LAKE LEMON MONITORING PROGRAM
2009 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 2009 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 5/21/09, 6/11/09, and 7/31/09 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, 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 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 on 5/21/09, 6/18/09, and 7/31/09, 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). We also sampled another small tributary, Bear Creek, for bacteria levels during the storm event, 6/18/09, and late summer, 7/31/09.

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). Plankton counts were made using a standard Sedgewick-Rafter counting cell. Fifteen fields per cell were counted. 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.

Turbidity. Turbidity (measured in Nephelometric Turbidity Units) is a measure of particles suspended in the water itself. It is generally related to suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. According to the Hoosier Riverwatch, the average turbidity of an Indiana stream is 11 NTU with a typical range of 4.5-17.5 NTU (White, unpublished data). Turbidity measurements >20 NTU have been found to cause undesirable changes in aquatic life (Walker, 1978).

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 235 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). Determined by filtering water through a net having a very fine mesh (63-micron openings = 63/1000 millimeter). The plankton net is towed up through the lake's water column from the one percent light level to the surface. 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. 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.

RESULTS

Water Quality

Temperature profiles indicated slight to strong thermal stratification at Riddle Point, while Reed Point primarily illustrates weaker to no stratification (Figures 1–5). In most Indiana lakes, thermal stratification is weakest in the spring and gets stronger as summer progresses, which is demonstrated at Riddle Point. The May temperature at Riddle Point is stratified; however, the temperature decreases with each depth until the reaching the epilimnion temperature of 16°C. By August, the Riddle Point temperature profile was stratified with the hypolimnion at approximately 25°C. Reed Point was slightly stratified in May but had an isothermal profile in August, which means that temperature is the same throughout the water column. Reed Point is shallow enough that turbulence from winds and boating activity keeps it well mixed.

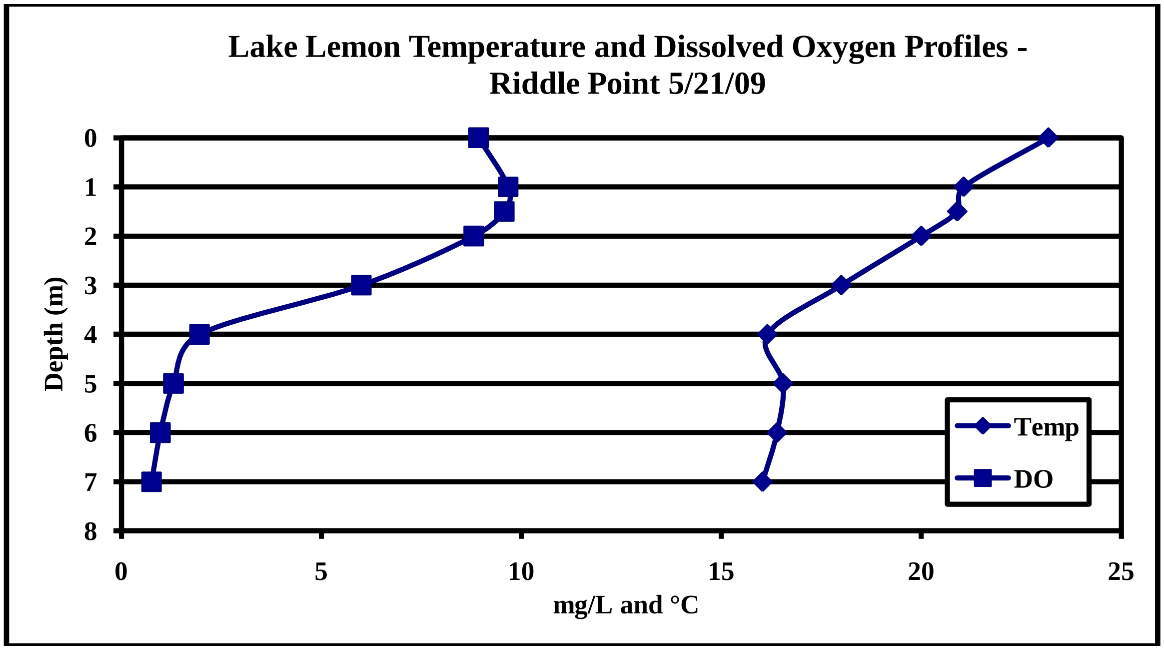

FIGURE 1. Temperature and dissolved oxygen profiles for Lake Lemon at Riddle Point on 5/21/09.

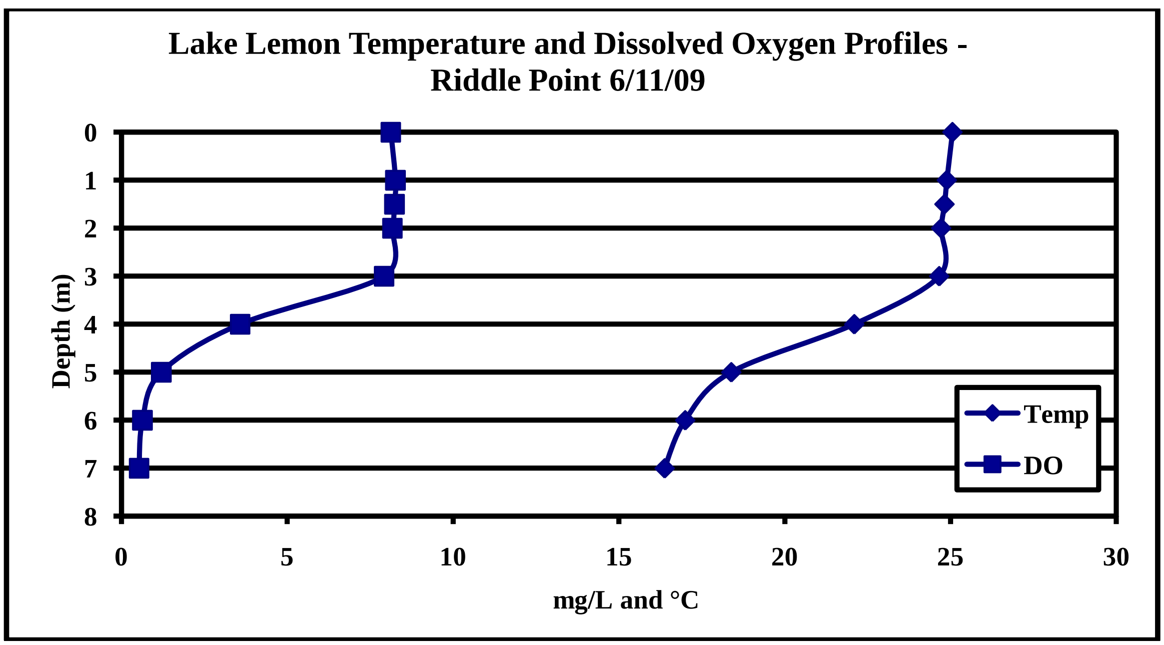

FIGURE 2. Temperature and dissolved oxygen profiles for Lake Lemon at Riddle Point on 6/11/09.

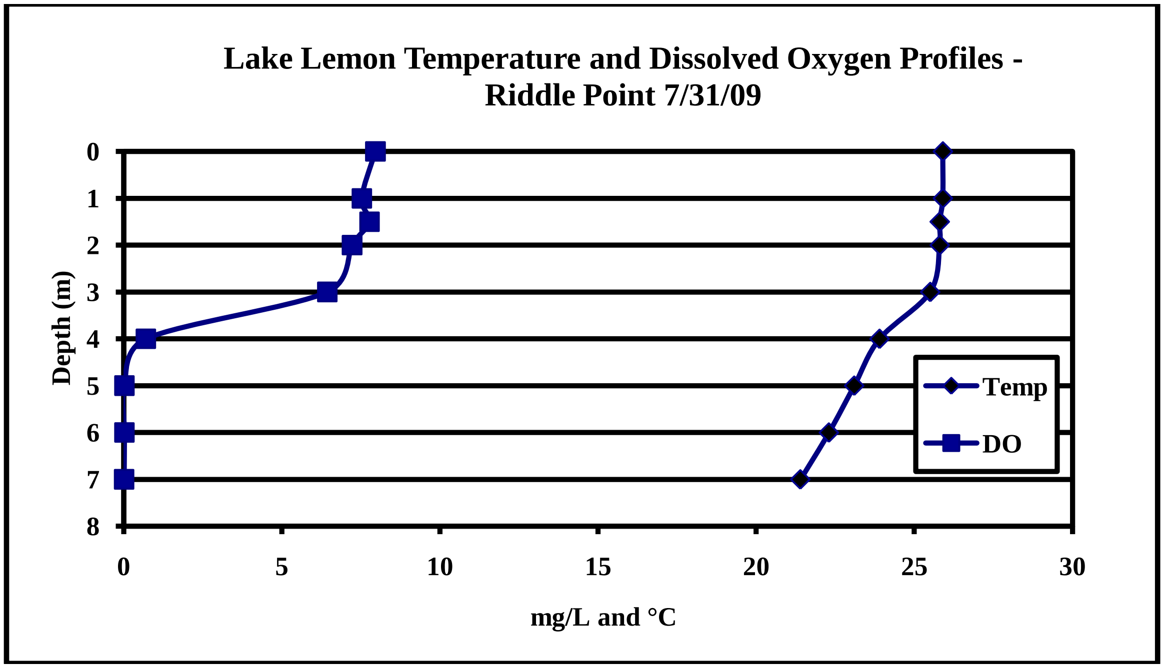

FIGURE 3. Temperature and dissolved oxygen profiles for Lake Lemon at Riddle Point on 7/31/09.

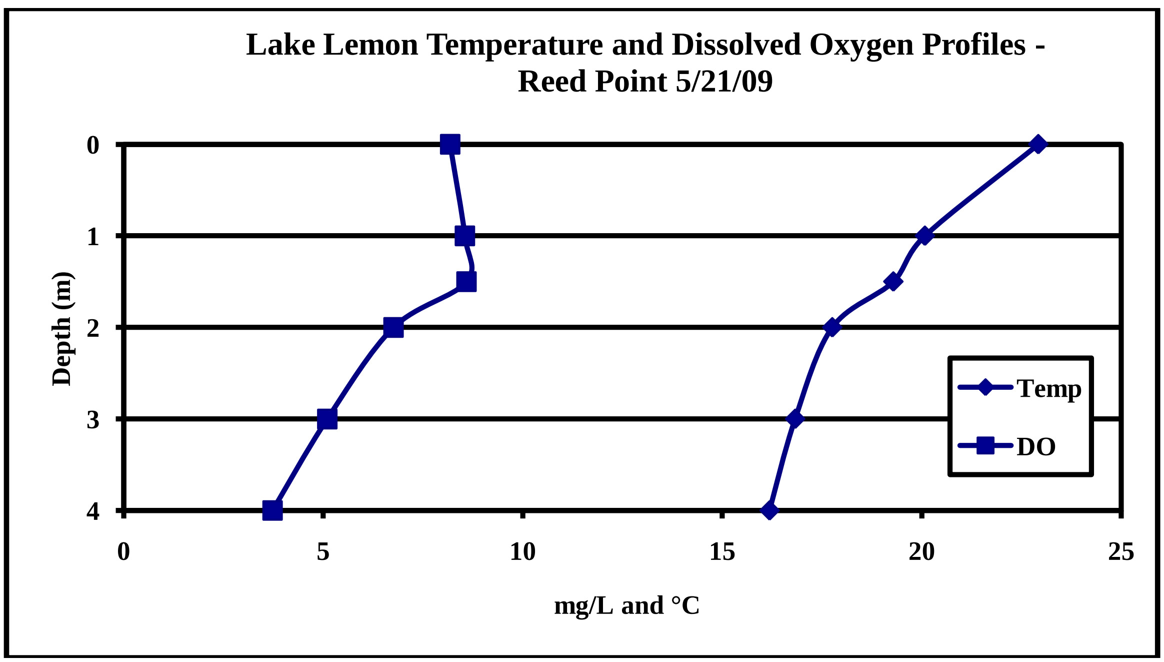

FIGURE 4. Temperature and dissolved oxygen profiles for Lake Lemon at Reed Point on 5/21/09.

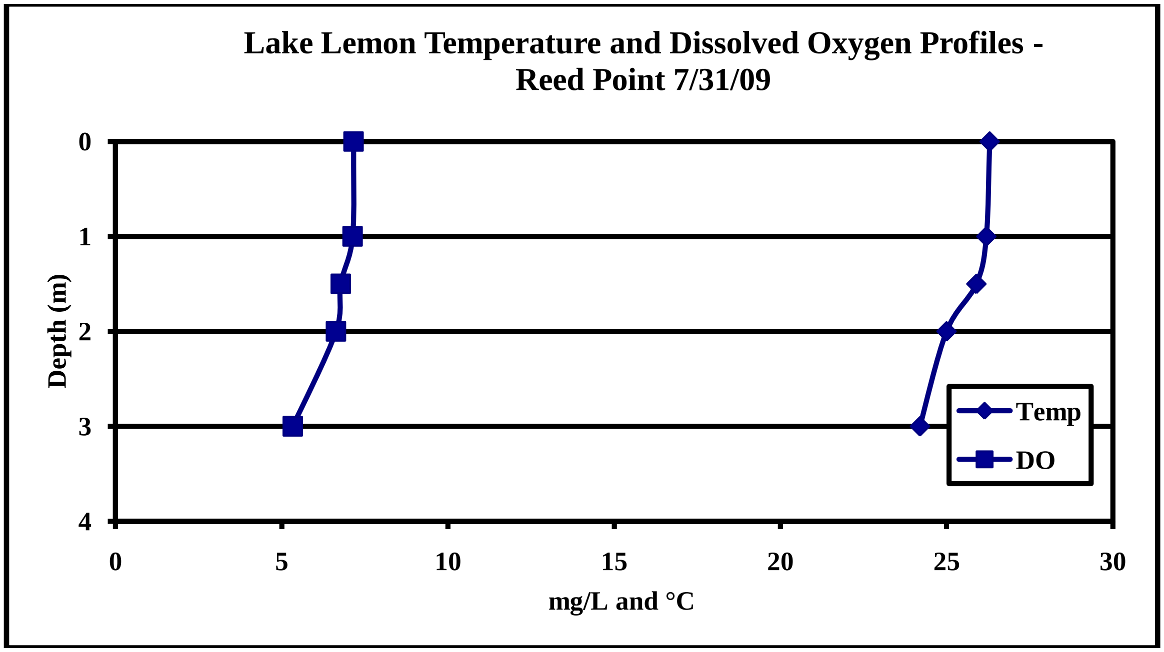

FIGURE 5. Temperature and dissolved oxygen profiles for Lake Lemon at Reed Point on 7/31/09.

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 because of recent spring turnover. However, Lake Lemon is characterized by a clinograde oxygen profile even in May, where oxygen levels decrease below the thermocline and continue to decrease rapidly in July. The upper 4 meters of water remained oxygenated during both June and July samples at Riddle Point (Figures 2 and 3). The July dissolved oxygen averaged 7.5 mg/L in the epilimnion, which is near saturation at 93.4% D.O. Anoxic conditions develop below 5 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. Because Reed Point never fully stratifies none of the measurements were anoxic. The shallow depth of Reed Point and lake turbulence keep this portion of the lake well-mixed and oxygenated.

Water quality data for Lake Lemon are presented in Tables 1- 5. 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; however, mean TP concentrations actually decreased from 0.018 mg/L to just above the method detection limit of 0.010 mg/L (Figure 6). While Reed Point TP concentrations increased over the sampling season, they remained below the level indicative of eutrophication (0.030 mg/L). Soluble phosphorus (SRP) concentrations are lower than total phosphorus because algae rapidly take up and use soluble phosphorus. SRP concentrations were below or near the method detection limit in all samples.

Typically we only detect low concentrations of nitrate-nitrogen throughout the sampling season. Nitrate concentrations decreased throughout the sampling season for both Riddle and Reed Points (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. Ammonia increased throughout the summer in the Riddle Point hypolimnion. Riddle Point increased from 0.061 mg/L to 0.256 mg/L (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 remain low throughout the summer. 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, 5/21/09.

Parameter	**Epilimnetic Sample**	**Hypolimnetic Sample**	**Indiana TSI Points (based on mean values)**
pH	8.62	6.99	-
Alkalinity	46.4 mg/L	47.9 mg/L	-
Conductivity	0.142 mS/cm	0.143 mS/cm	-
Secchi Disk Transp.	0.8 m	-	6
Light Transmission @ 3 ft	1 %	-	4
1% Light Level	6.2 ft	-	-
Total Suspended Solids	10.17 mg/L	19.39 mg/L	-
Total Phosphorus	0.018 mg/L	0.018 mg/L	0
Soluble Reactive Phos.	0.010* mg/L	0.011 mg/L	0
Nitrate-Nitrogen	0.030 mg/L	0.112 mg/L	0
Ammonia-Nitrogen	0.030 mg/L	0.091 mg/L	0
Organic Nitrogen	0.264 mg/L	0.448 mg/L	1
Oxygen Saturation @ 5 ft.	105.8 %	-	0
% Water Column Oxic	83 %	-	0
Fecal Coliform Bacteria	16 per 100mls	-	-
Plankton	9,422 N.U./L	-	2
% Blue-green algae	11.8 %	-	0
Chlorophyll *a*	18.42 μg/L	-	-
* Method Detection Limit		TSI	13

TABLE 2. Water Quality Characteristics of Lake Lemon – Reed Point, 5/21/09. The light meter malfunctioned during field sampling so the full Indiana TSI was not calculated. Instead, a range is included for general comparison based on possible TSI scores for Light Transmission.

Parameter	**Epilimnetic Sample**	**Hypolimnetic Sample**	**Indiana TSI Points (based on mean values)**
pH	7.81	7.1	-
Alkalinity	43.8 mg/L	51.1 mg/L	-
Conductivity	0.14 mS/cm	0.15 mS/cm	-
Secchi Disk Transp.	0.8 m	-	6
Light Transmission @ 3 ft	n/a	-	(0-4)
1% Light Level	6 ft	-	-
Total Suspended Solids	12.56 mg/L	12.11 mg/L	-
Total Phosphorus	0.018 mg/L	0.013 mg/L	3
Soluble Reactive Phos.	0.010* mg/L	0.010* mg/L	0
Nitrate-Nitrogen	0.098 mg/L	0.161 mg/L	0
Ammonia-Nitrogen	0.019 mg/L	0.018* mg/L	0
Organic Nitrogen	0.451 mg/L	0.245 mg/L	0
Oxygen Saturation @ 5 ft.	91.5 %	-	0
% Water Column Oxic	100 %	-	0
Fecal Coliform Bacteria	24 per 100mls	-	-
Plankton	8,257 N.U./L	-	2
% Blue-green algae	17.79 %	-	0
Chlorophyll *a*	18.22 μg/L	-	-
* Method Detection Limit		TSI	(15-19)

TABLE 3. Water Quality Characteristics of Lake Lemon – Riddle Point, 6/11/09.

Parameter	**Epilimnetic Sample**	**Hypolimnetic Sample**	**Indiana TSI Points (based on mean values)**
pH	7.9	7	-
Alkalinity	52 mg/L	78.5 mg/L	-
Conductivity	0.146 mS/cm	0.169 mS/cm	-
Secchi Disk Transp.	1.4 m	-	6
Light Transmission @ 3 ft	0.16 %	-	4
1% Light Level	12 ft	-	-
Total Suspended Solids	3.27 mg/L	12.17 mg/L	-
Total Phosphorus	0.010* mg/L	0.012 mg/L	0
Soluble Reactive Phos.	0.010* mg/L	0.017 mg/L	0
Nitrate-Nitrogen	0.019 mg/L	0.021 mg/L	0
Ammonia-Nitrogen	0.019 mg/L	0.483 mg/L	0
Organic Nitrogen	0.272 mg/L	0.814 mg/L	1
Oxygen Saturation @ 5 ft.	100.8 %	-	0
% Water Column Oxic	67 %	-	1
Plankton	2,096 N.U./L	-	0
% Blue-green algae	42 %	-	-
Chlorophyll *a*	4.63 µg/L	-	-
* Method Detection Limit		TSI	12

TABLE 4. Water Quality Characteristics of Lake Lemon – Riddle Point, 7/31/09.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.13	7.3	-
Alkalinity	68.5 mg/L	75.8 mg/L	-
Conductivity	0.16 mS/cm	0.16 mS/cm	-
Secchi Disk Transp.	1.2 m	-	6
Light Transmission @ 3 ft	0.7 %	-	2
1% Light Level	11 ft	-	-
Total Suspended Solids	5.31 mg/L	7.04 mg/L	-
Total Phosphorus	0.010* mg/L	0.011 mg/L	0
Soluble Reactive Phos.	0.010* mg/L	0.010* mg/L	0
Nitrate-Nitrogen	0.021 mg/L	0.023 mg/L	0
Ammonia-Nitrogen	0.018* mg/L	0.247 mg/L	0
Organic Nitrogen	0.453 mg/L	0.291 mg/L	0
Oxygen Saturation @ 5 ft.	93.4 %	-	0
% Water Column Oxic	50 %	-	2
Fecal Coliform Bacteria	22 per 100mls	-	-
Plankton	2,895 N.U./L	-	0
% Blue-green algae	17.7 %	-	0
Chlorophyll *a*	9.61 μg/L	-	-
* Method Detection Limit		TSI	10

TABLE 5. Water Quality Characteristics of Lake Lemon – Reed Point, 7/31/09.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	7.9	7.6	-
Alkalinity	68 mg/L	63	-
Conductivity	0.171 mS/cm	0.149 mS/cm	-
Secchi Disk Transp.	0.6 m	-	6
Light Transmission @ 3 ft	0.45 %	-	3
1% Light Level	6 ft	-	-
Total Suspended Solids	13.6 mg/L	39.32 mg/L	-
Total Phosphorus	0.012 mg/L	0.034 mg/L	0
Soluble Reactive Phos.	0.010* mg/L	0.015 mg/L	0
Nitrate-Nitrogen	0.013* mg/L	0.09 mg/L	0
Ammonia-Nitrogen	0.018* mg/L	0.062 mg/L	0
Organic Nitrogen	0.550 mg/L	0.688 mg/L	2
Oxygen Saturation @ 5 ft.	84.3 %	-	0
% Water Column Oxic	100 %	-	0
Fecal Coliform Bacteria	9,272 per 100mls	-	-
Plankton	6,885 N.U./L	-	2
% Blue-green algae	16.3 %	-	0
Chlorophyll *a*	6.62 µg/L	-	-
* Method Detection Limit		TSI	13

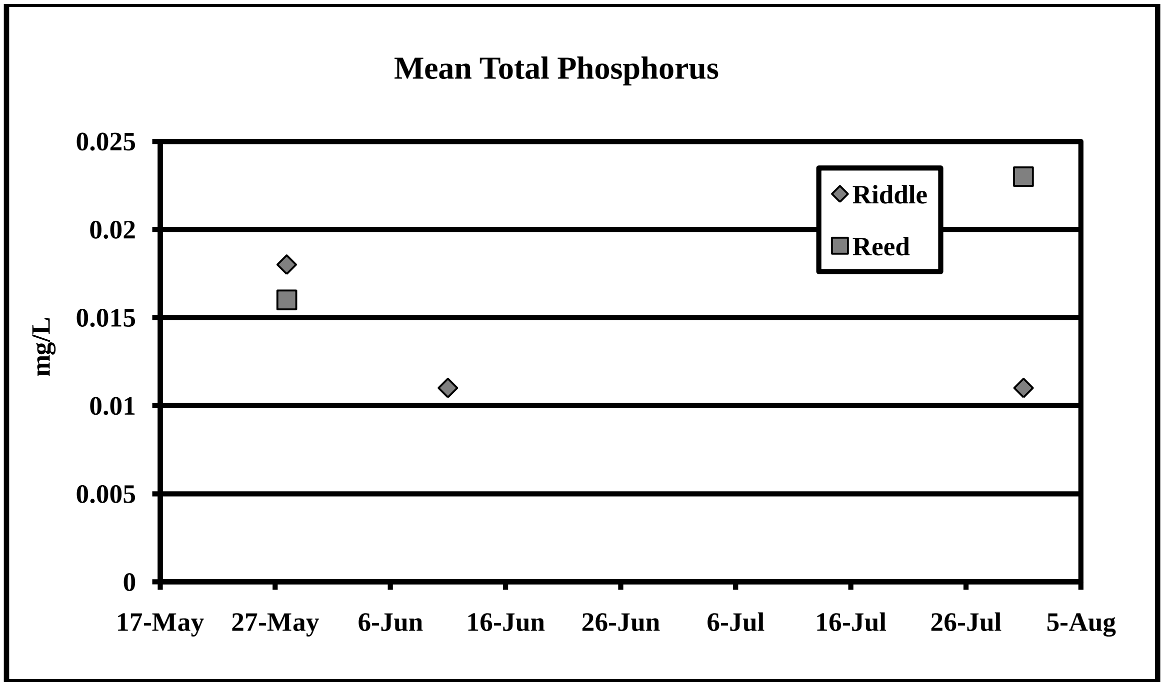

FIGURE 6. Mean total phosphorus concentrations at Riddle and Reed Point during summer 2009.

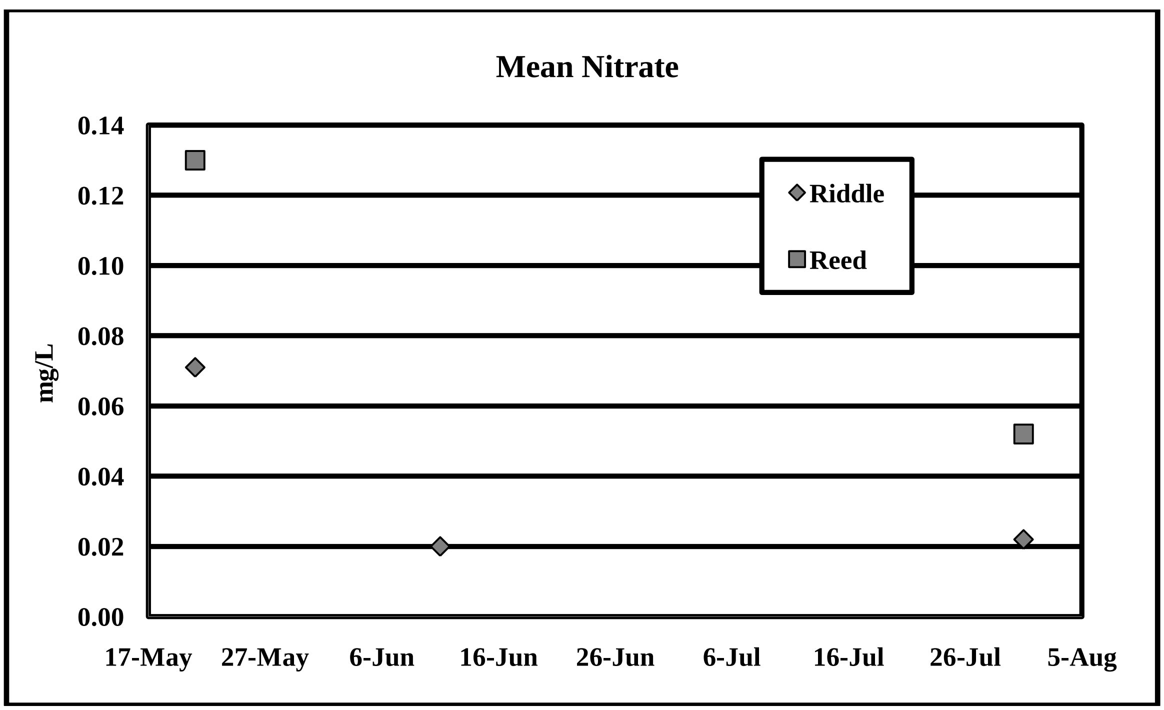

FIGURE 7. Mean nitrate concentrations at Riddle and Reed Point during summer 2009.

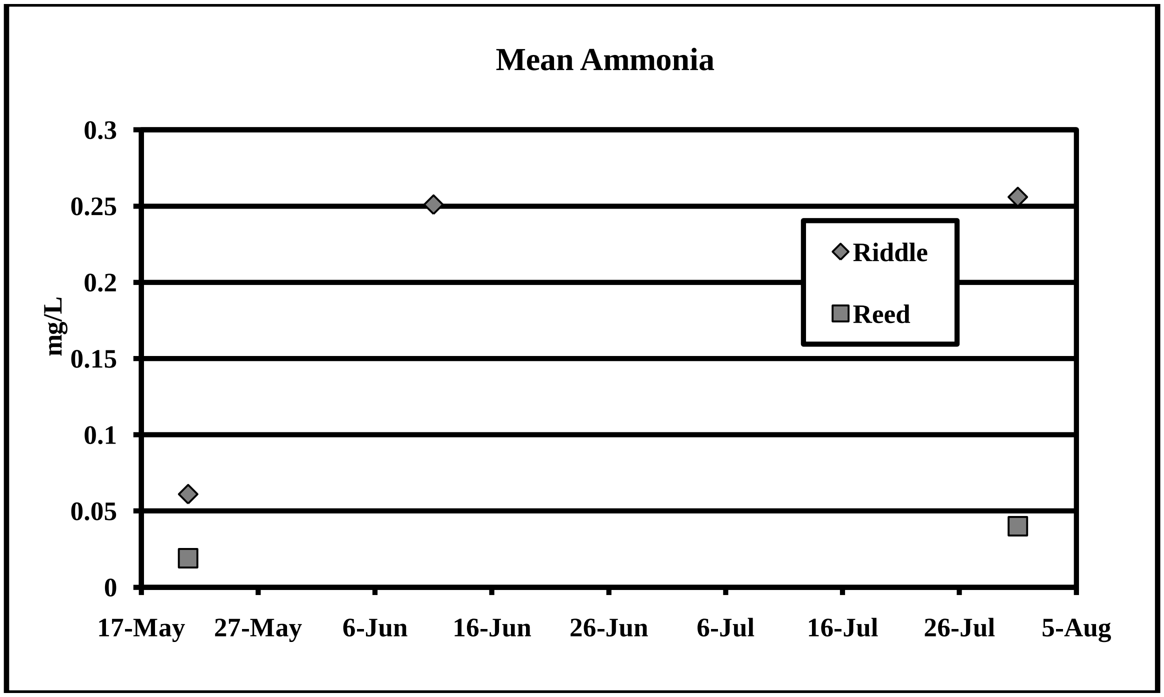

FIGURE 8. Summer 2009 mean concentrations of ammonia.

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 9). Ecologically healthy lakes need healthy, balanced plankton populations.

Lake Lemon is characterized by relatively low to average plankton densities. Usually, Lake Lemon is characterized by lower spring densities and increasing by July and August (Figure 10). In 2009, however, both Riddle Point and Reed Point samples were higher in May (early in the growing season) and lower in July (Table 6 and 7). Typically, the plankton assemblage shifted towards a strongly dominant blue-green algae proportion by August. However, in 2009, blue-greens accounted for 18% of all plankton at Riddle and only 16% at Reed on July 31 (Figure 11). 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.

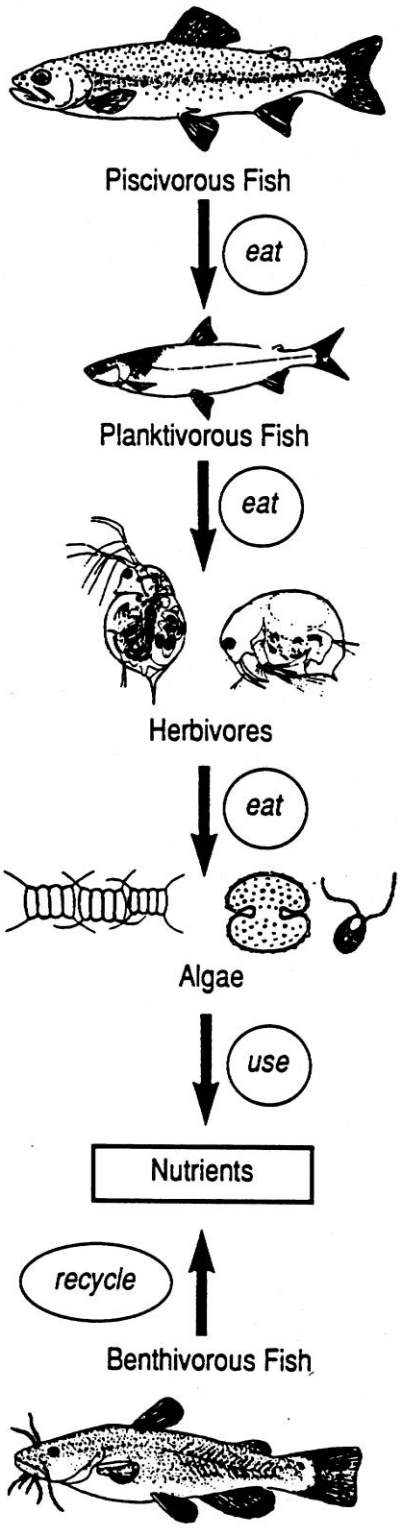

FIGURE 9. Generalized aquatic food chain. Tiny shrimp-like animals called zooplankton eat algae. Zooplankton, in turn, are eaten by small plankton-eating fish such as minnows, gizzard shad and young sunfish.

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

	5/21/09		6/11/09		7/31/09	
Species Classification	**Total #**	**%**	**Total #**	**%**	**Total #**	**%**
Blue-green Algae	1,108	12%	880	42%	512	17.7%
Green Algae	2,586	27%	682	33%	285	9.8%
Diatoms	1,847	20%	132	6%	1,480	51.1%
Other Algae	3,399	36%	356	17%	57	2.0%
Rotifers	443	5%	22	1%	341	11.8%
Zooplankton	37	0.4%	24	1%	220	7.6%
Total Number	9,422		2,096		2,895	

TABLE 7. Phytoplankton and Zooplankton Community for Lake Lemon at Reed Point.

	5/21/09		7/31/09	
Species Classification	**Total #**	**%**	**Total #**	**%**
Blue-green Algae	1,464	18%	1,120	16.3%
Green Algae	1,782	22%	1,362	19.8%
Diatoms	1,273	15%	2,816	40.9%
Other Algae	3,627	44%	939	13.6%
Rotifers	64	1%	484	7.0%
Zooplankton	48.1	1%	163.6	2.4%
Total Number	8,256		6,885	

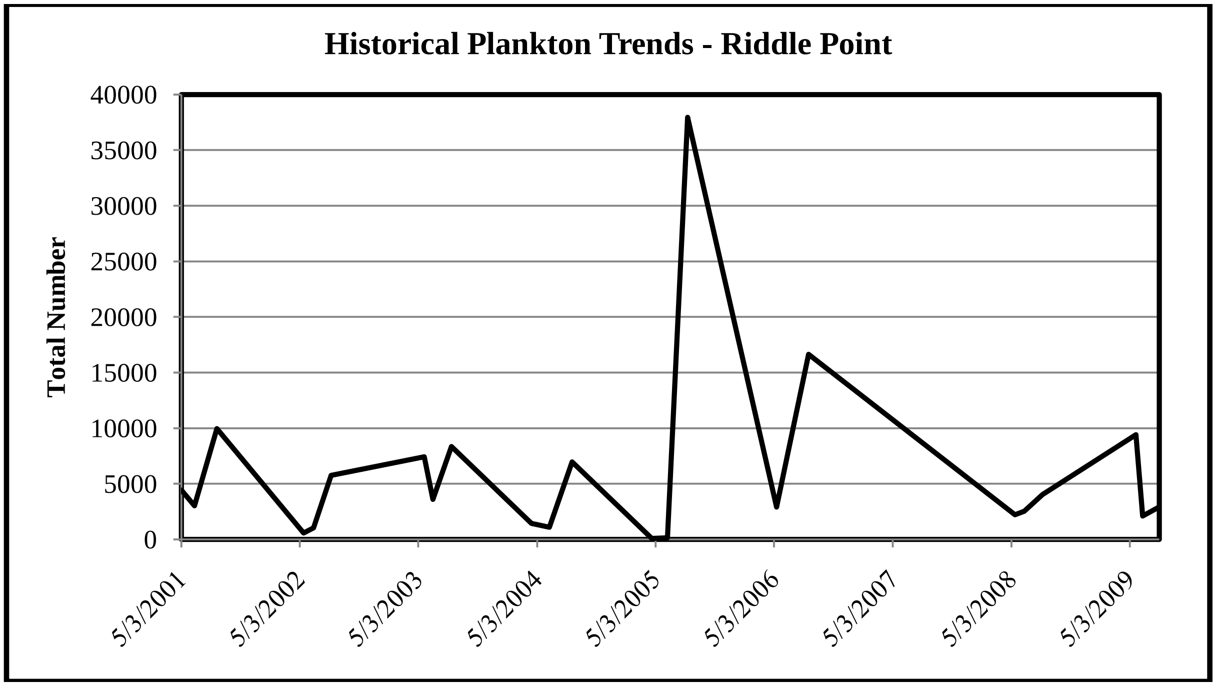

FIGURE 10. Historical trends of total plankton densities at Riddle Point. During the 2005 sampling season, we added another sampling protocol for even smaller Cylindrospermopsis, allowing us to collect much smaller specimens than our typical samples. This is reflected in the large spike for 2005.

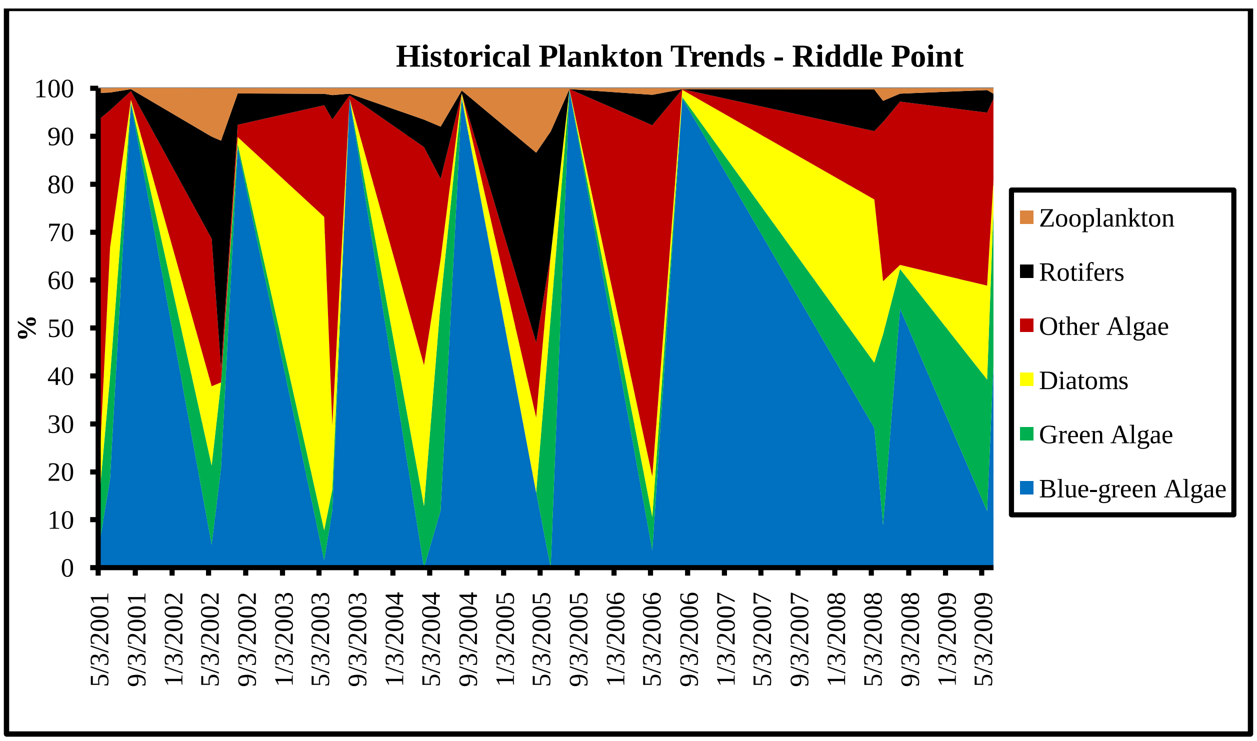

FIGURE 11. Historical trends of plankton percent representation for Riddle Point.

Green algae typically decrease 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. Green algae are usually outcompeted by blue-green algae. This year the June samples had high percentage of green algae representing 33% at Riddle Point (Table 6, Figure 11). This is very likely due to the increased watershed inputs of nitrate. 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. However, with the increase nutrient inputs from the very rainy May and June, the green algae had enough nutrients to have a more dominant role in the algal community.

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. Diatom densities typically are barely represented by the end of the growing season; however, diatoms are the most dominant species classification in July representing 51% at Riddle Point and 41% at Reed Point (Figure 11). Plankton diversity typically decreases in Lake Lemon in regards to plankton groups throughout the summer. With the green algae, diatoms, and multiple "other" plankton species maintaining a strong presence, the diversity is maintained during 2009. The strong dominance of blue-green algae does not occur for 2009.

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 improve as the total suspended solids (TSS) and the TP concentrations decrease (Figure 12 and 13). 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 18.42 μg/L in May decreasing to 4.63 μg/L in June (Figure 12 and 13). Chlorophyll *a* concentrations >7 μg/L are indicative of eutrophic lake conditions.

Overall, we see a seasonal pattern of nutrient decrease by late summer, which is uncharacteristic for Lake Lemon. This pattern is mirrored by decreases in chlorophyll *a* concentrations (Figures 12 and 13). This suggests that conditions exist for decreasing growth of algae.

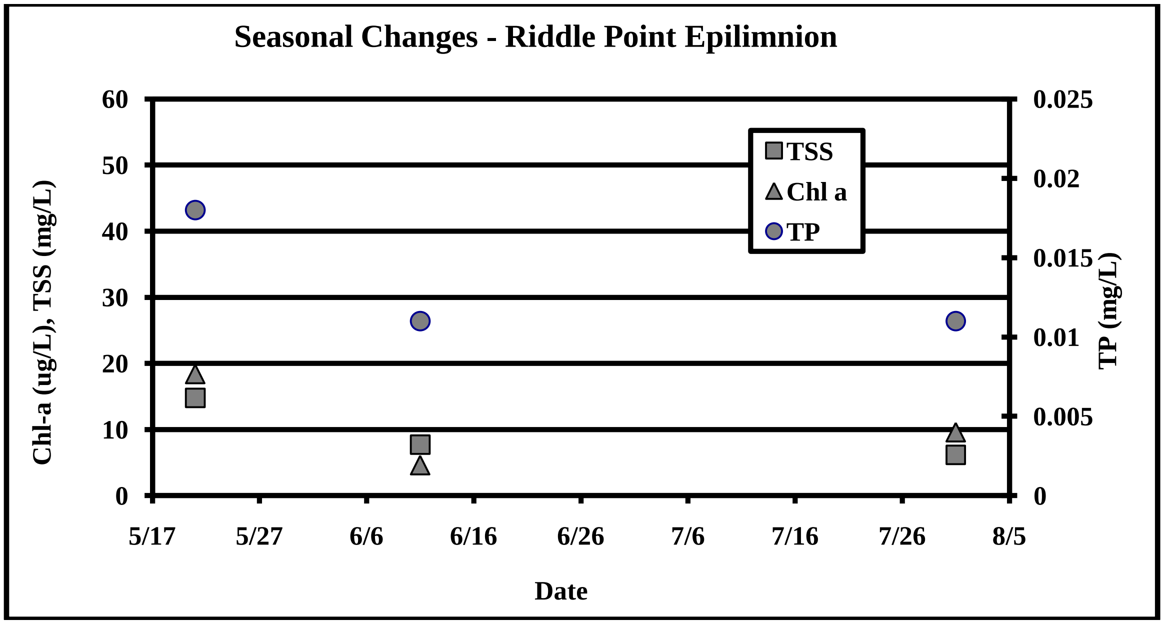

FIGURE 12. Seasonal changes in total phosphorus, total suspended solids, and chlorophyll *a* in the surface waters (epilimnion) at Riddle Point in Lake Lemon in 2009.

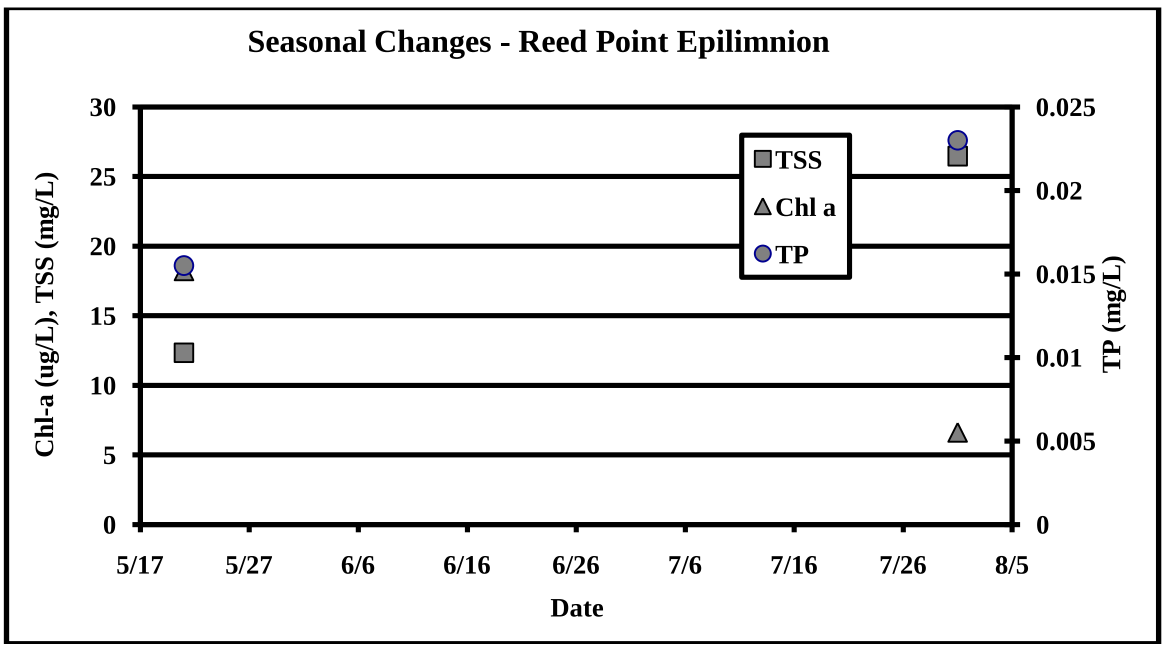

FIGURE 13. Seasonal changes in total phosphorus, total suspended solids, and chlorophyll *a* in the surface waters (epilimnion) at Reed Point in Lake Lemon in 2009.

COMPARISON WITH OTHER INDIANA LAKES

Table 8 gives values of water quality parameters determined for 355 Indiana lakes during July-August 1994-2006 by the Indiana Clean Lakes Program. This table can be used to compare values determined for Lake Lemon with other Indiana lakes. Table 8 shows that only ammonia and chlorophyll a exceeded the median values for these 355 lakes, but fell well below the maximum concentrations.

TABLE 8. July-August Water Quality Characteristics of 355 Indiana Lakes Sampled From 1994 thru 2006 by the Indiana Clean Lakes Program compared to Riddle Point of Lake Lemon (7/31/09). 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	0.037	0.07	1.101	0.058	0.01	4.11
Maximum	16	21.12	27.14	27.54	3.73	2.84	380.38
Minimum	0.1	0.013*	0.018*	0.230*	0.01*	0.01*	0.01
Mean Values for Riddle Pt. (7/31/09)	**1.2**	**0.022**	**0.133**	**0.619**	**0.011**	**0.01***	**9.61**

* Method Detection Limit

STREAM RESULTS

Results from the Beanblossom Creek samples are given in Table 9. Stream values generally fell within the range of lake parameters. Two moderate flow samples were collected on 5/21/09 and 7/31/09. Storm event samples were collected on 6/18/09.

Variation among the sample parameters was slight. Historically, most of the parameters increased throughout the summer. Nutrients remained high for both base and storm flow events, especially the nitrate. The most notable parameter for Beanblossom Creek and all the other sampling sites was the increase in Fecal coliform bacteria. Fecal coliform bacteria increased from 150 colonies per 100 mls to 136,400 colonies per 100 mls. Fecal coliform bacteria results for all lake and stream sites are summarized in Table 10. May samples were below the state standard of 200 colonies per 100mls. All June and July samples, except Riddle Point, significantly exceeded the state standards for full body contact and recreation (Table 10).

TABLE 9. Water Quality Characteristics of Beanblossom Creek. The 6/18/09 sampling was a storm event.

Parameter	5/21/09	6/18/09	7/31/09
pH	7.31	7.6	7.5
Alkalinity	66.9 mg/L	65 mg/L	63 mg/L
Temperature	18.71˚C	21.97˚C	22.5˚C
Dissolved Oxygen	6.78 mg/L	7.29 mg/L	7.18 mg/L
Oxygen Saturation	71.2 %	86.1 %	84.3 %
Conductivity mS/cm	0.188 mS/cm	0.199 mS/cm	0.150 mS/cm
Total Suspended Solids	5.76 mg/L	6.25 mg/L	30.0 mg/L
Fecal Coliform Bacteria	150 per 100mls	1,050 per 100mls	136,400 per 100mls
Total Phosphorus	0.021 mg/L	0.048 mg/L	0.091 mg/L
Soluble Reactive Phos.	0.010* mg/L	0.010* mg/L	0.030 mg/L
Nitrate-Nitrogen	0.264 mg/L	0.227 mg/L	0.275 mg/L
Ammonia-Nitrogen	0.033 mg/L	0.027 mg/L	0.041 mg/L
Organic Nitrogen	0.112 mg/L	0.598 mg/L	0.093 mg/L

* Method Detection Limit

TABLE 10. Fecal coliform bacteria summary for 2009 Lake Lemon samples. The state standard for full body contact and recreation is 200 colonies per 100mls.

Site	Fecal Coliform Bacteria (#/100mls)		
	5/21/09	**6/18/09**	**7/31/09**
Riddle Point	16	-	22
Reed Point	24	-	9,272
Chitwood #1	88	-	16,560
Chitwood #2	40	-	11,600
Beanblossom Creek	150	1,050	136,400
Bear Creek	102	2,452	112,710

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 (Figure14). 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.

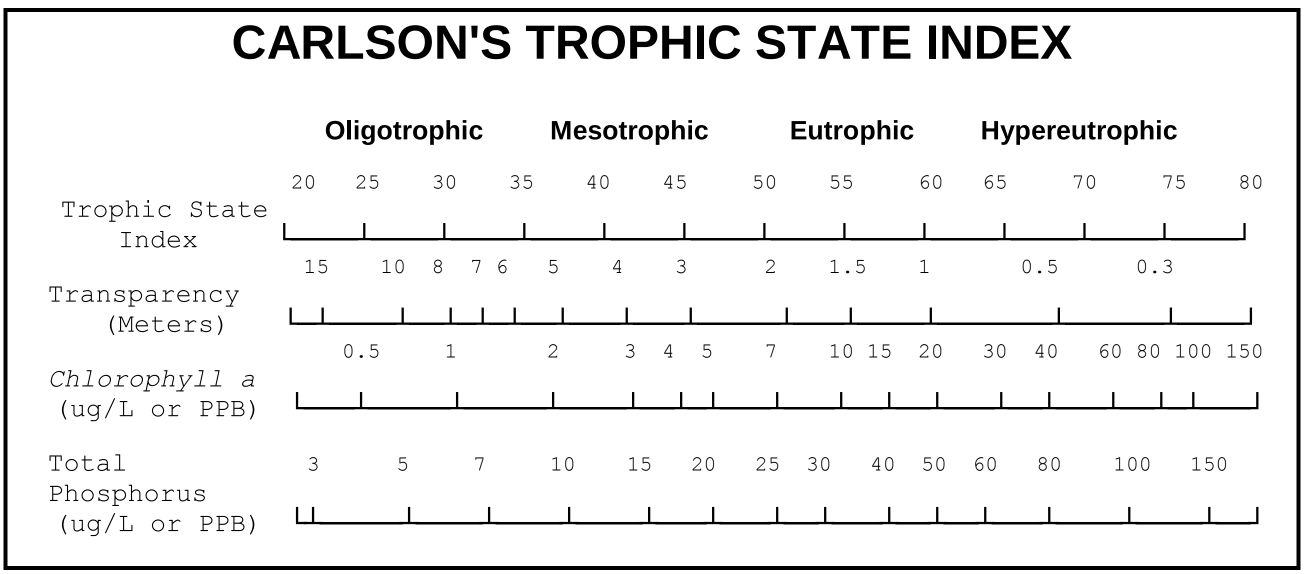

FIGURE 14. Carlson's trophic state index.

Trophic State Scores

Using Carlson's TSI for the May, June, and July data, Lake Lemon varied by parameter and month, ranging from mesotrophic to hypereutrophic (Table 11). The earlier May TSI scores start the growing season with eutrophic and hypereutrophic conditions. All the TSI scores decreased slightly throughout the growing season, but did not deviate from general Lake Lemon trends over the last decade.

TABLE 11. Summary of Trophic State Index Scores Using Mean 2009 Water Quality Data for Riddle/Reed Points. Reed Point was not sampled during June.

DATE	Carlson's Secchi Disk TSI	Carlson's Total Phosphorus TSI	Carlson's Chlorophyll TSI
May	64/64 Hypereutrophic	45/45 Mesotrophic	57/57 Eutrophic
June	56/x Eutrophic	37/x Mesotrophic	46/x Mesotrophic
July	71/66 Hypereutrophic	37/48 Mesotrophic	55/48 Mesotrophic/Eutrophic

TROPHIC STATE TRENDS

Using Riddle Point Carlson TSI scores to look at the historic trend for Lake Lemon shows that the lake generally scores between eutrophic and hypereutrophic. Figures 15-17 illustrate the Carlson TSI historic trends for Secchi disk, total phosphorus, and chlorophyll. 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 Chlorophyll *a* samples for 2005 – 2008 (Figure 17) were generally below the 10-year mean, 2009 concentrations were very close to the 12-year mean. Despite the less eutrophic conditions early in the season, the decade average for all three parameters maintain at least a eutrophic score.

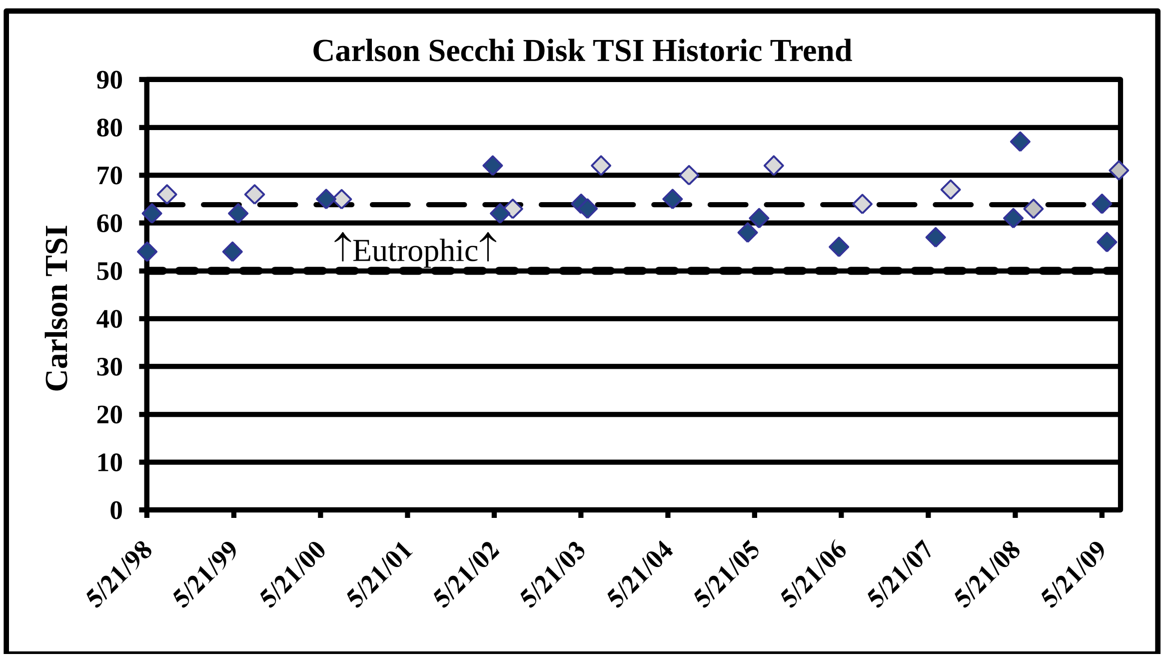

FIGURE 15. The 12-year historic trend for Carlson Secchi disk TSI scores. All but three late summer (August) samples, shown in gray, scored above the mean for eutrophic status. The large dashed line illustrates the 12-year mean. The small dashed line illustrates eutrophic status for the Carlson TSI.

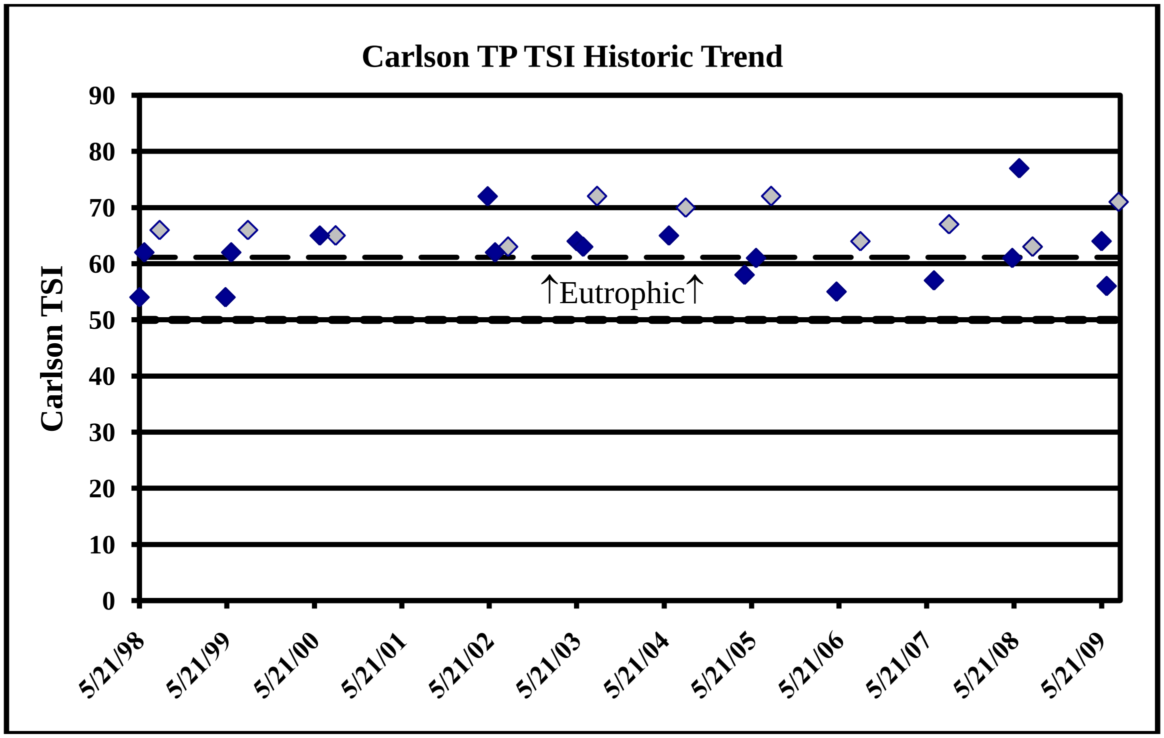

FIGURE 16. The 12-year historic trend for Carlson total phosphorus TSI scores. All August samples, shown in gray, score above the mean for eutrophic status. The dashed line illustrates the 12-year mean. The small dashed line illustrates eutrophic status for the Carlson TSI.

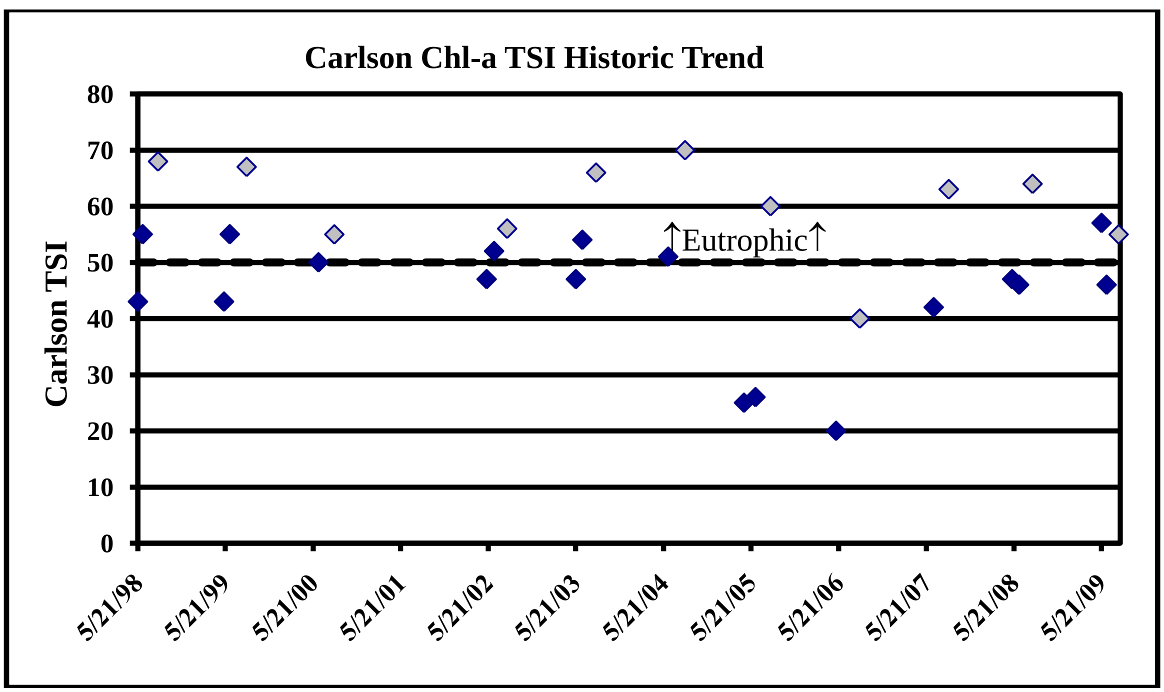

FIGURE 17. The 12-year historic trend for Carlson chlorophyll -a TSI scores. All August samples, shown in gray, score above the mean for eutrophic status. Both the 12-year mean and the Carlson TSI eutrophic status score a 50 (small dashed line).

WATER QUALITY TRENDS

Compiled Secchi disk transparency data from volunteer monitors and SPEA monitoring studies over the past 20 years are shown in Figure 18. 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 20 years at Lake Lemon's Riddle Point sampling site (Figure 19). There is little visible long-term trend. Most of the values were above the eutrophic threshold of 0.030 mg/L. All of the 2009 samples were below this threshold, which is a positive trend.

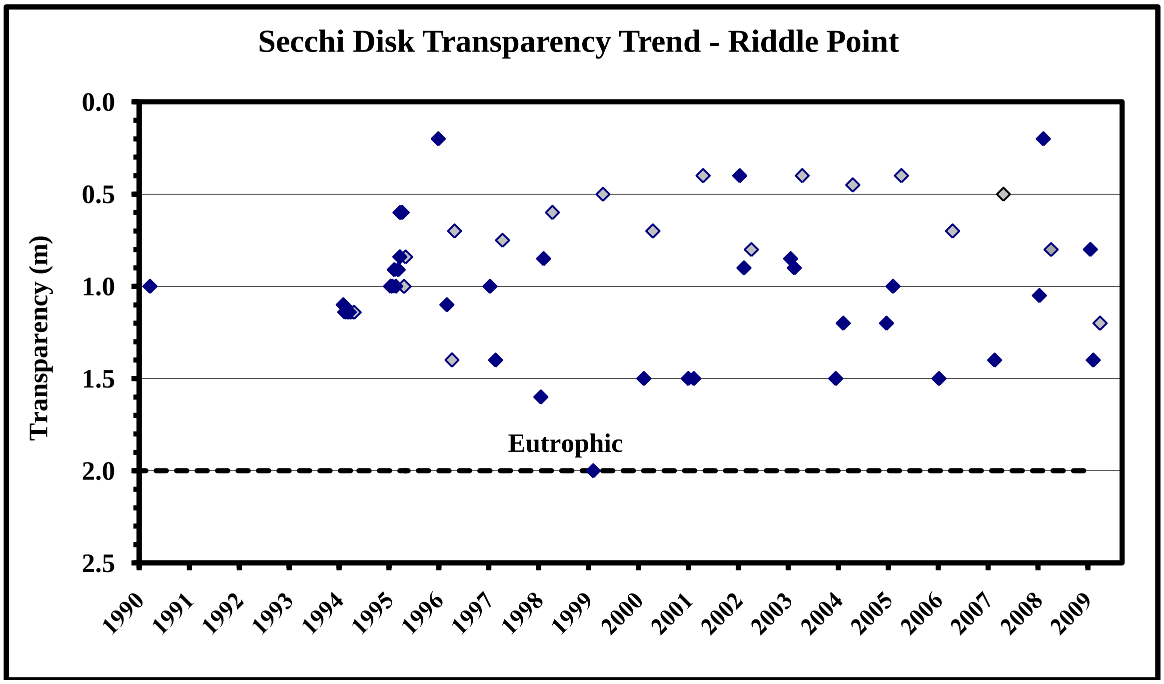

FIGURE 18. Historic Secchi disk transparency data for Lake Lemon. All data are less than the general eutrophic indicator of 2 meters. Gray markers indicate August samples.

Epilimnetic total phosphorus concentrations at Riddle Point are mostly in the eutrophic range but the resulting chlorophyll *a* concentrations (Figure 20) do not always reach the eutrophic range of greater than 7 µg/L; however, the majority of the August chlorophyll *a* samples over the sixteen years do fall above the eutrophic classification.

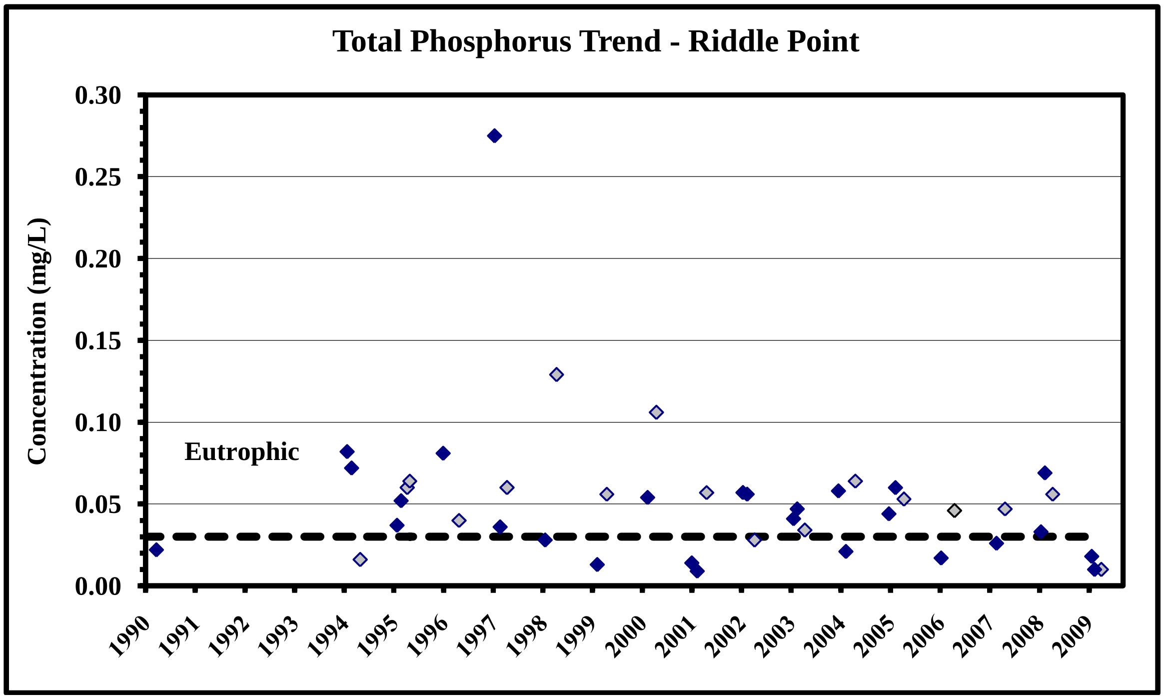

FIGURE 19. Historic epilimnetic total phosphorus trend for Lake Lemon. Most concentrations are higher than 0.030 mg/L, the level generally considered high enough to support eutrophic conditions. Gray markers indicate August samples.

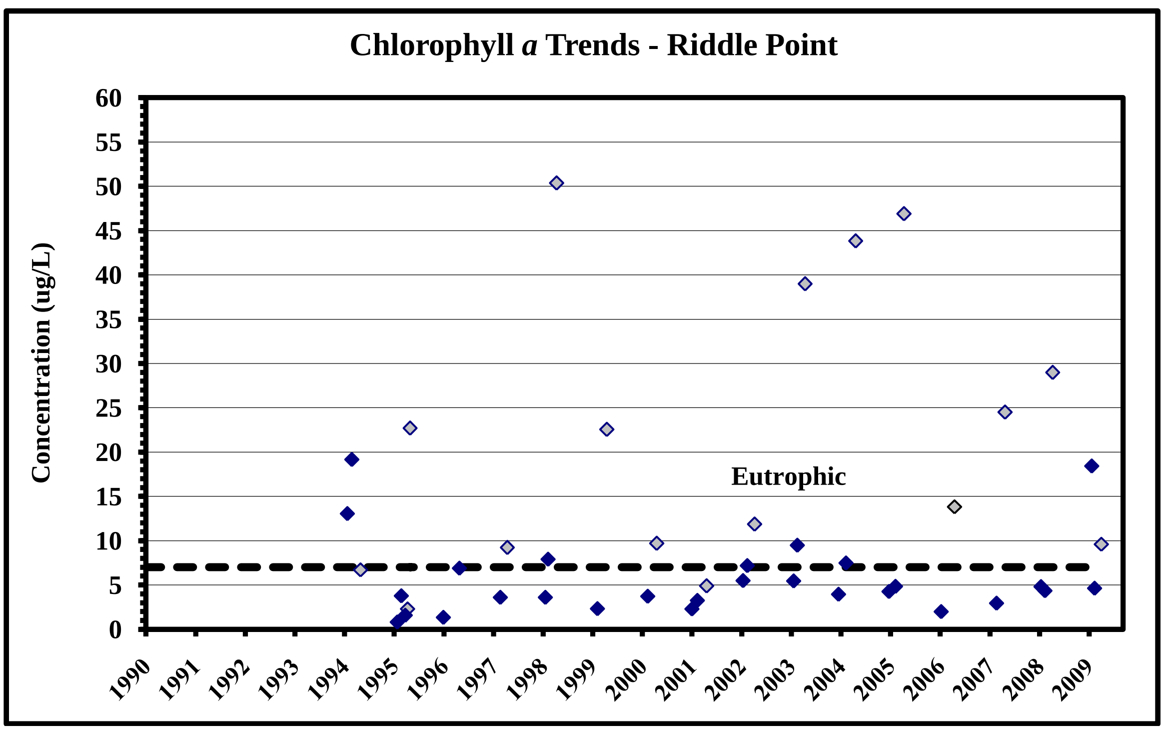

FIGURE 20. Historic chlorophyll *a* data for Lake Lemon. Gray markers indicate August.

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 21). 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 22). All 2009 sampling events were within a week of a rain event. Particularly mild temperatures and multiple heavy rain events characterized the summer of 2009. 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. While some particular parameters have lower concentrations during the 2009 sampling events, the overall trend for Lake Lemon has not changed in the last 12-years (Figures 15-20). 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.

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.

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 12-years. Key eutrophy parameters (total phosphorus, chl-*a*, secchi disk transparency) have produced similar yearly results. While Lake Lemon's eutrophy status has shown a slight decrease for the 2009 sampling season, it has not significantly deviated from the 12-year average.

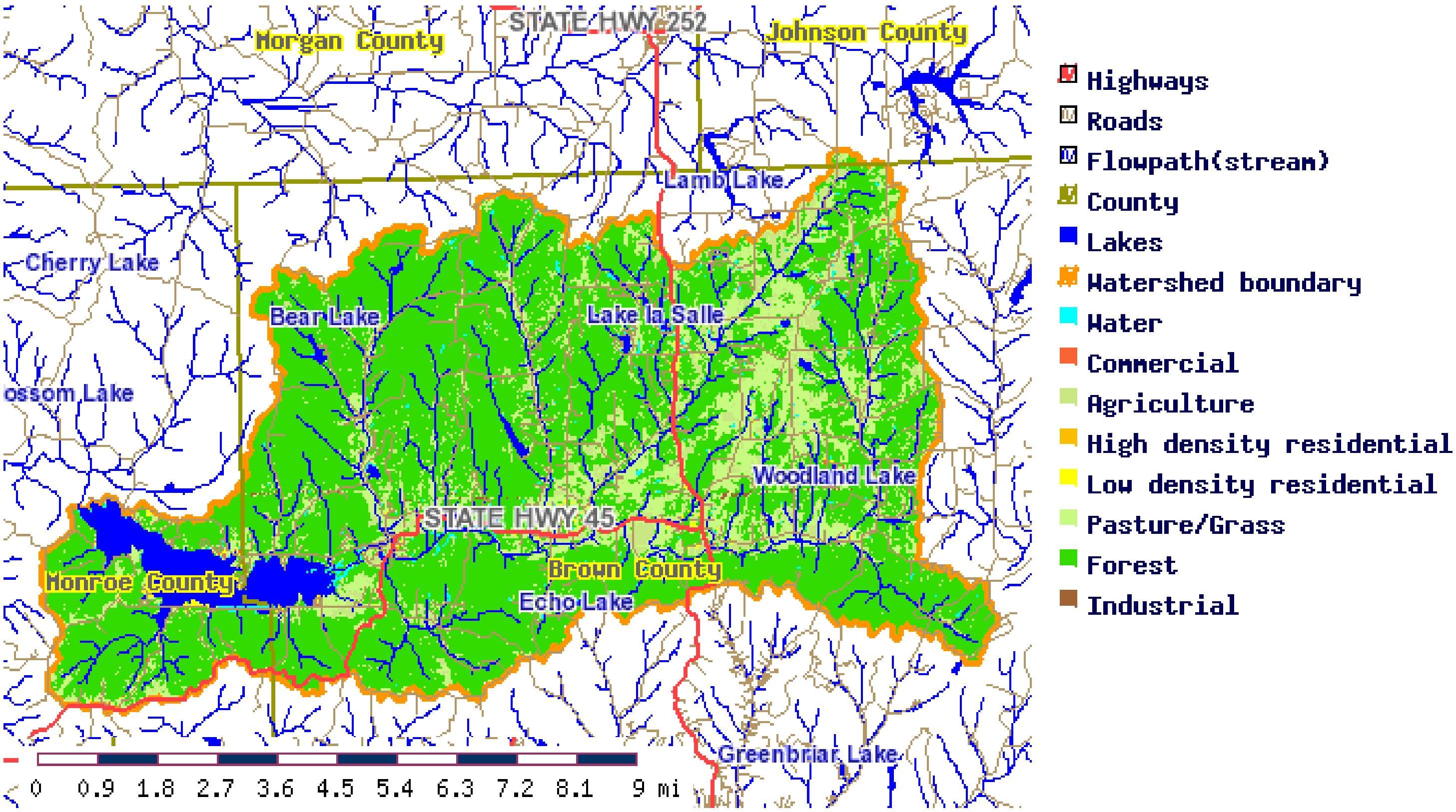

FIGURE 21. Lake Lemon watershed. Source: Choi and Engel (2005).

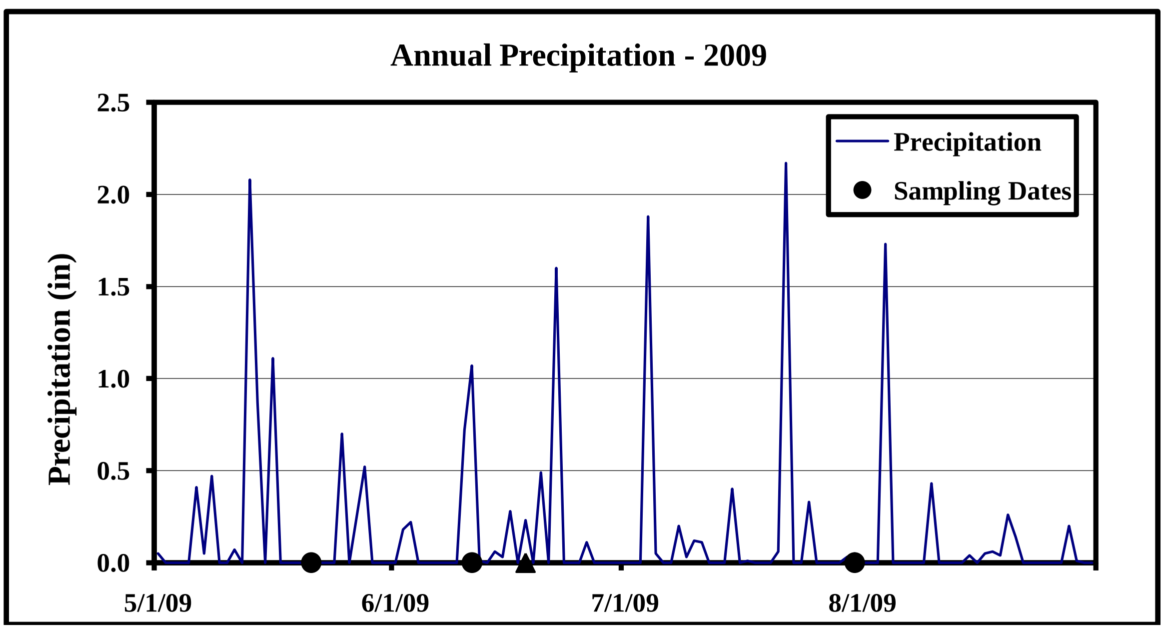

FIGURE 22. Annual precipitation during the sampling season, Bloomington, Indiana (Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, 2009). The ▲sampling point is the storm event.

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