Appendix A

Water Quality Assessment of the Prairie Creek Reservoir
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Significance of reservoir monitoring

“Every lake is a mirror of its environment” (Stumm, 2004). Lakes and reservoirs provide many valuable services that can be negatively affected by environmental changes (in the atmosphere, watershed, and groundwater) as well as human activities. While change in reservoirs and lakes through time is a natural occurrence, human activities can further accelerate it. If the causes of the changes are known, human-implemented management practices can control, or even reverse, detrimental changes in these water bodies. Consequently, field monitoring has been widely utilized to assess the status of water quality, identify emerging water quality problems, evaluate existing management practices, and to determine the effects of land use on lake and reservoir water quality (EPA, 2006). Monitoring usually results in a modification of land and water management practices within a watershed to improve or maintain quality of water and its intended uses.

In the United States, limited water quality monitoring is performed by the US Environmental Protection Agency (EPA) and the US Geological Survey, while major monitoring efforts are undertaken by states, local agencies, researchers, and volunteers. In the State of Indiana, monitoring of publicly owned lakes and reservoirs is performed and assessed by the Indiana Department of Environmental Management (IDEM) on a five-year rotating basin approach with about 1-2 basins monitored each year (IDEM, 2006). The goal of this state-wide monitoring is to evaluate the suitability of water resources to support its beneficial uses such as aquatic life, water supply, recreation and fishing, and subsequently submit this evaluation in a report to the U.S. EPA (IDEM, 2004). The results of such monitoring showed that nutrients have been the major cause of the pollution of Indiana reservoirs (EPA, 2002). Although nutrients, such as nitrogen and phosphorous, occur naturally in the environment, human activities (e.g., fertilizer use, wastewater discharge) add excessive nutrients into water sources. Persistent nutrient load to a lake or reservoir can result in unwanted growth of algae, algal blooms, overabundance of macrophytes, increased sediment accumulation rates, and eventually to depletion of dissolved oxygen from the water and fish kills (EPA, 2000). Algal growth can lead to reduced water transparency (clarity), increased turbidity, decreased concentration of dissolved oxygen required by aquatic organisms, development of undesirable taste and odor of water when the supply is used for drinking water purposes, and
increased cost of drinking water treatment (Jørgensen et. al 2005). These conditions may result in unsuitability of a lake or reservoir to support its beneficial and intended uses. Therefore, monitoring of a reservoir is essential if a community wants to maintain or improve its water quality and follow up with appropriate management activities to sustain its beneficial uses into the future.

**Prairie Creek Reservoir Status**

In Delaware County, Indiana, privately-owned Prairie Creek Reservoir serves as a secondary water supply for the City of Muncie by means of water releases into the White River during dry seasons. The reservoir also offers recreational opportunities, such as fishing, camping, swimming, and boating and for these purposes it is leased to the City of Muncie's Department of Parks and Recreation until 2021 to maintain and operate the grounds (Cescon, 1997). The future of development and land management within the reservoir’s watershed beyond the year 2021 is unclear.

Several stream tributaries to the reservoir drain adjoining and predominantly agricultural land. The watershed is located in a rural area where agriculture utilizes 73% of its surrounding land while 12% of the land is occupied by green space (WRWP, 2004). The reservoir is situated at the lowest point of the watershed, collecting water from its agricultural drainage ditches and small streams. The reservoir outfall is located on the north side of the reservoir and drains to the White River (Figure 1).

The condition of any reservoir at a particular time is related to the land use within its watershed, climate, geology, human influence, and characteristics of the reservoir itself (Garn, 2003). Because of a predominantly agricultural land use in this watershed, a concern is to prevent negative effects of watershed activities through implementation of appropriate land and water management practices within the watershed and therefore to protect water quality of the reservoir. It is well known that fertilizers (used for agriculture as well as for domestic applications) designed to increase the biological productivity of agricultural soils also increase the biological productivity of waters draining these soils and contribute to lake and reservoir eutrophication (Jørgensen et. al 2005).

Eutrophication, defined as increased biological production due to excessive load of nutrients, supports growth of algae and aquatic weeds in the reservoir which causes problems with water use for fisheries, recreation, industry, and drinking (Sharpley et al, 1995).

To maintain this reservoir as a valued feature in this county it is, among other things, necessary to maintain its good water quality. A limited number of studies have addressed biological water quality issues of this reservoir (Haman, 1964, Gathman, 1968, Cescon, 1997) and water quality
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of its watershed (Goward, 2004, and WRWP, 2004). However, direct reservoir monitoring to assess its chemical water quality status was not performed. The final White River Watershed Project (WRWP) project report (WRWP, 2004) called for development of land management practices to reduce non-point source pollution within the watershed as well as continuous monitoring of the Prairie Creek Reservoir. In summary, up to 2003, historical information about the reservoir’s water quality had been limited which justified the development of a more comprehensive reservoir monitoring study to gain knowledge of its water quality and thus support future land management decisions and uses of the reservoir.

The goal of this study was to assess the current water quality status of the Prairie Creek Reservoir in Delaware County, Indiana, and to initiate a long-term monitoring effort that will hopefully continue into the future. The results of this two-year study provide only a glimpse into the reservoir’s water quality issues. Trends in a reservoir’s water quality develop over a long period of time (e.g. 8 to 10 years) and thus it is essential that this monitoring effort continues in order to support future management decisions in this watershed.

Methods employed in the Prairie Creek Reservoir field monitoring

Seven reservoir monitoring sites, located in open waters (Figure 1.), were monitored weekly (in 2005) and bi-weekly (in 2006) for the following water quality parameters:

- **pH** – determines acid or basic character of the water. Very low pH, usually below 5, will harm fish and other aquatic organisms. Normal lakes have a pH of 6.5 to 9. Algal growth tends to increase pH, especially during the daytime hours.

- **Dissolved oxygen** in water is necessary to maintain good water quality, support aquatic life (fish, insects, plants) and to maintain good aesthetic quality. Water bodies containing low levels of dissolved oxygen can be fatal to fish and other aquatic species. Additionally, water with depleted oxygen (anoxic conditions) is characterized by its black color and unpleasant smell. Oxygen concentration in water can be reduced by decomposition of organic matter such as algae, grass clippings, dead plants or animals, animal droppings, and sewage. This organic matter is decomposed by bacteria that use dissolved oxygen to perform this natural process. The more
organic matter available to bacteria, the more dissolved oxygen will be used, leading to its depletion.

Figure 1. Prairie Creek Reservoir – location of monitoring sites.

- **Water temperature** determines survival of species by affecting concentration of dissolved oxygen in water. Warm water contains less dissolved oxygen. Therefore, warm water
temperatures will support only those fish species that can withstand lower oxygen levels (warm water fish) and eliminate those that cannot (cold water species).

- **Transparency** (clarity) of water is measured by lowering a Secchi disk (a black and white disk) into the water and reading the depth at which this disk is disappears. Visibility or transparency of water can be negatively affected by its color, and/or the presence of algae or suspended solids. In lakes and reservoirs, the measurement of Secchi Disk transparency has been used to determine their biological quality (trophic status) and correlated with the concentration of nutrients and algae. It has been shown that with increased input of nutrients to a lake or a reservoir, Secchi disk transparency decreases as a result of increased algal growth.

- **Nitrate** and **orthophosphates** are nutrients readily available for algal growth and their excessive input to a lake/reservoir can spurt the growth of algae and eventually lead to the development of green algal mats. When these algae die, bacteria at the bottom of the lake decompose them and use up dissolved oxygen in water. This can cause depletion of dissolved oxygen, development of anoxic conditions, and even fish kills. Therefore, increased input of nutrients from the watershed can negatively affect oxygen concentrations in a reservoir and can also lead to growth of toxic algal species in a water body, negatively impacting human health.

- **Ammonia**, also a nutrient available for assimilation by algae, is produced by decomposition of organic matter, such as decomposition of algae at the bottom of a reservoir. Ammonium hydroxide is toxic to fish and its concentration increases with rising water temperature and pH, which are the conditions of the Prairie Creek reservoir in summer.

- **Chlorophyll a** is a measure of algal growth. Any organism that undergoes photosynthesis requires chlorophyll. Increased concentration of Chlorophyll a indicates increased algal growth.

- **E.coli** is measured to indicate and assess the presence of fecal contamination in water. Fecal waste from animal or human sources carries pathogens that are responsible for gastrointestinal and other waterborne disease. Recreational waters must comply with the state standard of 235 coliform-forming units (CFU)/100 ml to be able to sustain its recreational use and thus protect public health from waterborne diseases.

- **Vertical depth profile** analysis (water quality measurements from the water surface to the bottom of the reservoir) at all seven reservoir locations was performed in 2006. The profile measurements included dissolved oxygen, pH, temperature, and chlorophyll a within the entire water column. This measurement is useful in determining thermal regime of the reservoir, changes in pH, and chlorophyll as a function of depth as well as the extent of any anoxic zone.
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(layer with depleted concentration of dissolved oxygen) throughout the summer season that is a result of nutrient load and algal growth.

Results of the monitoring study

The results of this two-year study provide only a glimpse into Prairie Creek Reservoir’s water quality issues. Trends in reservoir water quality develop over a long period of time (e.g. 8 to 10 years) and thus it is essential that this monitoring effort continues in order to support future management decisions at this watershed. Water quality at the Prairie Creek reservoir did not differ significantly between the 2005 and 2006 monitoring period. In addition, the results from seven monitored locations were not significantly different from each other for any measured water quality parameter except transparency. Results are compiled in Table 1.

- **Water Temperature**: Average annual temperature of the surface water was 74.1°F (23.4°C) in both 2005 and 2006. Summer (June 15 through September 1) average surface water temperature was 80.7°F (27.0°C) in 2005 and 80.0°F (26.6°C) in 2006. The maximum temperatures of surface water at all locations were achieved on August 9 in 2005 and on July 17 in 2006. The average bottom water temperature in 2006 (May through November) was also 74.1°F, with a minimum measured temperature of 49.1°F. In summary, the reservoir is a warm water body – a characteristic which will be reflected in dissolved oxygen concentration and aquatic species selection as well.

  In general, reservoirs in temperate regions typically stratify during the summer, meaning that the upper warmer layer with uniform temperature (epilimnion) is separated from the bottom cooler layer (hypolimnion) by a layer where temperature changes significantly (thermocline). This stratification can limit mixing of a reservoir’s water and create a hypolimnion with depleted or very low oxygen concentration, especially in the case of a reservoir with high input of nutrients and algal growth (eutrophic reservoirs). This can affect fisheries as some fish species will not be able to survive at low oxygen concentrations.

  In the case of Prairie Creek Reservoir, the measurement of temperature profiles at its deepest location (near the release tower, measured at PCR 6) revealed that the reservoir was not completely stratified and it lacked the bottom, cooler layer. Thermal stratification began to establish itself in early June; however, it never reached three distinctive, thermally-stratified layers, as would be expected. On September 21, 2006 the reservoir temperature at its deepest point
Table 1. Statistics: Average, Minimum and Maximum values measured at PCR during 2005 – 2006 monitoring period.

<table>
<thead>
<tr>
<th>Study Average†</th>
<th>Summer* 2005 average</th>
<th>Summer* 2006 average</th>
<th>Study Minimum†</th>
<th>Study Maximum†</th>
<th>Number of analyzed samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Water Temperature (°F)</td>
<td>74.1</td>
<td>80.7</td>
<td>80.0</td>
<td>52.0</td>
<td>86.9</td>
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<tr>
<td>Bottom Water Temperature (°F)</td>
<td>70.2</td>
<td>NA</td>
<td>74.1</td>
<td>49.1</td>
<td>80.1</td>
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<tr>
<td>Secchi Disk transparency (cm)</td>
<td>80</td>
<td>85</td>
<td>77</td>
<td>40</td>
<td>130</td>
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<td>Dissolved Oxygen in surface water (mg/L)</td>
<td>8.8</td>
<td>8.0</td>
<td>9.3</td>
<td>3.1</td>
<td>15.2</td>
</tr>
<tr>
<td>pH (s.u.)</td>
<td>8.4</td>
<td>8.4</td>
<td>8.5</td>
<td>6.1</td>
<td>11.5</td>
</tr>
<tr>
<td>Chlorophyll a (μg/L)</td>
<td>8.1</td>
<td>11.5</td>
<td>4.9</td>
<td>2.0</td>
<td>26.2</td>
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<td>Conductivity (μS/cm)</td>
<td>347</td>
<td>339</td>
<td>339</td>
<td>302</td>
<td>563</td>
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<td>Nitrates-N (mg/L)</td>
<td>.38</td>
<td>0.24</td>
<td>0.26</td>
<td>ND</td>
<td>2.3</td>
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<tr>
<td>OrthoPhosphates-P (mg/L)</td>
<td>.17</td>
<td>0.19</td>
<td>0.12</td>
<td>ND</td>
<td>1.48</td>
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<tr>
<td>E. Coli (CFU/100 mL)</td>
<td>18</td>
<td>19</td>
<td>4</td>
<td>0</td>
<td>450</td>
</tr>
</tbody>
</table>

† Average is calculated from all data acquired from April 2005 through November 2006; winter data from November through April were not collected
* Summer is defined as the period from June 15 through September 1

was uniform, suggesting a complete mixing of water at that time. This temperature regime also has an effect on concentration of dissolved oxygen within the reservoir profile.

- **Dissolved oxygen**: Average concentration of dissolved oxygen in surface water was 8.3 mg/L in 2005 and 9.6 mg/L in 2006. This indicates a very good quality of the surface water that is easily achieved by wind mixing, a predominant characteristic of this reservoir. However, monitoring of
the reservoir profile for dissolved oxygen revealed a more serious situation: a significant portion of the depth profile was anoxic (less than 1 mg/L of dissolved oxygen) between June and September 2006 (Figure 2). During the period of anoxic conditions nutrients bound to sediment, such as phosphorous and ammonia, may be released into bottom water and encourage additional algal blooms. In other words, depletion of oxygen, that is a result of increased input of nutrients from external sources and subsequent algal growth in the reservoir, can create a situation within the reservoir where more nutrients are released from the bottom sediment to further exacerbate this situation. These low concentrations of dissolved oxygen and warm temperatures will affect fish communities in this reservoir. In addition to nutrients (such as ammonia and phosphorous), metals (such as iron, managenese) and hydrogen sulfide can also be released from the sediment during anoxic conditions which may cause taste and odor problems and negatively affect fish communities that are repelled by higher concentrations of ammonia. The condition of oxygen levels in the reservoir is a result of watershed activities (input of pollutants from agricultural, rural sources, and wastewater seepage from septic systems) that most likely have been occurring throughout the entire lifetime of this reservoir.

- **Nitrates** are nutrients readily available for consumption by algae. Nitrate concentration was 0.45 mg/L in 2005 and 0.28 mg/L in 2006, respectively. This concentration is well below the current drinking water standard of 10 mg/L and therefore it does not pose any problem to public health or aquatic life. However, nitrate is an algal nutrient and can exacerbate eutrophication that leads to consequences mentioned previously, such as depleted oxygen, fish kills, taste and odor.

- **Ammonia** concentration was measured only in the 2006 monitoring season. The maximum permissible ammonia level allowed in water bodies is provided by the Indiana Administrative Code (IAC, 2000) and is dependent upon pH and temperature. For example, a sample with a pH of 8.5 and temperature of 25 °C should not exceed a concentration level of 0.2137 mg/L. Only the concentrations measured in September 2006 exceeded these allowable limits when the ammonia concentration at the surface was 0.34 mg/L at location 4 (in the center of the reservoir), and 0.24 mg/L near the release tower. This higher concentration was most likely caused by release of ammonia from the sediment during anoxia and then mixing of the entire water volume that began in September. Concentrations of ammonia in the bottom water are expected to be higher due to its production during decomposition of organic matter and depletion of dissolved oxygen.
Figure 2. Depth profiles of dissolved oxygen concentrations monitored at various sites at the Prairie Creek reservoir. Red areas denote zones with depleted oxygen. Refer to Figure 1 to locate the monitoring sites.
Orthophosphates, a form of phosphorous, are readily available to algae for their growth and high levels of this nutrient can contribute to excessive nutrient loading and eutrophication. There is neither a drinking water nor surface water standard for phosphorus; however, levels as low as 0.005 mg/L have been found to cause eutrophication (Correll, 1998) and EPA recommends the concentration of orthophosphates not to exceed the level of 0.025 mg/L in lakes and reservoirs to prevent eutrophication. At Prairie Creek reservoir the average concentration of orthophosphate was 0.17 mg/L for 2005 and 0.18 mg/L for 2006, significantly higher than the recommended concentration to prevent eutrophication, which is a cause for concern. The recommended level was exceeded in 92.4% of samples. There was no statistical difference found either among the seven study sites or between the two monitoring years.

Orthophosphate concentration from the bottom waters was analyzed only in 2006. The average concentration of orthophosphates in bottom water was 0.33 mg/L, well above the recommended level. The concentration of orthophosphate is expected to be higher in the bottom waters because it is released from the sediment during anoxic conditions such as those that occurred from June through September (Figure 2) when dissolved oxygen concentration was less than 1 mg/L. Thus, concentration of phosphorous in this reservoir is of concern. Sources of orthophosphate and any other species of phosphorous are fertilizers used in agriculture as well as in urban and rural areas, wastewater seepage from surrounding septic systems, and soil erosion. Since the exact source cannot be identified, it is important to design proper management strategies within the watershed to control input of nutrients into the reservoir.

Secchi disk transparency (SD): Average SD transparency was 0.8 m (2.6 feet) with an average of 0.85 m in summer 2005 and 0.77 m in summer 2006. According to the EPA guidelines for Ecoregion VI that includes Midwestern areas, the SD reading should be a minimum 1.36 m (4.46 feet) (EPA 2003). Low transparency at the local reservoir in comparison to the guidelines suggests the eutrophic state of the reservoir meaning that transparency is reduced due to the presence of algae as well as sediment. According to the IDEM, a SD transparency of less than 5 feet is an indicator of eutrophic state (IDEM, 2006).

The E. coli standard of 235 colony forming units per 100 mL for a single sample (IAC, 2000) was exceeded only in 3 samples during the two-year monitoring period; a total of 160 samples were analyzed. Because of a large dilution factor that occurs in the reservoir, the monitoring of the levels in open water, however, is not informative. The input of fecal contamination to the reservoir should be monitored at the beach area (currently performed by the Department of
Conclusions

It is said that “Every lake is a mirror of its environment” (Stumm, 2004). This expression is appropriate in the case of Prairie Creek reservoir water quality, which is a mirror of its watershed activities. The reservoir is a warm eutrophic water body, meaning that the nutrient input has been the cause of algal growth and resulted in the current state of water quality: dissolved oxygen depletion within 40-60% of the reservoir depth from June through September, low water clarity, and concentrations of orthophosphates that exceed levels required to prevent eutrophication (increased biological production). Eutrophication at this reservoir has been an ongoing process and will continue into the future unless some measures are taken to manage input of nutrients from its watershed.

While this was the first study of the reservoir’s water quality, the results and consequences are not to be taken lightly since it is impossible to predict the future conditions and changes in water quality. Lack of dissolved oxygen throughout 40-60% of water depth measured in 2006 can negatively affect fishing, recreation, and water supply. As uncontrolled input of nutrients to the reservoir continues, algal growth is expected to persist and even worsen, and thus affect the value and benefits of this water resource in the future. Therefore, improved management of current land use practices, wastewater disposal, and properly planned future development is absolutely necessary if the community wants to maintain the benefits of this reservoir. It is important to keep in mind that all pollutants from surrounding land are continuously drained to the reservoir either by stormwater runoff or through stream and ditches and therefore affect its water quality, and current and future uses and enjoyment.

While the reservoir itself can be managed for oxygen depletion and algal growth by various chemical methods, this strategy should be used as a last resort and watershed management upstream from the reservoir should be considered in order to deal with the consequences of eutrophication. These in-reservoir management practices only “medicate and reduce the symptoms” rather than solve the real problems, which lie within the watershed. For example, it is necessary that future development and watershed activities include management strategies that (1) reduce production of pollutants from various sources within the Prairie Creek watershed through mitigation and
improvement of current onsite wastewater treatment and reduction of pollutants input from tile drains; and that (2) retain pollutants upstream from the reservoir to prevent their accumulation in the reservoir.
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References:


You may receive more information about the results of this study by contacting Dr. Jarka Popovicova, Assistant Professor, Ball State University; Phone: 765-741-8757; Email: jpopovicova@bsu.edu.