy points while a concentration of 0.29 would be assigned 4 eutrophy points. The eutrophy points assigned for each parameter are summed to give the total TSI score.

The Indiana TSI is heavily weighted toward plankton. Up to 35 of the 75 total points (47%) are assigned to plankton parameters. Thus, there can be large TSI differences between lakes due only to plankton. For example, ten points are assigned if plankton are dominated by blue-green algae. Secchi disk transparency is also an absolute scale (0 or 6 points) rather than a variable scale like total phosphorus has. These factors cause the Indiana TSI to be less acceptable outside Indiana and Indiana TSI scores do not correlate well with Carlson's or other TSIs in use around the country

Trophic State Scores

Indiana TSI scores for Lake Lemon are shown in the right-hand column of Tables 1 – 4 and scores for both TSIs are summarized in Table 11. For the Indiana TSI, Lake Lemon scored in the oligotrophic range in April (11-12 points). By August, once the lake warmed up and algae become more productive, the Indiana TSI scores ranged from 28-36. These scores are within the oligotrophic and mesotrophic category

Using Carlson’s TSI for the August data, Lake Lemon was hypereutrophic for all parameters except the chlorophyll *a* concentration, which generated a mesotrophic score. These hypereutrophic states appear to better represent the actual conditions in Lake Lemon, which are quite different from the Indiana TSI scores. All the parameters shift towards a more eutrophic condition with the Carlson TSI.

WATER QUALITY TRENDS

Compiled Secchi disk data from volunteer monitors and SPEA monitoring studies over the past 16 years are shown in Figure 12. There is no apparent long-term trend in transparency except that August samples are generally much lower in transparency. All measures of record would be considered indicative of eutrophic conditions.

Total phosphorus (TP) concentrations are quite variable over the past ten years at Lake Lemon’s Riddle Point sampling site (Figure 13). There is little visible long-term trend. Most of the values were above the eutrophic threshold of 30 μg/L.

TABLE 10. The Indiana Trophic State Index

Parameter and Range			Eutrophy Points
I.	Total Phosphorus (ppm)		
	A.	At least 0.03	1
	B.	0.04 to 0.05	2
	C.	0.06 to 0.19	3
	D.	0.2 to 0.99	4
	E.	1.0 or more	5
II.	Soluble Phosphorus (ppm)		
	A.	At least 0.03	1
	B.	0.04 to 0.05	2
	C.	0.06 to 0.19	3
	D.	0.2 to 0.99	4
	E.	1.0 or more	5
III.	Organic Nitrogen (ppm)		
	A.	At least 0.5	1
	B.	0.6 to 0.8	2
	C.	0.9 to 1.9	3
	D.	2.0 or more	4
IV.	Nitrate (ppm)		
	A.	At least 0.3	1
	B.	0.4 to 0.8	2
	C.	0.9 to 1.9	3
	D.	2.0 or more	4
V.	Ammonia (ppm)		
	A.	At least 0.3	1
	B.	0.4 to 0.5	2
	C.	0.6 to 0.9	3
	D.	1.0 or more	4
VI.	Dissolved Oxygen: Percent Saturation at 5 feet from surface		
	A.	114% or less	0
	B.	115% 50 119%	1
	C.	120% to 129%	2
	D.	130% to 149%	3
	E.	150% or more	4

TABLE 10 (continued)

VII. Dissolved Oxygen:

Percent of measured water column with at least 0.1 ppm dissolved oxygen

A.	28% or less	4
B.	29% to 49%	3
C.	50% to 65%	2
D.	66% to 75%	1
E.	76% 100%	0

VIII. Light Penetration (Secchi Disk)

A.	Five feet or under	6

IX. Light Transmission (Photocell): Percent of light transmission at a depth of 3 feet

A.	0 to 30%	4
B.	31% to 50%	3
C.	51% to 70%	2
D.	71% and up	0

X. Total Plankton per liter of water sampled from a single vertical tow between the 1% light level and the surface:

A.	less than 3,000 organisms/L	0
B.	3,000 - 6,000 organisms/L	1
C.	6,001 - 16,000 organisms/L	2
D.	16,001 - 26,000 organisms/L	3
E.	26,001 - 36,000 organisms/L	4
F.	36,001 - 60,000 organisms/L	5
G.	60,001 - 95,000 organisms/L	10
H.	95,001 - 150,000 organisms/L	15
I.	150,001 - 500,000 organisms/L	20
J.	greater than 500,000 organisms/L	25
K.	Blue-Green Dominance: additional points	10

<u>Water Quality Classifications</u>

Oligotrophic	0-15
Mesotrophic	16-30
Eutrophic	31-45
Hypereutrophic	46-75

TABLE 11. Summary of Trophic State Index Scores Using Mean 2006 Water Quality Data for Riddle/Reed Points.

DATE	Indiana TSI	Carlson's Secchi Disk TSI	Carlson's Total Phosphorus TSI	Carlson's Chlorophyll TSI
May	11/12 Oligotrophic	55/60 Eutrophic	46/52 Meso-eutrophic	20/22 Oligotrophic
August	36/28 Oligo-mesotrophic	64/66 Hypereutrophic	75/65 Hypereutrophic	40/27 Oligo-Mesotrophic

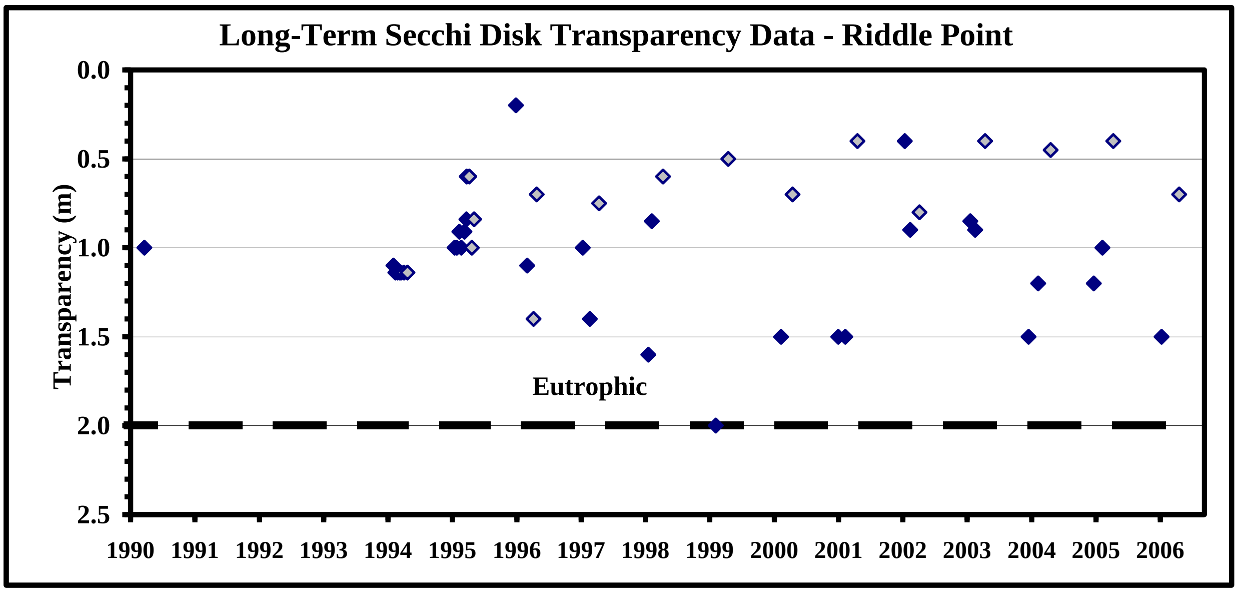

FIGURE 12. Historic Secchi disk transparency data for Lake Lemon. All data are less than the general eutrophic indicator of 2 meters. Gray markers indicate August samples.

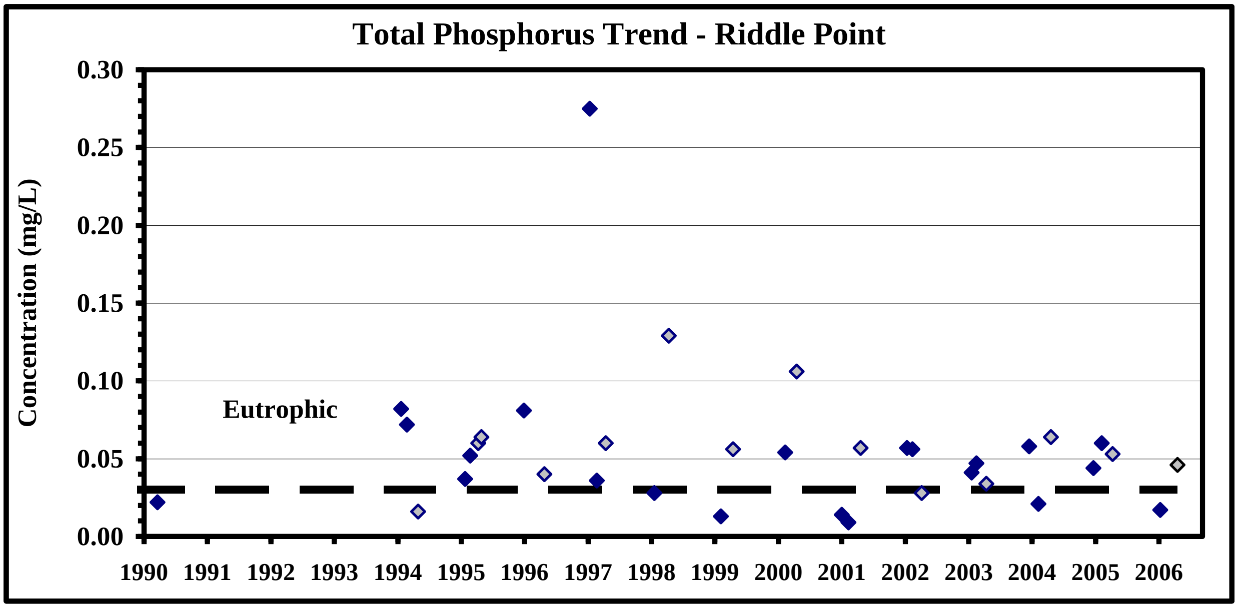

FIGURE 13. Historic epilimnetic total phosphorus trend for Lake Lemon. Most concentrations are higher than 0.030 mg/L, the level generally considered high enough to support eutrophic conditions. Gray markers indicate August samples.

Lake Lemon seemingly produces less phytoplankton than would otherwise be predicted based on the availability of phosphorus. Epilimnetic total phosphorus concentrations at Riddle Point are mostly in the eutrophic range but the resulting chlorophyll *a* concentrations (Figure 14) do not always reach the eutrophic range of greater than 7 μg/L; however, the majority of the August chlorophyll *a* samples over the twelve years do fall above the eutrophic classification. This increase is especially evident over the past four years (Figure 14).

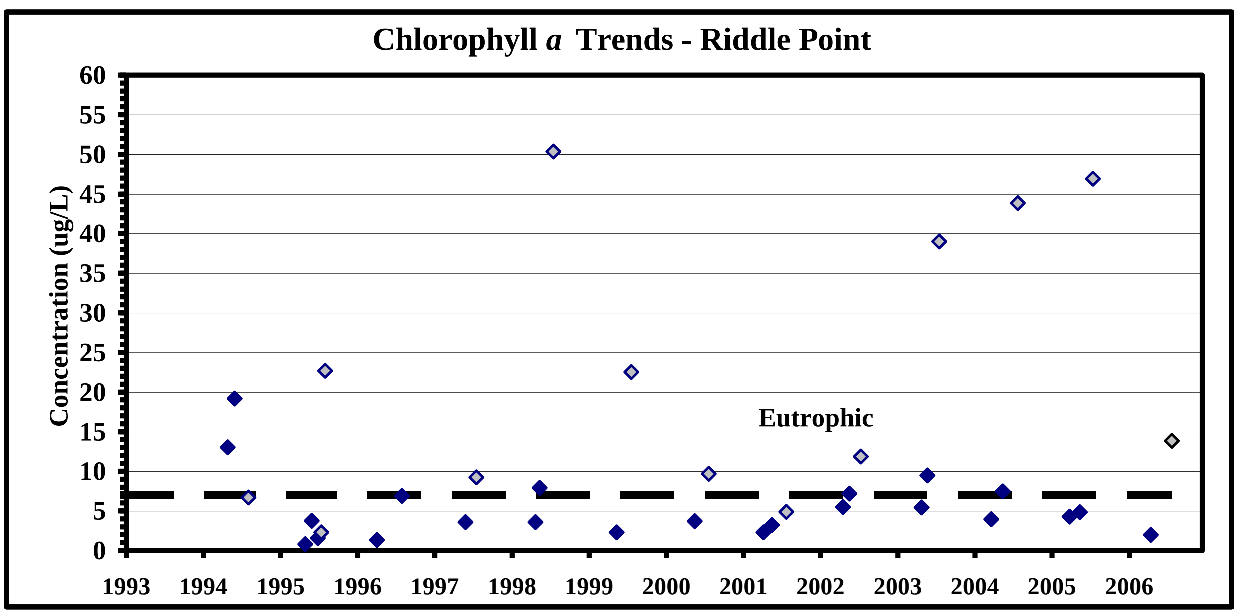

FIGURE 14. Historic chlorophyll *a* data for Lake Lemon. Gray markers indicate August.

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 15). 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 (Figure 16). Our two sampling trips fell within some typical rain events. While these variables affect other Indiana lakes and reservoirs, they have a much greater influence at Lake Lemon because of its very large watershed.

Lake Lemon suffers from seasonally high levels of phosphorus, suspended sediments and fecal coliform bacteria, and relatively low Secchi disk transparency throughout the year. 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.

Biological productivity of algae in Lake Lemon would be greater than it currently is if it were not for the high levels of suspended sediments in the water that reduce the depth of the euphotic zone (the area with enough light for plants to grow). These suspended sediments are derived from watershed land erosion and the erosion of alluvial sediments from stream banks and floodplains. Motorboats and strong winds resuspend sediments from the lake bottom into the water.

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. As a result, there is an abundance of rooted plants in the lake. These rooted aquatic plants then provide additional hydraulic resistance encouraging sedimentation, which exacerbates the siltation in the eastern end of the lake.

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

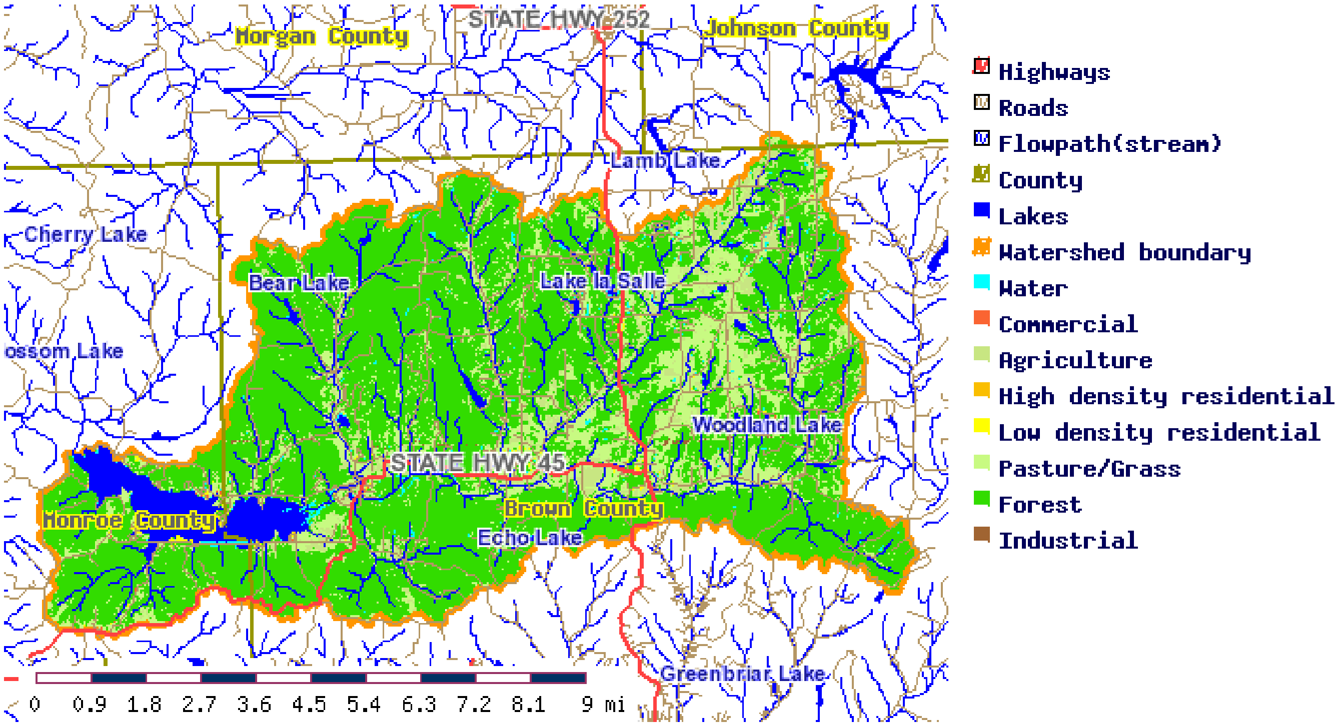

FIGURE 15. Lake Lemon watershed. Source: Choi and Engel (2005).

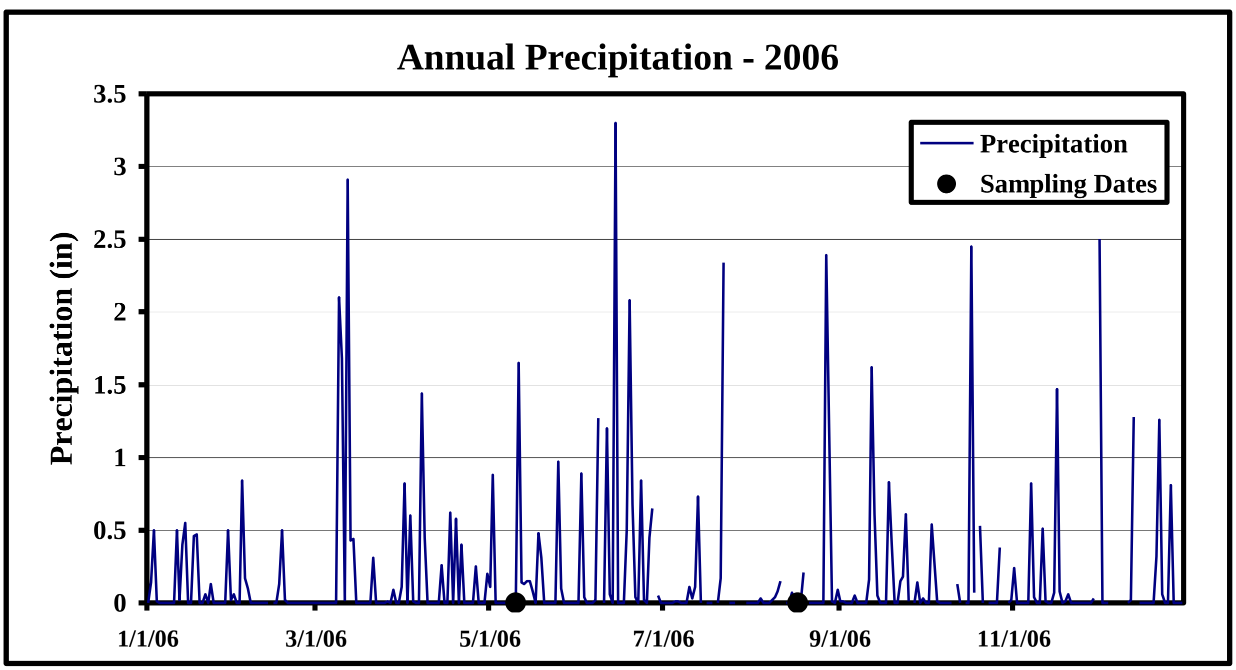

FIGURE 16. Annual precipitation, Bloomington, Indiana (Source: Department of Agronomy, Purdue University, Indiana State Climate Office, Iclimate.org).

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